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A prospective vision of the evolution of immersive technologies: Towards a definition of metaverse

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ABSTRACT

This article focuses on identifying and describing the current status of immersive technologies, to project them, from this initial point, towards the near future, by considering the evolutionary trajectory of these technologies based on mechanisms of progress and innovation. The ambition of this study is then on the one hand to describe a next point of arrival for these technologies, but above all to confront it with the current vision of the concept of the metaverse, and even to extract a more completed and structured vision. The conclusions of the article underline the compatibility between the potential evolution of present immersive technologies and the current vision of the concept of metaverse. Moreover, a metaverse framework is presented to consolidate and structure this concept. Finally, the framework is broken down into the properties inherent to the nature of a metaverse and evaluated through two real cases relating to crisis management training and immersive teaching.

1. Introduction

Immersive technologies (virtual reality, augmented reality, mixed reality, etc.) seem on the one hand to be in their early infancy in terms of current uses, applications, and adoption, and on the other hand to have already reached a significant level of maturity in terms of available performance and potential to disrupt the digital market. Immersive technologies look incredibly promising, but no one is ready to wear a heavy, awkward headset and handle controllers daily, except for video games and leisure activities. This paradox has placed immersive technologies at a turning point, just like computer technologies in the 60s: at that time, computers were very large (the size of a room), very expensive, and mainly dedicated to pure calculation. Nobody would have thought that it would take such a place in our daily lives, both professionally and privately. However, this is what happened as soon as computers could be slipped under the desk, cost less than a few thousand dollars, and, above all, spreadsheet and word processing software appeared (no need to mention the second booster that was the appearance of the internet). It's a safe bet that immersive technologies will follow the same type of pattern: as soon as immersive headsets are the size of sunglasses, cost a reasonable amount of money, have a day's worth of battery life, and, most importantly, incorporate killer applications related to personal and professional life, their adoption will certainly skyrocket! Metaverse on the other hand is often seen as the future main application domain of immersive technologies but without formally checking the consistency of this hypothesis. This article aims to address key questions on the future of immersive technologies, including metaverses: **how will they evolve, which trends will be most significant, and do metaverses truly embody their future?**

The research presented in this article is transdisciplinary and takes a holistic approach to describing the current and potential uses of immersive technologies. Section 2 presents two states of the art on (i) immersive technologies and (ii) metaverses, and the first contribution of this article, which is the theoretical contribution: a clear and unified *definition of the concept of metaverse*. Section 3 presents the *TEI formalization (Technological Expectations vs. Innovation)* as a tool to assess the expected evolution of a field versus the actual evolution of a field. This section also applies that previously introduced TEI formalization to the state of the art of immersive technologies to emphasize the expected trajectory for these technologies. Section 4 presents the main results of this research work: first, the conceptual contribution: the *IMT (Integrability, Multiplicity, Temporality) Framework*, and the associated mapping between this *IMT Framework* and the unified definition of Metaverse. And second, the applied contribution: a holistic, generic, and

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transdisciplinary model of the structure of a metaverse, the *MetaMap*. **Section 5** evaluates the MetaMap model on *two case studies*: a *crisis training environment* and a *virtual campus*. **Section 6** takes up the contributions of the article and opens new perspectives.

2. State of the art on immersive technologies and metaverses

This section first studies immersive technologies and the trends related to their evolution, and second studies metaverses as described and defined in the literature, as well as their potential uses and prospects they offer, beyond the buzzword.

2.1. State of the art on immersive technologies

As definitions of these **Extended Reality (XR)** technologies, combining real and virtual worlds, we refer to the research work of Bordeleau et al., De Momi et al., and Mütterlein (Bordeleau et al., 2022; De Momi et al., 2022; Mütterlein, 2018).

- **Augmented Reality (AR),** with virtual content added to the real world; where an operator's perception of the real world is enhanced by superimposing virtual objects and information.
- **Virtual reality (VR),** with only virtual content; where the operator is immersed in a 3D virtual world; the three pillars of virtual reality are immersion, presence, and interactivity.
- **Mixed Reality (MR),** mixing virtual and real content; where the user can both view and interact with digital content that overlays the real world.

As early as the 1950s (Colburn and Chang, 1977), the defense was the first application area for AR/VR. In the 1990s, AR/VR took off and new display concepts were developed. In 2012, the first immersive AR/VR HMDs (Head Mounted Displays) appeared, based on display panels, smartphones, or micro-projectors. Today, these HMDs are evolving into more specific technologies, better adapted to immersive needs, which will foster a paradigm shift (Kress and Chatterjee, 2021). This paradigm shift is illustrated by three trends, presented in the sub-sections below: **the convergence of technologies, the diversification of uses, and the emergence of environments that are sometimes realistic and concrete, sometimes metaphorical and abstract.** These three viewpoints are proposed to structure this state of the art by analogy with smartphones and computers, which are also evolving in line with these trends.

2.1.1. Convergence

The first trend is the convergence of immersive technologies. The merging of XR technologies will be facilitated by mass production, nanofabrication (Xu et al., 2023), and reduced manufacturing or development costs of smart glasses (also called smart eyewear or digital eyewear), their materials, technologies, and software (Kress and Chatterjee, 2021). These developments will be driven by investments related to the growing use of metaverses. Gartner et al. (Gartner, 2022) predict that by 2026, 25% of people will spend at least 1 h a day in the metaverse.

These developments will also be spurred by **current weaknesses** in XR technologies. According to Sanfilippo et al. (2022), The best VR solutions are Cave Automatic Virtual Environment (CAVE) VR systems and head-mounted displays (HMDs). In contrast, AR solutions rely solely on low-cost, low-performance devices (Sanfilippo et al., 2022). Alas, some inexpensive solutions do not offer full immersion, and response delays, or jerky movements, can cause users to experience motion sickness (Clay et al., 2019). As smartphones, watches, computers, game consoles, and tablets become increasingly interchangeable, AR and VR solutions will a priori evolve into a set of MR solutions, enabling both AR and VR.

These developments will also be driven by **broader sensory spaces** to integrate senses such as visual, auditory, kinesthetic, and tactile (VAKT (Sanfilippo et al., 2022)), but also smell and taste, to ensure better sensory coverage and multisensory interaction. The goal should be to propose to the user to control XR interfaces through intuitive and natural behaviors (Innocente et al., 2022; Ke et al., 2018), especially when the solution allows the simultaneous manipulation of real and virtual environments, as mentioned by Zhang (Zhang et al., 2022).

Finally, these developments will be driven by the **increasing number of use cases** and associated software: total spending on AR and VR products is expected to exceed $215 billion in 2021 (Zhang et al., 2022) or **to improve human-machine interaction through real-time instruction exchanges** across the production system in the manufacturing industry (Eswaran et al., 2023). The global AR and VR healthcare market is expected to reach $5.1 billion by 2025 (Zhang et al., 2022).

2.1.2. Usages

The second trend concerns the emergence or confirmation of **usages**. If it is obvious, as the past decades have shown, that the field of video games clearly constitutes the initial driving niche for these technologies (Pavithra et al., 2020), it is no less true that other uses are also emerging. We can mention the fields of maintenance, health and safety, industrial production, and assembly (Lee et al., 2022; Suh and Prophet, 2018). Nevertheless, all these emerging applications remain niches that, although they open real industrial and business perspectives, will not constitute sufficiently driving forces to change the dimension of the immersive technology industry. The thesis that this article defends is the following: there are three main domains that structure the perspectives of future use of immersive technologies: the domain of **immersive leisure**, the domain of **immersive training**, and the domain of **immersive artificial intelligence** (in the order of appearance assumed by the authors of this article). The first domain (leisure) encompasses everything related to video games of course, but also immersive tourism, board games, and festive, cultural, or artistic events (Fan et al., 2022; Lee, 2022; Roussou, 2001). The second domain concerns professional training (good practices, health and security, and knowledge capitalization) as well as education and the emergence of immersive or hybrid classrooms or academic campuses (Pavithra et al., 2020; Abich et al., 2021; Falah et al., 2014). Finally, the third area is more specifically focused on facilitating access to and interaction with artificial intelligence (AI) tools. The progress of AI is obvious, but access to this potential remains complicated. Beyond purely textual/vocal AI (chatbot, vocal assistant), it is currently difficult to use more complex AI software and to interact with the analysis or decision support functionalities offered. The projection of business intelligence and data sciences in an immersive context (Kabil et al., 2018; McCormack et al., 2018) is a significant example of that. For instance, the evolution of dashboards and analysis tools in contexts where immersion offers not only innovative 3D visualization perspectives, but also (and above all) interaction perspectives never before envisaged (grabbing concepts, moving ideas, merging notions, feeling decision), or in a collaborative manner between (potentially distributed) human users (Dwyer et al., 2018).

