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A DESIGN REVIEW SESSION PROTOCOL FOR THE IMPLEMENTATION OF IMMERSIVE VIRTUAL REALITY IN USABILITY-FOCUSED ANALYSIS

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SUMMARY: *Research and applications related to Virtual Reality (VR) in the Architecture, Engineering, Construction and Facility Management (AEC/FM) industry are steadily increasing, being considered as one of the current trends in digital innovation. A convergence is currently on-going between Building Information Modelling (BIM), VR implementation and the soft landings principles, which highlight the need for a smooth transition from design to operation through the early involvement of clients and end-users. In particular, immersive virtual environments could allow stakeholders to experience the full-scale representation of a virtual facility prototype in an intuitive and engaging manner through immersion and sense of presence, promoting feedback collection during usability-focused design review meetings. On the other hand, despite the renewed interest in immersive VR, both technological and procedural challenges to its effective implementation still exist. The latter are within the scope of this study, which aims to address them in a systematic way as a comprehensive guideline for clients and design teams. This study describes the development of a VR-aided usability-focused design review session protocol for implementing immersive VR when clients and end-users are involved in design review meetings. It is the result of an inductive approach associated with qualitative research methods for data collection and data analysis. A case study has been selected as a main research method for facing the first step into the research problem. A further iteration of data collection and analysis was adopted to guarantee the validity of the research, including talks with experts and literature comparison. Finally, the session protocol has been developed in the form of a process map representing all the necessary phases and activities to consider for the effective adoption of immersive VR to evaluate design intents with clients and end-users. As a comprehensive summary, the session protocol fills a gap in the research on the adoption of virtual reality in the AEC industry, which was lacking a prescriptive and structured process to drive the effective use of this technology in collaborative meetings and decision-making processes.*

KEYWORDS: *design management, design review, usability evaluation, stakeholder engagement, virtual facility prototype, virtual reality, procedural guidelines*

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1. INTRODUCTION

Research and applications related to Virtual Reality (VR) in the Architecture, Engineering, Construction and Facility Management (AEC/FM) industry are steadily increasing in number and scopes. This growing and renewed interest in VR systems, which are currently considered as one of the next trends of digital innovation (Mansouri and Akhavian, 2018), since previous research efforts dating from early 2000s, is closely linked to the ever-increasing adoption of Building Information Modelling (BIM) processes, procedures and technologies that characterises the on-going digital transition of the industry (Mastrolembo Ventura et al., 2019).

A building information model, in fact, could be the starting point for the development of a virtual facility prototype. In product design, virtual prototypes of design proposals are known as the anticipation of a product that does not exist in reality yet (Bordegoni and Rizzi, 2011). Virtual facility prototypes can be also effectively explored, tested and evaluated before being physically realised (Tutt and Harty, 2013). The use of virtual prototypes implies the adoption of virtual reality systems as visualisation and interaction platform. In particular, immersive virtual environments allow stakeholders to experience the full-scale representation of a virtual facility prototype in an intuitive and engaging manner through immersion and sense of presence (Paes et al., 2017). Based on those characteristics, immersive VR could be classified as semi-immersive VR and fully-immersive VR. The former is an experience where a portion of the field of view of the user is covered by the system; the latter is an experience where the entire field of view of the user is covered by the system thus increasing the sense of presence within the design intent virtually prototyped (Mastrolembo Ventura et al., 2019; Whyte and Nikolić, 2018; Castronovo et al. 2013; Shiratuddin et al. 2004).

Previous studies have already discussed a range of purposes and use cases for VR implementation in the building process. In particular, the role of virtual prototypes is recognised to support the generation of ideas more than physical ones (Tiainen et al., 2014). Communication and review of design proposals have resulted to be the main purposes for implementing virtual reality in BIM-based design processes (Lather et al., 2018). Moreover, previous researches in product design as well as previous applications from both academia and industry in the construction domain show how virtual reality systems could support collaboration through improved communication and access to information for all the stakeholders, regardless of their technical background. It has been demonstrated, for example, how VR systems could support the stakeholders from the demand-side of the building process, such as clients and end-users, who may lack technical expertise (Boyd et al., 2016), to more effectively participate in the decision-making process than using only traditional representations (e.g., 2D drawings, renderings, video-renderings) to access information (Castronovo et al., 2018; Paes et al., 2017; Castronovo et al., 2013; Bullinger et al.; 2010).

1.1.1 Immersive virtual reality in usability-focused design reviews

Within the multiple purposes and use cases VR systems could be applied for, the scope of this study has been narrowed down to the convergence that is currently on-going between BIM, VR implementation and the soft landings principles, which highlight the need for a smooth transition from design to operation through the early involvement of clients and end-users (BS 8536-1:2015). Virtual reality, in fact, has been also applied in previous researches as an occupancy evaluation tool to support clients, end-users and facility managers in collaboratively evaluating the functionality and usability of building spaces in order to feed back into the design stage the experience of the built environment in operation (Whyte, 2002; Hilfert and König, 2016; Tseng et al., 2017; Liu, 2017). For example, Liu et al. (2014) showed how virtual facility prototypes allow reviewers to deeper understand the implications of design decisions. Van den Berg et al. (2017) reviewed the literature to explore how design reviews can be supported by immersive virtual environments to communicate design intents as well as to ask for design feedback, allowing designers and clients to navigate through and comment on a design in progress. Exploration from a user perspective, participation in solution-finding and feedback on a design proposal are the patterns they identified in relation to VR implementation in collaborative design reviews.

