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# ICE Breaking: Disentangling Factors Affecting the Performance of Immersive Co-creation Environments

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## ABSTRACT

Engaging users for co-creating alternative solutions and usage scenarios is, as revealed in previous studies, not so obvious. Very often, it necessitates expensive high-tech resources, such as a CAVE (Cave Automatic Virtual Environment), for setting-up an immersive environment in which all project stakeholders, especially users, would feel comfortable enough for unleashing their valuable contribution. Our previous empirical study on low-cost immersive environments has unveiled the great potential of close-to-real-life immersion that fulfils the realism principle of a Living Lab facilitating users' contribution to alternative solutions and usage scenarios. However, this previous work had a limit of addressing individuals through their capacity of behaving naturally within different types of immersive platforms. As a step further, this paper presents the outcomes of an investigation to identifying and disentangling factors characterising a group immersion in the context of co-creation instead of an individual's immersion.

## Categories and Subject Descriptors

H.5.1 [Information interfaces and presentation]: *Multimedia Information Systems* – artificial, augmented, and virtual realities, evaluation/methodology. H.5.1 [Information interfaces and presentation]: *User Interfaces* – graphical user interfaces (GUI), User-centered design.

## General Terms

Design, Co-creation, Human Factors, Measurement, Immersion, Collaboration, Performance.

## Keywords

Immersive Virtual Environment; Mixed Reality; Augmented Reality; Virtual Reality; User eXperience, Living Lab; eXperience Design;

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## 1. INTRODUCTION

Co-creation is one of the most important activities for designing innovative ideas and usage scenarios, through an iterative eXperience Design process, with users. It allows to anticipate the resulting User eXperience; hence, evaluating the potential technology acceptance and solution adoption by users. This is an essential difference with users observation-based design approaches like contextual design or even design thinking.

In this paper, we present the continuation of our previous work [1, 2] on Immersive Virtual Environments (IVE) towards the design of a specific framework for experimenting and evaluating Immersive Collaboration/Co-creation Environments (ICE). Such kind of IVE is intended for several users and has been, up-to-now, often implemented through the use of a CAVE. However, CAVE solutions are not so affordable for SMEs and especially Start-ups. Recently, low-cost immersive technologies have emerged, which further explains why we want to experiment and evaluate different ICE platforms that could be more affordable for small organizations. Besides discussing the research publication stream on ICE, we explore the previous work related to immersive collaboration within the context of Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) technologies. Our goal is to identify and disentangle factors impacting immersive co-creation in the view of preparing appropriate experiments and related evaluation approaches.

## 2. PREVIOUS WORK

We have previously [2, 5] introduced most of the concepts used in this work, such as: Open/ Collaborative Innovation, User-Driven Innovation (UDI), Living Lab, Immersive Technologies (VR, AR, MR), eXperience Design (XD), Co-creation, Collective User eXperience (CUX), Immersive eXperience (IX), Quality of Service (QoS) and Quality of Experience (QoE). Our UDI vision fits with the Von Hippel studied "Consumer Innovation" paradigm [5].

### 2.1 Co-creation

Ramaswamy and Gouillart [31] consider that Co-creation is about engaging people to create more value together and involves redesigning interactions based on individuals' experiences. They argue that through co-creation, organizations can unleash the creative energy of people — especially employees and internal stakeholders, but also customers, suppliers, and related external stakeholders and communities — to create mutual value. The term "co-creation" is a typical design collaboration activity synonymous to ideation but refers to the engagement of customers/users/citizens for co-creating value [2]. Furthermore, co-creation is a group activity, based on social interaction, which

implies the notion of co-presence (or social presence) when it occurs in immersive environments. Hence, co-creation is one of the activities characterising User-Centred Design (UCD) methods, such as eXperience Design (XD).

When a group of participants representing different disciplines and stakeholders have to collaborate, distance factors affect their collaboration performance [28]. One could argue that it is exactly the same for co-creation in immersive environments because it is just a particular form of collaboration involving users as experts of usage scenarios. For example, interpersonal distance is a well-identified factor impeding collaboration effectiveness and efficiency between humans [30] or between humans and virtual humans [32] within an immersive environment.