2.1.3. Degrees of abstraction

The third trend that this article proposes to take into consideration is the evolution of the **degrees of abstraction** that immersive technologies offer. If, very naturally, the initial and classical approaches concerning immersive technologies were oriented towards very **concrete** functional and visual proposals aiming to replicate physical reality as closely and as faithfully as possible, there is a significant evolution aiming, on the contrary, to use these technologies to escape from reality as much as possible and to propose much more **abstract** environments and functionalities, for instance, to represent abstract data, as detailed in

(Rosenbaum et al., 2011). These abstract proposals still benefit from the incredible realism inherent to immersive environments, and since the solicitation of the users' senses remains familiar and not disturbing,[1] one can envisage immersing these users in totally unreal environments in which visual metaphors can replace abstract notions concretely and allow interaction with these metaphors (McCormack et al., 2018; Boeck et al., 2005). As an illustration, we can mention the virtual piloting of a vehicle or a machine as representative of the *concrete* end of the spectrum (Goedicke et al., 2018; Ni et al., 2013), while the *abstract* end of the spectrum could be illustrated by a virtual space without any particular orientation (no walls, ceiling or floor) in which the abstract concepts of risks could be represented by actual colored spheres, floating around the user, of which, for example, the proximity would represent the probability of occurrence, the color would represent the dangerousness, and the size would represent the range of the impacts (Benaben et al., 2019).

2.1.4. Conclusion on immersive technologies

The three paradigm shifts presented in this first state of the art, all together represent the first step in answering the questions raised in the introduction: understanding and anticipating the evolution of immersive technologies, including metaverses. As an additional comment, it is important to note that the previous considerations are only oriented toward the prospects for users, not the projections for owners: owners are likely to orient the use of immersive technologies towards mercantile exploitation, using (activity tracking, eye monitoring, integration of messages or advertisements, etc.). If the perspectives of users alone guarantee "first-order" avenues, for owners it is obvious that their perspectives create "second-order" avenues (naïve perspective) or have already created "zero-order" avenues in the current plans about immersive technologies business (cynical perspective).

2.2. State of the art on metaverse

This second state of the art aims to propose a definition of metaverses and metavers. The query "metaverse*" on Scopus returned 388 documents, including 155 journal articles. Of these, only 23 articles presented a metaverse or its possible uses. Based on these results, the subsubsections below present: the origins of the term, the definitions from the corpus, the possible uses identified from the corpus, and our first contribution: a full and comprehensive definition of the Metaverse.

2.2.1. Origins of the term "Metaverse"

The term "*metaverse*" comes from the ancient Greek "meta", which means *beyond*, and "verse", which is the contraction of *universe*. A metaverse is then an environment that goes beyond the universe, overcoming its limitations. The word first appeared in 1992, in the novel Snow Crash written by Neal Stephenson. It then designates a virtual world interfaced with the physical world, accessible through glasses and in which users would be represented by avatars allowing them to interact with each other and with the metaverse. If the description of the metaverse by Stephenson is not totally coherent with nowadays' reality and with our conception of the internet, several of his ideas are still relevant today, such as the possibility of developing an economic activity inside the metaverse. Other examples of metaverses can be found in fiction, such as the OASIS of Ready Player One. The idea behind this paper is to propose a model to define the notion of metaverse that could be used to anticipate the uses and benefits of metaverses. **The Metaverse is widely anticipated to be the next evolution of the Internet** (Cheng et al., 2022)**.**

2.2.2. Definitions of the concept of "Metaverse"

Although there is no universal definition of the metaverse (Park and Kim, 2022)**, it designates by consensus a virtual, collective space, created by the convergence of a physically persistent virtual space and a virtually augmented physical reality** (Chow et al., 2023)**. Users, represented by avatars, can communicate, collaborate, socialize, or interact with objects** (Wang, 2022)**. If** the design and development of metaverses still require the **integration of many different technologies** (Chow et al., 2023), it uses immersive technologies to integrate virtual and physical environments together. With its Metaverse, the company Meta© envisages an environment where everything seems virtual, but where physical elements usually present in the real world are included (shops, people, brands …). Many companies have already invested in virtual lands, or virtual brands, while the economy of a country already has to deal with virtual currencies. The frontier between virtual and physical reality is becoming thinner and thinner.

Dionisio et al. (2013) define metaverses as **an integrated network of 3D virtual worlds**. In this definition, a virtual world corresponds to an online computer-generated environment in which users from multiple physical locations can join and interact in real-time, for purposes as varied as work or entertainment. One particularity of this kind of environment is that they are persistent, which means that they continue to exist when the user leaves them. He proposes 4 features considered central elements of a fully realized metaverse: *realism*, *ubiquity*, *interoperability*, and *scalability*.

Much more recently, Mystakidis (2022) proposes a more complete definition, adding the idea that the metaverse would include physical reality. He defines the metaverse as **perpetual and persistent connected multi-user environments merging physical and virtual realities**. It would be based on technologies such as VR and AR, offering real-time multisensorial interactions between the users and the metaverse.

Mozumder MA, Sheeraz M, Athar A et al. (Mozumder et al., 2022) state that **metaverses are shared online spaces in which physical, augmented, and virtual reality converge to offer an environment that can be modeled and altered by the user inside it**.

2.2.3. Possible uses of the "Metaverse"

Several uses of metaverses can be found in the literature in several domains such as tourism or culture (Lee, 2022; Choi and Kim, 2017), education or training (Lee et al., 2022; Park and Kim, 2022; Akour et al., 2022; Suh and Ahn, 2022; Guo and Gao, 2022), entertaining and social applications (Park and Kim, 2022), and even retailing or marketing (Hassouneh and Brengman, 2015; Hollensen et al., 2022). Metaverses are intended as models and extensions of the physical world, hence the importance of the social aspect (Davis et al., 2009). People can interact as avatars with each other and with non-player characters in metaverses without having to physically be in the same place. Metaverses allow a wide range of activities, from playing to working through commerce and information-seeking interaction. They are intended as parallel worlds, complete with their own digital economy that should be transparent, stable, and sustainable, and their own society (Duan et al., 2021). Metaverses present several advantages to overcome physical limitations and propose services that are "impossible" in the physical world, such as high interactivity or the possibility of developing features to overcome the physical world's shortcomings (Lee, 2022; Guo and Gao, 2022). For instance, during the COVID-19 pandemic, concerts have been organized in metaverses when people were unable to meet in such crowdy events: the concert of Lil Nas X on Roblox in November 2020 gathered 30 million viewers, Travis Scott in April 2021 in the game Fortnite was attended by 27.7 million participants (Suh and Ahn, 2022). Metaverses are also said to be the future of online shopping (Hassouneh and Brengman, 2015), and brands such as Toyota and L'Oréal have set up virtual stores in metaverses.