Virtual reality gives clients, end-users and facility managers the ability to explore and understand a design intent from the egocentric viewing perspective they normally experience the built environment (Whyte, 2002). Research works indicate that exploring a design proposal from a user perspective may be beneficial to evaluate its compliance against performance-based requirements, taking into account the needs of the prospective occupants that will use the building spaces based on their related functional destinations (Hilfert and König, 2016; Simeone et al., 2013; Shen and Shen, 2011). Several research works describe the use of VR in pre-occupancy evaluations

in order to predict human-building interactions that can feed designers and researchers with reliable user behaviour and occupant-related data (Bassanino et al., 2010; Kuliga et al., 2015; Adi and Roberts, 2014; Heydarian et al., 2015a; Heydarian et al., 2015b, Heydarian et al., 2015c; Heydarian et al., 2017). For example, Heydarian et al. (2015a) used immersive virtual environments to collect data on behaviours and preferences of occupants in relation to lighting conditions and so evaluating design options aiming to both meet their lighting preferences and, at the same time, increase the energy efficiency of the building. Saeidi et al. (2015) also investigated the effectiveness of immersive virtual environments to be used as a tool to collect data on the behaviour of the occupants during the design stage and to align the design proposal to their needs and preferences (Khashe et al., 2018). Saeidi et al. (2018) develop a spatial-temporal event-driven modelling approach that include the use of immersive virtual environments as a viable tool to observe the behaviour of occupants in design proposals and generate data to support predictive models related to the building energy performance. Schneider et al. (2018) developed a BIM-based framework for user-centred evaluation of complex building in virtual environments; such a framework is integrated in the architectural design process and aims to anticipate how future users of a building will experience and behave in it. For example, the compliance of a design proposal with requirements that relate to access for people with disabilities could be demonstrated by simulating their movements within a virtual space (Marchant, 2016; Mastrolembo Ventura et al., 2018a). Moreover, Hilfert and König (2016) implemented fully-immersive VR systems and haptic technologies in combination with a game engine to simulate various building usage scenarios, such as the behaviour in case of an emergency for testing multiple options of escape routes, expert training to control special machinery on the construction site and accessibility validation from the perspective of an end-user while using a wheelchair.

The implementation of virtual reality systems and the possibility to walk through the virtual facility prototype from the user perspective might also improve the engagement of stakeholders in design review and their participation in solution-finding processes (Van den Berg et al., 2017). Virtual reality, in fact, enables a more qualitative representation of spaces from a user perspective showing them in full-scale and with the possibility to walk through them as a prospective end-user (Castronovo et al., 2013) thus supporting stakeholder engagement presenting spatial information in a more engaging manner, giving users a better sense of spatial (i.e., scale, distance and adjacency) and visual (i.e., appearance and view) factors (Eastman et al. 2011; Shen et al. 2012; Liu, 2017). Virtual environments aimed at clients may stimulate their participation in the process, since such tools increase their access to design information (Shiratuddin and Thabet, 2011), allowing them to recognise how a design proposal meets their needs and requirements and facilitating the identification of any problematic design issues (Dossick, 2014). Through participatory design, in fact, the experience of the built environment in operation can be fed back into the design stage (Whyte, 2002). Maftei and Harti (2013), who examined how designers used an immersive virtual environment to consider how users move and interact within a new hospital facility, stated how running design reviews in a semi-immersive environment affected the further development of the project and the engagement with the client. Benefits in conducting design reviews using virtual prototypes have been demonstrated in a case study for a courtroom design (Maldovan and Messner, 2006) and in the design review process of operating and patient rooms (Dunston et al., 2011). Kumar (2011) has shown the benefits of interactive virtual prototypes in design reviews of healthcare facilities. Van den Berg et al. (2017) also suggested to let clients navigate into VR representations (e.g., using non-immersive VR systems) in advance of design review meetings, in order to promote the involvement of clients in solution-finding and, in turn, help designers to organise the agenda of the design review meeting effectively based on their preliminary feedback.

Several examples of immersive VR applied to the iterative design review and feedback process exist in literature. Feedback on a design proposal can support the design team in better understanding the need of clients and end-users in order to identify and focus on "key areas for improvement", "with the potential to impact on the subsequent design process" (Van den Berg et al., 2017; Følstad et al. 2013; Salter and Torbett 2003). Majumdar et al. (2006), for example, used immersive virtual environment to collect feedback on the functionality of a building at its conceptual design development and noticed how this type of tool "makes it easier to focus the collective attention of the participants on one issue at a time" supporting stakeholders in suggesting changes for the next evolution of the design. Shen et al. (2013) also demonstrated how the adoption of a visualisation and simulation tool can improve the proposed design; in particular, the design team can take advantage of this feedback in order to determine whether the proposed design is compliant to what the client required (Shiratuddin and Thabet, 2007) and, otherwise, to evaluate which actions are necessary to take for ensuring that the design intent meets needs and expectations of clients and future occupants (Van den Berg, 2017; Jensen, 2011). Moreover, immersive VR can

be effectively applied as a communication tool in user-centred design processes (Bullinger et al., 2010). Bullinger et al. (2010), in fact, described an approach to enable the design team to involve end-users by using virtual environments as immersive and spatial prototype of the building facility. They demonstrated that "the transfer of the User Centred Design (UCD) approach to architectural planning combined with the provision of an adequate prototype can make a significant contribution towards an increase in quality and performance in building and construction projects".

