Introducing the material experience concept in the metaverse and in virtual environments

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Abstract

Metaverse consists of a set of virtual spaces populated by avatars and allows humans to move from the commonly known detached browsing interaction to inhabiting what is now called the immersive internet or spatial web. Here another dimension is added to interactivity by merging the virtual and real worlds. MetaverseIt is creating new interaction possibilities in content consumption for various fields: health, mobility, architecture, fashion, art, social, retail, etc., improving user engagement.

Material experience plays a key role in how human beings perceive and interact with the world through their senses. While in physical artefacts, material perception is intrinsic to what they are made of, in the case of virtual objects can simulate materials with existing behaviours or even have the potential to create modes of material interaction without precedents.

The Metaverse's technological ecosystem can directly affect how we interact with objects in real, virtual, and mixed environments. However, it still requires intensive research and development to reach its full potential.

This article aims to investigate how material experience is approached in Metaverse ecosystems and in virtual environments in general from two main perspectives: by the users who populate these virtual dimensions interacting with virtual materials and by the designers who take part in their creation and development.

To do so, a framework has been created to classify all the possible characteristics that virtual materials can have in the virtual environments, hence in the Metaverse, following the five senses and in the meantime, a correlation has been traced with the related virtual output defined by the designer who develops material experiences for virtual environments.

This analysis highlighted that it becomes vital for the designer developing material experiences for virtual environments to be aware of the possible hardware devices available stimulating the virtual material experience in the user; that a balance needs to be created between the richness of details and the performance to ensure fluid experiences in relation to energy consumption and the speed of the connection; that, especially nowadays, living in times of conflict, designers should develop more inclusive virtual material experiences opting for a multi-modals experience stimulating multiple sensorial channels fostering connectivity and creativity.

Author keywords

Metaverse, material experience, design, material, virtual environment, virtual materials, augmented reality, virtual reality, mixed reality, user experience, user interaction

Introduction

Mixed reality (MR) is the merging of physical and virtual worlds, where virtual stimuli are overlaid with a real scene in real-time. It allows us to create a fluid and interactive interconnection between the virtual and the real world and potentially become the next big change in the media world (Mott et al. 2019).

The enhancement of MR creates new possibilities of interaction in content consumption in various fields: health, mobility, architecture, fashion, art, social and retail. It creates unprecedented ways to interact with products, from improving customer involvement in the purchasing phase (Grewal et al., 2017) to enriching the product usage experience. The current content is mainly based on visual cues complemented by some audio integration. In this virtual and mixed environment, material experience (MX) plays a key role in how people perceive and interact with physical and virtual objects (Bardt, 2019). While in physical artefacts, the material perception is intrinsic to what it is made of, the processes used in the manufacturing and with respect to the laws of physics, virtual objects have the potential to explore new laws to create unprecedented ways of interaction (Milgram and Kishino, 1995). However, interaction with virtual materials can only be related to the means, tools and devices available to enhance that. MR technologies have been explored for decades and are already available through different devices. It will be possible to consider MR as a continuous between physical and virtual in the very near future (Peddie, 2017). However, it still requires intensive research and development to reach its full potential as the next breakthrough media.

In this paper, the concept of MX is not related only to the physical dimensions but also to the digital ones. Furthermore, the digital dimension is not referring to the actual materiality of the medium (e.g. computer, smartphone, VR glasses), but also to the digital representation of materials in virtual spaces, such as their aesthetics and interactive qualities. Considering the metaverse as a space web (Accenture, 2022), all representations of its elements, objects and environments displayed need to be manifested somehow to the user called to occupy a virtual space and to interact with their contents. Objects and environments need to be addressed with a visual appearance (e.g. colour, glossiness, texture, etc.) and/or designed to give responses and feedback when the user interacts with them. Therefore, looking at the Metaverse and virtual spaces in general from this perspective makes emerges how MX plays a central role in how users experience them and what the designers need to take into account to create a meaningful experience.

