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Computer-Aided Design AND APPLICATIONS

The Kandinsky Experience: A Multisensory Augmented Reality Application for Cultural Heritage

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Abstract. Kandinsky - Experience Book is a multisensory Augmented Reality experience that involves sight, hearing and smell senses and aims at improving the users' engagement in the Kandinsky's artworks. Specifically, the aim of the application is to augment the experience of the user creating a journey throughout Kandinsky's work by using an AR application for smartphones integrated with audio and olfactory stimuli, in order to allow him/her to be more immersed in the piece of art. The research project has been inspired by the synesthetic approach of the abstract painter to the theory and the perception of art in his books. Starting from the artist's considerations about the relationship between different sensorial stimuli in works of art, we decided to amplify some of his theories suggesting a connection between the main pictorial elements and some corresponding olfactory stimuli, grounding our hypotheses on the content of papers concerning the crossmodal synesthetic correspondences between olfactory stimuli and other sensorial modalities. Thanks to the simultaneous presentation of the specifically developed AR contents and the olfactory stimuli, the users' feelings and emotions during the experience are amplified as a result of the sensory integration. Moreover, by using AR technology and olfactory devices to stimulate visual and olfactory perceptual channels we aimed at increasing the generation of longer-lasting memories in the users' mind.

Keywords: Augmented Reality, Multisensory Perception, User Experience, Cultural Heritage
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1 INTRODUCTION

Traditionally, books are considered as objects used for reading and learning activities. Besides the ones read for pleasure, books are used for educational purposes and for improving readers' knowledge about specific topics. In recent years the widespread of ICT technologies in everyday life has also had an impact on books, which have been subjected to a radical transformation. Instead of ink and paper, today digital contents are displayed on various devices, such as e-book readers, computer displays, tablets, and smartphones. This revolution, which has been embraced with skepticism by some "purist" users, is based on a change of the support, from physical to digital. Consequently, people are trying to adapt to these new technologies and change their reading behaviors in order to exploit the digital potential [31].

However, even though today technological devices used for reading e-books (tablets, e-readers etc.) are still poorly exploited, they can represent a fundamental tool to make the reading experience more immersive by using a complete multisensory approach, in which more senses are stimulated. Moreover, digital books lack somehow of the multisensory appeal of traditional books (e.g., smell of pages, texture of paper, weight, temporal information determined by turning the pages serially etc.), something that might lead to a reduction in learning performance and awareness of information presented (see [8], for a recent meta-analysis where digital and traditional reading is compared).

Indeed, the possibility to use a digital support opened new possibilities, namely from the addition of sounds and audio tracks, or the interaction through touch displays to a transformation into Virtual Reality (VR) and Augmented Reality (AR) applications. Specifically, three trends and directions of book evolution have been identified by Park et al. [35]: digitalization, augmentation and hypermediation. These approaches are strictly related to traditional interactive books, which require the active involvement of the reader with different interaction modalities based on touch, audio and smell, integrated with illustrations and text. Consequently, interactive books are intrinsically multisensory in their nature.

Augmented and multisensory approaches have been proven to be effective both in the case of books for children and young people, and in the case of adults, allowing them to keep their attention high [1, 42].

The primary objective of the use of interactive technologies is to make the reading and learning activities much more engaging, immersive, efficient and suitable for different types of readers (not to mention their value for language-related developmental disorders). In particular, the common idea is to "extend" the target audience of these products also to those who are not experts in the topics described in the books who, through the new co-communication methods, can better and more intuitively understand complex concepts. In this sense, in fact, the possibility of viewing the history of the pieces of art and their meaning instead of only reading or listening to the explanation, or rather of looking at images / animations instead of reading texts, reduces the need to have experienced and knowledgeable users, and increases the possibilities of learning and remembering information. This also complies with the well-established 'dual code theory of learning' in human cognition, suggesting that learning is more efficient when information is not presented only via a single channel (e.g. [6]; see also [34]). In the "non-expert users" category, it is also possible to include children, who are often fascinated by science, nature and art, but are hardly interested in static representations that are very difficult to understand. Similarly, university students may benefit from the use of augmented contents for the appreciation and comprehension of concepts that are generally difficult to mentally visualize in their full complexity.

Moreover, nowadays the user experience is one of the fundamental features of books and is strictly linked to the user - device (book) interaction at physical, perceptual and cognitive levels. This also means that in order to improve the user's engagement, this experience must include the design of multisensory experiences that satisfy sight, touch, hearing and smell senses. In fact, scientific research has clearly shown that the human brain integrates information from different sensory modalities [41] in order to define a univocal final experience of the external world.

Psychological and neuroscientific research has also shown that perception is always multisensory in nature: whenever we interact with the external world our brain integrates pieces of information from different sensory modalities as a function of certain binding principles [41].

The sense of smell certainly plays an important role in the multisensory processing of information, since it recalls memories and deep emotions both at conscious and unconscious level [16, 36]. In human history odors have represented important elements of culture and religions and from a phylogenetic point of view chemical senses, such as olfaction, are among the first to develop in the animal kingdom. In fact, they can signal potentially relevant and distant sources of food, as well as danger (e.g., poison or fire). Thanks to these effects on humans, smells can engage people to feel involved into and emotionally linked with any kind of stimuli, such as the artworks analyzed in the present study.

