Dance Choreography Driven by Swarm Intelligence in Extended Reality Scenarios: Perspectives and Implications

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***Abstract*—Recent developments in artificial intelligence (AI) foster creativity in all its forms. In particular, with the advent of extended reality (XR), we have witnessed an explosion of once unimaginable artistic creations and products, one above all the Metaverse. Dance and the process of creating dance choreography can benefit from the use of these new technologies, but so far little has been done in this regard. This paper provides an overview of the existing literature on the use of AI tools in combination with XR technology within the artistic context of dance. Furthermore, we propose new application scenarios that involve human interactions mediated by XR technologies. In particular, we focus on dance choreography performed by artificial agents driven by Swarm Intelligence mechanisms, and we discuss the perspectives and potential implications for both artificial and human creativity through the integration with XR.**

***Index Terms*—Swarm Intelligence, Dance Choreography, Dancing in Extended Reality.**

I. Introduction

Since its foundation, artificial intelligence (AI) has been interested in replicating human capabilities in solving problems, using language and forming abstractions and concepts [1]. Creativity is a key ingredient not only for the production of novel and surprising artistic creations and expressions, but also for problem solving tasks, and until a few decades ago it was a prerogative of humans. Recently, thanks to technological advances in AI, this is no longer the case and we see computers creating creative artifacts sometimes indistinguishable from those produced by humans.

According to Guilford [2] two distinct groups of intellectual abilities concur in creative thinking: the "divergent-production" abilities are concerned with generating ideas and solutions in an open-ended way, while "transformation" abilities focus on reinterpreting a concept and reorganizing objects and ideas to find novel meanings, functions and patterns. Margaret Boden [3], [4] further refine this classification by defining three categories of creativity: *(i) combinational creativity* encompasses the recombination of existent ideas, *(ii) exploratory creativity* involves the exploration of conceptual spaces to produce unexpected ideas, while *(iii) transformational creativity* entails radical modifications of the conceptual space itself to find truly new ideas.

In the first phase of the history of AI, we witnessed the realization of software capable of performing complex tasks, outperforming human abilities, e.g. playing games [5], [6], process human languages and elaborate complex plans [7], software that is not truly creative but is driven by sophisticated algorithms or recombines existing knowledge extracted from data. With the advent of generative AI and extended reality (XR), however, we have opened the door to creative artificial systems capable of (at least to some extent [8]) divergent thinking and transformational creativity, such as GPT-4 [9], DALL-E, Gemini, and the Metaverse [10]–[12]. These technologies have the potential to foster and enhance not only AI creativity but also the evolution of of mutual creativity [13], expanding the conceptual space in which the physical human mind operates.

By focusing on the artistic domain of dance, in this paper we present some possible application scenarios that propose the use of extended reality as a suitable environment for fostering creativity in the performance art of dance. In particular, we exploit an approach recently proposed for dance generation by a subclass of AI, namely swarm intelligence. Then, we describe scenarios involving human-machine interactions, exploiting XR visors, that pave the way for a new landscape of creativity for dancers, choreographers, and ballet audiences.

In section II, we present related work on the contribution of AI and XR tools in the context of dance and performing arts in general. Section III introduces a recently proposed approach that combines elements of swarm intelligence to generate dance choreography for artificial agents. Section IV outlines future application scenarios making use of XR tools that we have devised to promote mutual human-machine creativity in the field of dance. Finally, Section IV concludes the work.

II. Related Work

In the last years, the connection between dance choreography and technology has evolved. The application of AI techniques in dance education and generation has changed from traditional methods to multimodal learning [14]–[17]. This integration has the potential to enhance the creative capabilities of human choreographers and also to define new perspectives for dance performance in extended reality scenarios.

The concept of choreography itself is evolving in the digital age. As explored by recent researches [18], [19], digital technologies can create immersive choreographic experiences

that challenge traditional notions of space and movement. The integration of motion capture technology allows for the translation of dance into interactive digital environments, further expanding the possibilities for choreographic expression [20], [21]. These developments can enhance the artistic potential of dance, and also open challenges about the future of choreographic practices in an increasingly digital world.