The Metaverse and its challenges

Metaverse is an evolution of the current internet that allows people to move from browsing interaction to inhabiting (Accenture, 2022). It is also defined as the immersive Internet or space web, the spectrum between merging the virtual and real world where the 3D dimension is added to the interactivity. We can see the *"Metaverse not as virtual space but as the junction or nexus of our physical and virtual worlds"* (Smart et al., 2007). In this sense, the metaverse is not necessarily something detached from our reality, a virtual place to escape, but rather it can be integrated into our reality, an evolution in content consumption in a more immersive, natural and interactive way (Giang Barrera & Shah, 2023).

One of the clearest limits of the Metaverse's user experience is that, for the majority of cases, it happens only through two sensorial modalities: vision and sound. Users are still using their old devices (e.g. computers, mobiles, etc.) to navigate in it, so the Metaverse is being designed e developed to respond only to those types of interfaces. This contributes unequivocally to creating poor experiences, even causing some users exclusion in case they have some disabilities (Zhao et al. 2018). The near future of MR technologies is to explore multi-sensorial experiences enabling the construction of a 3D Web (Heller et al., 2019), having the potential to reduce the gap between disabled or regular users by improving mental imagery and the *sense of presence* (Sun et al., 2022). The term *presence* is used because it offers a broad perspective of phenomena and doesn't limit the interaction to certain technologies enabling the users to both *be there* (immersion in a virtual environment) and *be here* (the virtual contents are displayed in your current physical environment). In the context of the Metaverse, the *sense of presence* can be defined as "a psychological state in which virtual (para-authentic or artificial) physical objects are experienced as actual physical objects in either sensory or nonsensory ways." (Lee, 2004).

Material experience in virtual environments

Through the latest decades of technological advancements, people rely heavily on screens to conduct digital interaction. TVs, computers, smartphones and tablets are the dominant technologies to access data, communicate or produce content. However, while on one side, there is a great development in image processing, creation and representation, the other typologies of stimuli have been slowly developed. For this reason, digital interaction has become less and less tangible (Jung & Stolterman, 2010). It was partially caused by the slow technological developments in this area but mainly because the content characteristics developed for web 1 and 2 are characterized by interactions happening in 2D displays (Heller et al., 2019). With the advances done and the expectation of Web 3 spreading, the Metaverse opens wide new possibilities of interactions in three-dimensional environments and richer multi-sensorial experiences. The new generation's powerful processors allow the renderisation of better images, sounds and haptic feedback with more quality and richness at high rates. Faster connections allow exchanging data faster than ever. Hardware sensors are able to make experiences more aware of our surroundings and adapt the content to make us experience the *sense of presence* in digital environments. AI not only assist in performing faster and smarter tasks but also curate meaningful content and create experiences more personal to each user (Huynh-The et al., 2022). All this converges to new levels of interactions and contents. In this way, inhabiting a virtual environment means adopting new rules *augmenting* physical objects and environments or even creating representations of new ones. To this end, the digital materials experience (MX) comes on stage, which means, for designers, designing the MX of new virtual artefacts and environments.

Virtual materials and the Metaverse: cases from the contemporary phenomenology

The number of users spending more time in virtual environments is rising, a trend that has evolved since the beginning of the internet but that intensively increased in the last 3 years of the pandemic with the wide migration of activities and interactions performed in the physical world to a virtual environment (Mott et al. 2019). This creates the need for virtual environments to allow people to express themselves through virtual features such as avatars' appearance, avatars' clothes and accessories, private virtual spaces, virtual artefacts and art (Giang Barrera & Shah, 2023). These push design practitioners to go beyond the laws of the physical world, allowing themselves to design speculative new aesthetics, interactive modalities, narratives, experiences and even identities. The merging of physical and virtual dimensions has been one of the sparkles to the rise of some of the most significant speculative design case studies in the last decades, touching materials as part of their themes. Among them, we can mention the work done by Antony Dunne in the Hertzian *Tales: Electronic Products, Aesthetic Experience and Critical Design*, where the author questions the relevance of materials perception in the perspective of progressive virtualization of electronic products (Dunne, 2008). Still, Dunne, together with Fiona Raby in *Speculative Everything: Design, Fiction, and Social Dreaming*, imagines solutions were treating alternatives to the current dynamic (imagining how things might be) and operating outside reality, proposing radical solutions that affect current society, politics, and economy, thus challenging the building system. Thus, virtual worlds create critical, alternative realities that challenge the real world by contrast (Dunne & Raby, 2013). In this context, Virtual designs emerge from the real and shape the unreal; they are re-individualized spaces where the boundaries of identity are constantly reshaped, as are meeting places hosting new communities and generating new networks (Koozarch, 2022).