2.2.4. A definition of "Metaverse" as synthesis

From these definitions, the main extracted and refined components

[1] even if the fact of soliciting the senses in different and antinatural ways could also be a perspective of further evolution.

are the *combination of physical and virtual spaces* (Chow et al., 2023; Dionisio et al., 2013; Mystakidis, 2022; Mozumder et al., 2022), a *multi-user* environment (Mystakidis, 2022), *persistent* spaces (Chow et al., 2023; Mystakidis, 2022), and spaces that *can be changed and altered* (Mozumder et al., 2022). We can then come up with the following definition as our **first contribution: a metaverse is an environment connecting virtual and physical environments that can be altered and modeled from within, by multiple, potentially immersed, users. It is a perpetual and persistent 3D world implemented through virtual, augmented, and physical reality**. This is the theoretical contribution. This proposed definition is thus a combination of the four definitions presented above (Chow et al., 2023; Dionisio et al., 2013; Mystakidis, 2022; Mozumder et al., 2022) that all provide interesting characteristics of metaverses but also lack other crucial characteristics. We also retain that a metaverse is all about connections: between the user and the virtual world, between the user and the physical world, between the physical and the virtual worlds, and between the different virtual worlds.

Hence, Fig. 1 presents the very upper layer of one of our contributions that will be detailed in section 5: the MetaMap. At this stage, it mainly represents the potential connections between users, virtual worlds, and the physical world. A person from the physical environment (shown in red) can have one or multiple virtual identities (shown in orange), one for each virtual environment he belongs to (like in a medical record system, an internet forum, etc.). The same identity can be used across several virtual environments and two identities, within the same virtual environment, can communicate. An avatar in the Metaverse (shown in blue), which encompasses multiple physical and/or virtual environments, can link all these identities.

3. The TEI formalization to draw the line between today and tomorrow

Now that we have a clear definition of the Metaverse and a model to represent its structure, this section introduces the TEI (Technological Expectations vs. Innovation) formalization. This method compares the technologies currently being developed with the latest trends in innovation and the expectations we might have of them. **The aim is to anticipate the future of immersive technologies and determine whether they will bring us closer to the Metaverse.** The ultimate aim is to refine and enrich the definition of the Metaverse and the MetaMap model. The subsections below present **the TEI formalization as a transformative tool and its implementation in immersive technologies.**

3.1. Building the TEI formalization

As presented in (Benaben and Benaben, 2020), innovation, as a progress, is primarily based on two research philosophies: **innovation-pushed** (discovery-oriented) and **need-pulled** (market-oriented). The two following diagrams present these two different ways of achieving **innovation**, seen as the *ability to push the world toward the next steps of its trajectory*.

The **innovation-pushed** approach concerns the *active influence on this trajectory*. Research activities associated with this approach aim at achieving significant, potentially disruptive *innovations* to generate its *assimilation* by a society that was not necessarily aware of the potential of this idea or even of the associated need.

Fig. 2 illustrates the **innovation-pushed** approach inherited from the work presented in (Rogers, 2010) about innovation diffusion and the social adoption of innovation. It consists of the time-related curves of *innovation maturity* (purple line) and *social assimilation of the innovation* (blue dashed line).

The **need-pulled** approach concerns the *passive anticipation of the progress trajectory*. For this approach, research activities aim to meet an identified and described societal *need* in line with current trends. The time frame depends on the urgency of the need, on the existing response potential, and on the ability to climb the response curve.

Fig. 3 formally describes the **need-pulled approach**. It illustrates the relationship between the *social need for innovation* (orange dashed line) and the *research/scientific response* (purple line) that is directly connected to the "university-enterprise cooperation" (so-called "Channel 1") of (Cao et al., 2023).

It is reasonable to think that most innovations are nourished by both approaches.

- The **need-pulled** vision mainly concerns the "WHY" of the innovation and this approach addresses four of the seven criteria from the degrees of innovation from (Moore and Benbasat, 1991): *relative advantage, compatibility, image, voluntariness of use.*
- The **innovation-pushed** vision is more concerned with the "HOW" of the innovation and, it addresses three of the seven criteria from (Moore and Benbasat, 1991): *complexity, observability, and trialability.*

The same mapping can be done with (Venkatesh and Davis, 2000) and the extension of the Technology Acceptance Model (TAM2) that is presented in this article, which add to the TAM components of (Davis, 1985): *perceived usefulness*, *perceived ease of use*, *intention to use*, and *usage behavior*, the following ones: *result demonstrability*, *output quality*, *job relevance*, *image*, *subjective norm*, *experience*, and *voluntariness*.

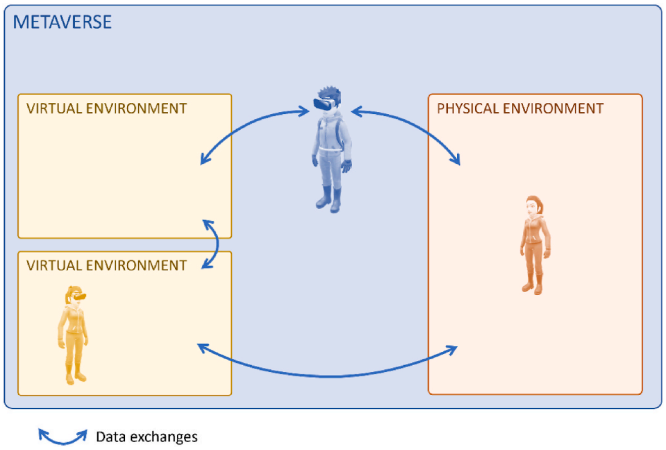

Fig. 1. Connections within the metaverse.

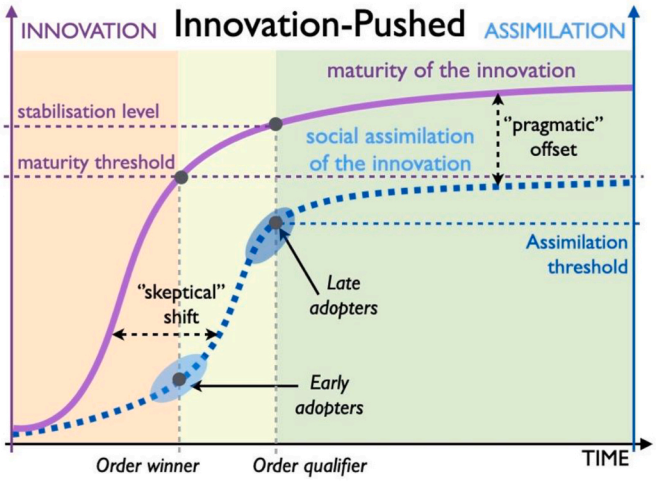

Fig. 2. Innovation-pushed approach.

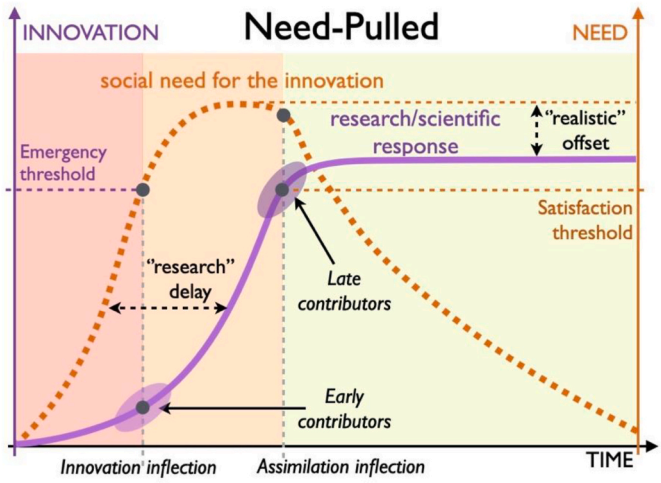

Fig. 3. Need-pulled approach.

If these two visions (innovation-pushed and need-pulled) can exist separately and provide significant results, the social need for innovation and the social assimilation of the innovation do often exist simultaneously. In such a case, that combination becomes a powerful propeller for innovation as both main reasons ("we can" and "we want") are present. The main ambition of this section is to formalize this combination to demonstrate how this situation actually applies to immersive technologies. So, Fig. 4 illustrates the TEI Formalization: a merged vision of scientific and technological progress dedicated to projecting the definition of the metaverse in its probable evolution over time. This vision is in line with the one presented in (Shi and Herniman, 2023). The purple curve represents the innovation response as the compromise between, on the one hand, the *orange* wave of *need* (cf. Fig. 3), and on the other hand, the *blue* wave of *potential assimilation* (cf. Fig. 2).