Scholars have studied co-creation and a related form of social immersion. Pallot et al. [30] argue that innovation paradigms and design approaches promote distributed collaboration among organisations and user communities. However, project stakeholders are mainly trained for improving their individual skills through learning experience (i.e. practical exercises, role playing game) rather than getting a live user experience through immersive environments (e.g. Virtual Reality, Serious Games) that could unleash their creativity potential. Authors discuss issues related to the use of innovation games for enabling user co-creation in the context of collaborative innovation and experiential living labs. They also argue that people are trained for enhancing their individual skills and improving their productivity rather than for enhancing their collaboration skills and improving their interpersonal productivity. On the one hand, users or citizens have to experience something new while sharing feedback, meaning and understanding within the community; on the other hand, researchers collect data for better understanding emerging behaviours and usage patterns as well as embedded adoption mechanisms. Authors try to evaluate the role of distributed cognition and collective intelligence, including both social and emotional intelligence in the decision making process. Recently, Rihova et al. [29] introduce a Customer-to-Customer (C2C) co-creation perspective, conceptualizing the social layers within which value is formed. This approach extends current value co-creation discussions by providing conceptual insights into co-creation within customers' social sphere; hence, allows benefiting from understanding how customers can be "nudged" into more socially immersive co-creation layers.

## 2.2 Immersion

According to the Oxford dictionary, the term 'immersion' means "*the action of immersing someone or something in a liquid*" or "*deep mental and social involvement in something*" like the very famous "*learning by immersion: a method of teaching a foreign language by the exclusive use of that language*". Therefore, one could conclude that there is a notion of physical immersion, a notion of mental immersion and a notion of cultural/social immersion. According to Freina and Ott, immersive environments in education have been mainly deployed in the area of educational games due to expensiveness of immersive technology platforms and limited usability [45]. They investigate the scientific literature, over 2013-14, on the advantages and potentials of using immersive environments in Education. Brown and Cairns [8] consider that immersion is a graded experience that progresses through degrees of engagement.

As mentioned by Nordin et al. [21, 23], concepts such as fun, flow, presence and immersion have been widely used to describe the digital games user's experience. According to these authors,

both Brockmyer et al. "Gaming Engagement Questionnaire" (GEQ) [4] and Jennett et al. "Immersive Experience Questionnaire" (IEQ) [3] are relevant examples of questionnaires for evaluating digital games user's experience. The IEQ has been applied in different scenarios and game types [9, 10, 11]. While Nordin and colleagues considered including Usability [12] in their future work, the Social Presence Questionnaire [13] that appears in their review of existing relevant questionnaires is not included.

## 2.3 Immersive Platform

According to Pallot et al. [27], an immersive platform is composed of both assembled immersive technologies (hardware and software) and a specific 3D content application. This kind of platform represents the technological facet of an IVE. They consider that an IVE encompasses 3 different but complementary perspectives, namely: the physical implementation of the immersive technologies, the resulting Immersive eXperience (IX) representing a specific form of UX and an evaluation framework for assessing all factors constituting the overall performance.

The IVE structure is composed of Immersive technologies (VR, AR, MR) and Immersive (3D) Content delivering an IX to users. The resulting perceived sensations are then evaluated through IX's factors. Measured QoS technical factors (e.g. Field-of-view, frame-rate, resolution and latency factors) and evaluated QoE factors (e.g. ease-of-use, usefulness, presence) allow to assess the overall quality of the resulting IX. However, the degree of immersiveness varies also according to the type of used technologies (AR, VR, MR) and goals of the immersive application [27].

Based on reviewed publications in [27], Pallot and Richir argue that immersion represents the state of being deeply engaged (e.g. swimming), recognised as a tactical/sensory-motoric immersion; or fully absorbed in solving a problem (e.g. playing chess), seen as a strategic/cognitive immersion; or reading a captivating story or watching an exciting movie, considered as a narrative/emotional immersion. These types of immersion make one's brain so busy that everything else around simply disappears; Nordin et al. [21] refer this phenomenon to real-world dissociation. A pretty good way to measure the deepness to which a person is engaged is to observe whether time passes without being noticed and whether external world disappears. To make it short, one could argue that a 360° VR immersion bubble operates like a mind-blowing teleportation, instantaneously transporting a user in an existing remote place or a different world that is persistent enough to become another reality, even if it is a virtual one.