In addition to the artistic implications, many works focused on the technical aspects of dance choreography automation. The work of Joshi and Chakrabarty [22] provides a thorough review of computational techniques that automate various aspects of dance, from notation to choreography generation. This automation can facilitate the creation of complex dance sequences, making choreography more accessible to a wider audience. Furthermore, the application of hybrid models [14] demonstrates how combining different computational approaches can enhance the synthesis of dance movements in virtual environments. Such advancements indicate a promising future for the integration of AI and XR in dance, where choreographers can explore new creative avenues while engaging with audiences in innovative ways.

In this context, where the convergence of AI, XR, and dance choreography presents a transformative opportunity for artistic expression and audience engagement, we present new possible application scenarios. In particular, we leverage a recently proposed framework for creating artificial dance for agents through swarm intelligence. Swarm intelligence uses simple agents to create complex, self-organizing behavior and, in dance, can offer choreographers new perspectives, encouraging them to explore beyond traditional [23] approaches. In this context, we highlight new perspectives involving humans and agents interacting mediated by XR technologies to create new forms of dance choreographies. Furthermore, the possible implications on artificial and human creativity in the creation of dance choreographies resulting from this approach and the use in particular of XR technologies are discussed.

III. Swarm Intelligence Driven Dance Choreographies

Recently, a new approach for generating dance choreography for artificial agents has been proposed [23].

The idea behind the defined approach is to exploit the complex and rich dynamics that characterize the behavior of social insect colonies, such as bees, termites and ants, to give rise to abstract dance choreography for artificial agents. The central point of this approach lies in the possibility of generating dynamics that cannot always be predicted even by the designer who devised them, by exploiting the property of self-organization that characterizes these natural systems. Indeed, the overall dynamics of these systems is the complex result of the multiple direct and indirect interactions between the simple agents that compose them, their autonomous dynamics and the perturbations they experience. This aspect, according to the authors, can be crucial in creating or imparting a trait of unpredictability, and thus at least partly conferring creativity, to the resulting dance.

The input source modality for the generation of the dance choreography is the music. Specifically, the musical features extracted for each musical bar of the song are fed into a machine learning model that dynamically controls the parameters of the swarm intelligence algorithms and potentially the parameters that control the dance floor. Then, at this point, the proposed approach involves the automatic design of the choreography, employing automatic procedures that in turn can act on the parameters of the machine learning models to improve the choreography produced by the swarms, based on the metrics defined for their evaluation, metrics that may be automatic, human or both. The first implementation of the approach has been developed using NetLogo [24] and Figure 1 reports some screenshot of the dancing agents in action in their dance floor represented by the two-dimensional (2D) world of NetLogo.

We start from the idea that dance design based on swarm intelligence can emphasize local rules guiding agent-dancers and also enhance human-AI collaboration and interaction through real-time tuning. Based on that, we further push the idea of human-AI collaboration in the artistic domain of dance, by proposing application scenarios with the integration of XR and Natural Language Processing techniques through generative AI modules (e.g., GPT-4 [9]).

IV. Future Application Scenarios

From the previous sections, it is clear that thanks to generative AI, extended reality and its multiple declinations such as augmented, virtual and mixed reality, a future is emerging for human creativity that will be increasingly inextricably linked to artificial creativity.

Indeed, in dance choreography, the use of motion-tracking sensors, wearable devices and XR environments can help accurately map dancers' positions, gestures and speed, and this can also enable real-time interaction and feedback in a virtual or augmented space [25]. Through sensor integration, choreographers can explore new creative possibilities, by dynamically adjusting choreography based on dancers' movements or generating visual effects that respond to movement. Furthermore, sensors can facilitate the data collection of movement patterns, by offering information to refine the choreographic process.

In this paper, we start from a recently proposed approach based on Swarm Intelligence for dance choreography creation and we focus on a new integration with XR to promote human-IA co-creative processes in the context of dance. In this perspective, we propose three integrated approaches in this domain, by boosting the use of simulation and generative AI through NLP for the interaction with the user. Each of the following examples will require the employment of an extended reality visor which, due to the level of abstraction adopted, can be indifferently represented by the models currently available on the market. From an implementation point of view, tools such as WebXR [26] or its derivatives such as WiXaRd [20] can be a useful resource as they provide high-level abstractions for rapid prototyping of XR applications.