The purpose of the research work presented in this paper is to design and develop an interactive multisensory AR application (based on sight, hearing, and olfaction), which can be used for improving the user's experiences of art books, and the comprehension of their contents. Specifically, the paper presents a case study where a multisensory AR book concerning the Kandinsky's artworks was designed and developed. The paper presents some preliminary comments and opinions from some participants that have tried the applications.

2 LITERATURE REVIEW

Traditionally, humans use writing and images to preserve and transmit knowledge. Books are the objects used to "contain" this knowledge in written form and depicted in images.

In recent years also books have been subjected to important modifications related to the widespread of ICT technologies. Instead of ink and paper, today written contents are displayed on technological devices, such as e-book readers, computer displays, tablets, and smartphones. This revolution is based on a change of the support, from physical to digital, while printed and digital pages keep having the same aesthetic appearance. However, the physical interaction with the printed book, rather than with the display of a device, is very different. So, the use of digital versions of books can have a strong impact on the fruition of knowledge, which is much faster but, sometimes, more superficial. For this reason, a mere transposition of the same content from the traditional media to the new technological one has been proven to be not effective.

However, the possibility to use a digital support opened new possibilities such as, from the addition of sounds and audio tracks, or the interaction through touch displays to a transformation into Virtual Reality (VR) and Augmented Reality (AR) applications. Specifically, three trends and directions of book evolution have been identified by Park et al. [35]: digitalization, augmentation and hypermediation. Moreover, they suggested three research and business directions: open hypermediation, e-book augmentation, and mobile-device based augmentation [1]. These approaches are strictly related to traditional interactive books, which require the active involvement of the reader. Interactive books are usually created for children, in order to capture their attention. In these books the interaction can be usually based on touch (by using different textures, moving parts, and so on), audio (with musical pages), smell (with the so-called "scratch and sniff" stickers). Stimuli from these senses are typically integrated with illustrations and text. Consequently, interactive books are intrinsically multisensory in their nature.

Augmented and multisensory approaches have been used both in the case of books for children and young people, as well as in the case of adults. Children and young people can particularly take advantage of augmented multisensory approaches, allowing them to keep their attention high [1, 42]. For instance, Welch et al. [46] developed an immersive Virtual Reality book for surgical training. Their immersive electronic book environment combines an immersive 3D VR-Cube with a tablet for environment navigation and annotation tasks. Dalim C. [10] developed an AR training system, with the aim of providing an interactive learning process for children to enhance their understanding about astronomy. Alam et al. [1] presented a multisensory approach of annotation based on haptic-audio-visual interaction with the traditional digital learning materials. Specifically, a prototype in

which haptic interfaces are integrated within a home entertainment system has been developed and tested to examine whether the use of this augmented environment can influence the user's learning patterns. Simeone et al. [39] presented the case of a book, released by the Italian publisher FakePress, based on the use of QR codes and fiduciary markers to retrieve and show contents, with the aim of fostering new educational practices. Moreover, attempts have been made in order to develop applications for people with special needs. For instance, Matosa et al. [32] presented a research work in which multisensory stimuli (audio, video, tactile and smell) are used to motivate people with intellectual disabilities to assist their learning process.

Mostly, these works aim at improving the reading experience, through increased user involvement in the narrated story. Similarly, museums and cultural institutions are more and more modifying their role and approach to improve the users' experience of their exhibitions and make learning new knowledge an interesting and pleasant experience. Also, in these cases, VR and AR technologies can be effectively used in the context of a museum exhibition to support both storytelling and interaction [11]. For example, "The Modigliani VR: The Ochre Atelier" experience was developed as part of the Modigliani exhibition at the Tate Modern Museum in London [24] and was integrated in the collection made of paintings, sculptures and drawings. In this experience, visitors had the possibility to explore the objects in the studio of Modigliani, learning more about his creative process, and materials and techniques he used. In 2017, the Kremer Collection launched "The Kremer Museum", that is an innovative concept of a museum, where 74 Dutch & Flemish Old Master paintings from the Kremer Collection are accessible exclusively through Virtual Reality technology [25]. "Rome Reborn" [23] is an international initiative launched in the mid-1990s by the UCLA Cultural Virtual Reality Laboratory with the goal of developing 3D digital models illustrating the urban development of ancient Rome from its foundation to the depopulation of the city in the early Middle Ages. Rome Reborn presents a series of products for personal computers and VR headsets and aimed at guiding students and the general public in virtual tours of the now-vanished ancient city. Again, "The Private World of Rembrandt" is an AR exhibition concerning the personal story of Rembrandt. It is based on original seventeenth-century documents owned by Amsterdam City Archives and original works by Rembrandt. Specifically, by using the "Rembrandtviewer", a tablet in custom-made wooden case with a specifically-developed AR application, visitors were able to frame the original documents, visualize AR contents and listen a voiceover that tells the story behind the document [20].