3.2. Applying the TEI formalization

This section applies our merged vision (TEI formalization) of scientific and technological progress to immersive technologies (see Fig. 5). The following uses the identified trends from section 2.1 to show how immersive technologies are concretely in the case of benefiting from both social need for innovation (digitalization of the society, need for remote activities, etc.) and second social assimilation of innovation (massive progress in the domain of immersive devices). But the following also aims to point out emerging characteristics of these technologies and identifies the potential cross-fertilizing approaches that could satisfy these needs (mainly to determine whether the Metaverse is consistent with our findings).

The global methodology is based on the states of the art and the merged vision of scientific and technological progress. The state of the art presented in subsection 2.1 on immersive technologies highlighted three trends.

- The expectation of **convergence** of technologies, sensory spaces, and ecosystems.
- The expectation of **emerging usages** such as leisure, training, and AI.
- The expectation of **new degrees of abstraction** bringing users in realistic, abstract, concrete, or metaphorical environments.

For each of the three expectations of the previous paragraph, this subsection highlights how these three trends place immersive technologies on a trajectory of merged innovation (Fig. 4) and explores the innovations that could contribute to these trends from the TEI formalization perspective.

- The expectation of **convergence**: This trend is the result of (i) mixed reality devices, haptic wearables, and sensory extension technologies, (ii) simulation tools, (iii) the culture of the digital twin (in the sense of Kritzinger et al. (2018)), and (iv) Internet of Things and network capacities (4G, 5G, and beyond). This encourages the development of **integrated and persistent** immersive environments that can be used anywhere, anytime, and easily, while merging physical and virtual spaces, customized according to individual needs.
- The expectation of **emerging usages**: This trend relates to the rapid growth of hyperconnected communication networks since the 1990s, paired with the growth of Massively Multiplayer Online Role-Playing Games (MMORPGs), serving various purposes (including training, leisure, and so on). This shift is accentuated by remote activities and the desire for equality and fairness, to reduce disparities and offer similar services to everyone, everywhere. This encourages the development of **accessible and useable multiplayer immersive environments** that can offer complementary points of view whatever the goals of the users.
- The expectation of **new degrees of abstraction**: This trend comes from the fast and accurate exploitation of 3D captures, using tools like cameras, drones, and Lidar, various data sources (images, heat signatures, radar signatures, or electromagnetic signatures), and artificial intelligence which can then bring these components to life, creating realistic simulations. In immersive environments, visual, auditory, or tactile metaphors, can be used to facilitate creation, reflection, and interaction with abstract concepts. This encourages the development of **liberated** and **creative** immersive environments where physical, natural, and realistic limitations are removed.

4. Main results

This section proposes the results of the TEI **formalization** applied to immersive technologies as a unified framework to represent future metaverses. The ambition is really to show how the results of section 3.2 (the characteristics identified from the three trends) can be used to structure and define the space in which future immersive technologies will evolve. This section also challenges and refines the definition of the Metaverse to introduce the IMT framework and to create the MetaMap model based on these results.

4.1. The IMT metaverse framework

Thanks to the points discussed above, we can sketch out a potential and realistic future for immersive technologies which, according to our conclusions, will be (i) integrated and persistent; (ii) multiplayer, accessible, and useable; and (iii) liberated and creative.

We can then extract from these characteristics a three-dimensional vision of a potential and realistic future of immersive technologies. These dimensions can be described more precisely as follows.

- **Integrability:** this dimension concerns the *degrees of immersion for users*, through dedicated technologies and interactions with visual metaphors or real components. This dimension also concerns the different embodiments (all avatars in all spaces and even the physical incarnation) and their topology[2] as well.

[2] By *topology of embodiment*, the authors mean the set of rules that formally define the way in which these users' embodiments can, according to needs, uses and users, be merged, divided, totally or partially, and more widely reconfigured on the fly.

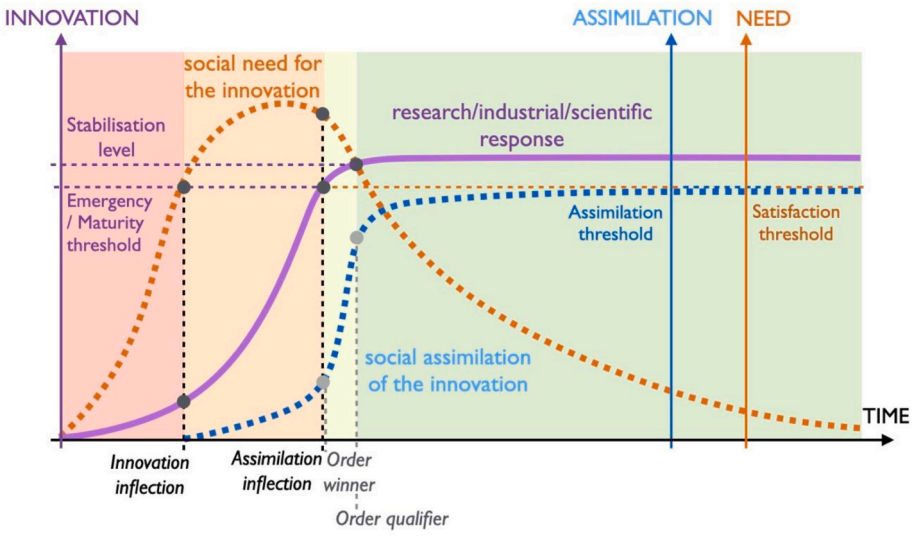

Fig. 4. The merged vision of scientific and technological progress.

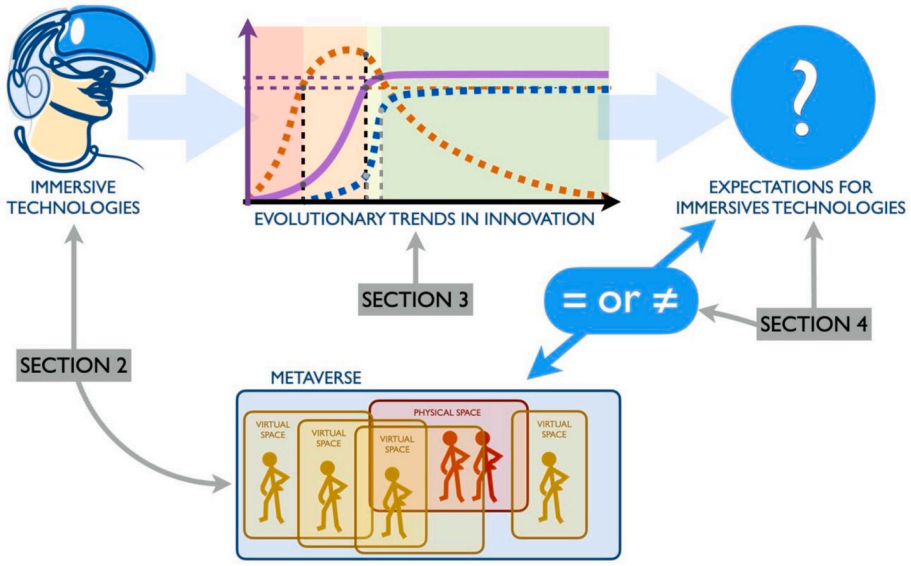

Fig. 5. Big Picture of the ambition of the article implementing the TEI formalization.

- **Multiplicity:** this dimension concerns the management of the *plurality and variety of spaces*. This dimension concerns all aspects of the topology[3] of these spaces, which can be integrated, duplicated, merged, or separated as they are used (to create richer, more precise, or more adapted spaces).
- **Temporality:** this dimension concerns the temporal coverage of the proposed spaces, their lifespan, their moment of creation, their time frames of use, and the moments concerning their eventual dormancy or destruction.