## 2.4 Social Immersion

While 'Social Interaction' and 'Social Presence' are quite well established constructs in both IVE and ICE empirical studies [20, 25, 39], the 'Social Immersion' or 'Social Immersive' perspective is rarely mentioned excepted in the areas of Interactive Storytelling and Massive Multiplayer Online Roleplaying Games (MMORPGs) [41, 42, 43, 44]. Such a social immersion or social immersive perspective characterises a 'Socially Immersive eXperience' (SIX) [44]. In the collaboration research area, the constructs of 'Interpersonal Distance' [28, 32] and 'Interpersonal Trust' [26] represent the people capacity to interact together in a virtual environment whatever barrier separates them (e.g. remote places, lack of confidence). Previous empirical studies revealed that the interpersonal or trust distance hinders the social presence. Other Scholars have been studying social inhibitors in IVE [40].

## 2.5 Immersion and collaboration

There are mainly two publication streams dedicated to immersive co-creation, namely: Immersive Collaborative environments (ICE) and Collaborative Virtual Environments (CVE). There are numbers of empirical studies on different immersive technology platforms that were conducted through experiments involving several participants (see Table 1).

**Table 1. Previous Work on Immersion & Collaboration**

Seq	Title	Reference	Related Notions & Potential factors
S1	Literature Review: CAVE & HMD	Freina & Ott [45]	Spatial immersion stimulating interactivity & motivation; visual, auditory or kinaesthetic learning style
S2	Story Immersion of Videogames for Youth Health Promotion: A Review of Literature	Lu et al. [6]	Story immersion; videogame; Narrative transportation; Story immersion complements behavioral change theories, including the Theory of Planned Behavior, Social Cognitive Theory, and Self-Determination Theory
S3	What do we mean when we call a game 'immersive'?	<a href="https://www.theguardian.com/technology/gamesblog/2010/aug/10/games-science-of-immersion">https://www.theguardian.com/technology/gamesblog/2010/aug/10/games-science-of-immersion</a>	How do you know you are immersed in a game? There are lots of obvious signifiers (symptoms): time passes unnoticed; you become unaware of events or people around you; heart rate quickens in scary parts; you empathize with the characters
S4	The development of the game engagement questionnaire	Brockmyer and Fox [4]	Measurement is the process of developing an equal- interval linear representation of a quantitative attribute, in common units, and then subsequently tested for its consistency (reliability) and validity (interpretive meaning).
S5	Too many questionnaires: measuring player experience whilst playing digital games	Nordin et al. [21]	Emotional involvement, Cognitive involvement, Real world dissociation, Challenge, Control, social interaction, Immersion, Absorption, Flow, Presence, Psychological involvement, Behavioral engagement, Usability.
S6	Measuring affect, physiological and behavioural diff.	Gabana et al. [14]	Engagement, immersion, frustration, stress, enjoyment, effort, boredom.
S7	Evaluating the user experience of interactive digital narrative	Roth and Koehnitz [20]	Appreciation of interaction (agency), narrative (immersion) and Combined outcomes (transformation).
S8	Experiencing interactive storytelling	Roth [15]	Usability, Flow, Presence, Character believability, Role-identity, Aesthetic, Curiosity, Suspense, User satisfaction, Affect, Enjoyment.
S9	Measuring and defining the experience of immersion in	Jennett et al. [3]	Engaging Experience: Flow, Cognitive Absorption & Presence. Immersion is clearly distinct. Emotional engagement.

Seq	Title	Reference	Related Notions & Potential factors
	games		Eye Tracking for immersion studies.
S10	A grounded investigation of game immersion	Brown and Cairns [8]	Engagement, Engrossment, Concentration, Experience, Total Immersion, Enjoyment. Emotional involvement, Transportation, Attention, Control and Autonomy
S11	Quality of immersive experience in storytelling	Zhang et al. [16]	Human factors: Physiological, Neuropsychological, Behavioural; System factors: Haptic Feedback, Graphical Fidelity, Screen Size, Quality of Service; Design factors: Narrative, Interactivity, Spatiality, challenge
S12	Augmented sport: exploring collective user experience	Pallot et al. [5]	Experiential engine: Social Presence, Social Emotion, Emotional Response. Rational engine: Flow, Presence, Acceptance.
S13	Impact of vocal communication on UX in 3D IVE	Eynard et al. [18]	Attention, Social Presence, Mutual Comprehension, Performance, Interdependence, Self Presence, Control, Concentration, Enjoyment, Translucence
S14	Exploring the appropriateness of different immersive env.	Dupont et al. [1]	Immersion, Engagement, Interaction, Self Presence, Environmental Presence, Social Presence, Collaboration
S15	Interactive storytelling in a mixed reality env.: the effect of interactivity on UX	Nakevska et al. [19]	Presence, Agency, Satisfaction, Behavioural measures
S16	Attention, time perception and immersion in games	Nordin et al. [23]	Immersion, Attention, Time Perception, Dissociation
S17	In game: from immersion to incorporation	Calleja [22]	Immersion: six involvement dimensions: Kinaesthetic, Spatial, Narrative, Shared, Affective (emotional) and Ludic Involvement.
S18	Social Studies Education Game Development as Undergraduate Immersive Learning Experience	Gestwicki et al. [33]	Learning Games, Fun, Flow, Multidisciplinary team, game design, Immersive Learning Experience
S19	Immersion, Narrative, and Replayability as the Motivational & Attractiveness Factors in Serious Games	Mustaro & Mendonça [34]	Serious Game, Instructional Design and Learning, Immersion, Narrative, Replayability, Motivational, Attractiveness, Communities, Knowledge Building, Competences.
S20	Collaborative Distance: Investigating Issues Related to	Pallot [28]	Sense Making: Relevance, Context Awareness, Translucence, Diversity, Trust Building, Collective

