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Exploring how to use virtual tours to create an interactive customer remote experience

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ABSTRACT

This paper investigates the use of Virtual Reality (VR) to develop virtual tour applications for marketing purposes. The aim is to explore how virtual technologies can support the creation of knowledge about a specific food product and the achievement of user engagement by a multi-sensory virtual tour of the real production site. The study provides design guidelines to create a valuable, multisensory experience by VR tours and demonstrate how the adoption of a user-driven approach, instead of a technology-driven approach, allows to achieve a positive intention to buy. The case study was represented by one of the excellences among Italian food products, the Parmigiano Reggiano (PR) cheese. The PR virtual tour was validated by a user testing campaign, involving more than 70 users: users' reactions and feedback were collected by human physiological data monitoring and questionnaires' administration. The research results demonstrated how virtual technologies could effectively help people to create a solid knowledge about a food product to support the marketing process and to form an intention to buy thanks to a better understanding of the quality of the local and traditional productions.

1. Introduction

Virtual Reality (VR) is a new way of perceiving experience and imaginary space with the help of specific tools and artificial intelligence [1]. In the modern era, VR can re-shape the idea of space and time, real and imaginary, thanks to the great familiarity with digital spaces [2]. Using widespread VR technologies like headsets, interactive and immersive virtual tours (VTs) can be easily enjoyed; they represent a good way to promote tourism by improving the user's knowledge about remote sites, which cannot be visited for different reasons (e.g., distance, cost, time, or any other constraint) [3]. The interest in VTs in the marketing field has been recently accelerated by the Coronavirus Disease 2019 (COVID-19) pandemic world scenario [4], because of the large-scale social restrictions lasting for months, preventing people from traveling. Indeed, the recent conditions due to the COVID-19 outbreak strongly affected the areas of tourist attraction and food tourism [5]. Thus, the application of VTs seems particularly promising for remotely visiting food tourism locations. VTs allow to bring the visitor inside the desired location through a totally virtual environment, reconstructed with a high level of realism and accuracy. Different devices can be used to access the virtual experience: from web-based platforms to smartphone apps, to VR head-mounted displays [6]. Recent works analysed the application of VTs for marketing purposes, in particular in food tourism [7–10]. However, the analysis of the recent literature revealed the main literature gaps. From one hand, it has been demonstrated that VR technologies can help food tourism only if the virtual experience is properly structured and user-driven. Although recent papers dealt with the analysis of user experience (UX) using different monitoring tools in virtual environments [11], there are limited applications concerning the analysis of the customer experience in virtual spaces. Moreover, the current research on VTs is focused on the available technologies and the advances in computer graphics to virtualize real environments, without caring about the generated consumer experience and the adoption of the most suitable design strategies to achieve an effective, multisensory users' involvement. On the other hand, the analysis revealed the lack of guidelines to design user-driven, effective VR-based tours able to create a positive UX and promote the intention to buy in potential customers, to be used for marketing purposes.

In this context, the main challenges of the research are:

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- Adopting a user-driven approach to design an interactive and multisensorial VT using low-cost VR technologies: about this challenge, the research provides a set of guidelines to design the virtual tour based on UX-driven techniques (e.g., storytelling, task analysis) and focuses on the need of rethink the use of virtual technologies from a marketing perspective, to attract people and improve their knowledge about a territory, a food process, and finally an agri-food product. This topic is particularly relevant in the context of the industry's transition towards industrial integration and informatization, considering the introduction of digital technologies and their use;
- Providing useful insights about food product promotion using innovative digital tools and multidisciplinary information taken from the production process: about this challenge, the paper describes how to implement a remote customer experience, from the virtualization of the food production process to the VT development, with the aim to involve users into the different production stages and to build a solid knowledge about the origins, the ingredients, and the food characteristics, to finally generate a pleasant UX. The VT will promote the visit of the real site and, finally, the product purchase. To enhance the remote customer experience, particular features called Key Marketing-Oriented Features (KMOFs) are implemented into the virtual tour.

The proposed approach has been validated to an Italian food product, the Parmigiano Reggiano (PR). The paper describes how to implement a remote customer experience of the PR production process by an immersive, multi-sensory VT and analyses the generated UX by a user testing involving a sample of 76 users. User testing was organized at the XiLab facilities (www.xilab.unimore.it) of the University of Modena and Reggio Emilia, in collaboration with the Parmigiano Reggiano Cheese Consortium. During tests, users were equipped with a wearable sensor to collect useful physiological parameters (e.g., heart rate, electrodermal activity) able to assess the user engagement and the emotional involvement and were asked by a post-test questionnaire to gather subjective impressions. A first user group was also stimulated with olfactory stimuli in specific phases of the VT, while a second group did not receive any olfactory stimulation. Experimental results show that the virtual visit can help build a solid knowledge about the product by the understanding of the production process and create a robust remote customer experience also for users who have never visited a cheese dairy before, also pushing to buy the product.

The main methodological and technical contributions of the research are as follows:

1. Adoption a user-centered approach to the design of digital immersive, interactive and multisensory tours. Even though user-centered design is not a novel practice, its use in the design and development of VR applications is still limited and main attention is usually focused on technological aspects, neglecting the users' needs and the customer experience requirements. Inclusion of such aspects is rare and usually left to the sensibility of the designer / developer. Diversely, this research defined a structured set of design guideline on how to build an effective virtual experience using multidisciplinary information taken from industry for marketing purposes, able to guide also not-experts in human factors and user studies to adopt a user-centered perspective for the development of valuable virtual experiences;
2. Definition of a low-cost technological set-up, including commercial VR technologies but combining them in a new way in order to digitize the real environment, virtualize it and provide a remote customer experience with a limited budget (less than 5000 euros);
3. Analysis of the remote customer experience by a testing campaign involving real users, based on the global provided UX and the final intention to buy the product. This represents a real novelty in marketing areas. Moreover, particular attention has been paid to the analysis of the impact of the olfactory stimulation during the virtual experience, in order to understand if it can be related to an improved emotional activation: the integration of olfactory stimuli and the analysis of its impact represent a further novelty due to the lack of studies in this field, as discussed in the related work section.

2. Related work

2.1. Virtual tour typologies

VTs are based on 3D photogrammetry reconstruction and creation of digital environments able to replace real places. The first applications of VTs appeared in education (e.g., virtual trips or virtual training programs) [12,13] and cultural heritage (e.g., web-based virtual tour systems able to replicate historical artifacts or archaeological sites) [14]. The easier way to create a VT is using 360° panoramic images to have a web-based virtual tour that can be navigated by the user [15]. A more complex application is having a VT guided by a virtual agent, as appeared in different contexts since the 90 s [16,17]. However, in that period the VT concept was not yet fully developed as in the modern era and technologies were not well performing like today. Nowadays, VR can be successfully used to create effective VTs. VR is a computer-generated simulation of a three-dimensional environment that can be interacted by a user using special electronic equipment and has the power to increase the user's perception by stimulating the human senses, via various activities [18]. Moreover, recent works demonstrated the positive adoption of immersive VR systems in creating virtual experiences able to improve the intention to buy a specific product [19]. Three types of VTs can be recognized in the scientific literature, according to their development strategy: image-based, video-based, and model-based. An image-based VT is realized by a series of 360-degree images that can be navigated by the user through specific features (e.g., arrows, floor plan hot points) [20] and enriched with additional data information (i.e., QR codes, panels, tags, pop ups, interactive features that improve the visual presentation and spatial understanding of the place being visited) [21]. It is the simpler type of VT, that can be available also using low-cost devices, like smartphones or google glasses. Such VT technology has a widespread diffusion in the tourism context, due to the ease of data to be collected from real places (just spherical images) and the low-cost post processing that requires minimal technical expertise for execution [22]. Video-based VT is based on the collection of a series of 360-degree videos, which can be assembled with a storytelling flow [23]. The best technology to navigate 360-degree videos and create an immersive experience is VR, using head-mounted displays (HMDs) that are actually widely spread and relatively cheap. A further push to the use of video-based tours is the YouTube VR platform, which allows users to upload 360-degree videos in an easy way and make it accessible to the general public in different ways: from a 2D computer screen by moving the screen with a cursor, to a google cardboard device, or in a most immersive way through a VR HMD. The key strength of video-based VT is the increased sense of presence [24] and immersion [25] in a location, with respect to the image-based tours. The third type is model-based VT, which is based on the reconstruction of the real world by 3D digital models. Such a type is especially used when a direct interaction between the user and the virtual objects is required. For instance, it well fits tourism or educational purposes to make the user aware of the preservation process of heritage or cultural sites or for tourist promotion according to a gaming approach [26].