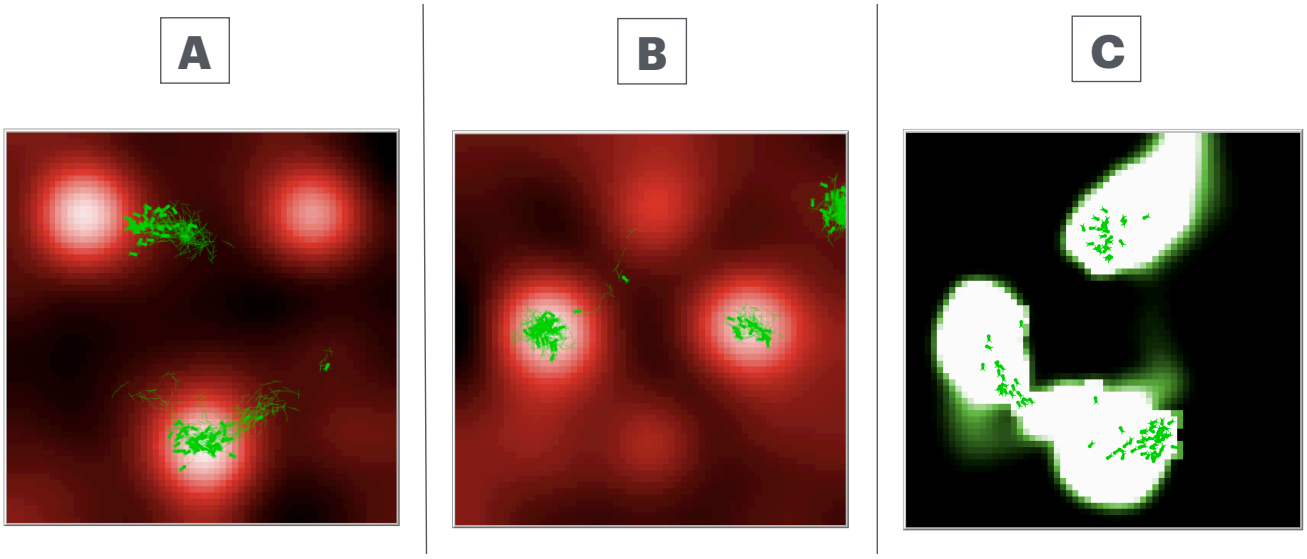

Fig. 1. Presentation of the dancing agents in action and the simulation environment of the NetLogo application implementing the approach for creating dance choreographies using swarm intelligence. **(A)** Screenshot of the dance floor during a simulation characterized by three food sources (remember that the food source pattern in our application represent a basic dancing structure composing a choreography) and agents moving in an attempt to reach them; **(B)** Presentation of a change in the food source pattern, which occurs at the end of a musical bar; **(C)** Graphical representation of the pheromone trail, from green to white, that each agent leaves during the simulation and contribute to the modulation of the formation of clusters of agents.

A. Dancing in XR Worlds

In its most trivial definition, a dance performance is characterized by a codified or improvised sequence of movements (i.e. a choreography) by a possible multitude of dancers. Each movement in the physical space (the "dance floor") accompanies and enriches a piece of music, if present. As described in the previous section III in this paper we consider a specific reification of artificial dance choreography, that of artificial agents with dynamics governed by the principles and algorithm of swarm intelligence.

Thanks to the abstractions provided by the XR tools, we can transpose the concepts introduced in the swarm intelligence approach into 3D simulations in virtual worlds. Figure 2**A** represents precisely this process: the 2D simulation of the NetLogo application is translated into the 3D virtual world made accessible and visible through the use of head-mounted display devices (HMDs). In this way, an HMD-equipped dancer can actively "enter" the 3D virtual dance floor and participate in the simulation. The agents in the virtual world can indeed perceive the dancers and move in accordance and in response to them. To ensure that virtual agents are informed of the dancer's movements, body movements must be tracked with the use of wearable sensors [25]. More generally, multi-sensor approaches can be used to collect and transmit data about the physical world to create immersive and responsive virtual environments [28].