1.1.2 Research gap and scope of the study

The understanding of the research problem is based on the literature review, which was performed in order to (1) analyse the relevance of the research topic, (2) define the motivation behind the study, as well as the related problem scope (Costa et al., 2016), and, finally, (3) formulate the research question. Within this research background, virtual reality is being used "to feed back the knowledge that clients, and end-users have about inhabitation into the design stage" (Whyte, 2002). Virtual reality, in fact, could be used as part of a strategy of obtaining feedback adopting a participatory approach as an attempt to bridge the gap in understanding between the design team and users from the demand-side of the building process (Van den Berg et al., 2017, Mastrolembo Ventura et al., 2019). On the other hand, while research in the application of virtual reality systems is growing, both technological and procedural challenges to its effective implementation still exist. The latter are within the scope of this study.

Procedural challenges to VR implementation are illustrated, for example, by the need to implement VR in a structured manner and as part of a larger narrative during design reviews (Whyte, 2002; Lather et al., 2018). However, this need is currently not answered due to the lack of indications on how to structure a VR-aided design review meeting effectively (Liu et al., 2018). Moreover, other practical implications should be considered such as the need to guide the navigation of the stakeholders through the virtual facility prototype, the need to consider contractual constraints preparing VR representations as well as the need for setting the most appropriate level of detail or realism up, which could greatly affect the quality of the feedback and the overall effectiveness of the design meeting (Whyte and Nikolić, 2018; Liu et al. 2014; Whyte, 2002). Furthermore, motion sickness, novelty effect and previous user experience with VR systems also affect the result of the design review (Liu, 2017; Khashe et al., 2018).

The need for addressing procedural challenges and practical implications in a more systematic way as a guide for the design teams when planning to use VR with other stakeholders is within the scope of this study, which proposes a design review session protocol to adopt as a comprehensive guideline for implementing immersive VR in usability-focused design reviews effectively, especially when clients and end-users are involved. The VR-aided usability-focused design review session protocol is an answer to the following research question, which drove the study described in this paper: *what are the process, phases and activities that are necessary to conduct design reviews with designers, clients and/or end-users in an immersive virtual environment?*

2. RESEARCH METHODOLOGY

The VR-aided usability-focused design review session protocol as described in this paper was developed and validated adopting an inductive research approach based on grounded theory methods for qualitative data collection and data analysis (Maftei et al., 2018; Liu et al., 2018; Van den Berg et al., 2017; Liu et al., 2014; Tutt and Harty, 2013). Grounded theory, in fact, is an inductive and comparative methodology to gather, synthetise, analyse and conceptualise qualitative data for the purpose of theory construction (Charmaz and Belgrave, 2012). According to the grounded theory methodology, a theory is first generated (e.g., from observation) and then validated and improved with more incoming data adopting a flexible strategy based on multiple data sources. Grounded theory, in fact, accepts the joint use of multiple data collection techniques in order to progressively focus and inform data collection by the emerging theory (Willig, 2013). Applying this strategy, the researcher is able to triangulate, gathering data from different data sources and using different methods of data collection, which give the "researcher confidence that theoretical saturation is being approached" (Willig, 2013). Moreover, the triangulation and cross-verification of data from multiple sources result to be beneficial in theory generation, involving "multiple methods to examine the same dimensions of the research problem" (Aksenova et al., 2018). Furthermore, the implementation of such a research method could require "the researcher to move back and forth between data collection and analysis" (Willig, 2013).

2.1.1 A case study as first source for data collection

Practical experience is "the best guide" to "understand implementation of virtual reality" (Whyte, 2002). For that reason, a case study has been selected as a main research method for facing the first step into the research problem. Observation through direct involvement in design review meetings was used as main data collection method. It was supported by field notes, video and audio recordings. Seven design review sessions have been organised involving a representative panel of design stakeholders (i.e., twenty-four participants including clients, designers, end-users and an accessibility expert) in the evaluation of immersive VR as a medium to support the usability-focused analysis of a new school building (Table 1). The aim of the sessions was to investigate process-related aspects and practical implications for adopting virtual reality in design review meetings from the perspective of design stakeholders. Designers and clients were selected based on their previous experience with BIM implementation and involvement with design and procurement of school buildings. Moreover, an accessibility expert, who is both a designer and a wheelchair user, was involved to discuss usability-related aspects, as well as a representative panel of end-users (i.e., school directors, students, teachers, parents) of a similar building.

TABLE 1: Organisation of the VR-aided design review sessions with a representative panel of design stakeholders

Session	Type of stakeholders involved	Participants (n.)
S1	BIM manager (architecture)	1
S2	Designer - Accessibility expert	1
S3	BIM manager (architecture)	2
S4	Public client	3
S5	BIM manager (architecture, structure, MEP)	3
S6	End-users (director, teachers, students, parents)	11
S7	Public client	3
	Total number of participants:	**24**

Before starting the data collection phase and the design review sessions, an *initial session protocol* was developed in order to organise the preliminary agenda of the meetings. According to the initial session protocol, participants were first (1) briefed on the objective of the research (Phase 1, 10-15 minutes) and then (2) introduced to the VR environment, learning how to use it to move and interact within the virtual facility prototype (Phase 2, 5-10 minutes). During the (3) navigation within the virtual facility prototype, stakeholders were asked to review operational requirements related to the functionality and effectiveness of internal spaces based on their use and destination (Phase 3, 30-40 minutes). Finally, (4) a discussion phase was planned to comment the VR experience with the participants (Phase 4, 15 minutes) (Fig. 1).