As we become more reliant on technology, the speculative design will most likely become more focused on how we interact with devices and virtuality (Chakrabarty, 2023). A contemporary speculative design case study is the work developed by the designer and creative technologist Billy Kwok called *Metaverse Design Manifesto, Undystopianizing the Metaverse*.

The designer developed an artwork including an interactive augmented reality experience that serves as a cautionary tale for the Metaverse and a design manifesto that lays out ten principles to make the Metaverse a positive evolution rather than a potential dystopia. Among his *Metaverse Design Manifesto*'s 10 principles, we can find pr point n°9 *Embrace digital materialism*. Billy suggests to designers to add a bit of physicality and substance to virtual objects to avoid pure photorealism or minimalism, embracing a balanced mediation between digital augmentation and digital augmentation (Billy Kwok, 2023).

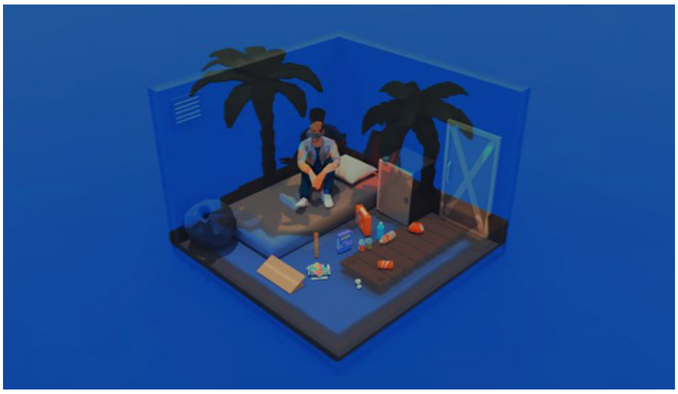

Figure 1. Metaverse Design Manifesto, Undystopianizing the Metaverse

The Metaverse is creating endless possibilities to make speculative design cases virtually or hybridly experienceable by users worldwide; on the other hand, it is possible to see that, as a reflection of our physical reality dominated by capitalistic logic, it is possible to provocatively say that the kind of speculation widely spread in it is also the economical one (Giang Barrera & Shah, 2023). In this regard, some designers have been able to lean on the MX to create new virtual artefacts and environments, generating revenues and interesting case studies.

Andrés Reisinger explored the new possibilities of virtual materials in his furniture pieces. He raised US$450.000 on auction with his furniture collection "impossibles" in 2021 (Dezeen, 2021). As the name suggests, the pieces are surreal, looking and behaving in unconventional ways if compared to physical laws. On the Tangled chair (Figure 2), he played with the perception of structured softness by breaking users' expectations when they saw the armchair collapsing, revealing the empty core. Similarly, the Deep Space sofa (Figure 2) presents similar initial characteristics of softness built by exterior fabric texturing and emptying over time, however, there are incongruences between the initial volume movement, the emptying speed, and the final volume. At first glance, it is possible to imply the sofa back is filled with some liquid inside due to the swinging weaving. However, as it starts emptying, the speed is faster than an actual liquid would flow out the volume, remitting to air behave as the final volume also indicates. In both cases, it's primordial the time dimension of the experience. The material and object performed to bring the surprise effect increase the distinction and value attributed to the virtual product.