The previous Fig. 6 illustrates the complete vision of the **IMT Metaverse** with the three *dimensions* as dimensional axes (Integrability, Multiplicity, and Temporality), *spaces* are represented as plans (with merging and forking features), and several *notions* are distributed on the figure as icons to illustrate the three dimensions (the used colors are related to the dimension they relate to).

4.2. Application of the IMT vision with the concept of metaverse

Considering as a reminder that the definition of metaverse that resulted from subsection 2.2.4 is the following: ***a metaverse is an environment connecting virtual and physical environments that can be altered and modeled from within, by multiple, potentially immersed, users. It is a perpetual and persistent 3D world implemented through virtual, augmented, and physical reality***, the objective is to analyze the equivalence between that definition and the vision underlying Fig. 6, seen as the anticipated evolution of immersive technologies. Here are the findings of this analysis.

1. The aspects of "**connecting virtual and physical environments**", "**potentially immersed users**", and "**[a] 3D world implemented through virtual, augmented, and physical reality**" correspond to the expectations of integration of the real and virtual worlds and to

[3] Similarly, by *topology of spaces*, the authors mean the set of rules defining how spaces can be merged, divided, totally or partially, and reconfigured on the fly.

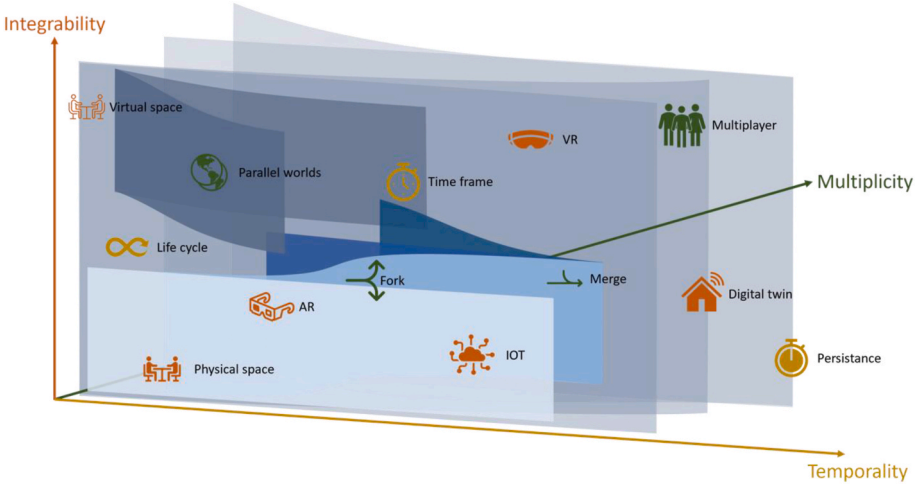

Fig. 6. Big picture of IMT metaverse framework (Integrability, multiplicity, temporality).

the convergent use of immersive technologies to different degrees. These elements of the definition thus cover the "**Integrability**" dimension.

2. The notions "**an environment connecting […] environments**", and "**multiple […] users**" cover the plurality of spaces on the one hand and the multi-user part on the other. The "**Multiplicity**" dimension is thus captured in this part of the definition.
3. Finally, the aspects "**an environment […] that can be altered and modeled from within**", and "**it is a perpetual and persistent […] world**" cover both the notions of the life cycle (creation, modification, and even destruction) of the spaces, but also the notions of life span and time frame of the "**Temporality**" dimension.

The fact that the components of this definition exhaustively cover the dimensions of Fig. 6 and that moreover, there is no element of this definition that is not found in one or the other of these dimensions, brings the following answer to the initial questions of section 1: **the concept of metaverse, such as it emerges from the study of the literature, seems to be able to legitimately claim to represent a coherent future for immersive technologies in human societies**. This conclusion and the corollary enrichment of the definition of the metaverse by the multi-dimensional vision proposed in Fig. 6 constitute the **second contribution** of this article: the conceptual contribution.

4.3. MetaMap: a model to represent a structured vision of metaverses

The IMT framework introduces dimensions for metaverses implementations (*Integrability*, *Multiplicity*, and *Temporality*). As presented in section 2.2.4, and especially in Fig. 1, a metaverse is all about virtual and physical spaces, virtual and physical embodiments of users, and connections (between the user and the virtual/physical worlds, and between the different virtual/physical worlds). In the following subsections, the MetaMap is presented as the result of the impact of the IMT framework dimensions on spaces, user embodiments, and various connections, to ensure that metaverses following the MetaMap offer Integrability, Multiplicity, and Temporality. The MetaMap can be seen as a practical, useable element extracted from the IMT framework that can be invaluable when designing a metaverse.

4.3.1. Consequences of the integrability dimension from the IMT framework

The first notion to be clarified concerns the *incarnation* or *embodiment* of the user of the metaverse: how is one user of the metaverse personified within the spaces that compose the metaverse? For this, two relations are defined.

- **Personification:** the embodiment of the metaverse's user by a digital personification in a virtual space (this incarnation can range from an account in a digital administrative space to a visual avatar in a 3D virtual space).
- **Representation:** the embodiment of the metaverse's user by a physical representation in a real space (this embodiment can go from the physical envelope in the real world, to a telepresence robot).

The following Fig. 7 represents these first two relations:

The second notion to be defined concerns the *relationships* between the metaverse users. The four following relations have been defined for this purpose.

- **Socialization**: the ability of *virtual personifications* of metaverse's users to interact with a *user*. This can be visual, sound, tactile, etc. solicitations making the user aware of the flows coming from the *virtual incarnations* of other users at his destination.
- **Extraversion:** the ability of a *user* of the metaverse to interact with the *virtual embodiments* of other users. It can be solicitations of all kinds, based on the media offered by the virtual spaces in which the targeted avatars are located.
- **Inclusion**: the ability of *physical representation* of metaverse users to interact with a *user*. This can be visual, sound, tactile, etc., solicitations making the user aware of the outgoing flows of the *physical embodiments* of other users at his destination.
- **Collaboration**: the ability of the *user* of the metaverse to interact with the *physical representations* of other users. It can be solicitations of all kinds, based on the media offered by the physical spaces in which the targeted representations are located.

The four previous notions can be grouped as *communication*, i.e. the ability of a user of the considered metaverse to interact directly with other users.

The third notion to be defined concerns the *relationships* between the user and the spaces of this metaverse. It is noticeable that these two relations are also consequences of *Multiplicity*, but as they are from user to spaces, they have been put in this subsection.

- **Interaction**: the ability of a *user* to *act* on a *virtual space* and its components. It can be a manipulation of component(s) of the virtual space or of the whole space.
- **Action**: the ability of a *user* in question to *act* on *physical space* and its components. It mainly concerns the manipulation of component(s) of the physical space.

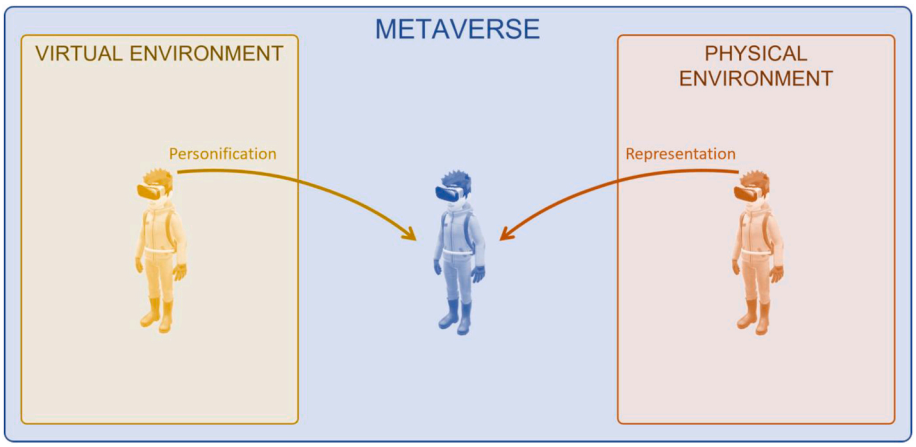

Fig. 7. Embodiments of the user within different types of spaces of the metaverse.