Moreover, several experiences based on a multisensory approach have been developed and different interaction modalities (usually audio, video, and tactile) are integrated. For example, in 2012, the sense of touch has been embodied in the light installation of Takahiro Matsuo [19]. This interactive Aquatic Colors installation emulates a glowing, underwater sea filled with jellyfishes, which respond to the movements of visitors. However, the use of sense of smell is underexplored, even if its possible application and impact can be quite effective. Indeed, the sense of smell is one of the most evolutionary ancient senses in humans and animals, and it is linked to visceral emotions in comparison to the other senses. Because of that, odors can have an impact also on implicit (unconscious) processing of information, thus affecting our feelings, moods, memories, etc. The use of smells for cultural purposes is rare and still experimental, but some exhibitions that integrated odors have been presented in the last years. In "The Art of the Scent (1889-2012)" exhibition at the Museum of Art and Design in New York scents have been celebrated as a true artistic media [18]. The "Multisensory Met" exhibition at the Met Media Lab Intern Expo aimed at creating a multisensory environment to enhance the overall effect of pieces of art. So, they created more fulfilling experiences for museum visitors, which are satisfactory for multiple senses. Different multisensory products have been used: booklets, sculptures, clay replicas, scratch-and-sniff paintings, scented powder materials and sound paintings [22]. Also, Verbeek presented two case studies of cultural heritage exhibitions in which odors have been integrated [45].

In some cases, device named Olfactory Displays have been used. Olfactory Displays are systems based on several technologies used to generate and deliver scented air that is eventually smelled by the users [33]. In particular, in recent years, digital olfaction has been advanced in different areas like improving the realism of virtual environments, stimulating users' attention and making the

reading experience more immersive [5], improving the users' experience of cultural heritage [3, 4, 7], etc. As example, "Flip the Book – Flip the Memories" is an artwork that combines odors with audio and visual stimuli and the reading experience. By turning the pages of the physical book, users trigger different videos with the corresponding odors and can enjoy a "memory book" experience [29]. Also, the multisensory digital interface and art installation Zelige Door on Golborne Road presents a tool for capturing and displaying the living heritage of members of Moroccan migrant communities. The interface includes physical objects and Augmented Reality and olfactory technologies have been used in the interface to superimpose pre-recorded video material and smells to the objects [44]. Even if olfactory display devices are still evolving and some technical issues still remain unsolved, some companies have developed olfactory displays for VR/AR applications. Recently, some new devices have been launched on the market. For example, the Vaqso device (https://vaqso.com/), the Olorama scents generator (https://www.olorama.com/professional-scent-generators/), and the Feelreal device (https://feelreal.com/).

For what concerns the specific topic of the experience presented in this paper, the authors focused on the artistic production and theories of the Russian painter Wassily Kandinsky (1866-1944), generally credited as one of the pioneers of abstract art. Interestingly, he carried out a wide theoretical analysis about the correlation among different sensorial stimuli, such as sounds (music) and visual cues (pictorial works of art). Starting from his peculiar artistic vision and suggestions, we integrated vision and hearing, and we extended his work to the olfactory realm in order to further enrich the experience of his paintings. So, a deep analysis of Kandinsky's work and his theories about colors, shapes, lines, sounds and the synesthetic relationship between them has been carried out.

In his books "The Spiritual in Art" [27] Kandinsky investigates the essential quality of the colors and their relationship with other sensorial stimuli, describing them as "light" or "deep" or defining associations such as the ones with the sounds of musical instrument. His aim was to underline an existing bound between the work of art and the spiritual dimension inside of the human being. Moreover, in "Point and Line to Plane" [28] he focuses on the basic elements that define works of art, analyzing their geometrical definition, their relationship with music, color, and the other geometrical elements, their value in modern culture and their essential role inside the composition.

So, it is possible to affirm that the Kandinsky's approach to art is intrinsically experimental and multisensory. Indeed, this vision of art is not just limited to pictorial works, but embraces the overall sensorial realm, including auditory and olfactory stimuli. More specifically, it is based on the idea that each element used to create artistic compositions arouses a specific vibration in the soul of the viewer, and that the combination of these stimuli generates a unique emotional experience. In particular, he focused his attention on three couples of antithetical elements: the blue and yellow colors, the straight and the curved lines and the triangular and circular shapes. For example, yellow is considered as a perfect match with the triangle shape and is associated to the sound of trumpets or brass bands. The perfect shape to match the blue color is the circle shape, due to the fact that both elements are characterized by calmness and introspectiveness. The blue color is also associated with the sound of a cello. The line is defined by Kandinsky as a secondary element, derived from the movement applied to the point. In particular, the curved line resembles the calmness of a conscious and mature being. It is the antithesis of the straight line, perceived as the birth of the line from the point.

Also, Kandinsky developed a complete and structured theory about how each element of a pictorial work of art could be perceived by the viewer, could influence the perception of other elements, and how the combination of many elements could create a specific emotional response in the viewer. Each element of the composition is characterized by a specific mood, almost a behavior, defined in relation to other elements.