Seq	Title	Reference	Related Notions & Potential factors
	Distance Factors Affecting Collaboration Performance		Intelligence. Shared Meanings: Knowledge sharing, New Knowledge: Group Consciousness, Emergent Behaviour. Helpfulness (learning from others), Mutual Understanding.
S21	The Immersive Virtual Environment of the digital fulldome: Considerations of relevant psychological processes.	Schnall et al. [35]	Egocentric/ exocentric spatial strategy, Field of View (FOV), Field of Regard (FOR), degree of cognitive control, control the environment, Memory for visual and spatial information, both on a small and a large scale, networking individual units, allowing users to communicate directly
S22	Studying the effectiveness of multi-user immersive environments for collaborative evaluation tasks	Lorenzo [36]	Content quality, learning goal alignment, feedback and adaptation, motivation, presentation design, interaction usability, accessibility, reusability and standards compliance Convergent Participation Model
S23	Collaborative science learning in an immersive flight simulation	Ke et al. [37]	Communication- and action-embodied meaning making, and the joint feedback process Level of physical fidelity or sensory immersion has failed to reinforce communicative and collaborative learning processes
S24	Can Presence Improve Collaboration in 3D Virtual Worlds?	Cruz et al. [38]	Presence: Two kinds of measures exist: objective measures, relating to physiological responses; and subjective measures, based on questionnaire Collaboration in virtual worlds achieved by communication, awareness, interaction, sharing of artefacts and cooperation Collaboration can exist without presence, but is clear that a strong feeling of presence can enhance collaboration

### 3. Resulting ICE Model and Structure

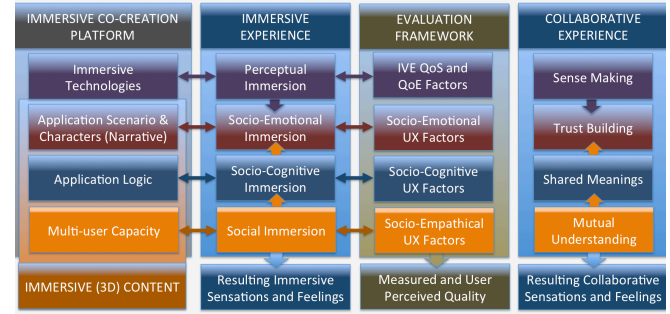
#### 3.1 ICE Model based on four Immersive Facets

Our main goal is to experiment and assess the performance of different immersive environments in the context of co-creation with users/customers/citizens. Therefore, we had to turn the IVEs into ICEs and include the multi-user context in the usage scenario. Figure 1 presents an ICE model as an extension of the IVE model that includes the social immersive perspective and resulting socio-empathical factors characterising the social dimension of the resulting user experience.

There are different forms of social interaction but vocal interaction is the one that requires the highest level of participants' attention. While vocal interactions support the

feeling of social presence, it makes easier the ability to reach a shared mutual understanding for each participant [18]. According to Eynard, an experiment participant declared during the focus group debriefing of an experiment [18]: *"I was staying as close as possible to my team partner in the virtual environment as if I was willing to remain audible while I perfectly new that we were in fact talking to each other through the use of a headset"*.

In the same empirical study, it is demonstrated that vocal interaction tends to lower the feeling of being present; while at the same time it increases the feeling of co-presence [18].