Figure 2. Impossible sofa collection by Andrés Reisinger

The opportunity to play with materials and interactions has not only been applied to artefacts but also to proper environments designed to generate experience in the user through their virtual materials. The designer/artist Krista Kim designed Mars House, an NFT 3D house. It reached the price of 288 Ether (equivalent to $512,000). It was described by SuperRare (2021) as "the first NFT digital house in the world". The owner Has access to this digital space through VR technology. The aim was to create a zen environment, an escape place to relax. To this, it applied colour gradients on the floor and ceiling similar to sunset pallets, Kwon, to promote relaxation in users. The dichroic effect on the furniture surfaces also creates the gradient to reach the same effect. The use of translucent material emphasizes the environment's lightness avoiding creating solid visual barriers. On the upholstered furniture objects such as sofas and armchairs, it was applied a texture mimicking velvet. It improves the perception of softness, smoothness and worminess strangely related to the idea of comfort and comfortable seating. Even if the cues are strictly visual, we link the visual information to our previous knowledge and past experiences and attribute the idea of comfort and relaxation to the Mars House (Figure 3).

Figure 2. Mars House by Krista Kim

Material experience introduction

Material experience (MX) is usually inherent to the design process of physical goods, and since the early design schools materials have been involved in the creative process. Bauhaus design schools introduced MX by studying materials, advocating that thinking, knowing and exploring materials were fundamental for good design practice.

The designed physical artefact exists in volume, represented by an outer surface and an inner core. An object only exists if it's made of something (Ashby & Johnson, 2013). With the digital revolution, the conception of existence evolved from physical products with physical features to a blurred border between physical and digital until encountering virtual objects built by bits. However, even purely virtual artefacts are still manifested by the representation of substances. Before jumping into how MX occur in virtual experiences is vital to understand its nature briefly. The designed physical artefact made by its essence (matter) is a medium to arise an experience, and MX are those experiences generated with and through the product's materials (Karana et al. 2008). MX consists of four main experiences that users can encounter interacting with materials:

1. *sensorial experience*, those coming from appraisals inspired by material sources, such as smoothness/hardness, warmness/coldness, glossy/matt, deep/shallow sound, etc.;
2. *meaning experiences*, thank the contact with the material, the user can project ad introject a series of meaningful connections with his/her own experience;
3. *emotional experiences* generated on users that are able to create make the MX recall some emotional content inspired by the material;
4. *performative*, how people would interact and how materials can guide them to certain actions.

Designing physical objects means transforming materials into desired artefacts. The materials' proprieties and characteristics directly affect the creative process and final result. It determines possible shapes, functions, interactions, durability, value and sensorial stimulus. Aesthetic shapes, which stimulations we receive according to the *human five senses*. The received inputs will be processed by the person and judged into meanings according to personal standards, raising the question of what the material means to us. It's a cognitive process based on association, situation, memories, past experiences and symbolic significances to objects. It's highly influenced by personal characteristics, cultural differences and actual psychological state (Rognoli, 2010).

Translating physical to digital

This section intends to present an analysis of how the designers are often called to understand the correlation between the envisioned MX, the qualities of the material they want to design and their virtual representations. Consequently, it will be presented as an in dept exploration of the tools, aspects and commands at the disposal of designers working for digital environments. To do so, a framework (Figure 1) has been created to classify the possible interactions (passive and active) doable by the users with the materials present in virtual environments (also the Metaverse) following the five senses. Meanwhile, a correlation has been drawn with the related virtual cues defined by the designers developing material experiences for the virtual environments.

In Figure 1, the lines are divided according to the five human senses, while the columns represent the different subjects divided into:

- » *material qualities:* are the characteristics that materials in the physical world can have, e.g. surface, volume, rigidity/elasticity, weight, etc. These are the starting point for giving and designing the qualities of virtual materials.
- » *material proprieties:* are those to be designed by the designers for the virtual environments; they can be passive or active.
- » *virtual correspondence cues:* are properties and characteristics that the designers use to obtain the desired MX. They can be commands present in software or parameters controlled by the designers to obtain a certain effect.