The degree of potential (co)creativity is to a large extent shaped by the specific role assumed by the human dancer within the system. We can conceive different implementations, each characterized by a different role for the dancer and so with a different set of possible actions, selectable and modifiable by the dancer even during the same performance. The choice of its role modulates the ways of use and thus the possibilities in terms of creativity and affordances [29] that this system can offer.

Indeed, he/she can assume the role of a simple agent on a par with the other virtual agents (in the image represented by simple dots) and in this sense participate in the choreography as a simple agent not driven by swarm intelligence algorithm.

On the other hand, it can play the role of a food source, thereby significantly modifying the choreography of the entirety of the agents, acting as a first dancer or a full-fledged choreographer. Indeed, his/her presence influence the formation of the higher level metastable spatio-temporal patterns of agents along performance time. A possible representation of the latter possibility is offered in Figure 2**B**, where a dancer with an XR visor attracts virtual agents. Thus, in this application, HMDs, and thus XRs, become enablers of this new type of human-machine interaction otherwise not possible and with unpredictable creative trajectories.

B. Observer-centric XR applications

The second visionary application scenario involves a human equipped with an HMD device observing a simulation of a dance choreography taking place in the XR world. This class of applications can be conceived as an extension towards the XR realm of the *SwarmArt* project [30], [31].

We can imagine different types of observer-swarm interactions characterized primarily by the role we attribute to the observer:

- **Passive Observer**: This is the least interesting case, because the observer passively attends the dance choreography of the artificial agents, just as he does in the NetLogo simulation. The only change is the medium