The following Fig. 8 represents these six relationships.

4.3.2. Consequences of the multiplicity dimension from the IMT framework

Still as part of the third notion (about the *relationships* between the spaces of the metaverse and the user), here are two other relationships (they are also consequences of *Integrability*, but as they are from spaces to user, they have been put in this subsection).

- **Immersion**: the ability of a *virtual space* to *transmit* messages inducing a feeling of presence in the *user* (for example the quality of the 3D landscapes of a virtual space or the haptic feedback of an operator manipulating a virtual tool).
- **Emission**: the ability of a *physical space* to *transmit* messages to a *user* (for example the sending of signals to one's senses such as the change of colors of a traffic light).

The fourth component of exchanges to be defined concerns the four relationships between the spaces (virtual and physical) that make up the metaverse.

- **Intervention**: the ability of a given *virtual space* to *receive* information from *other spaces* (physical or virtual) and to process it. This capability also includes the ability of a virtual space to react to a merger or separation request from another space.
- **Influence**: the ability of a given *virtual space* to *transmit* information to *other spaces* (physical or virtual) and to induce processing of this information, or even modifications in these spaces. This capability also includes the ability of a virtual space to trigger the merging or separation of other spaces.
- **Solicitation**: the ability of a *physical space* to *receive* information from *other spaces* (physical or virtual) and to process it. This capability also includes the ability of a physical space to react to a merger or separation request from another space.
- **Response**: the ability of a *physical space* to *transmit* information to *other spaces* (physical or virtual) and to induce a processing of this information, or even modifications in these spaces. This capability also includes the ability of a physical space to trigger the merging or separation of other spaces.

The following Fig. 9 represents these six relationships.

4.3.3. Consequences of the temporality dimension from the IMT framework

Finally, six properties have been defined to support the *Temporality* dimension within a metaverse. These are expected properties of *principal components* of metaverses: *virtual* and *physical spaces*, as well as of *physical representation* and *virtual personification*.

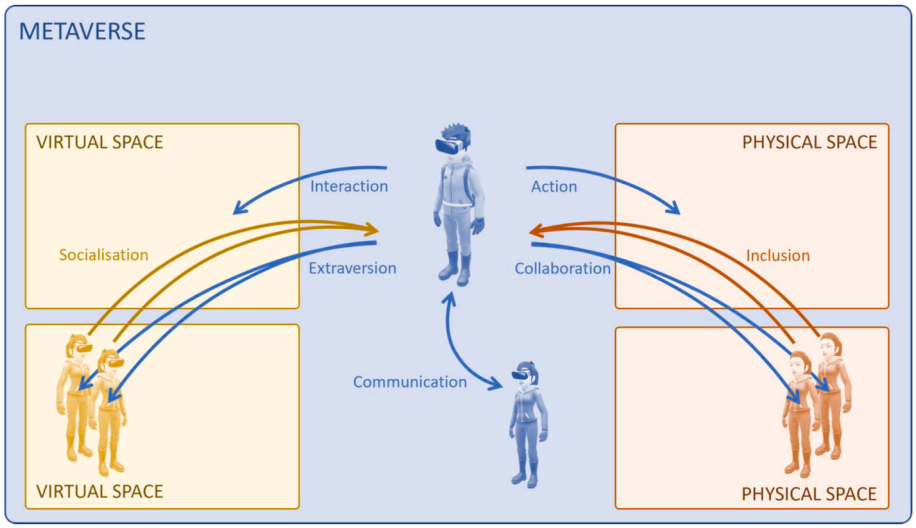

Fig. 8. Exchanges (i) between users, and (ii) from the user to spaces of the metaverse.

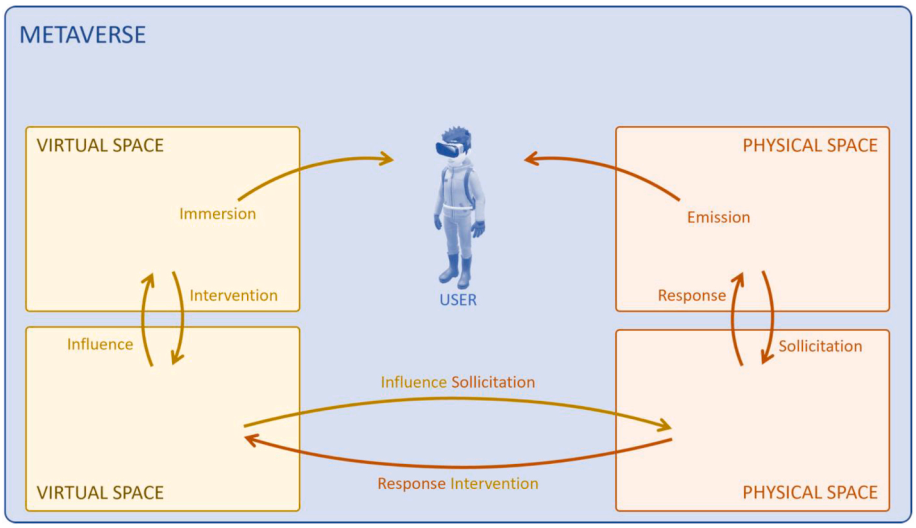

Fig. 9. Exchanges (i) between spaces of the metaverse, and (ii) from spaces of the metaverse to the user.

- **Creation**: the ability of a principal component to be created (by an authorized creator and under valid circumstances of time, context, etc.).
- **Destruction**: the ability of a principal component to be destroyed (by an authorized destructor and under valid circumstances of time, context, etc.).
- **Modification**: the ability of a principal component to be modified (by an authorized modifier and under valid circumstances of time, context, type of change, etc.).
- **Replication**: the ability of a principal component to be replicated (by an authorized replicating entity and under valid circumstances of time, context, etc.).
- **Merging**: the ability of several principal components to be merged (by an authorized merger and under valid circumstances of time, context, etc.). Merging implies strong restrictions in terms of the mergeability of components, which are not discussed here.
- **Splitting**: The ability of principal components to be split into several components (by an authorized divisor and under valid circumstances of time, context, etc.). Like Merging, Splitting implies strong restrictions in terms of component separability, which are not addressed here.

4.3.4. *Conclusion about the MetaMap*

The MetaMap introduced in the previous subsections should be seen as the set of properties to be verified by a metaverse: the spaces (virtual and physical) and incarnations (virtual and physical) should verify the properties of *creation*, *destruction*, *modification*, *replication,* and *merging*. Users should verify the properties of *personification*, *representation*, *socialization*, *extraversion*, and *inclusion*. Spaces should verify the properties of *intervention*, *influence*, *solicitation*, and *response*. Finally, users and spaces should verify the properties of *interaction*, *action*, *immersion,* and *emission*. The MetaMap is then the **third contribution** of this article: the applied contribution.

5. Experimentation and evaluation of the MetaMap model

We applied the MetaMap to two case studies: (i) a research project on a *virtual crisis management training environment*, and (ii) an educational project on an *immersive teaching campus*.

5.1. *The virtual crisis management training environment*

The results of this research project on a virtual crisis management training environment are presented in (Conges et al., 2019). This metaverse aims at improving the training of crisis responders through three virtual environments illustrated in Fig. 10.

- **The Exercise Context space** (Conges et al., 2020; Evain et al., 2021), implemented in virtual reality, represents a crisis theater. The on-site crisis responders evolve in this space facing the crisis scenario set up in the *Exercise Animation Space.*
- **The Exercise Animation space** (Evain et al., 2023) allows a game master to set up the crisis scenario planned for the training within the *Exercise Context Space.* It can be used before the exercise to configure it as well as during the exercise to adapt it to the trainees' reactions and the pedagogical objectives.
- **The Exercise Decision space** (Conges et al., 2023) represents a virtual crisis management cell linked with a decision-support system. This module interacts with the *Exercise Context space* to provide a real-time model of the situation to crisis responders (bottom-up) and offers tools to improve the decision-making process for crisis management to send instructions to on-site responders (top-down).