The *material proprieties* column is divided into *passive* and *active*. *Passive proprieties* are those that do not require an active response, effect or animation. On the other hand, *active proprieties* require something to be performed by the object or the environment made of the designed material. This can be a variation of the original shape, appearance change, displacement, sound, etc. It was chosen to make this clear distinction because it influences how the designer will develop and envision those virtual materials. During the process of designing the MX, it is required to define the materials' qualities to improve the material performance and so the user experience in interacting with them. These aspects are particularly important when we deal with *active material proprieties* that have an important role in the virtual MX. This is because they are designing materials in an environment where they can decide their own reality, with new laws of physics and impossible phenomena. To do so, designers should first understand how the user will actively interact with the object and which device will mediate the experience (screen, mouse,

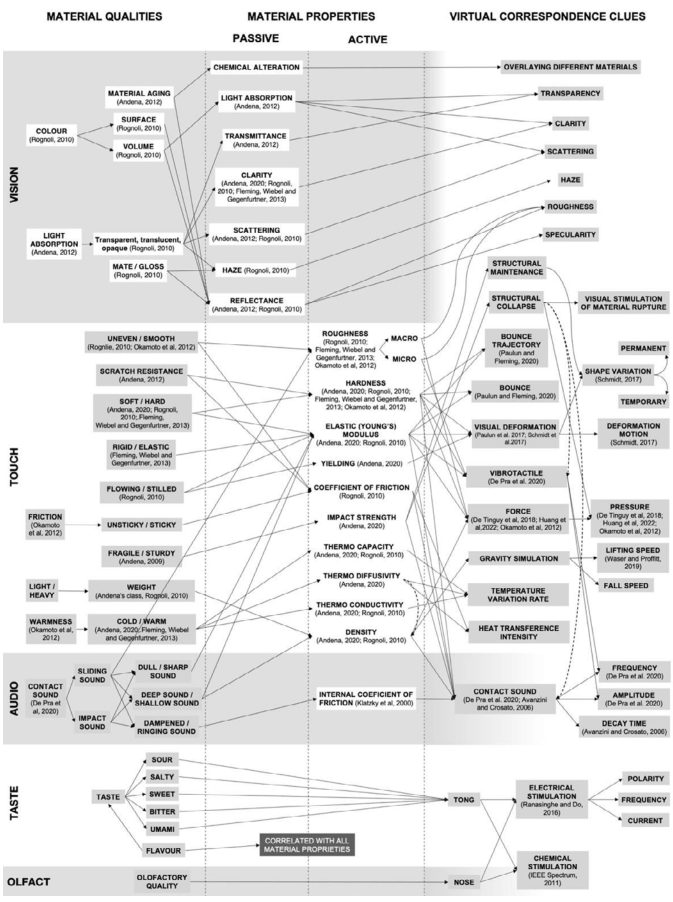

Figure 3. Virtual material experience framework

mobile, VR set, etc.). This is vital to understand which stimuli can be generated and which types of input users will give during the interaction generating virtual correspondences cues as consequent outputs feedback. In the case of *passive material proprieties*, the object would not require any active performance; the object would exist on the scene and react to the environment proprieties (such as global illumination and light interferences from other objects).

Here following, we raised some considerations and mentioned some case studies that have been analysed following our framework (Figure 1). This one has been put together through a rich literature review on MX, materials-related design methodologies, physical materials properties and design for virtual, augmented and mixed reality.

A first consideration observing Figure 1, is that, in general, visual material qualities have a more linear and direct correlation to the virtual correspondence cues. The main explanation for this link is that most of the graphic rendering software uses the PBR technique to render. The PBR means Physically Based Rendering; it is based on real-life surface properties to generate a visual representation being represented by pixels screes. This approach creates a more intuitive and accurate workflow by making analogies with our physical world materials (Souza & Mota, 2021). It calculates the rays of light received in one specific point (referred to as cameras on rendering software) from the light scene. Since the physics phenomena are consolidated, well studied and defined, rendering software programs represent virtually those characteristics.