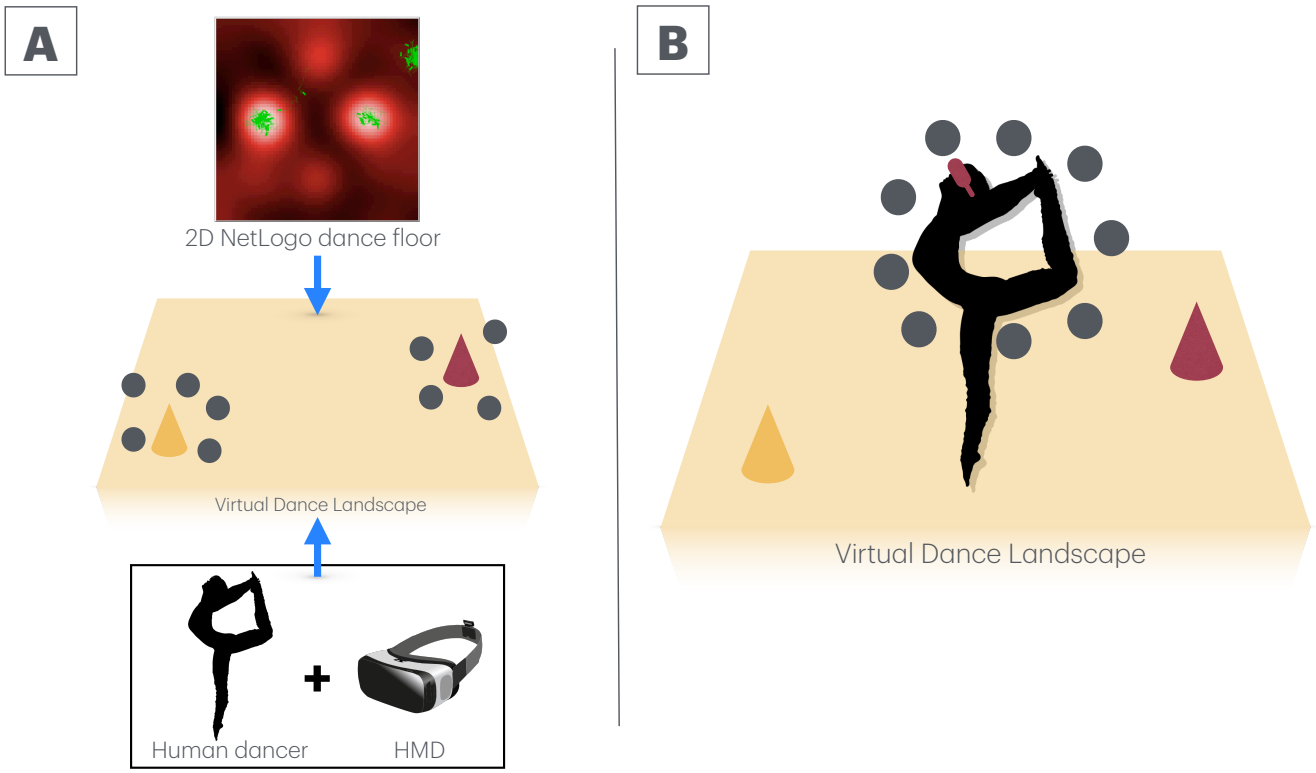

Fig. 2. Dancing in extended reality. **(A)** Describe the software process that transforms the NetLogo 2D simulation of dancing agents guided by swarm intelligence into an XR application visible and accessible by a human dancer using an HMD device. Food sources are represented in NetLogo as circles in a red-white gradient, while conical shapes are the relative representation of food sources in extended reality. **(B)** Pictorial representation of the end result: a dancer equipped with an XR visor can dance with virtual agents, mutually influencing each other.

through which the choreography is reproduced, moving from a 2D to a 3D virtual reality or augmented reality environment will certainly result in a more immersive experience for the spectator, but nothing will change from the point of view of creating new creative artifacts.

- **Observer as Demiurge** This case encompasses a number of different possible interactions, ranging from simple changes to the XR application from a graphical point of view o the structural and dynamic modification of the system components that give rise to the choreography itself. Here generative AI technology can have a prominent role and unleash human creativity to the fullest. To give a far from an exhaustive list of practical examples, we can say that models such as GAN and diffusion models can change the scenery, the dance floor and change agents' shape and appearance in real time. Tools such as [32] can be a game changer for altering the XR world on demand and in real time according to observers' requests. At the same time, the observer can take a more active role in the generation of the choreography. For example, he/she can use hand movement to erase the pheromone left by the agents, thus changing their trajectory, or he/she can erase, add and move components of the system; in the Figure 3**B**, the observer is shown moving a food source using voice commands. Obviously, a Natural Language Processing (NLP) module [27] is required to interpret the observer's voice command.
- **Observer as Music Creator**: Since the choreography of the agents is created from the selected piece of music (as described in the section III), and thus causally dependent on it, a new scenario in which the observer plays the role of a musician who creates the music from scratch or accompanies the chosen music track can be imagined. In this way, the observer can generate or perturb the process of creation of the swarm's dance choreography by playing his/her own instrument, e.g. a guitar, and the resulting dynamical (visual) organisation of the swarm can in turn influence the observer's future musical choices (e.g., the