2.2. Virtual tour applications

From the analysis of the scientific literature, we identified several fields that took advantage from the application of VTs, such as medicine [27], education [28] tourism [29], marketing and retail [30]. Table 1 provides an overview of the most relevant application areas where the

Table 1
Overview of the main fields of VT applications.

Application area	Type of VT	Scope	Reference
Medical-Psychological	Image-based	–	–
	Video-based	Reducing preoperative anxiety	[31–33]
	Model-based	–	–
Educational	Image-based	Platform for cultural tourism education	[34]
	Video-based	–	–
	Model-based	Creation of a virtual educational tour	[35,36]
Tourism-Marketing	Image-based	Valorise geodiversity	[21]
	Video-based	–	–
	Model-based	Exploring user acceptance of 3D virtual world	[30]
	Video-based + Model-based	–	–
Cultural heritage	Image-based	Preservation of the intangible cultural heritage	[22,37]
	Video-based	Preservation of both the physical built environment and intangible historical and sociocultural elements	[23]
	Model-based	Conservation of cultural heritage sites	[15,38]
	Model-based + Image-based	Virtual Museum dissemination of cultural heritage	[39]

concept of VT has been successfully applied, indicating the type of tour (image-based, video-based or model-based), and the main scope.

2.3. Virtual tours and user experience

Human-centred design (HCD) is a widely recognized, standardized approach to interactive systems design and development that aims to make systems usable and useful by focusing on the users, their needs and requirements, by applying human factors and ergonomics [40]. This approach enhances effectiveness and efficiency, improves human well-being, user satisfaction, accessibility and sustainability, counteracting possible adverse effects of use on human health, safety and performance. In particular, user experience (UX) refers to the individual perceptions and responses resulting from the use and/or anticipated use of a product, system or service, including the users' emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviours and accomplishments that occur before, during and after use [41]. In the design of digital experiences, the integration of human factors and ergonomics to generate a valuable UX is crucial to create effective environments, promoting knowledge creation.

In this term, VT applications should be designed according to UX principles, starting from the users' context analysis, and integrates a multi-sensory stimulation. Indeed, having an immersive, interactive experience is found as fundamental in attracting new visitors to the production sites [42] and in general promoting tourism [29]. Since the development of an effective virtual experience requires the presentation of virtual contents in a very realistic way, based on the involvement of the different human senses according to a coherent and convincing sensorial stimulation, it requires the integration of several sensory contributions, recreating realistic experiences. Thanks to the UX-driven perspective, the proposed VT uses an enriched stimulation modality involving multiple human sensorial channels. In recent years, several research works have focused on improving mainly visual and audio simulations, which give the users the impression of being faced with a good simulation of reality. As a result, most VT applications rely just on audio-visual stimuli and do not exploit other sensory cues. Diversely, the proposed VT adds hand interaction and olfactory stimuli. Hand interaction and head motion tracking are widely adopted in gaming and cultural heritage applications, but they are not fully exploited in marketing and tourism. Furthermore, the addition of olfaction to VR experience is not fully supported today, so it represents a novelty in VTs. Olfaction has been found very significant in influencing the human experiences also in VR environments related to food exploration and knowledge [43], and some dedicated hardware tools are emerging to add scents to virtual scenes (e.g. [44]), but olfactory displays are still very undeveloped if compared to the other sensory VR interfaces [45], and there is not ready-to-use equipment. Even if the use of odours to enhance an audio-visual media is not a new idea [46], there is a lack of devices available on the market, but just few prototypal applications with several limitations for real applications [47]. The main problems rely on the synchronization of the sense of sight with that of smell, in particular from the perceptual point of view, and the generation of the smells. More recently, some interesting prototypal solutions have been developed in research: a compact, low-cost olfactory display fitted to the hand controller of the HTC Vive VR system to enable control of scent magnitude and blending has been proposed by [48]. It allows the combination of odours with virtual objects, suitable for recreational, educational, scientific, or therapeutic functions. In addition, a skin-interfaced olfactory feedback systems with wirelessly, programmable capabilities based on arrays of flexible and miniaturized odor generators for olfactory VR applications has been proposed by [49]. However, they are prototypal solutions not available in the marker so far.

In this direction, the proposed VT provides a direct exploration of the virtual place by multisensory stimulation, by combining VR audio-visual simulation with the olfactory stimulation provided by real food scents.

3. Methods and materials

3.1. Research approach

In order to design a valuable remote experience that can satisfy the users and attract new customers at real sites, the user-centered design (UCD) approach was adopted. UCD suggests structuring the process into 4 phases (i.e., requirement gathering, alternatives design, prototyping and evaluation), as described in [40]. Such an approach can assure that the design meets the user requirements and can produce a valuable UX. It is an iterative process, which goes on until a positive UX evaluation, usually by user-based assessment methods [50]. The added value of this approach is the involvement of users from the beginning of the design process to understand what users want and need [51]. Requirements gathering is the first and the most important phase that helps to create proper user requirements to be satisfied. The main techniques adopted to collect the users' impressions and to define the requirement list are: user observation (observing people during physical tours on the field), questionnaires (asking people their potential interest in digital visits of the production site of specific food product, as reported in a previous publication [42]), and interviews (asking people impressions and reactions about the physical visit on the field and collecting comments about the potential use of virtual technologies). Moreover, two specific tools are used to present the collected requirements: "personas" and "storytelling". Personas have been used to represent the emerged requirements. Personas are fictitious representations of target users, inspired to all information collected from the user research [52], and able to provide an effective and synthetic description of the users' needs, lifestyle habits and purchase reasons [53]. Storytelling is used to describe the user journey [54] and support the definition of the main contents of the virtual experience. Both tools are very useful for driving the development of the proper knowledge transfer, from industrial information collected on the field to the creation of the most proper virtual experience. About the design, the proposed approach fills the gap between the current technological issues, related to the combination of video-based and model-based VTs, with UX-related aspects. Indeed, the VT proposed in this research uses both descriptive 360-degree videos of the real places and 3D models as reconstruction of interactive items to create a more true-to-life, immersive, and multisensory tour, enhancing the remote virtual visit of the production site. The customer experience is further enhanced by the presence of virtual characters into the scene to promote social relations, and meta data to augment the reality and provide additional value. Prototyping has been realized using a VR platform and different hardware and software tools to enable a multi-sensory stimulation and the designed features of the virtual scene, as described in detail in the next paragraph and summarized in Fig. 2. Finally, evaluation is carried out by user testing, as carefully described in Section 4.

Fig. 1 depicts the user-centered design paradigm defined for marketing-oriented VTs.