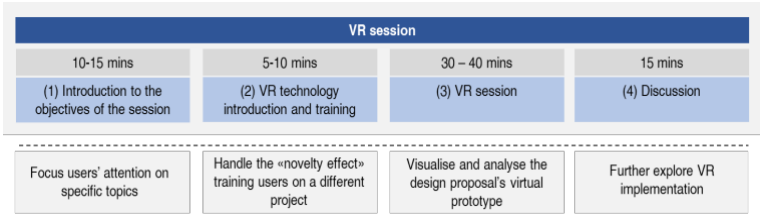

FIG. 1: Initial session protocol

The method of multiple investigators (Eisenhardt, 1989) was adopted, with team members having unique roles during data collection. A team member acted as facilitator and guided the design review sessions. Another team member drove the navigation within the virtual facility prototype. Other two team members, designers of the school building, took part in the design review sessions describing the design intent and answering questions about design choices. A VR expert managed technical questions about the VR system. Moreover, the facilitator handled the meeting having a personal interaction with the participants, while other team members were recording notes and observations, keeping a more distant view (Eisenhardt, 1989). Furthermore, as already said, design review meetings were audio and video recorded; in one case (i.e., session 6) video recording was not possible because of the presence of minors.

Qualitative data have been later explored through "initial open coding" in order to establish "tentative linkages between categories" (Willig, 2013). Moreover, data analysis and data collection often overlapped during the

development of the case study. This was to optimise the session protocol from one session to the following one, using the former to inform the latter. In order to analyse the collected data, a framework was induced to compare the results from each design review and data collection session. Based on data collected during the development of the case study, a preliminary VR-aided usability-focused design review session protocol was developed.

2.1.2 Talks with experts and literature comparison for validity

In qualitative research, the use of mixed methods and multiple data sources is needed in order to extend and validate research findings thus providing the evidence of their generalisability (Jonsen and Jehn, 2009). For that reason, a further iteration of data collection and analysis was adopted to extend and validate the preliminary version of the design review session protocol. Talks with experts have been used as a further data collection method. They have been managed in the form of semi-structured interviews, allowing the authors to sharpen research generalisability and raise the theoretical level of the contribution from the practical experience of lead VR users.

The experts involved in the validation process (i.e., ten VR experts, equally distributed on academy and industry from the construction domain) (Table 2) represent seven different organisations. In particular, five experts from the academia correspond to three universities, one in Germany and two in the United States of America. They all have experience in both developing VR representations and in managing the BIM-to-VR workflow from BIM authoring platform to VR visualisation systems. Based on their experience, they have worked with both fully-immersive and semi-immersive VR systems. The experts from the industry represent, instead, five leading international firms in the construction domain and they are all responsible for the strategic implementation of virtual reality systems in their own organisations from a procedural and process-related perspective, aiming at the optimisation and innovation of current design practises. They jointly work with the visualisation team of their firms. In three cases, the experts represent global design, architecture and engineering firms; in one case the expert represent a leading European manufacturer for architectural aluminium solutions. Finally, in one case the expert represents a large UK public client from the infrastructure sector; this expert has been classified as "expert from the industry".

TABLE 2: Organisation of the talks with experts

Talk	Role of the expert	Academia (A) / Industry (I)	Participants (n.)	Interview duration (hrs)
T1	PhD Candidate	A	1	1
T2	Post-doc Researcher	A	1	1
T3	Design technology manager	I	1	1
T4	Global BIM/IM Director	I	1	0.35
T5	- Research project responsible - BIM/VR product manager for international business development	I	2	1
T6	Global BIM/IM Director	I	1	1,10
T7	Associate Professor	A	1	1
T8	PhD Candidate	A	1	1
T9	Assistant Professor	A	1	1
T10	BIM Strategy Manager	I	1	1
	Total number of VR experts:		**11**	**9.45**

The preliminary version of the design review session protocol that resulted from the case study was shared and discussed with each expert in web conference calls that lasted from 35 minutes to 1 hour and 10 minutes. Each call was managed as a talk on the basis of an interview plan (i.e., semi-structured interview). As a semi-structured interview, each talk consisted in predetermined open-ended questions, which provided the opportunity for identifying new ways of seeing and understanding the topic (Cohen, 2006). The experts were asked to comment the preliminary version of the design review session protocol in order to understand: (1) its contribution to the theoretical and practical body of knowledge (i.e., general thoughts), (2) its comprehensiveness and (3) the need for additional factors to consider (i.e., missing factors). Each talk was transcribed and then analysed adopting a coding procedure at the end of the entire data collection process.

Moreover, the results from the talks with experts have been integrated with information coming from literature comparison until the evolution of the session protocol did not require further modification, which is a sign of data saturation (Eisenhardt, 1989). Finally, the VR-aided usability-focused design review session protocol has been developed in the form of a process map representing all the necessary phases and activities to consider and resulting in a comprehensive reference framework for the effective adoption of immersive VR to evaluate design intents with clients and end-users.

3. PRELIMINARY VERSION OF THE VR-AIDED USABILITY-FOCUSED DESIGN REVIEW SESSION PROTOCOL

As mentioned in section 2, a case study was adopted as initial data collection source. A semi-immersive VR environment was used to support a representative panel of design stakeholders in the evaluation of the internal spaces of a new school building in relation to operational requirements of functionality and effectiveness (Fig. 2) (Mastrolembo et al., 2018b). The focus was on the flexibility of learning spaces as required to fit a variety of learning styles and activities with frontal lessons no longer considered the leading model in pedagogy (Giordani et al., 2017). The semi-immersive VR environment featured a stereoscopic projector and a single portable rear-projected wall with a user-tracking system, while a 3D mouse, a flystick and a keyboard were used as VR controllers. The Virtalis Visionary Render visualisation package was used to import the Industry Foundation Classes (IFC) version of the building information model into the immersive virtual environment and to prepare the VR representation. The IFC data format was used in order to visualise both geometrical and non-geometrical attributes during the VR sessions when selecting the objects of the virtual facility prototype during the walkthrough (Hilfert and König, 2016). It is important to note that, though the use of this specific type of VR system was determined by its availability, the focus was not on the system but on the user experience during the VR-aided usability-focused design review meetings (Paes et al., 2017).