2.1 Multisensory and Crossmodal Correspondences among Visual, Auditory and Olfactory Stimuli

In order to offer a pleasant and effective artistic learning experience, a number of papers about synesthesia phenomenon (a perceptual condition where stimuli presented via a sensory channel, give rise to perception in a different sensory channel) and crossmodal correspondences have been analyzed. In particular, we focused the research on the associations that people commonly make among shapes, colors, pitches and odors.

Concerning the associations between colors and odors in the mind of participants, according to [26], odors seem to produce distinct and reliable color profiles. These odor-color mappings in the brain are often mediated by the sensory features of the natural source and can change depending on the label associated with such source of information (i.e. lexicon-semantic association). That is, smelling an odor triggers identification attempts in the brain and the odor source impact on the visual mappings within the mental representations of the subject. For example, once an olfactory stimulus is identified as lemon, participants predominantly associate the odor with the color yellow (given the frequent association between these stimuli experienced in everyday life), while they pick the color green whence the stimulus is identified as lime. On the opposite, uncommon odors produce less meaningful and inconsistent color matchings. For example, in [14] yellow was matched by participants to bergamot, green to galbanum, red to cinnamon, and brown to caramel; in [12] yellow and orange were significantly associated to lemon, green to cucumber, turquoise to spearmint, brown to caramel, while pink and red to strawberry.

Also, for what concerns the correspondence between odors and shapes, experimental results described in [15] showed that angular shapes were associated with more intense or unpleasant smells (e.g., lemon or pepper), while rounded shapes were associated with less intense smells but with a more hedonic value (e.g., vanilla or raspberry). A similar pattern of results was found by [2]: odors associated with a sour taste (e.g., lemon) have been evaluated as *angular*, while sweet tastes (e.g., vanilla) as *rounded*. Moreover, odors generally considered as pleasant were paired with circles or curved shapes, while unpleasant odors with square or angular shape [13]. Finally, according to [37] congruent smell-shaped combination increases the pleasantness and perceived intensity of odors.

Concerning the crossmodal associations between pitches and odors, according to [38], background sounds can be matched with specific odors and increase the odor's pleasantness when sound and odor are considered congruent. Also, according to [9] stimuli judged as happier, more pleasant, and sweeter tended to be associated with higher pitch. At the same time, high notes typically correspond to the most volatile compounds in a perfume, those that reach first the nasal epithelium [30].

A number of hypotheses have been made about the origin and explanation of these non-arbitrary cross-sensory associations [43]. Some of them have already been taken into account above when mentioning the "pleasantness" and "semantic" factors. For instance, two different sensory dimensions might be matched because they are both located at the same position along an imaginary hedonic tone continuum (i.e., unpleasant odor and unpleasant angular shape). Language may also play a role here: Knowing the name of the odor being sniffed also influences the sensory associations (e.g., an odor being presented with the "lemon" label is quicker matched to yellow). Whatever is the reason of the crossmodal correspondences described earlier, here we are interested in implementing the results of scientific research to support the design of the Kandinsky Experience.

3 RESEARCH SCOPE

The Kandinsky experience is a multisensory AR experience that involves sight, hearing and smell senses to provide a multisensory, interactive and entertaining way to approach art, to create a memorable experience for the user, and to improve her/his understating of the content of the Kandinsky's work.

Specifically, the aim of the study was to augment the experience of the user by means of a journey throughout the Kandinsky's work performed with the aid of an AR application. Auditory and olfactory stimuli were integrated in order to provide the user with a greater immersion in the subject of the artwork.

The multisensorial approach is a fundamental element to create a unique experience because it enriches in meaningful details the conveyed contents, allowing users' memory to easily record and store information. Indeed, thanks to the simultaneous presentation of specifically developed AR multisensory contents (including olfactory stimuli), when users appreciate the artworks, their feelings and emotions are amplified also as result of this sensory integration process. Moreover, the usage of AR technology and olfactory devices to stimulate visual and olfactory perception increases the chances of generating long-lasting memories in the users' mind. In fact, smell plays a crucial role in creating and retrieving emotional memories, thanks to the direct link between the olfactory cortex and the limbic system in the brain [17].

The AR multisensory experience is based on a deep analysis of the Kandinsky's work and his theories about colors, shapes, lines, sounds and the synesthetic relationship as described in the section about "Literature review". Specifically, after the analysis phase, the most representative pictorial elements have been selected to become the main characters of the experience.

Consequently, the experience has been designed to illustrate Kandinsky's theories through some of his artworks organized in three main sections, which are the Colors, the Lines, and the Shapes. In these main sections, the relationship between the pictorial element and the auditory stimuli is enhanced respecting the author indications, while the corresponding relation with olfactory stimuli, that was just suggested by Kandinsky, has been reinterpreted. The associations between odors and paintings have been chosen according to the characteristics of each visual element described by the artist combined with the analysis of literature review previously presented. Specifically, the selected six odors cover a wide range of different volatility and have been already used in previous research works. On this point, the different degrees of volatility which characterize each odor impacts on the capability to perceive other odors, with lower volatility-odors being perceptually dominant on higher volatility-odors. Therefore, here for each section– related to the first painting – we presented a higher volatility-odor as first and a lower volatility-odor as second. By doing this, the user will be able to perceive the first odor, then the second one and, at the end, a mix of them.