3.2. Technological set-up

The research uses several hardware and software technologies to implement a realistic and immersive VR simulation based on the combination of descriptive scenarios rebuilt from the real plants, and interactive virtual scenes using 3D geometrical models, where touchable objects with life-like behaviours are included. Fig. 2 shows the provided technological framework, the role of selected hardware and software tools and the stimulation of the different human senses. In the figure, hardware tools are reported in italics black, software tools in italics blue, and the senses in regular font. All contributions are related to one of the human senses, represented in the light blue box at the middle of the picture. The five human senses are stimulated, and the sensorial perception is elaborated by the human brain to form a sensorial UX. Blue arrow refer to sensorial stimuli provided by the VR platform, while orange arrows refer to data retrieved from the field (e.g., production site or users). The provided framework is not linear, but circular, to better represent the reality: the user is at the centre of the provided virtual experience and all stimulations contribute the create the final UX based on sensorial perception and cognitive elaboration.

The hardware tools allowed the fruition of the virtual experience, created for a single user, through low-cost and easily replicable equipment. Such set-up can be used in University Lab as well as in any location (e.g., offices of the PR Consortium or dedicated spaces for the remote customer experience that could be arranged anywhere). The software tools allowed the creation of the descriptive virtual scenarios and the implementation of the interactive scenes, the 3D objects modelling and their rendering with high level of realism, and the video-audio editing necessary to create the desired storytelling of the tour.

In particular, the study adopts the following hardware tools:

- HTC VIVE Pro-eye: it is a head-mounted display (HMD) to support a single-user VR experience by providing 3D stereoscopic viewing, immersion and 3D sound to put the user into the virtual world thanks to head and body motion capture, by four VIVE base stations;
- Leap Motion: it is a marker-less human gesture recognition to make user intuitively and naturally interact with the virtual objects with its bare hands, without grasping wands or joystick or wearing a glove. In the study configuration, the Leap Motion is fixed in front of the headset to better record hand gestures. It is used to track the user's hand movements in order to interact with the virtual items during the tour;
- Insta 360 One X camera: it is a low-cost 3D camera to easily collect 360-degree images and videos from the real production site;
- RODE MT1A microphone: it is a regular microphone for voice recording, used to record the voce of a real guide to be moved into the virtual scenes;
- Empatica E4: it is a minimally intrusive, sensorized wristband adopted to analyse the users' emotional engagement. The wristband can be easily worn by users during the VT experience to collect real-time data on multiple human parameters such as skin temperature, photo-plethysmography (PPG), galvanic skin response (EDA) and arm accelerations. Such data, properly interpreted, can assess the emotional engagement and workload.

In addition, the following software tools are adopted:

- Unity3D: it is a one of the main VR platforms for generating virtual and immersive simulations, that manages all contents and input / output data from/to different devices;
- SteamVR: it is a specific VR platform to make the application usable through a head mounted display (HMD) and to manage the tracking user point of view from the headset and body sensors;
- CATIA V5: it is a 3D modelling tool adopted for modelling virtual objects;
- Blender: it is a free and open-source 3D computer graphics software tool set used for creating high-quality visual effects, 3D-printed models, motion graphics and video games effect;

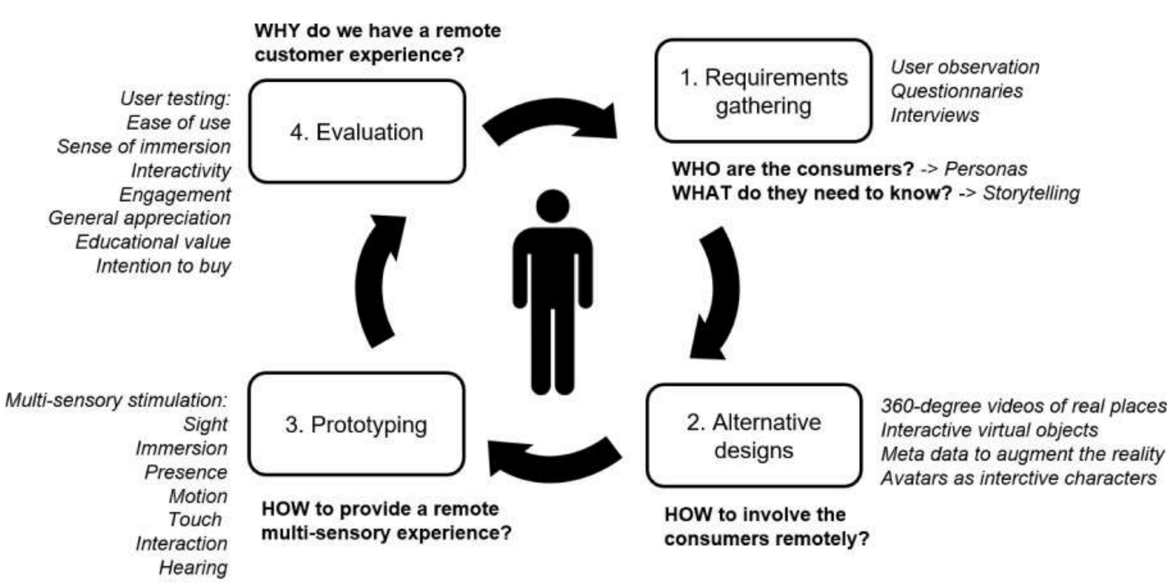

Fig. 1. User-centered design paradigm for marketing-oriented virtual tours.

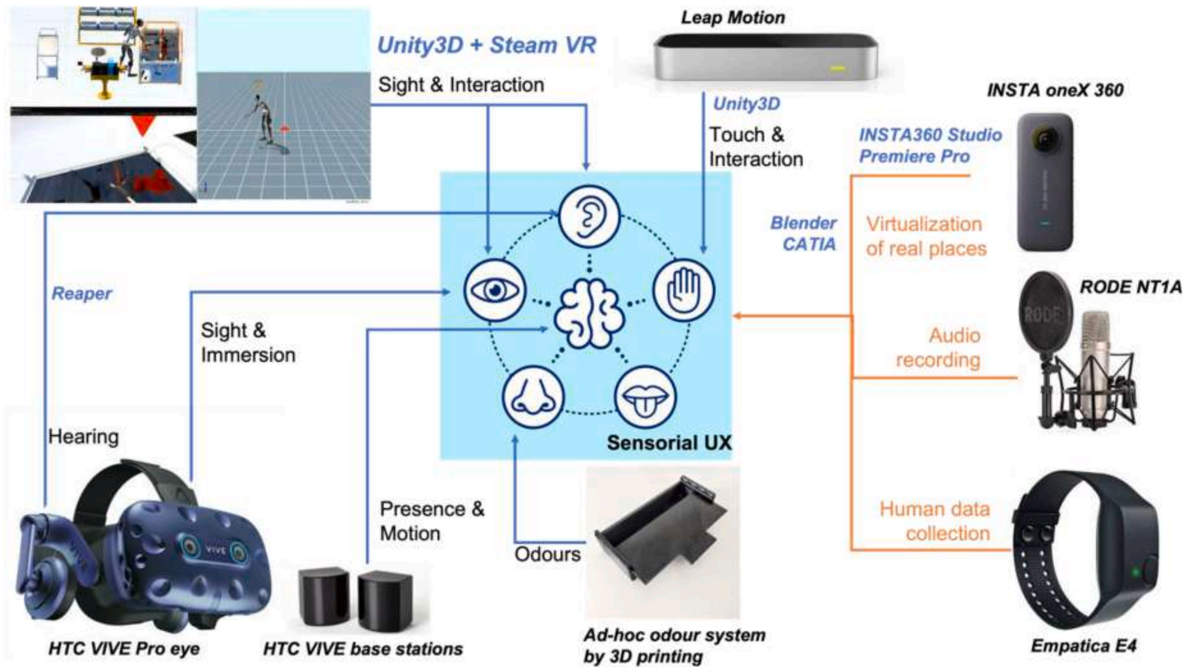

Fig. 2. Technological set-up (HW and SW) for multi-sensory stimulation.