FIG.2: Interaction with the virtual reality system

At the beginning of each session the objective of the research was stated (i.e., phase 1) as the evaluation of the implementation of VR systems to involve end-users and to manage the client-designer interface in the analysis of the functionality and effectiveness of design proposals. The design requirements to consider were reported to the participants. In order to avoid the novelty effect that can appear during the first attempt with immersive VR technologies, it was decided to let the participants test the VR system navigating through the virtual prototype of a different project (i.e., an automotive virtual prototype), considering VR training as a possible solution for the novelty effect (i.e., phase 2). The participants were taught how to (1) navigate within the virtual environment; (2) select and move objects; (3) measure geometric dimensions; (4) visualise non-geometric data embedded in BIM objects, (5) change materials to BIM objects selecting them from a library. The purpose was to avoid that participants would have been too distracted by the technology during the following step of the meeting agenda. This phase of the session was also used to illustrate why an open footprint single-wall was selected for the development of the case study rather than a fully-immersive VR, optioning for emphasising multi-user interaction instead of a high level of immersion and sense of presence (Castronovo et al., 2013). The navigation within the virtual facility prototype (i.e., phase 3) represented the core phase of the meeting agenda. Starting from a general description of the design proposal, the participants were asked to navigate the virtual prototype following the circulation paths they would have been followed in the real building. The purpose was to let them discover the design proposal and comment it, without intervening directly. The facilitator guided the VR sessions asking questions only when there was the need to re-focus the participants on the objective of the session. Moreover, this step of the agenda was used to understand if users (1) were able to move by themselves within the immersive virtual environment or if a third-person VR driver should have rather guided their walkthrough; (2) would have need further media available in the interactive workspace; (3) are effectively supported by immersive VR in the analysis of operational requirements. Finally, a discussion was conducted in order to collect further feedback from the participants (i.e., phase 4) in relation to the immersive experience.

A *revised session protocol* was developed as main contribution from the case study (Mastrolembo Ventura et al., 2018b), taking into account what emerged from the observation of the behaviour of the participants during the meetings and the results from data analysis. For each session, a coding process was adopted to analyse data and the following categories emerged:

- amendments to the *initial session protocol*, including the need for additional activities;
- media used during the sessions (i.e., traditional drawings, virtual reality, references and examples of similar buildings) and interaction of the users with the VR technology (e.g., do they prefer either a free or guided navigation through the virtual facility prototype?);
- limitations to follow the *initial session protocol* (i.e., motion sickness).

3.1 Amendments to the initial session protocol

First, the time spent by the participants in each phase of the *initial session protocol* was considered as well as the need for additional steps in the design review agenda. Coding video and audio records, it was possible to evaluate the actual time spent by the participants in each step of the session protocol. Moreover, the need for additional activities was discussed (Table 3).

*TABLE 3: Time needed for running the meeting agenda in each session**

		Timing for each session (min.)						
		Session 1	***Session 2***	***Session 3***	***Session 4***	***Session 5***	***Session 6***	***Session 7***
Phases	Objective of the session	5	8	5	10	5	10	8
	Introduction to key design requirements	-	-	5	-	-	15	-
	Introduction to the technology	8	5	10	10	12	15	15
	Restating the objective of the meeting	2	2	2	2	2	2	2
	Visualisation of the project on traditional drawings	5	5	5	25	-	5	-
	VR session	40	30	45	30	40	40	75
	Discussion	30	30	30	20	-	-	40

*in grey, phases of the session agenda that have to be added to the *initial session protocol*

For example, the need to introduce the participants to the key design requirements for school buildings when they are not familiar with the design process emerged. Moreover, the need to look at traditional drawings before and during the VR session was highlighted. Furthermore, motion sickness resulted to be one of the main limitations to the use of immersive technology as it affected five design review sessions out of seven (Mastrolembo et al., 2018b). For that reason, the need for scheduling breaks in the meeting agenda emerged in order to eventually recover from motion sickness. Finally, some practical implications emerged as well: (1) training people in using VR resulted to be a mistake in the *initial session protocol* and it should be avoided because it is out of the scope of the meeting and it might cause motion sickness; moreover, (2) the navigation through the virtual facility prototype should be guided by a VR driver and following pre-defined circulation paths based on the objective of the meeting. The revised phases of the session protocol are following described including relevant practical implications (Fig. 3).