With regard to the auditory part, the stimuli adopted are pieces of classical and experimental music. Most of them have been selected among the musical works of John Cage (1912 – 1992), who was an American musician, thinker, poet and artist. Indeed, his principles of inner resonance and his conception of art as a privileged conduit for universal ideas present similarities, references and correspondences with the Kandinsky's concept of art. This correspondence has also been described in the exhibition "Kandinsky → Cage: a major journey through art and music" at Palazzo Magnani in Reggio Emilia from November 2017 to February 2018 [21], which presented a journey from the spiritual abstraction of Kandinsky to the enlightened silence of Cage. The other visual, auditory and olfactory stimuli included on the present work are presented in Figure 1. The Kandinsky - Experience Book consists of three main components (see Figure 2).

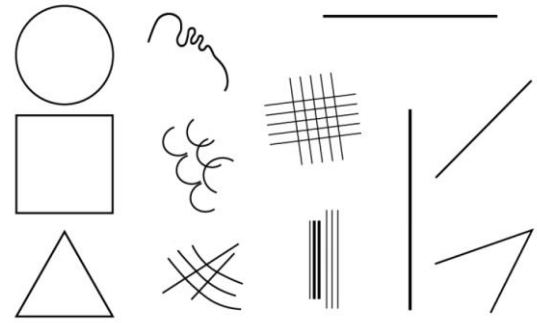
The first main component of the system is the book containing a brief description of the Kandinsky's theory divided into nine chapters, associated with nine selected paintings, each of them used as a marker for the AR application.

The experience has been designed to illustrate Kandinsky's theories through some of his artworks organized in three main sections, which are the Colors, the Lines, and the Shapes [27, 28].

Each main section contains three paintings and is characterized by a specific color (red, yellow and blue), to allow the user to easily navigate inside the book. Each painting has been selected to represent a specific topic of Kandinsky's theory. For each topic a quote from Kandinsky's books has been selected to better represent his concepts. Specifically, each time that the user opens the book, one page (the "top" page) reports the quote, while the opposite one (the "bottom" page) presents

the painting. In each chapter, there is also the indication of the correct cartridge of odor to be inserted in the device.

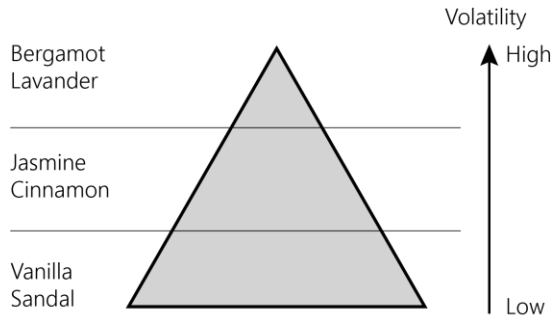
(a) Colors



(b) Shapes

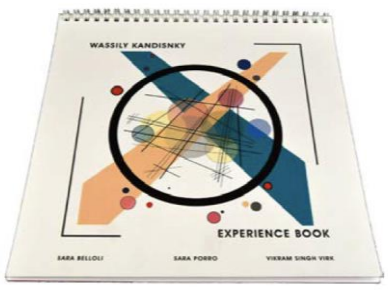
Trumpet	Violin	English Horn
Flute	Tuba	Tubular Bells

(c) Sounds



(d) Odors

Figure 1: (a) Colors (b) Shapes (c) Sounds (d) Odors. In image (d) odors have been ordered according to their volatility - the most volatile one corresponds to the top of the pyramid.



(a) book

(b) AR application

(c) case

Figure 2: The three main components of the Kandinsky - Experience Book: book, AR application and case.

The second component consists of the AR application displayed on tablets or smartphones, which allows the animation of the most representative paintings of Kandinsky. In order to interact with the

system, users are asked to open the AR application on their personal device and frame one of the paintings depicted in the book. Consequently, the AR application automatically recognizes the painting and displays the corresponding animation, music, odor and verbal description. For example, by framing the painting entitled Several Circles (see Figure 3), the users can see the flat representation of the painting coming alive, acquiring the third dimension and moving according to the criteria of movement and heaviness of the Kandinsky's theory and to the rhythm of the background music.

Figure 3: The painting entitled Several Circles and the corresponding AR digital content.

When triggered, the AR application provides two more sensorial stimuli associated with Kandinsky's work. For example, the Blue Painting by Kandinsky has been matched to the "8th Symphony" of Shostakovich and to the Sandal odor, creating an evocative AR animation in which movement, music and odor are combined to multisensory reflect the characteristics of the blue color, as described by Kandinsky. More, a second modality interaction has been implemented, allowing the user to explore the digital content of the painting scaling and rotating it to appreciate all its details. In the meanwhile, a recorded voice describes the main characteristics of each painting.