- Insta360 Studio and Premiere Pro: they are image- and video-processing tools to respectively used for 360-degree images and video post-processing;
- Reaper: it is a digital audio production application and is used for audio editing.

3.3. Use case

The use case is represented by one of the most famous Italian cheeses, the Parmigiano Reggiano (PR). In detail, the research design and developed a VT according to the proposed approach, with the final scope to immerse the user into the PR production process to create a solid knowledge about the PR excellence and quality, and to finally promote the intention to buy. The VT experience can achieve these results thanks to a high level of immersion and interactivity within the main phases of the PR cheese production. In this way, the developed VT can offer the chance to virtually visit the production site by a wide range of potential customers, who cannot physically visit the specific location. It means a huge opportunity for the producing companies to expand their market share.

At the moment, the main operating PR dairies are over 300 distributed in the Emilian territory in Italy, between the towns of Mantua, Parma, Reggio Emilia, Modena and Bologna. A specific dairy has been selected to carry out the preliminary analysis of the process phases and defining the storytelling. The selected dairy is one of the oldest dairies of the typical production area, but at the same time it is strongly attentive today thanks to a good organization of guided visits even with foreigners. Moreover, it is located in the Modena area and easily visited by the university researchers involved in this study (https://www.caseificio4madonne.it/). After the visit to the dairy, researchers defined the most crucial process activities and defined the storytelling.

The virtual experience aimed at replicating the storytelling in a very effective and engaging way, using the equipment described in Section 3.2 and the user-centered approach described in Section 3.1. According to UCD, the design of the VT was structured in four phases:

1 user research: analysis of the target final consumers and their needs, to understand the users' expectations and VT design requirements;
2 inspection of the production site and VT design: visits to the real production environment to collect data and information about the process and its virtualization:
3 virtualization of the production site and VT development: digitalization of the most important phases of the production process, according to the storytelling previously defined;
4 assessment of the remote customer experience: testing with users in Lab to assess the reactions and impressions of the developed VT. Users were monitored by human sensors to collect objective data about their experience and were asked to fill a questionnaire to collect their subjective feedback.

In the following paragraphs, each phase is described in detail.

Phase 1. - *User research:* this phase focused on the analysis of the users' needs and the definition of the user requirements to support the VT design. 3 personas were defined as target users in the research, belonging to different countries, social status, and professions, since the audience of this type of VT is quite broad. For the selected use case, target users ranged from experts in the agri-food industry to students or common people without a specific knowledge about Italian foods. As a result of this phase, the VT design had to include a combination of descriptive modality and gaming modality to engage the different potential users, and the provided information during the tour was configurable according to the different level of individual knowledge and personal interest in the topic.

Phase 2. - *Inspection of the production site and VT design:* this phase referred to the analysis of the real production site on order to schematize the process and define an appealing story to present to the user, focusing also on the multi-sensory experience offered by the traditional tour. Indeed, a traditional guided tour inside the dairy was carefully analysed to collect audio and video material to replicate a "typical" real visit tour. As a result, the storytelling of the VT to be designed was defined, as illustrated in Fig. 3. Each phase will be included in the VT and will focus on some specific features that will involve the user and create a new knowledge. Fig. 4 shows an example of video material collected from the real production site, related to the milk preparation in the milk boilers (step 2 of the storytelling).

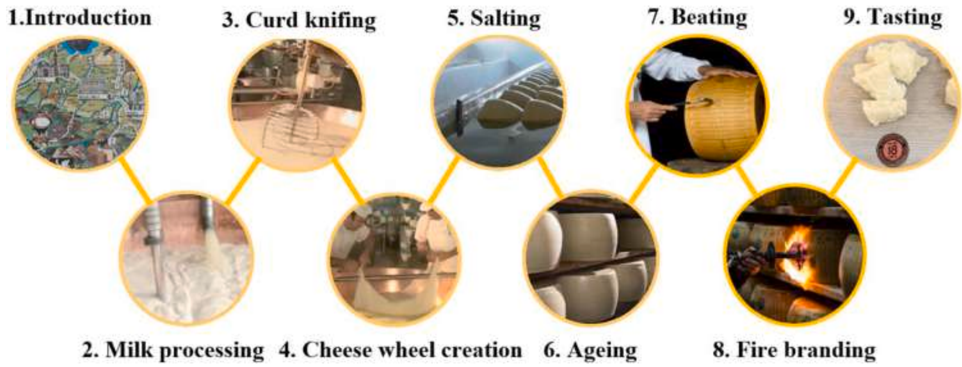

Fig. 3. Storytelling of the PR production process for the following VT creation.

Fig. 4. Example of video material collected from the real production site (step 2 - milk processing).

After the analysis of the on-site experience, the attention focused on the design of the digital VT able to create similar emotions by a remote digital experience. Moreover, starting from the material collected at the selected dairy, the research aimed at creating a generic virtual experience to promote the PR cheese independently from the specific production factory.

Phase 3. - *Virtualization of the production site and VT development:* this phase concerned with the digitization of the real production site and the design of the virtual experience, combining a video-based approach and a model-based approach for the VT creation.

The VT was structured into five scenes, according to the storytelling, by mixing descriptive modality and gaming modality: 1. Virtual welcome, 2. PR production process (from milk preparation to aging); 3. Beating virtual scene; 4. Fire branding virtual scene; 5. Virtual tasting.

Scenes were properly linked to each other to create a unique visitor flow, with a predefined set of information provided to the users. Extra-contents were added in the scenes to make users autonomous in the content selection and fruition, to satisfy the different users' expectations. In order to generate a realistic experience and push the users to buy the product, some specific items were introduced into the VT, called Key Marketing-Oriented (KOM) features. The adopted KMO features were as follows: A. presence of a human-like virtual guide (e.g., an avatar) to provide useful information about the process and interact with the real user, replacing the physical guide at the real site. Having a reliable guide is considered essential to achieve an engaging experience; B. autonomous and interactive transition among the scenes, that the user can select according to a gaming mode (e.g., moving to the next scene by grabbing a virtual item like a cheese flake); C. learn-by-doing activities to stimulate the active participation and emotional engagement and stimulate the learning process (e.g., some virtual scenarios include activities that the user can perform directly by grasping the virtual objects).

In more details, the welcome scene represented a generic reception room, with the specific function of introducing the user to the tour, the quality of the brand, the typical product, and its territory of origin. It uses interactive panels and a virtual avatar to provide the information. The PR production process was virtually represented by a sequence of 360-degree immersive videos, where the user can navigate and freely move, guided by an external voice. The process is "augmented" by three virtual scenes (i.e., beating virtual scene, fire branding scene, virtual tasting), properly developed to implement learn-by-doing tasks: they included tangible, interactive objects, which can be touched and used by the visitor. In particular, the beating and fire branding refer to the maturing phase of the PR that includes the quality control operation known as "beating" or "expertization", and the subsequent practice to mark the brand of origin on the cheese crust, known as "fire branding". Finally, the virtual tasting regarded the description of different ages of

PR cheese, the virtual grasping of cheese flakes and the possibility to move them until the mouth to evoke a virtual tasting. Virtual testing is empowered by olfactory stimulation thanks to a dedicated drawer, realized by 3D printing and attached under the VR HMD. The drawer contained little cheese pieces and release their odour when useful to add also smell stimulation in a realistic way.

Fig. 5 provides examples of interactive virtual scenes as developed in Unity3D (welcome, beating, fire branding, tasting).