Physical-virtual perception

Applying a force to an object's body shape influences how people perceive its mechanical properties. Hardness and elasticity are basic mechanical proprieties and are perceived mainly through physical interaction by the users, therefore, they also can be inferred by visual cues. When objects are shown deforming by the action of an external force in dynamic images, people can imply a level of stiffness by comparing the initial shape with the final one when the force is applied to it. Effects such as light, self shadows and surface texture displacement can indicate the deformation of a surface, creating the illusion of deformation and softness during the interaction. As much the texture deforms, and the differences between highlight and darker the self-shadow areas are, the softer the material is perceived. The visual motion of the process of deformation is a key stimulus to perceive the softness/hardness otherwise observer could lose this correlation when presented just with a static image mode of the initial and final shape. Another factor that collaborates with people correctly perceiving hardness and stiffness is knowing the applied force. For example, users who are extremely familiar with this kind of force can easily perceive an object suffering gravity's action effect. Another example related to the perception of stiffness can be given when an object is in free fall and hits the ground, users are able to judge the bouncing and bouncing motion trajectory to estimate hardness and elasticity (Paulman and Falming, 2020). Material density also can be communicated through visual correspondence cues by, for example, controlling the object's lifting speed. In this case, users associate their notion/perception of weight with the fact that the slower the object moves up, the heavier the object is perceived. Moreover, by presenting objects with the same lifting speed but different volumes, the object with the smaller dimension could be perceived as heavier and denser. It indicates that users bring their notion of real-world behaviour to virtual environments (Lv et al., 2022).

Haptic interactions

Haptics cues also can contribute to stiffness perception. De Tinguy et al. (2018) developed a wearable haptic device that simulates the pressure on the finger. They tested the haptic device in combination with VR and AR, simulating interactive objects, such as buttons, balloons and the human body itself. The study revealed that users better perceived stiffness when combining visual stimulation with haptics, even if the force was not applied directly on the user's fingertip. The interaction was better obtained in AR mode when users interacted with tangible objects layering the haptic stimulus on top of the physical surface rather than in VR, where no actual object was handled (Billinghurst et al., 2015).

Auditory interactions

Haptics-auditory can also improve the perception of materials and improve the object's *sense of presence*. De Pra et al. (2020) conducted an experiment recording the vibration and sound from the contact sound of a ping-pong ball with three different materials: wood, plastic and metal. Those recordings were then reproduced through high-fidelity headphones and a low-quality haptic display on a glass surface which users could interact with. The result demonstrated that people can distinguish clusters of materials by vibrotactile and auditory stimuli with more assertiveness on metal (by its characteristic sharp waving sound), followed by plastic and the less recognizable wood sound. The author deduced that more precision on the stimuli could contribute to a more engaging and realistic experience. The same findings were pointed out by Avanzini and Crosato (2006) that said that in *cross-modal haptic-auditory* interactions, audio could compensate for the lack of high definition on haptic devices. Moreover, Avanzini and Crosato (2006) stated that the buttons perception of virtual buttons is improved when sound feedback is added.

Virtually tasty

Our perceived experience with food and beverages is very complex and can involve all 5 human senses. Let's take as an example the experience of eating a triangle of nachos. The crunchiness can be elicited by visual cues of how the piece of food collapses, by audio presenting the sound of crumpling, haptics from the breaking, the corny smell released and by taste with stimulation of salty and sweet in the mouth. One of the main challenges in many explored areas of virtual experiences is taste (Ranasinghe & Do, 2016). While some research areas try to recreate artificial taste and flavour sensation by the use of chemicals, others seek to stimulate it by electro stimulations. Using chemical substances can indeed create rich experiences, but it raises several issues, such as manageability, transferability and scalability of these applications due to the need to have several chemical compounds involved. Electro-stimulation, on the other hand, is presented as an alternative to solve most of these problems. Ranasinghe and Do (2016) proposed a Digital Lollipop, where a wearable device was placed on the user's tong and electro-stimulated. The experiment was able to manipulate the sour taste on users' tongs similarly to lemon juice just by manipulating the electric current, frequency and polarization. Furthermore, taste perception also can be influenced by other factors, such as the context where the taste experience is perceived. Narumi et al. (2010) conducted a study in this context, proposing that a possible solution would be improving the scene definition, stimulating the perception of different states in the user's mind through scanning and automatically generating a 3D scene in real-time.