The third main component of the system consists of the case made to accommodate the book and to place the olfactory displays that deliver the odors. Each olfactory display consists of a fan conveying air through a cartridge soaked with some drops of liquid scents. The case is equipped with two olfactory displays placed on two sides of the niche created for the book, to be able to provide a combination of two scents as olfactory stimuli when needed. Due to the fact that each painting corresponds to a specific olfactory stimulus, the cartridges can be easily replaced when indicated by the AR application. Each cartridge has been named with the letter "L" or "R", depending on which side of the case it should be inserted, and the letters A, B or C, corresponding to each chapter of the book. Moreover, each couple of cartridges has been painted with the same color chosen to characterize each chapter, in order to make it easier for the user to recognize them (see Figure 4).

4 PROJECT DEVELOPMENT

In the AR application each paint is used as a marker to trigger the application. The Unity3D (https://unity.com/) and the Vuforia (https://developer.vuforia.com/) software tools have been used to develop the AR application. Specifically, the animations of the paintings have been developed in Unity3D, and the Vuforia software has been used for the implementation of the AR visualization of the contents.

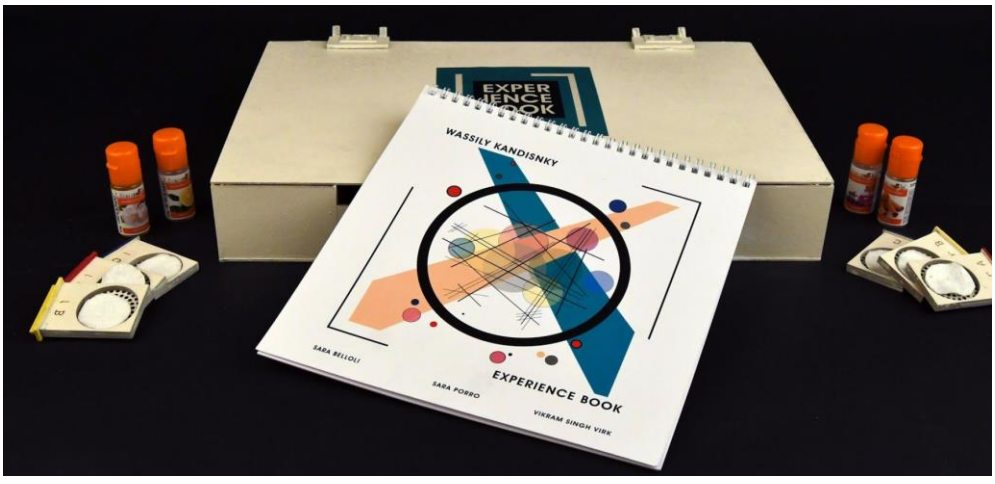


Figure 4: Prototype of the Kandinsky - Experience Book.

The interface of the app has been designed to be coordinated to the aesthetic of the book and the case. A recurrent color palette has been chosen, together with a coherent formal language for menus, buttons and texts (see Figure 5). Two-dimensional icons have been chosen to achieve a simple and intuitive result. The green color has been chosen as main reference and it has been used for the icon of the product. The yellow, red and blue colors, the primary colors used and analyzed by Kandinsky, have been used to highlight the different chapters of the interactive book. For the AR application some more simple and white icons have been designed to have a light impact on the perception of the image during the AR activity. For the UI some of the most used gestures, like the scroll and the swipe ones, have been chosen as navigation method throughout the application. The icons have been positioned to allow a comfortable use of the interface while using the physical book.

Figure 5: Visual identity of the application.

All the paintings used as markers for the application have been uploaded and stored in a Vuforia database and then downloaded as package to be imported in Unity, in order to be recognized by the AR application. For this purpose, only images with high contrast and very recognizable elements have been chosen in order to be effectively recognized by the AR camera.

Each painting, with his own three-dimensional models, has been developed in a different scene, and the corresponding digital contents have been developed in that scene. Specifically, the three-dimensional model of the elements of each painting has been developed by using the 3DStudioMax software, while the textures have been created starting from the original paintings using Adobe Photoshop. Then, for each painting the three-dimensional models have been placed in a different scene, carefully overlapping them to the original painting, together with the corresponding digital contents. The 3D elements have been placed inside the virtual scene taking into account the Kandinsky's theory regarding the movement of the colors. In particular, the yellow elements have been placed in the upper part of the space, while the blue ones have been positioned in the bottom. Also, the background color has been represented taking into account both the mood of the painting

and the Kandinsky's theory. The shape, dimension and proportion of each element have been faithfully respected as long as it could be perceived from the original painting. The third dimension has been interpreted trying to follow Kandinsky's theories and to create an evocative composition. The aim was to place each element in the three-dimensional space being inspired by Kandinsky's description of the qualities of each attribute and emphasizing the emotional atmosphere of each painting. The criteria used to transpose the two-dimensional elements in three-dimensional models has been defined according to the content of each chapter. Chapters concerning colors and lines do not focus on the third dimension of each single element, but on the three-dimensionality of the whole composition. Instead, in the chapter concerning shapes, more importance is given to each single element. So, we used the third dimension to emphasize two-dimensional shapes according these different approaches. For some paintings, in which an illusion of a collapsing background is presented, it has been reproduced with the use of depth masks. Finally, the three-dimensional elements of the painting have been animated according to the rhythm of the corresponding music.