Phase 4. - *Assessment of the remote customer experience:* this phase referred to the user testing and the related UX evaluation. During the test, every user was asked to wear the Empatica E4 wristband for real-time physiological data streaming and visualization, in order to understand the level of emotional activation during the interactive scenes and in relation to the olfactory stimulation. The wearable sensor allowed detecting various physiological parameters, such as EDA (Electrodermal activity), BVP (Blood Volume Pulse) and acceleration. EDA acts as a proxy indicator of sweating, measured by the electrical conductance of the leather. BVP measures the Heart Rate according to the volume of blood that passes in an area over a certain period of time, in order to evaluate the heart rate variations in relation to the stimuli offered by the tour. Finally, the acceleration of the bracelet indicates the user's arm movements. Fig. 6 shows an example of the physiological parameters in the time domain, collected during a user session.

A post-test questionnaire was defined to specifically understand the remote customer experience and the intention to buy. The questionnaire was structured according to the theory of planned behaviour adapted to the VT context for a food product. It contained measurement items derived from extant literature and adapted to the specific context of this study, as also applied in [42].

4. Experimental user testing

4.1. Participants

The first part of the questionnaire collected information about users (i.e., gender, age, affiliation) and their previous knowledge on the product and familiarity with VR-based tours. A total of 76 people participated in the user testing (51 male, 25 female, age range 20-over 60, M = 37.18 years, SD =13.22 years). Most of the participants (71%) were members of the University of Modena and Reggio Emilia (professors, students, personnel), while other users belonged to the PR consortium (12%) or external, recruited by social networks and website promotion (17%). From the analysis of the user demographic and information data, it emerges that 41 people had never visited a PR cheese dairy, while 45 people had already visited a PR dairy at least once. Fig. 8 provides the age distribution of the participants.

User testing was carried out from June 2021 to October 2021. Users were divided into two homogeneous groups, for age range and level of familiarity with VR devices: the first group received the olfactory stimulus during the virtual testing, while the second group did not receive any olfactory stimulus. More specifically, 63 users tested the VT with olfactory stimulation, while 13 users tested the VT without the olfactory stimulation. The groups were not aware about the type of VT they experienced. All groups were monitored by the E4 wristband during the testing.

Fig. 5. Examples of interactive virtual scenes developed in Unity3D (from the left top: welcome, beating, fire branding, tasting).

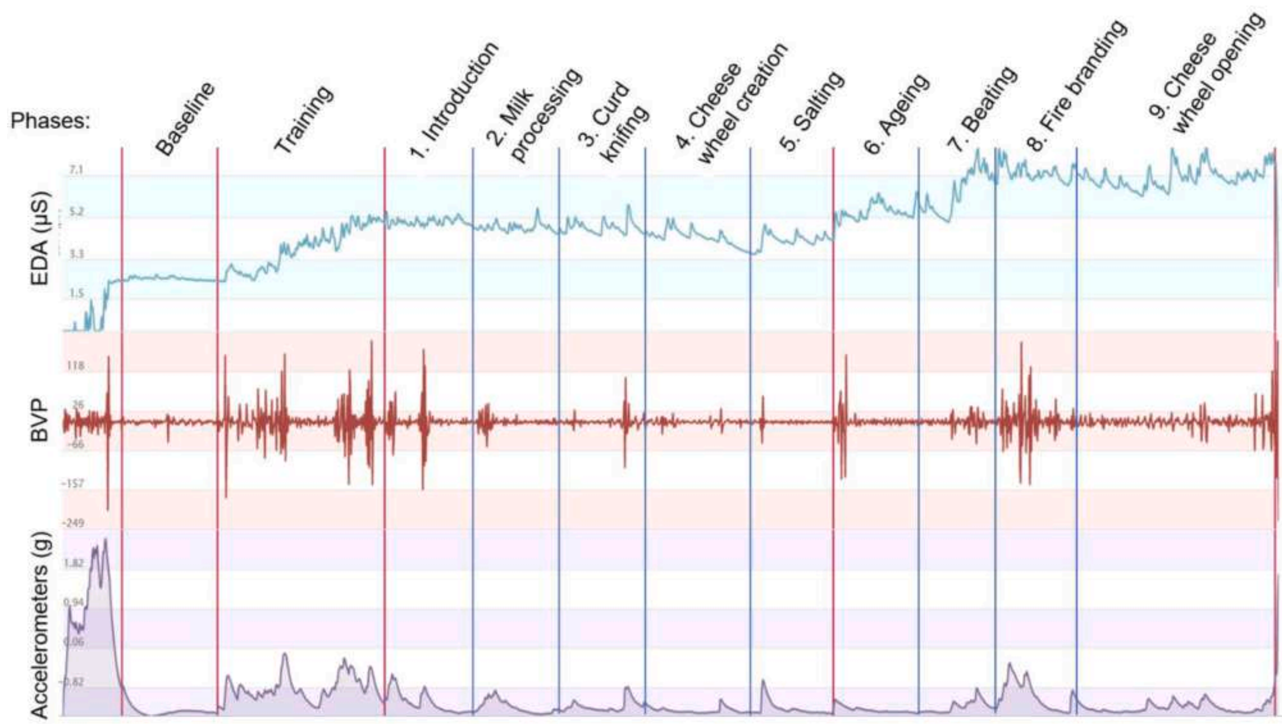

Fig. 6. Example of parameters measured by E4 wristband during the testing phase.

4.2. Experimental procedure

User testing was carried out at the XiLab facilities at the University of Modena and Reggio Emilia, at the Engineering Department "Enzo Ferrari" (www.xilab.unimore.it). Tests were carried out according to a structured protocol analysis that concerns the following phases:

- *Warm up*: a brief description of the VT and the project is provided to the user. An informed consent is obtained from all participants at the beginning of this phase;
- *Baseline*: the user wears the E4 wristband and takes relax seating for 2 min, meanwhile E4 collects the biometric parameters in a relaxed condition. The wristband will remain on for all the VT duration to collect data about the user during all the virtual experience;
- *Training room with VR*: the user wears the VR headset equipped with a Leap Motion. The VR scene is started by the users using an interactive menu visible in the virtual space. In this preliminary phase, the user receives a virtual training room, where some symbolic objects of the VT are replicated, and an expert teaches the user about how to move into the virtual space and how to manipulate and interact with the virtual objects properly. This phase has not a fixed time since it depends on the users' familiarity with VR tools. It lasts usually from 5 to 15 min;
- *VT experience*: the user keeps the VR headset and starts the enjoyment of the VT through the different phases. Within the VT experience, a specific phase could be enhanced with the olfactory stimulation. The VT experience lasts about 20–25 min, depending on the individual choices about the additional contents and activities. In order to relate the physiological parameters collected by E4 to the VT timeline, a set of markers were defined inside the E4 data recording software to easily synchronized the collected data with the VT phases. During the VT, two homogenous groups of users were organized. Group no.1 was stimulated by an odour coherent with the specific food product (i.e., PR cheese), thanks to the drawer realised into the VR headset. A little piece of the product was inserted by expert at a specific moment of the VT, without any interference with the VT experience. Users were completely unaware of it. Group no.2 did the same activities without the olfactory additional stimulation;
- *Post-test questionnaire*: after the VT, the user is asked to fill out an evaluation questionnaire for the assessment of the remote customer experience. The questionnaire is structured according to the theory of unplanned behaviours and included some specific questions related to the UX assessment and VR tools acceptability and familiarity, taken from the User Experience Questionnaire (UEQ) [53]. Users could express their ratings in different ways: according to the 5-point Likert scale, with multiple-answers or open-answers. The main aspects investigated by the questionnaire were: level of enjoyment and satisfaction of the VT, level of immersion and involvement during the VT, level of comfort and ease of use, educational value for knowledge creation, future intention to buy. Following the recommended translation procedure, a double translation English-Italian and Italian-English was used to reduce translation bias. To reduce response bias, the order of measurement items was shuffled. The questionnaire was filled on-line by a google form on computers provided at the Lab.