**Figure 1.** ICE Model based on four different but complementary immersive perspectives, extended from the IVE Model [27].

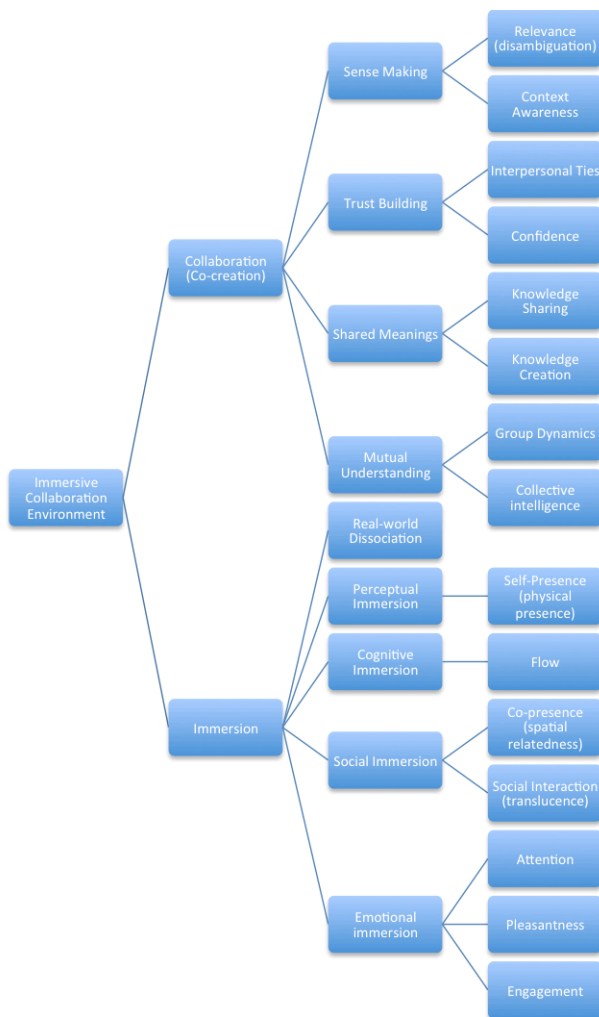
For sure, all participants do not necessarily need to be perceptually immersed (sensory-motoric immersion) because of the possibility given to participants to interact vocally with the one that is fully immersed and can interact with the virtual environment. It means that while participants are socially immersed and at least one of them is perceptually immersed then they can interact vocally with the immersed one for inducing actions on affordances. For example, one participant wears a Head Mounted Display (HMD) and all the other participants watch him evolving in the virtual environment on a large display while interacting vocally with him. The social immersion allows a group of stakeholders that are not necessarily all fully immersed to efficiently co-create together with a lower effort and cost. This is especially true for people that do not accept immersive technologies, such as people suffering from cyber-sickness (e.g. spatial disorientation).

#### 3.2 ICE Tree Structure

Presently, the elaborated ICE structure is a simple tree highlighting the two sides of the same coin, namely: the co-creation and immersion sides. Both include cognitive and social facets while the immersion side owns the perceptual and emotional facets. In the Figure 1, the immersion side is turned into the 'immersive experience' and the 'co-creation' side is turned into the 'collaborative experience'. They are both implemented in the immersive co-creation platform and in the resulting immersive collaborative experience that appears in the Figure 1 separately in two columns.

All elements appearing in the Figure 2 are inherited from the Table 1 and are intended to lead to the selection of factors for assessing the performance of different ICEs. We don't know yet whether the co-creation and immersion facets' elements or factors are correlated or not. This is to be revealed by the up-coming experiments. It is also expected a refinement and validation of the ICE structure and model based on the results of experiments.





**Figure 2.** ICE Tree Structure based on synthesized elements of the Table 1.

#### 4. CONCLUSION

We have created an ICE model and structure based on our own previous work and on a complementary literature review for identifying the most relevant elements and selecting the most appropriate ones for the context of immersive co-creation. As a conclusion of this work, though it is still on going work, we have identified a fourth facet to the construct of immersion that is ‘social immersion’. However, the social aspect was already perceived in the previous IVE model through the socio-emotional and socio-cognitive immersion facets. These two facets represented the potential group behaviour and collective intelligence that could already be observed in multi-user immersive games.

As future work, we need to reconcile the immersive and collaborative experience. The outcomes of the up-coming experiments will allow refining and eventually validating totally or partially this proposed ICE model and structure.

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