The architecture of the application has been organized in order to easily approach every painting starting from a main menu. So, after a brief tutorial, it is possible to access the paintings. Specifically, when a painting is framed, an opaque surface appears to cover it. Then, the user is asked to use the opaque surface as a button and press it to load the digital contents. Therefore, for each painting, two different interaction modalities have been developed.

The first one, named *Experience Book mode*, has been designed to immerse the user in the multisensory experience as created by the authors on the basis of the Kandinsky's work.

In this modality, once the selected painting is framed and the opaque surface has been pressed, the corresponding 3D animation and background music automatically start. Then, the user is asked to press the "odor button" to activate the corresponding olfactory display (or displays) for 10 seconds. After this time, the displays stop automatically, allowing the user to press the button again if needed. Also, the fans will be automatically turned off in case the user stops the application or goes back to the main menu. For instance, in the case of the "Lines" chapter of the book, the visual, auditory and olfactory stimuli associated with each painting are reported in Figure 6.

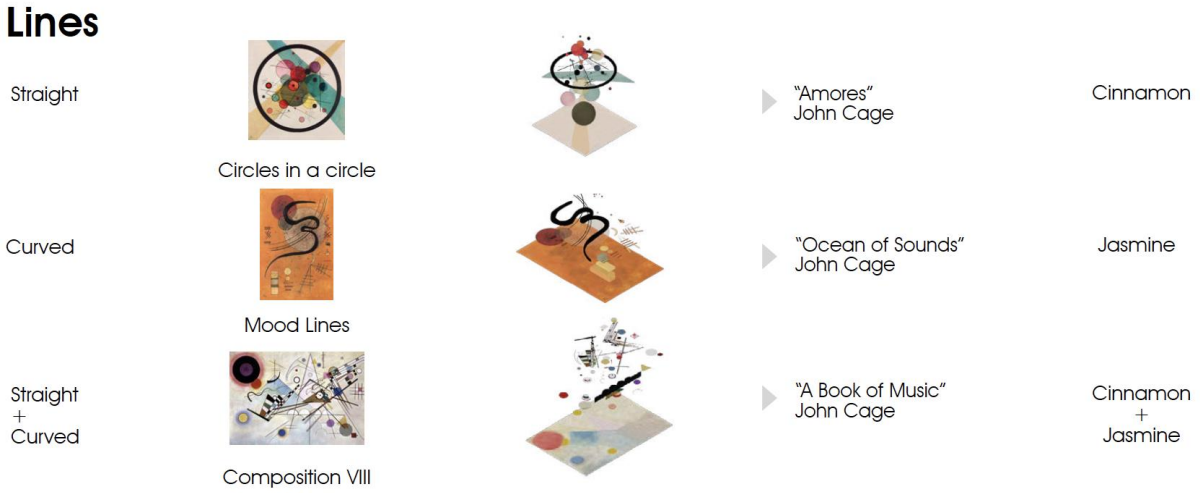


Figure 6: Example of the "Lines" chapter of the book: visual, auditory and olfactory stimuli associated with each painting.

The second modality, named *LabMode*, has been designed to allow users to interact with the paintings, manipulate the 3D models and eventually create personalized versions of the paintings. In the *LabMode*, for each painting, once the selected painting is framed and the user presses the

opaque surface, a recorder voice describing the painting features is automatically triggered and the user is asked to interact with the painting by scaling, rotating and translating the 3D models to better observe its details. In particular, in the *LabMode* the pinch is the chosen gesture to be used to interact with the 3D models. Similar to the *Experience Book mode,* also in this modality, the user is asked to press the "odor button" to activate the corresponding olfactory display (or displays) for 10 seconds.

Finally, a *Virtual Gallery* part has been developed to allow users to access the contents of the book even if they have not got it. More specifically, it is a *Virtual tour* of the Kandinsky's paintings accompanied by the quotes of Kandinsky's books. Some specific scripts have been used to manage both the swipe and the scroll gesture inside the single page, in order to navigate all the information about the paintings.

For what concerns the physical prototype, the case has been designed in order to comfortably allow the user to read the book, hold the device (smartphone or tablet) with the AR application in her/his hands and perceive the olfactory stimuli. The structure of the case has been obtained by using the laser cut technique.

The case also contains an Arduino Uno board equipped with a Bluetooth module that allows the communication between the AR application and the olfactory displays. As soon as one painting is framed and the digital contents are loaded, the device where the application is installed (smartphone or tablet) connects to the Arduino Uno board through a Bluetooth connection. Then, when the odor button is pressed, an input is sent to the board in order to activate the corresponding fan (left side, right side or both of them). Figure 7 shows how the olfactory displays are connected to the Arduino Uno board. The olfactory displays have been designed in order to host a single cartridge, inserted by the side of the case, to allow the user to perceive the correct olfactory stimulus for each painting.