Fig. 7 shows the experimental procedure for the VT participants and the use of the E4 biosensor before and during the experimental testing. Data collected from E4 are then analysis in order to define the user's emotional engagement and workload according to a rigorous procedure, as recently described in [55].

5. Results and discussion

Data collected during the experimental user testing were useful to understand the role of VTs in the food knowledge creation and the achievement of an engaging remote customer experience, with a consequent positive intention to buy. Firstly, the questionnaires' responses were analysed and interpreted. Secondly, the human physiological data were analysed in correlation with the VT phases and the sensory stimulation provided, together with the subjective impressions expressed by users to deepen the emotional involvement.

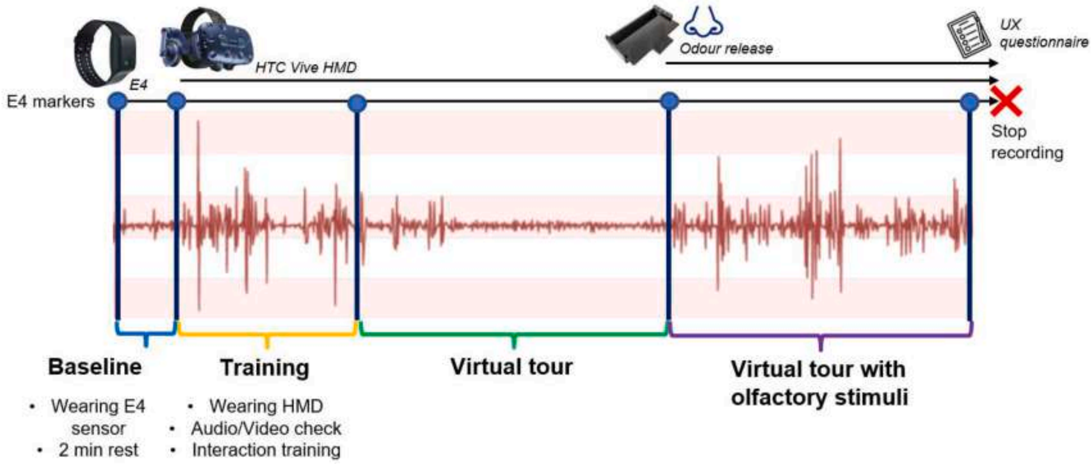

Fig. 7. Experimental procedure and example of data collection by E4 during the VT experience.

5.1. Analysis of post-test questionnaires

The first part of the questionnaire refers to the participants' information: in particular, it mapped the familiarity with VR-based tours and the previous knowledge and use about the product. As reported in Table 2, the majority of participants (89%) has never used a multimedia support like a VT to virtually visit an agri-food production site; only few of them (11%) have already experienced a VT for agri-food products or exploration of a food production site. This fact must be considered in the evaluation of the users' responses: indeed, the novelty of the virtual experience can amplify the initial subjective impact, but it could also dissipate once the technology is more widespread and known [56]. About the previous knowledge and use about the product, the questionnaire analysed the frequency of product consumption by users and the product purchase habits before the VT. As shown in Table 2, results highlighted a frequent use of the product: most of them consume it regularly (54% consumes the product 1–2 times a week and 29% almost every day), and the product purchase takes place frequently or very frequently (61%). We also collected that half of participants (50%) have already visited a PR diary, so the user sample is homogenous about the previous knowledge about the product-related production process.

Table 2
Participants' ($n = 76$) information.

Type of information about users		%
Gender	Male	67
	Female	33
Affiliation	University	71
	PR consortium	12
	External	17
Age	20–30 years	54
	30–40 years	17
	40–50 years	8
	50–60 years	16
	> 60 years	5
Familiarity with VR-based tours	It is the first time that I use a multimedia support to visit the production plant of an agri-food product	89
	I am used to exploring production sites through VT	4
	I have already used VTs to visit a food production site	7
Previous visits in PR diaries	Yes	50
	No	50
PR cheese consumption	Every day	29
	Regularly (1–2 a week)	54
	Sometimes (2–3 a month)	8
	Rarely (a few times a year)	7
	Never	1
PR cheese frequency of purchase	Very frequently	33
	Frequently	28
	Sometimes	26
	Rarely	9
	Very rarely	4

The second part of the questionnaire investigates the perceived UX during the virtual experience: according to a 5-point Likert scale (1 = low, 5 = high), the participants' feedback was collected for the different categories analysed (i.e., ease of use, sense of immersion, interactivity, engagement, general appreciation, educational value). The global feedback was extremely positive, as reported in Table 3 as mean value and standard deviation, included both groups (i.e., users receiving the olfactory stimulation and users without any olfactory stimulation).

Regarding ease of use, the VT was found highly accessible (4.17 out of 5), easy to navigate (4.16 out of 5) and users did not face any difficulties (4.03 out of 5). We can conclude that the VT was perceived by the users as an easily usable tool to virtually experience the production process. Regarding the sense of immersion, six questions examined specifically the sense of realism of the proposed simulation and its capacity to transport users inside the industrial production site. Immersion is a crucial indicator of the sense of presence, which is a scope of any VR simulation [57]. The VT was found close to reality (3.80 out of 5), immersive enough to make users feel into another world for a while (3.82 out of 5) and to avoid any external distraction (4.13 out of 5). Finally, the VT was mostly perceived as authentic (4.20 out of 5), which is extremely important considering the purpose of this study.

Similarly, the level of interactivity offered by the VT was investigated through five questions, concerning the modality of control of the scenes and interaction with virtual objects. The level of interaction achieved was positive (4.08 out of 5 on average). The VT was judged very interactive (4.16 out of 5) and flexible at the same time (4.16 out of 5), with a good control of the navigation (4.09 out of 5). The main limitation regards the navigation of 360-degree video scenes, in which the user is not able to move freely as in a real environment (3.84 out of 5).

As a result of the high levels of ease of use, immersion and interactivity reached by the proposed VT, also the engagement of users during the remote experience was judged positively: the VT was found enjoyable (4.55), interesting (4.71), funny (4.63) and engaging (4.63), with an average score of 4.71 out of 5. The participants also expressed their general appreciation of the VT by seven questions: participants declared to strongly recommend the VT (4.61), promote this experience (4.63) and were generally satisfied (4.70). Thanks to the adopted user-centered approach, the VT finally met the users' expectations (4.61). Participants were also asked to evaluate the knowledge creation of the VT through five questions, under the educational value category. The VT was found useful to acquire information about the product (4.43) and the process (4.47), and to learn more about the PR. In general, all

Table 3
Results about the participants' ($n = 76$) UX during and after the VT.