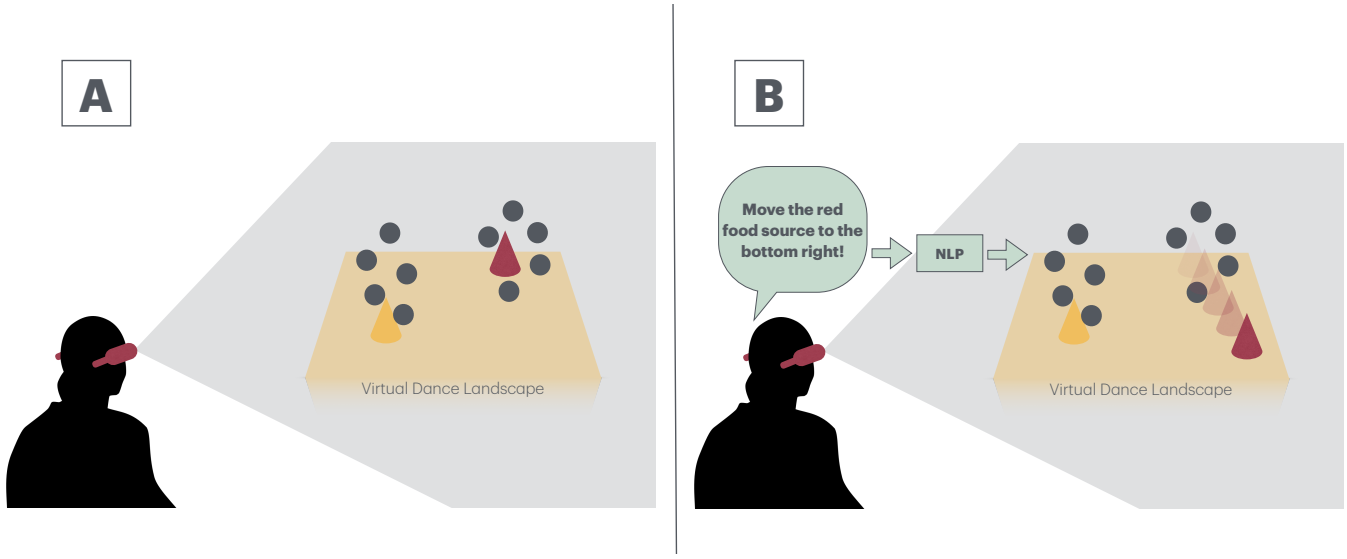

Fig. 3. **(A)** Application scenario involving a human observer equipped with an HMD device and the XR world in which the agents' dance choreographies take place. **(B)** Representation of one of the many possible interactions between the human observer and the XR application. In particular, one can appreciate the change of position of a food source in the virtual dance landscape as a consequence of the voice command imparted by the observer. The image also shows the need to develop an application that incorporates a Natural Language Processing (NLP) module [27].

next choice of notes or melody). This type of interaction triggers a novel collaborative feedback loop, and thus a creative process in its own right, between the musician and the swarm of agents whose possible evolutions and outcomes are a priori unpredictable, and may find formal explanation in theories of co-evolution of systems. Indeed, as in co-evolution, the musical compositions of the observer find explanation in the movements made by the virtual agents and vice versa. The possible creative trajectories are thus the result of their reciprocal interaction, the extemporaneity of the performance, the idiosyncratic structures formed and even the errors made [33].

C. Learning collective choreography in XR environment

Another application scenario is one in which XR tools support dancers in learning or improving a specific collective dance choreography. In this sense, the aforementioned technology, together with the choreography guided by swarm intelligence, lends a hand to the dancer who can gradually learn the positions and movements that make up a complex choreography without needing the simultaneous presence of human dancers or choreographers to direct it.

Indeed, collective dances of human performance, such as ballet, synchronized swimming, and groups of ice dancers, can provide models of inspiration for the development of dance choreography for artificial agents. The principles of swarm intelligence, in combination with automatic procedures guided by figure of merit computed during execution, can be used to design choreographies for swarms of agents that resemble those of humans, as outlined in the work [23].

Once installed in the XR system, the HMD-equipped dancer can substitute a virtual agent to replicate his movements and positions and then progressively learn the choreography. A real-time system based on the same figure of merit used to evaluate artificial agents can provide visual feedback to guide the human dancer, such as a green signal if the dancer is making the right movements in the space or a red signal vice versa (as illustrated in Figure 4**C**). Large Language Models (LLMs) can be exploited to provide not only graphical feedback to the dancer, but also instructions in the form of natural language, which are more easily interpretable. The power of LLM can also be an enabler for more complex interactions and tasks, including the retrieval and subsequent processing of data from sensors [34]–[36] and the prediction of possible future movements of the dancer based on his/her previous history [37], in order to try to prevent future errors in advance by means of alarms or signals.

V. Conclusion

In this paper, we presented a series of potential application scenarios that explore how human creativity and human-machine co-creativity in dance can be enhanced through the use of XR and generative AI technologies.

In this paper, we took as a starting point a recent approach that leverages Swarm Intelligence mechanisms to produce dance choreography of artificial agents. Specifically, we outlined three potential scenarios, each illustrating unique ways in which XR, generative AI, and swarm-guided choreography could give rise to novel immersive and dynamic experiences for human dancer.