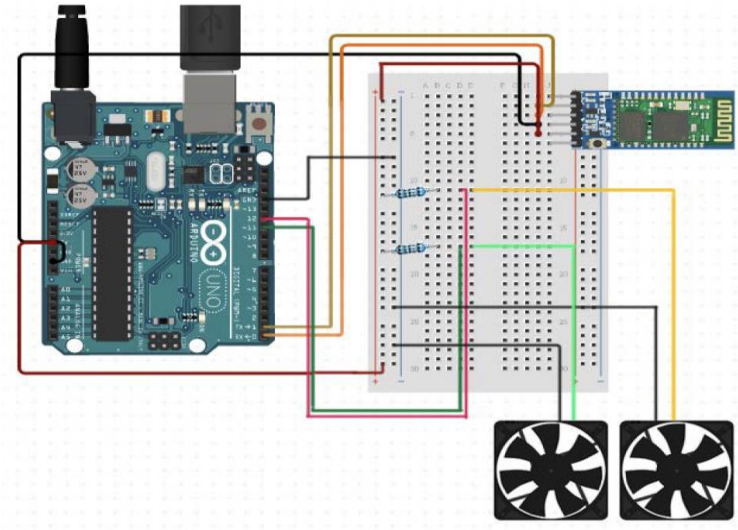


Figure 7: The wiring connecting the Arduino Uno board, the fans and the other components of the olfactory displays.

5 DISCUSSION AND CONCLUSION

The research work presented in this paper focuses on the possibility to improve the user experience of artwork books through a multisensory AR application (based on sight, hearing, and smell).

Specifically, the Kandinsky application has been designed and developed with the aim of improving the user's engagement and understanding of the content of Kandinsky's works of art. Particular attention has been devoted to the adoption of olfactory stimuli and their integration with the other senses. Indeed, the olfactory stimuli have been designed with the aim of impacting on the subconscious and conscious of users to evoke emotions and generate long-lasting memories.

Proper user-tests have not been performed yet. However, the authors have collected some preliminary comments and opinions from some participants that have tried the applications (see Figure 8). These participants reported a very high level of appreciation of the applications and a high level of pleasantness in using them. In particular, they stated that the addressed topic is very interesting and stimulating from a cultural point of view, and they learned new knowledge about Kandinsky's works of art.

For what concerns the visual part of the AR application and the interaction with the 3D models, they found the digital contents of great entertainment and stimulating to continue using the application. More importantly, they considered the experience very "immersive" thanks to the used multisensory approach. That is, the participants reported that music was very effective in isolating them from the real environment. Finally, as regards the olfactory stimuli, these were perceived correctly during the interaction and were considered as pleasant and stimulating.

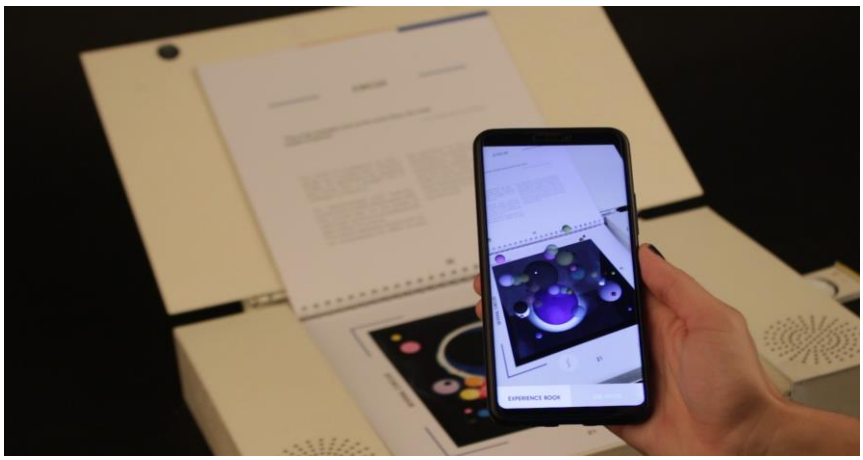


Figure 8: A participant interacting with the application.

In the near future, laboratory-controlled tests concerning the users' perceptual, emotional, physiological and cognitive reactions to the overall experience, as well as the usability of the interactive system, and the effectiveness of the device in the learning process, will be conducted.

It is worth saying that both the use of Augmented Reality and the multisensory approach are still rarely used for innovative books. On the opposite, these technologies can be effectively used to create an emotional link between the readers and artworks, to improve the users' experience and knowledge. These applications indeed can be exploited as valuable learning tools to be applied to a huge variety of topics and then have a powerful role from an educational point of view.

So, in an envisaged scenario, multisensory AR applications similar to those presented can be developed and implemented in a wide range of books (comprising scientific manuals from disciplines where olfactory stimuli are part of the topic or can enrich it) providing as the base product the case containing the olfactory device, designed to be able to host different books and applications.

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