Category	Questions	Mean value (1 to 5)	St. Dev.
Ease of use	It was easy to use the VT	4,17	0,81
	It was easy to navigate through the VT	4,16	0,82
	I had no difficulty using the VT	4,03	0,85
Sense of immersion	The VT seemed authentic to me	4,20	0,75
	During the VT I had no external distractions	4,13	1,14
	During the VT I felt in another world	3,82	1,12
	During the VT I lost track of time	3,41	1,32
	It was strange to come back to reality after experiencing the VT	2,89	1,37
	During the VT I felt that I was experiencing something real	3,80	0,91
Interactivity	The VT was highly interactive	4,16	0,77
	I was in control of the navigation through the VT	3,84	0,98
	I was able to freely navigate the spaces at 360°	4,09	0,88
	I was able to freely navigate the room at 360°	4,14	0,83
	I have found that the VT experience offers a lot of interaction flexibility	4,16	0,78
Engagement	The VT was engaging	4,63	0,49
	The VT was fun	4,63	0,51
	The VT was interesting	4,71	0,48
	The VT was captivating	4,57	0,62
	The VT was enjoyable	4,55	0,62
General appreciation	I am satisfied that I used the VT	4,70	0,43
	The VT met my expectations	4,61	0,50
	I am satisfied that I have used the functions offered by the VT experience	4,71	0,42
	I am satisfied with the contents offered by the VT experience	4,59	0,50
	I will recommend the VT experience inside the Parmigiano cheese factory	4,53	0,61
	I will positively promote this experience of the VT	4,63	0,49
	I will strongly recommend others to experience the VT	4,61	0,54
Educational value	Thanks to the VT I know more the PR cheese	4,36	0,81
	The VT allows you to know the PR cheese product better	4,54	0,60
	I learned something new about the PR cheese during the VT	4,39	0,82
	The VT facilitates a good learning experience on the PR cheese working processes	4,47	0,70
	VT allows me to acquire information about the PR cheese quickly	4,43	0,64

questions received a high score, demonstrating how VTs represent a good opportunity to disseminate food products and related process information, also with an education scope. Finally, the participants' intention to buy after the VT experience was analysed, as reported in Table 4. The results were very good, since 72% of participants strongly agree in the future purchase of the product and none of them declared not to buy the product.

Questionnaire data can be further investigated by inferential statistical analysis using a *t*-test to determine if there is a significant difference between the means of two groups, properly defined from the user sample. In particular, the user sample was analysed considering the gender (men / women), the age range (≤ / > 30 years old) and the prevision experience into a physical cheese diary (yes / no). The p-value from *t*-test express the probability that the results from the two samples of users considered occurred by chance. P-values are compared with $\alpha = 0.05$, expressing the 5% of probability that the result is correct. Low p-values indicate that the means of the two groups did not occur by chance. Thanks to this analysis, we can define it the gender, the age and the previous experience in a physical diary significantly affected the users' response. Table 5 shows the p-value results from *t*-test for the

Table 4
Results about the intention to buy after the VT.

Are you going to buy PR in the future?	Strongly agree	72
	Agree	12
	Neither agree nor disagree	15
	Disagree	1
	Strongly disagree	0

Table 5
T-test results during and after the VT (significant differences for gender, age distribution, previous experience in physical diaries) considering $\alpha = 0.05$.

Category	Questions	p-values Men/ Women	Age ≤ 30/ Age >30	Exp/ No exp
Ease of use	It was easy to use the VT	0.413	0.926	0.398
	It was easy to navigate through the VT	0.382	0.548	0.205
	I had no difficulty using the VT	0.636	0.783	**0.014**
Sense of immersion	The VT seemed authentic to me	0.099	0.484	0.375
	During the VT I had no external distractions	0.880	**0.007**	0.601
	During the VT I felt in another world	**0.001**	0.566	0.602
	During the VT I lost track of time	**0.017**	0.379	0.825
	It was strange to come back to reality after experiencing the VT	**0.014**	0.518	0.656
	During the VT I felt that I was experiencing something real	0.112	0.112	0.200
Interactivity	The VT was highly interactive	0.334	0.522	0.452
	I was in control of the navigation through the VT	0.079	0.845	0.903
	I was able to freely navigate the spaces at 360°	0.848	**0.024**	0.565
	I was able to freely navigate the room at 360°	0.687	**0.016**	0.569
	I have found that the VT experience offers a lot of interaction flexibility	0.987	0.132	0.186
Engagement	The VT was engaging	0.107	0.768	0.961
	The VT was fun	0.567	0.543	**0.021**
	The VT was interesting	0.104	0.545	**0.020**
	The VT was captivating	0.468	0.476	0.767
	The VT was enjoyable	0.393	0.870	0.217
General appreciation	I am satisfied that I used the VT	0.076	0.307	0.261
	The VT met my expectations	0.200	0.502	0.359
	I am satisfied that I have used the functions offered by the VT experience	0.263	0.281	0.379
	I am satisfied with the contents offered by the VT experience	0.154	0.383	0.117
	I will recommend the VT experience inside the Parmigiano cheese factory	**0.006**	0.412	0.431
	I will positively promote this experience of the VT	**0.023**	0.509	0.392
	I will strongly recommend others to experience the VT	**0.028**	0.834	0.680
Educational value	Thanks to the VT I know more the PR cheese	0.972	0.001	0.124
	The VT allows you to know the PR cheese product better	0.309	0.259	0.964
	I learned something new about the PR cheese during the VT	0.580	0.063	0.102
	The VT facilitates a good learning experience on the PR cheese working processes	0.457	0.865	0.401
	VT allows me to acquire information about the PR cheese quickly	0.417	0.462	0.520

above-mentioned groups. Significant values are marked in bolt, highlighting those replays where the difference between the two groups is significant. Differences in gender brought to significant differences on the sense of immersion ("during the VT I felt in another world" with $p = 0.001$, "I lost track of time" with $p = 0.017$, "it was strange to come back to reality" with $p = 0.014$) and the general appreciation ("I will recommend the VT experience" with $p = 0.006$, "I will positively promote this experience of the VT" with $p = 0.023$, "I will strongly recommend others to experience the VT" with $p = 0.028$) probably due to a different sensibility and trustiness to technologies between men and women. Age seems to have a limited significant impact, mainly about the sense of immersion ("during the VT I had no external distractions" with $p = 0.007$) and the level of interactivity ("I was able to freely navigate the spaces at 360°" with $p = 0.024$ and "I was able to freely navigate the room at 360°" with $p = 0.016$) probably linked to a different use of the technology. Diversely, the pre-existing knowledge of a PR cheese diary by a physical experience on-site seems to impact on the ease of use ("I had no difficulty using the VT" with $p = 0.014$) and the engagement ("The VT was fun" with $p = 0.021$ and "The VT was interesting" with $p = 0.020$) probably due to the deeper knowledge about the PR production process.

5.2. Analysis of human physiological data

After the analysis of the questionnaires' results, we analysed the human data collected during the user testing by the E4 wristband. Physiological data were elaborated according to the processing procedure detailed in a previous paper to extract meaningful parameters about the users' conditions [58]. Such a method has been defined to assessment the UX of users / workers in different context and is considered suitable also for the present application. Results from human data post-processing confirmed the positive engagement and individual appraisal collected by the questionnaire, and further allowed to understand the impact of the olfactory stimulation on the declared intention to buy, considering results collected on the two participant groups separately. By analysing the questionnaire results for the two groups we found that the addition of olfactory cues was well appreciated for group no.1, improving some subjective judges positively, even if it is not directly related to a higher intention to buy. Therefore, we could say that the product smell during the virtual tasting has a medium importance.

From the analysis of the users' physiological parameters and comparison between the two groups, we defined a general trend as shown in Fig. 8. Fig. 8-A shows an example of BVP recording for users from group no.1, who received the olfactory stimulation, while Fig. 8-B shows an example of BVP recording for users from group no.2 who did not receive any olfactory stimulation. Both datasets were collected during the different VT phases, highlighted by the vertical red lines. The training phase was characterized by a significant increase in the heartbeat and the BVP, due to both the user's movement and the novelty of the experience (therefore enthusiasm or possibly nervousness). Lines indicating the start and end of each phase are not perfectly aligned between users, since each phase can have a different duration. After training, the VT started and users had usually a calm reaction since they mainly observed and listened in the first descriptive part of the VT, so that the BPV decreased and stabilized. Diversely, the engagement and the user movements increased during the second part of the VT, where the users were involved in the interaction scenarios. After the ageing phase, the olfactory stimulation was provided only for group no.1 (A), not for group no.2 (B), by opening the drawer attached to the VR headset. At this moment, the BVP values showed an increase in the recorded values, highlighted by the green circle, probably due to the release of the fragrance, easily identifiable almost for all participants of group no.1. If compared with BVP values for users without any olfactory stimulation (B), a different BVP trend can be easily noted.