Related work section is included to contextualize this approach within existing research, demonstrating how our proposal contributes to the evolving intersection of XR, human-computer interaction, and artificial intelligence-driven choreography. Our discussion suggests that these applications have the potential to significantly enhance creativity, creating new

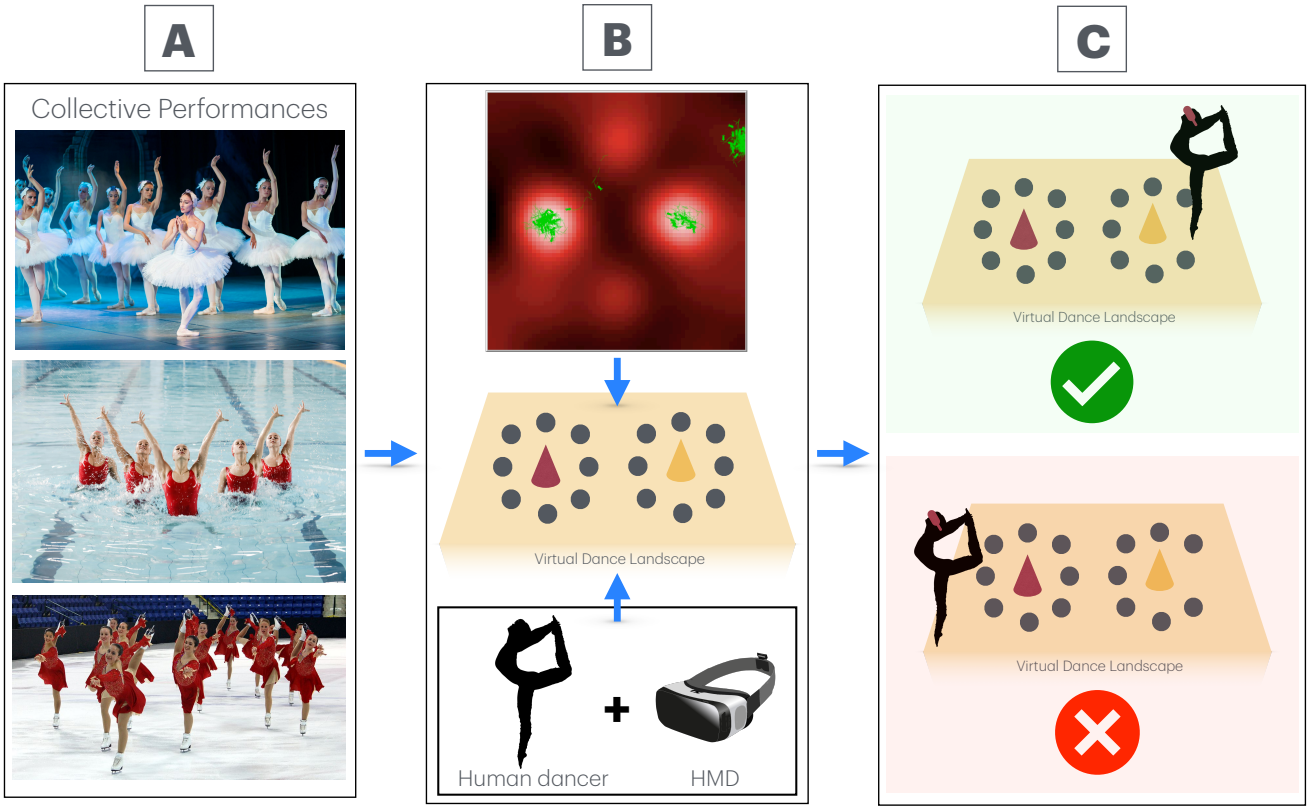

Fig. 4. Representation of the development process of the third application scenario. **(A)** Reports the collective dance performances that are to be replicated in the swarm intelligence system and that are to be learned or perfected by the dancer in the XR environment. **(B)** This box plays a central role, as it highlights the steps required to move from the choreography of the swarm (represented for convenience by the NetLogo application, but can be developed directly in the XR environment), guided by swarm intelligence algorithms and a figure of merit devised by the designer (the same one who will later guide the dancer with the visor), to its subsequent translation into the augmented reality (AR) environment, made possible by the dancer's use of an HMD device. **(C)** Resulting AR system in which the dancer replaces a virtual agent and improves his/her performance based on the visual feedback he/she receives in his/her visor, green if the movements are correct and red otherwise. The image of the dancers on ice is taken from Wikimedia Commons, credits to Rich Moffitt from Boston, USA, CC BY 2.0 https://creativecommons.org/licenses/by/2.0.

digital arts and collaborative dance performances previously unimagined.

Future work will focus on the implementation of these conceptual scenarios, with the aim of bringing the imagined possibilities closer to practical application and further investigating their impact on creativity and user engagement.

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