First, as avatars and spaces are virtual components that can be created, updated, removed, and copied, the three spaces (Exercise Context, Exercices Animation, Exercise Decision) and the virtual incarnations of users (Game Master, On-Site Responders, Decision Makers) verify the properties of *creation*, *destruction*, *modification*, and *replication*. However, the property of *merging* and *splitting* are not yet available.

Second, Fig. 11 shows how the three virtual spaces, the physical space, and the avatars are verifying the other properties of a metaverse:

The game master, the on-site responders, and the decision makers are real persons (*representation*) immersed in the respective virtual environments through their avatars (*personification*) and can interact with these virtual spaces (*immersion* and *interaction*). The three virtual environments can communicate with each other as shown in Fig. 10 (*influence* and *intervention*). The Exercise Context and Exercise Decision environments are designed to be used at the same time by several users who can talk to each other thanks to virtual sound spatialization (*socialization* and *extraversion*). The decision-makers and the on-site responders can communicate with each other to exchange oral information about the evolution of the crisis (*collaboration* and *inclusion*). The Exercise Decision virtual environment is linked to the physical crisis cell: information can be exchanged between the physical and virtual tools (*response/intervention* and *solicitation/influence*). The decision-makers in the metaverse can exchange information with the decision-makers in the physical crisis cell (*collaboration* and *inclusion*) and with the physical crisis cell itself (*emission* and *action*).

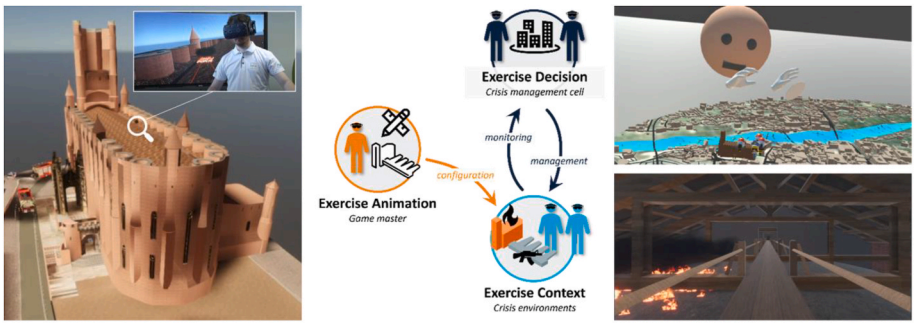

Fig. 10. Big picture of the virtual crisis management training environment.

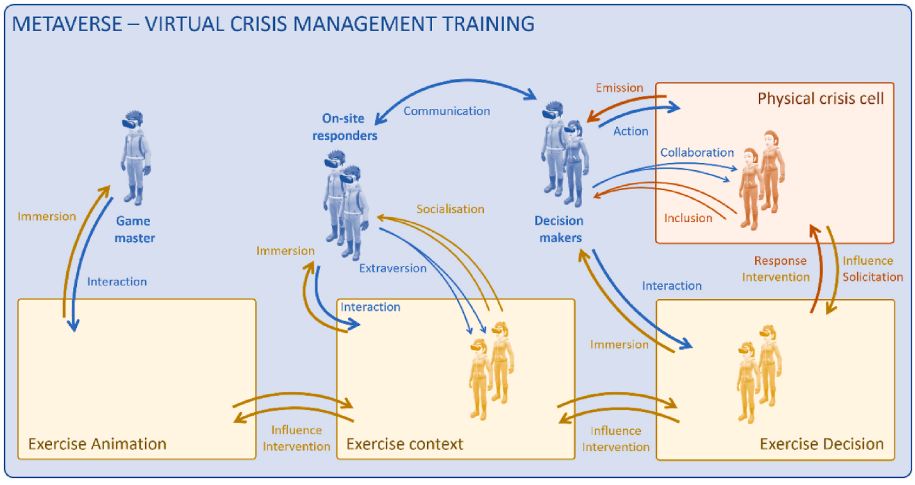

Fig. 11. Illustration of the MetaMap of the crisis management training environment.

In the next steps of this project, we can imagine that the virtual environment Exercise Context could be replaced by the physical context of the crisis: the decision environment (both virtual and physical) would gather data from the crisis site through various sensors (such as heat sensors, drones, smartphones or even social media) and information would be sent back to the on-site responders to help them assess the situation and solve the crisis.

5.2. *The immersive teaching campus*

The educational project on a virtual teaching campus is based on six main spaces that are presented on the next Fig. 12:

The hand metaphor is used to present the spaces.

- **THUMB** presents two transversal functions to the whole digital immersive platform: (i) tutorials for students and teachers to teach

Fig. 12. The immersive teaching campus overall structure.

them the basic manipulations actions inherent to the displacements in the immersive spaces, and (ii) accompaniment tools: intended to allow students to understand their academic pathway by using immersive visual tools (more instructive than the classic GPAs and syllabi).

- **INDEX** provides students with an autonomous immersive environment in which they can (individually or as a group, depending on the expectations of the course) face a pedagogical practical exercise, mimicking a real or fictional (realistic, simplified, complexified, or futuristic) situation.
- **MIDDLE** offers students virtual rooms in which they can gather cozily and efficiently and work on exercises and projects. In addition to replicating a physical meeting room (including presentation and content sharing tools, 2D/3D drawing features), this space should also include a feature for visualizing and handling INDEX components to allow students to discuss, demonstrate, and adjust their work and results.
- **RING** is an immersive capsule to consult, visualize, or re-experience any type of educational content. It can be (i) knowledge sharing (for example in the form of static content or more dynamic course sheets), (ii) the recording of offline content (for example a teacher presenting a lecture or an exercise), or even (iii) the replay of content previously broadcasted in an immersive component.
- **LITTLE** is a conference room in which teachers can give an improved immersive lecture thanks to three features: (i) *connection* with existing components to import material for an experiment, a lesson, or a meeting; (ii) *teleportation* to other rooms to enhance the students understanding and learning; (iii) *emphasis* thanks to the use of specific features (sensorial metaphors, interactive artifacts, 360 videos, etc.) designed to complement or replace traditional content delivery tools (slide projection).
- **GLOVE** is a large virtual space in which students can take a walk and enjoy the spirit and identity of the virtual teaching campus. It is a vast environment hosting all the other modules and providing unity to the whole.

First, and similarly to the previous example of the virtual crisis management training metaverse, students' and teachers' avatars as well as the six spaces are virtual components that can be created, updated, removed, and duplicated, the spaces and the virtual incarnations of students or teachers verify the properties of *creation*, *destruction*, *modification*, and *replication*. The properties of *merging* and *splitting* are also available as some rooms (for instance several MIDDLE rooms) can be merged, and some others (for instance a MIDDLE, a LITTLE, or an INDEX room) can be separated.

Second, Fig. 13 shows how the six virtual spaces, the physical space, and the avatars are verifying the other properties of a metaverse:

The teachers and the students are real persons (*representation*) immersed in the respective virtual environments through their avatars (*personification*) and can interact with these virtual spaces (*immersion* and *interaction*). The six virtual environments can communicate with each other as they can share students' works and other content (*influence* and *intervention*). Most of these spaces (especially LITTLE, MIDDLE, and INDEX) are designed to be used at the same time by several users who can talk to each other thanks to virtual sound spatialization (*socialization* and *extraversion*). The teachers and the students can communicate with each other to exchange information about the courses, exercises, projects, etc. (*collaboration* and *inclusion*). The virtual spaces interact with components of the physical space: a virtual space can send data to simulation software in the physical space and receive the simulation results to be displayed virtually (*response/intervention* and *solicitation/influence*).

In the next steps of this project, the virtual teaching campus is expected to become a hybrid teaching campus, allowing on-site and online students or teachers to interact in hybrid spaces. This feature would also demonstrate the features of interactions with the physical space (*emission* and *action*). To date, this environment cannot be considered a Metaverse according to the analysis provided by the MetaMap, however, the current coverage of capabilities and the next steps towards hybrid teaching clearly show the prospect of achieving Metaverse status.