No inferential statistical analysis is carried put for human physiological data due to the higher complexity in human data comparison due to the need of data normalization according to the individual baseline, for each participant.

5.3. Discussion of results

The combined analysis of results collected from questionnaires and human data analysis demonstrated that VR-based tours can be a good way to adopt digital technologies in supporting food marketing and food

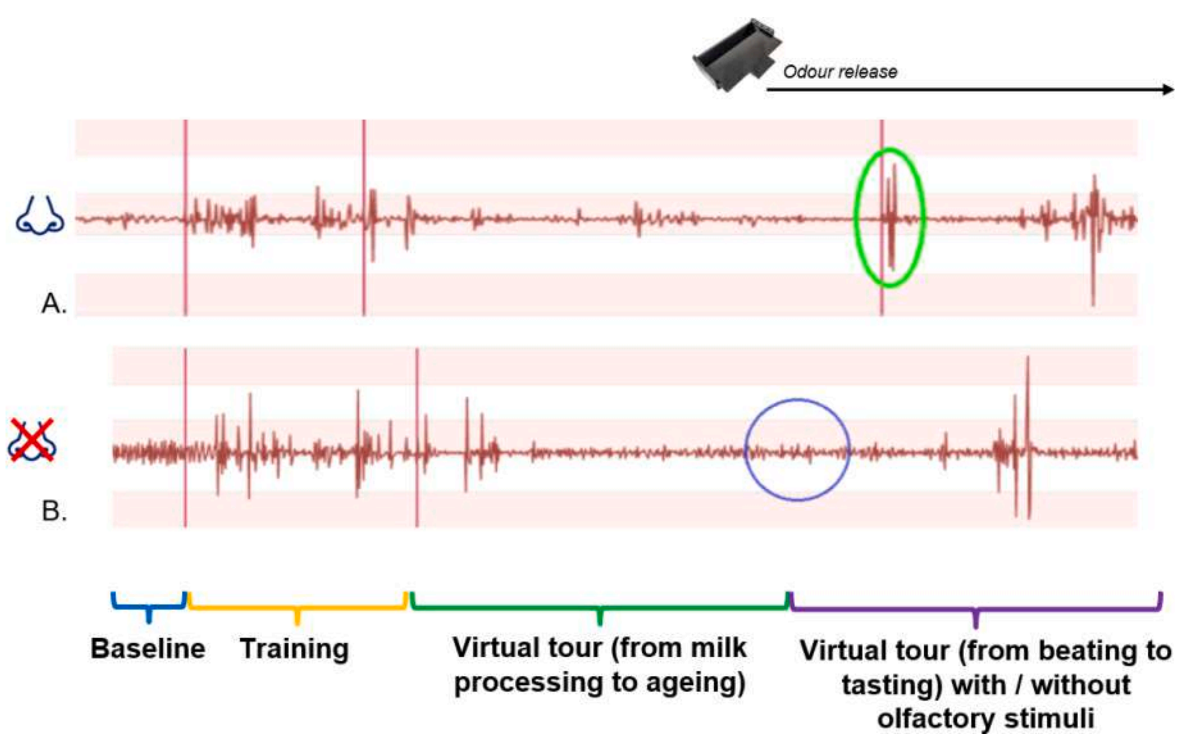

Fig. 8. Example of BVP measurement during user testing for group no.1 (A, with olfactory stimulation) and for group no.2 (B, without olfactory stimulation).

product tourism. With respect to the existing body of knowledge, the research demonstrated how a human-centered approach can be validly used to create a multisensory user experience, guiding the integration of different technologies to enable a good level of immersion, interactivity, and user engagement, as demonstrated by experimental results. Considering the previous works on the creation of VTs, the research proved that the combination of video-based and model-based approach for the creation of virtual scenes is well-perceived by the users and can validly support the creation of new knowledge, offering different interaction modalities to the users. Moreover, the impact on the intention to buy the product is positive. About the users' perception, we need to notice that some users were not fully able to properly complete the most interactive phases due to a low familiarity with VR devices, not necessarily related to their age. The low familiarity with VR technologies could limit the final UX by affecting the naturalness of interaction with the virtual objects and the navigation into the virtual scenes. In particular, few users were unable to properly complete the beating and fire branding phases interacting with the dedicated devices. A couple of users also complained that they could not freely move within the 360-degree video, diversely from the virtual interactive scenes in which they could freely move. These results should be taken into consideration in the VT adoption, considering the level of digital expertise of the VT recipients. The research also investigated the importance of adding olfactory stimulation to create an emotionally significant customer experience.

Despite the discussed criticalities, the developed VT was well perceived by the majority of users, as demonstrated by the positive results from questionnaires. The feedback obtained was very satisfactory, with very high ratings in almost all the evaluated parameters. Therefore, using a VT was found a win-win opportunity for agri-food tourism, improving both knowledge creation and the consumer intention to buy. Food companies, especially the most marketing-driven ones, could have the possibility to consider the implementation of VTs to promote their products worldwide.

6. Conclusions

This research provided design guidelines to use VR technologies in the development of valuable, multisensory and interaction virtual tours (VTs), according to a user-driven approach. The case study was represented by one of the most famous Italian agri-food products, the Parmigiano Reggiano (PR) cheese. A virtual immersive tour about the PR product was designed, developed and validated by an experimental user testing campaign, involving 76 users: users' reactions and feedback were collected by human physiological data monitoring and questionnaires' administration. The research also defined an experimental protocol to understand if VR-based tours can represent a valid tool to boost local products' tourism and purchase, and if olfactory stimulation can help. The final scope was understanding how to use novel digital technologies to increase the number of tourists visiting the real production site and generally enhance the product sales, also from different geographical sites.

Results showed that the VTs can represent an extremely useful and flexible tool, able to increase the user knowledge about both the product and its production process: the sense of being "on site" and being able to interact with the virtual objects (e.g., cheese-makers, specific tools used for product quality validation) positively affected the users' perception and provided an added educational value to the users. Moreover, the use of specific KOM features (e.g., the avatar-guide, interactive scenes implementing the learn-by-doing approach and emotionally engage the user, and a high level of autonomy of users that can freely select their tour steps according to a gaming modality, was found very important to increase the users' level of attention and to generate a funny, engaging experience. Finally, the use of olfactory stimulation has been qualitatively analysed and seemed to positively affect the users' emotional activation.

Limitations of the study mainly refer to three aspects: the limited number of participants ($n = 76$), the limited analysis of the VR tools evaluation, and some specific issues in the use of the VR equipment. The limited number of participants did not allow a reliable statistical data analysis nor the definition of specific correlations between the collected data. It was due to both the Covid19 pandemic situation, still persistent at the time of the project, which limited the number of people physically involved in the Lab testing due to strict disinfection procedure and ventilation needs, to be applied between tests. The evaluation of the VR tools was limited to the UEQ methods, focusing on familiarity with technologies and acceptability, but it could be improved in a future study.

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Informed consent statement and ethical issues

Informed consent was obtained from all subjects involved in the study. Ethical approval is not required for this study, because the ethical risk was minimal. The study was conducted at the university laboratory using non-invasive commercial devices; participants were carefully informed about the collected data and data processing. All the collected data have been anonymized.

Credits

Sara Cavallaro: study preparation, user testing, data collection and analysis

Fabio Grandi: data collection and analysis

Margherita Peruzzini: research design, paper conceptualization, paper revision

Elisa Martinelli: research design

Francesca De Canio: study preparation, user testing

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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