Conclusions

Metaverse is not a novel concept; however, its market application, widespread and naturalness in the interaction are constantly evolving. Over the past two decades, there was a great development in technologies that enabled the Metaverse to activate its next application level. The current 2D web interactions are evolving into 3D content awareness. This virtual content can be accessed through different devices able to render stimuli over the five human senses.

We are seeing that mixed-reality technologies initially focused on visual-audio experiences for ludic interaction such as video games (Karis & Epic Cames, 2013). In the meantime, tech companies are developing their products for professional applications in the Metaverse due to the economic potential generated by it.

MX in the Metaverse can improve the realism of virtual experiences and improve the *sense of presence*. It directly impacts how we interact and act in mixed physical-virtual environments. It can improve the comprehension and enjoyment of physical products' digital representations. It allows new interactive levels between actual objects and virtual information, for example, changing the visual aesthetic of certain product surfaces by applying an unexpected texture and colour or perhaps adding haptic feedback exploring tactile experiences on materials to enhance some of their characteristics (Baumgartner et al., 2013). Furthermore, MX can improve the experiences in virtual environments and objects, adding new self-expression possibilities by representing the users' personality through virtual customised characteristics allowing a better *sense of presence* and ownership over virtual objects such as NFT-certified artworks.

To better understand what the factors to be taken into account by the designers developing MX in virtual environments are, It has been essential to create a framework (Figure 1) linking the actual physical materials' attributes to virtual ones involved in the MX. In this way, this current work presents an effective correlation between *material physical qualities* in the physical world, *material proprieties* that could potentially be defined by the designers in the virtual one, and *virtual cues* to be set to obtain the desired MX. However, human perceptions are extremely complex and could be stimulated not only by the cues listed among the presented cues and the relative case studies or, as we could see in the above-mentioned examples, but cross-modal (stimulating more senses at the same time) interactions could also blur sensorial perceptions suggesting more effective stimuli (Huang et al., 2021). These could be, tasting colours or haptically feeling an image (Baumgartner et al., 2013).

Adopting the point of view of the designers, we can affirm that to create a meaningful MX in the virtual environments, the following aspects need to be taken into account:

- designers need to be aware of the hardware devices to stimulate the MX possibly used by the users and its processing capabilities.
- the designer needs to great balance between detail richness and performance to ensure fluid experiences taking into consideration the required consumption of energy efficiency and connectivity.
- design for the Metaverse, particularly, involves constantly thinking about accessibility and easy usage. At the present time, we are seeing the chance to define primordial standards for interface interactions and feedback, taking into consideration a more inclusive perspective and so the needs of users not able to adopt all the five senses (Baumgartner et al., 2013). Therefore, designing cross-modals MX can produce more inclusive solutions by stimulating different sensorial channels. In this manner, some stimuli can compensate in case of users' sensibility deficit.
- the convergence of technologies we are witnessing creates an environment that allows new levels of interactions through which designers can trigger MXs. In this context, Designers need to make several choices in the virtual MX design, for example, which method and equipment to use to discover material proprieties, which device to use to render the experiences, which software to use to create them, which sensorial channel to stimulate during the experience and so on.

The focus of this article wasn't to explain in detail particular software or technologies because it is highly variable, and only designers can take into consideration their available resources to define possible paths. This condition is quickly evolving, having novel technologies rapidly spreading, such as neural rendering and 3D scanning on personal devices combined with the intensive use of AI to automatize time-consuming and highly-skilled processes, which are making the production of virtual materials and objects more democratic and widespread. This can stimulate non-skilled users outside the professional environment making content creation more intuitive and faster, leading to additional ways for common users to express themselves on social networks, sharing not only images and audio, but sensations (through the 5 senses) through sharing objects and virtual artefacts.
In the end, we can firmly affirm that further studies need to be developed to understand the influences of sensing virtual materials possibly in the development of novel devices to fully simulate new and always more rich virtual MX.

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