6. Conclusion

Based on an initial state of the art on immersive technologies and

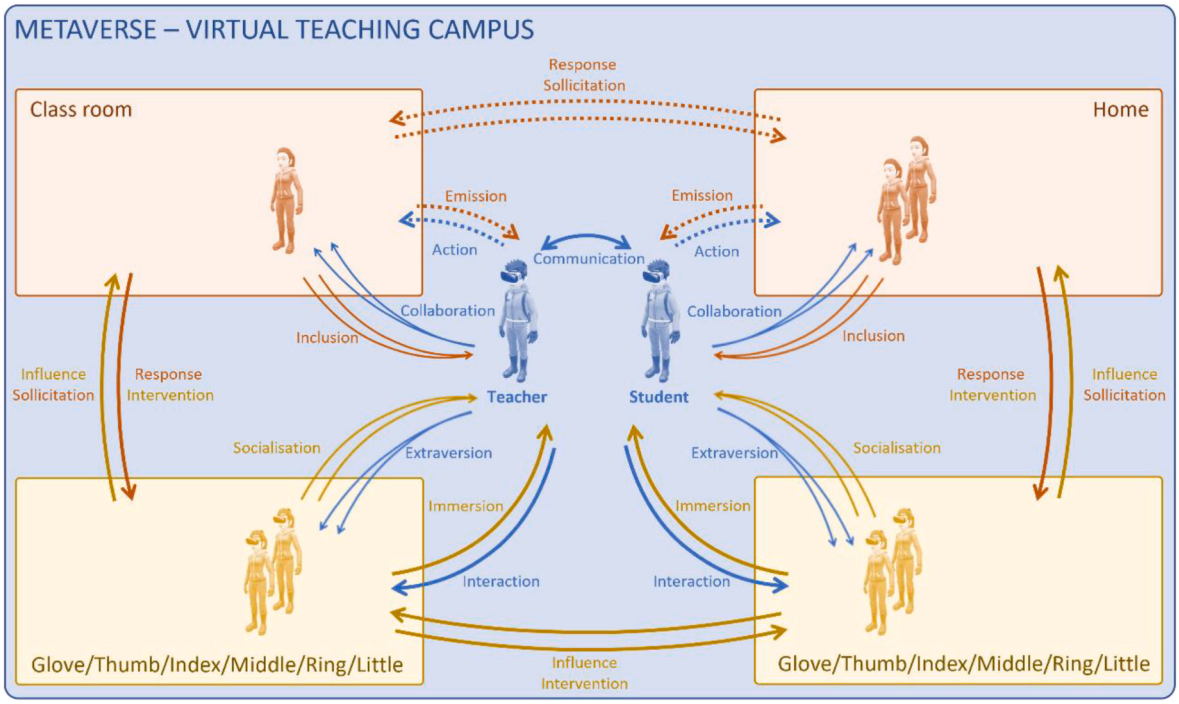

Fig. 13. Illustration of the MetaMap of the virtual teaching campus.

metaverses, this article connects the evolution of immersive technologies and of their potential usages by chaining **three contributions**: first, the theoretical contribution about a *unified definition of "Metaverse"*, second, the *IMT Metaverse framework*, as the conceptual contribution, which maps with the *unified definition of Metaverse*, showing that the metaverse can be legitimately considered as the future of immersive technologies. Finally, the applied contribution is the *MetaMap*, an analytic tool for Metaverse analysis, extracted from the *IMT Metaverse framework*, that brings this framework to an exploitable level. The contributions in this article aim at helping to conceive and produce metaverses that offer Integrability, Multiplicity, and Temporality, and thus are relevant depending on their intended use. More precisely on the concrete benefit perspective, and in a few words, the IMT Framework can be considered as a "multidimensional reading grid" that one can use to evaluate any immersive environment and assess its compliance and maturity as a metaverse. On the other hand, the MetaMap can be considered as a structured and structuring framework to design, implement, and maintain efficient, useful, and easy-to-operate metaverses. The following Fig. 14 illustrates this chain of contributions and how they relate to each other.

From the research work presented in this paper, we identified three types of outlooks linked to the **time, space,** and **social** aspects of the Metaverse.

- A metaverse should improve the relationship with **time**: taking advantage of virtuality to freeze time (pause a virtual or augmented activity) or relive a virtual or augmented experience (not as a simple replay but as a free immersion in this experience).
- A metaverse must also improve the relation to **space**: offering new characteristics inherent to its digital and hybrid nature as *teleportation* or the *merging* of virtual and physical spaces, the *parallel use* of the same space by several users, the *ubiquity* of users who can be in several spaces at the same time, interacting with groups of users and spaces that do not see each other, the *variety of points of view* of course, freeing oneself from gravity or distance by taking any point of view on a subject, by performing any zoom in or zoom out action, but also by sharing the point of view of another user, etc.
- But the metaverse should also offer progress regarding the **social** aspect: increasing accessibility for users. This great strength (and huge weakness) of social media must be positively exploited by the metaverse. These perspectives include instant channels to communicate or join actors in the metaverse (while respecting confidentiality and privacy constraints), contextual augmented social information and dynamic profiles (private and public), new means of communication to be invented (new immersive media to present a project or an idea) in the authoring and editing domain.

The last consideration is about the status of the human being within the metaverse. The existence of the users, the perspectives associated with their incarnations in spaces, and the dynamicity of these spaces, necessarily raise the question of "EXISTENCE", in the philosophical sense of the term, and of the associated consciousness. One will be able to wonder if it will be relevant to make existence evolve towards new concepts such as "INISTENCE", (INternal condition to be opposed to EXternal "EX-ISTENCE") or "IMMERSISTENCE" (IMMERGED reality to be opposed to the physical EXISTENCE), or even "IMMERSITUDE" as a plural immersed condition. The associated self-consciousness of the user will certainly depend on these visions of the condition.

CRediT authorship contribution statement

Frederick Benaben: Writing – original draft, Validation, Supervision, Methodology, Formal analysis, Conceptualization. **Aurélie Congès:** Writing – review & editing, Visualization, Validation, Formal analysis, Conceptualization. **Audrey Fertier:** Writing – review & editing, Methodology, Formal analysis, Conceptualization.

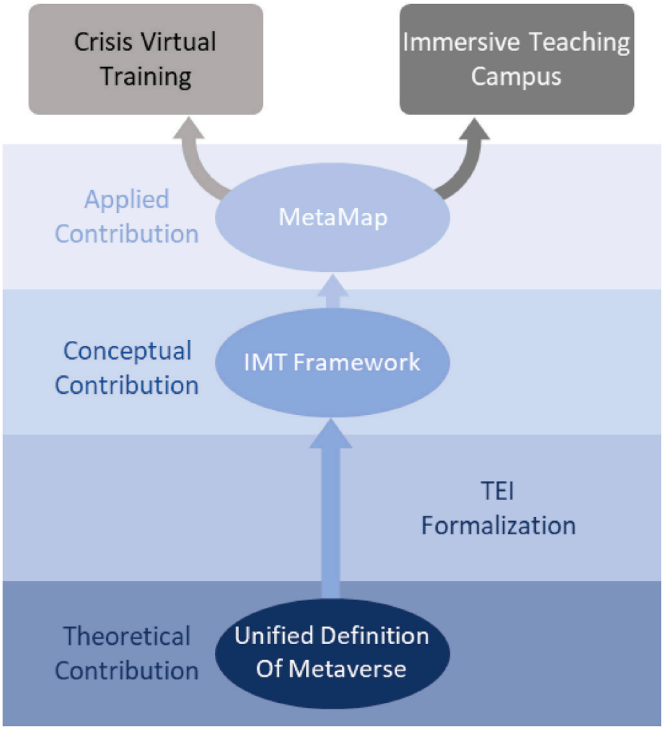

Fig. 14. Abstraction layers of contributions and their interactions.

Declaration of competing interest

None.

Data availability

No data was used for the research described in the article.

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