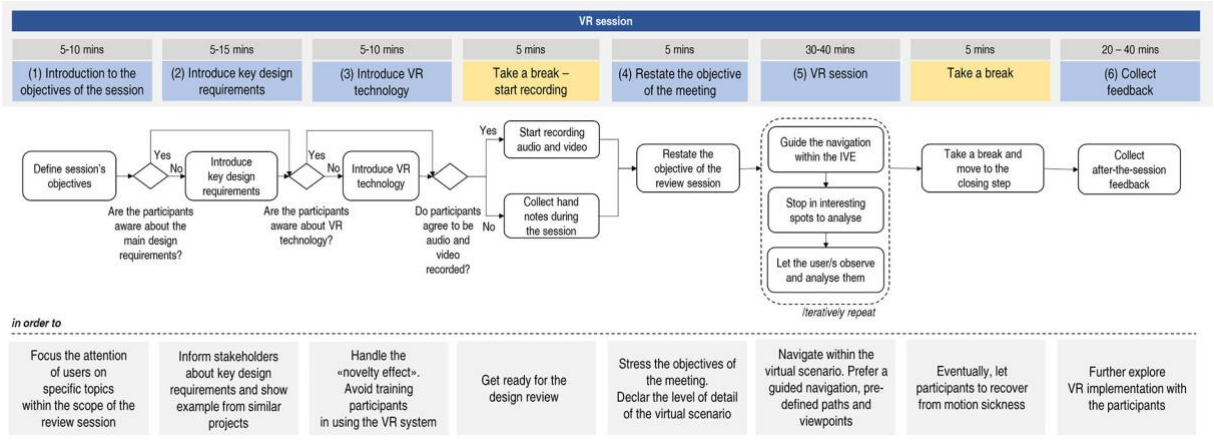

FIG. 3: Revised session protocol

- *Phase 1 – Objectives of the session*: the objectives of the VR-aided session should be clearly defined before using the immersive VR environment. It is needed to focus the attention of the participants on the project and the reason why the meeting was organised rather than on the adopted technology, aiming at reducing the risk for the novelty effect.
- *Phase 2 – Key design requirements:* end-users and clients might need to look at examples of similar building and/or being informed about key design aspects to focus on before evaluating the design proposal in order to better understand the design intent.
- *Phase 3 – VR introduction:* participants should be informed about the type of technology they are going to use, if they are not familiar with it. Anyway, they should not be trained in using the VR system during the design review session, unless it is strictly necessary. In fact, it might cause prematurely VR sickness.
- *Phase 4 – Restating the objective of the meeting:* the objective of the design review session should be restated, specifying the project phase the design proposal refers to and declaring the related level of detail, what has been already decided and what is just a placeholder in order to manage the expectations of the participants in relation to the VR representation and what they are going to experience.
- *Phase 5 – VR-aided design review session:* during the VR session, a member of the team is required to drive the navigation within the immersive virtual environment, following pre-defined paths previously defined. The driver should stop the navigation in interesting viewpoints to analyse the design proposal interacting with the virtual facility prototype. Those steps should be iteratively repeated based on the number of design aspects to be evaluated. Moreover, an interactive workspace should be provided with various media available to support communication and analysis of the design intent; a system for collecting and tracking comments directly on the BIM model should be provided as well. Finally, the facilitator should regularly ask participants if they feel motion sickness during immersion and; if they do, the session should either stop or continue in the non-immersive mode. Observations, in fact, showed that more than the level of immersion, the added value of VR implementation during the sessions was the possibility of looking at a full-scale virtual prototype of the building, levelling the ability to understand and comment on it by both technical and non-technical users improving the way they interact.
- *Phase 6 – Discussion:* during the discussion phase, some aspects of the design proposal should be further analysed and comments on the VR experience should be collected as well. A plan for conducting this phase should be prepared based on the scope of the design review meeting and the stakeholders involved.

4. VALIDATION OF THE REVISED SESSION PROTOCOL

4.1 Macro-level evolution of the session protocol

4.1.1 Peripheral and core activities

Based on data collected from the talks with VR experts from both the academy and the industry the design review session protocol has been initially modified at a macro-level. First of all, the validation process confirmed the need for clearly separated activities to perform before moving to the VR session (i.e., phase 5 of the *revised session protocol*) in order to (1) declare the objectives of the session, (2) eventually describe the key design requirements that would be taken into account, (3) introduce the VR technology to the stakeholders, aiming at preparing them and reducing the novelty effect and (4) manage their expectations restating the objective of the meeting, the phase of the design proposal and its related level of detail. For example, according to one of the experts "*it is a very good idea to divorce explicitly this part before the design review from the VR session. This part, in fact, states how we are going to work together, specifying what is realised, what there is and there is not in the model, the level of realism of the representation, etc.. It is great. You should then close it with something very deliberative: "now that everybody is on board, let's have the meeting"* (Quote_T6).

The need to split the agenda of usability-focused design reviews in separate parts have been also discussed by Liu (2017) and Liu et al. (2018). They suggested to organise the design review process in two main categories of activities: *core* and *peripheral* ones. In their Design Review Process Model, which describes the "post-occupancy focused design review process" (Liu et al., 2018), they define as core activities the "actions and communications that directly focus on the design content"; in contrast, peripheral activities "are discussions and actions that are not directly related to understanding and evaluating the design" proposal. Liu (2017) also suggests to further divide the peripheral activities into *process management* ones and *non-design review related* ones. The formers are "those

that start, transition or end a discussion". For example, they are used by the facilitator of the meeting to "explain the goal, scope and agenda for the review" at the beginning of the session as well as to "suggest the next topic or area to review" during the design review. The latter are represented by "miscellaneous discussions on topics not related to the review at all", when participants can take a break, as proposed in the procedural guidelines, or "talk about the other logistics arrangement after the review" (Liu et al., 2018).

4.1.2 Missing factors: pre-meeting and post-meeting activities

On the other hand, some missing factors emerged from the talks with VR experts. They are related to the need for including a pre-meeting phase to the session protocol as well as a post-meeting one. The pre-meeting phase should include all the activities that have to be considered in order to prepare both the meeting agenda and the most appropriate VR representation to support the objective of the design review session. *"What the agenda does not show is where the question is. (...). Is it a validation meeting? A design optioneering meeting? We need to have a view of the objectives (i.e., understand a solution, approve the solution, validate the solution) because the process and the way you use VR may look different"* (Quote_T6). Moreover, *"you should also try to think about the plain language questions you are taking over at each project stage. You do not know the appropriate level of information need of the VR representation until you do not set your PLQs up"* (Quote_T4). Plain Language Questions, in fact, are high-level questions in non-technical language that help the client to understand if the project proceeds as required and to obtain the necessary information at decision gates (BS 8536-1:2015).

Regarding the need for preliminary activities, it also emerged the opportunity to share the VR representation of a design proposal with the stakeholders before the meeting, in order to let them be aware of what they will be asked to review. For example, Van den Berg et al. (2017) explored how design reviews could be supported by pre-meeting virtual reality environments. The focus of their research is on the investigation of how "virtual environments can be used to communicate the design intent to clients and to communicate feedback to designers in advance of design review meetings" in order to support participation in solution finding and feedback collection. In their opinion, this possibility may help designers to "make a more informed choice about how and why to support design reviews". Moreover, as emerged from a talk with one of the academic experts, *"there are different ways how people interact"*; for example, *"some people do not actively participate during the group session but they prefer to look at the design and then comment"* (Quote_T7).

Finally, it has been also suggested the need for post-design review activities and the possibility to implement *"a mechanism to allow people to go back and to look at the model"* (Quote_T7). In fact, as stated by one of the academic experts: *"there are a lot of values in that (VR) exploration and stakeholders can look at it also later"* (Quote_T7) in a post-design review meeting phase; for example, it could be used in order to support the preparation of the next session of reviews, especially when decisions are suspended and demanded to a following meeting because it is not possible to reach a consensus on a decision (Liu et al., 2018).

4.2 Detailed evolution of the session protocol

Evaluating its comprehensiveness, the VR experts also commented in detail each phase of the *revised design review session protocol*. Based on the analysis of the talks with experts, some phases of the session protocol have been modified (i.e., phase 3, break 1, phase 4 and phase 5), while others have been confirmed (i.e., phase 1, phase 2 and break 2). A description of each phase as commented by the experts and integrated with the literature comparison follows in the next paragraph.

5. RESEARCH FINDINGS

5.1 Structure of the session protocol

The *VR-aided usability-focused design review session protocol* that resulted from the validation process is represented in the form of a process map and it consists in a comprehensive summary of all the processes, phases and activities that have to be performed when immersive virtual reality systems are implemented in collaborative design review meetings with clients and end-users (Fig. 4). The process map is in turn organised into three main sections. The group of activities representing (1) the core section of the session protocol is related to what happens *during the design review meeting*; the other two groups of activities are related to (2) what should happen *before the meeting* (i.e., the preliminary phase of preparation for the meeting based on the type of design review, the

objective of the meeting and the plain language questions to answer) (Fig. 5) and (3) what should happen *after the meeting* (i.e., the possibility to look again at the VR representation to further investigate aspects of the design proposal it was not possible to reach a consensus about during the meeting and, for that reason, a new design review session is necessary) (Fig. 8).

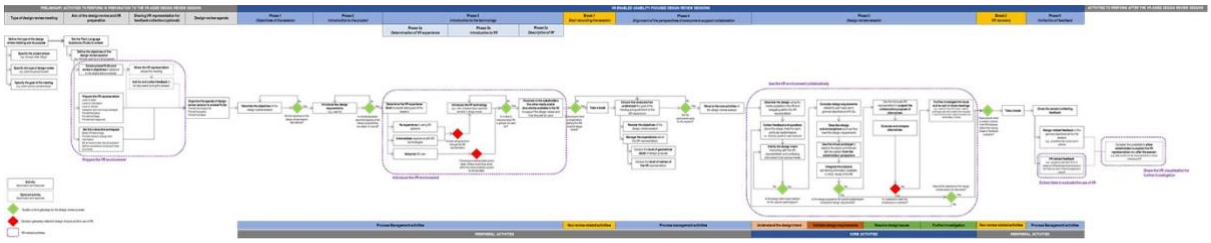

FIG. 4: VR-aided usability-focused design review session protocol

This possibility, which could include the use by the client of VR systems (e.g., VR headsets, non-immersive desktop viewers), is proposed in the new version of the session protocol as a group of optional activities that, according to what has emerged from the literature review, may support clients to feel "empowered to contribute building the design solution further with their feedback" as well as designers in being guided by the feedback express in the virtual environments in the design process (Van den Berg et al., 2017) (Fig. 5).

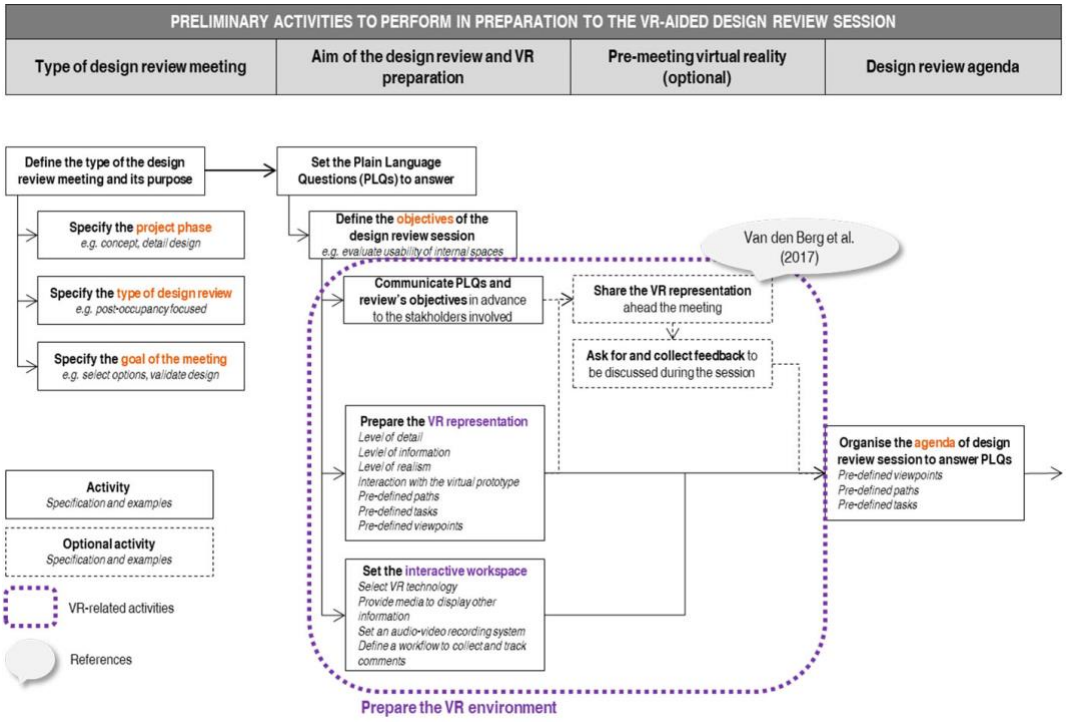

FIG. 5: Preliminary activities to perform in preparation to the VR-aided design review session

The syntax leveraged for the development of the process map includes activities represented by boxes, decision gateways represented by diamonds and sequence flow represented by lines. In particular, the activities of the process map have been distinguished into *mandatory* (i.e., continuous line) and *optional* (i.e., dotted lines) ones. Mandatory activities are considered as necessary in order to obtain reliable and consistent results from the design review session. The process map also contains *quality control gateways* (i.e., green) for the design review process as well as *decision gateways* (i.e., red) related to design choices and the use of virtual reality in order to guide the stakeholders alongside the process. Moreover, VR-related activities or groups of activities have been highlighted with a specific notation (i.e., dotted purple line) in order to point it out their insertion within the design review process, the validity of which continues to exist even if VR-related activities were removed. Finally, when literature comparison has been used as a method to validate and integrate the process map the related reference is highlighted.

Each group of activities and phases of the process map is colour-coded in order to support the stakeholders in the adoption of the session protocol, guiding the understanding of the function of each part of the process map. At the top of the process map, the groups of activities regarding the VR-enabled usability-focused design review session are represented in blue (i.e., phases to follow during the meeting) and light blue (i.e., sub-phases); the need for breaks is highlighted in yellow. At the bottom of the process map, the *core activities* of the session protocol are coded in dark blue (i.e., phase 5), while the *peripheral activities* are coded in dark grey. The latter are in turn colour-coded as *process management activities* (i.e., light blue) and *non-design review related* ones (i.e., yellow). The core activities have been in turn coded following the criteria defined by Liu et al. (2018), who differentiated the colour of each phase of the design review session to graphically indicate the main process driver for each phase.

5.2 Phases of the session protocol

5.2.1 Phase 1 – Objectives of the session

The importance of this initial phase of the session protocol for managing the VR-enabled design review meetings has been confirmed (Fig. 6). In particular, according to one of the experts from the industry, there will be the *"need to guide people to focus on objectives rather than on the technology at least for the first and second time (they use VR in design review meetings), until it becomes more regular"* (Quote_T6). Another said that *"the phases regarding the definition of the session's objectives and the introduction to the project and the technology"* (i.e. phases 1, 2 to 3) *"are useful at the beginning of the meeting"* (Quote_T5). Moreover, according to one of the academic expert *"a quality control gateway should be added to be sure that objectives have been well-defined and the meeting can skip to the next phase of the agenda"* (Quote_T9).

5.2.2 Phase 2 – Key design requirements

This phase was considered as one of the useful preliminary activities that are necessary in order to introduce the stakeholders involved in the meeting to the objectives, goals and scope of the design review, especially the ones who are not familiar with design activities and requirements such as the end-users (Fig. 6).

5.2.3 Phase 3 – Introduction to the VR technology

The talks with experts have confirmed some aspects that already emerged during the case study development in relation to the need to introduce the stakeholders to the VR technologies and the choice to avoid training them in the use of the VR system, differently to what was hypothesised in the *initial session protocol* version. Moreover, based on what emerged from the talks with experts, the number of activities to run in this phase has increased. In particular, analysing iteratively the interview transcripts, during the coding process the primary node was organised in further second-level nodes (Fig. 6):

- Phase 3a – determination of the VR experience: *"a phase to ask people if they have previous experience with VR technologies"* (Quote_T5) should be included at the beginning of this group of activities. In fact, the experience level using VR technologies has an effect on how the VR session will be run. According to the VR experts, the need for a third person driver guiding the VR session is mandatory when stakeholders have no or intermediate experience with VR technologies. Advance VR users, instead, could move alone within the virtual facility prototype, but being guided by the facilitator of the meeting (e.g., project manager) to follow pre-defined paths or to perform specific tasks useful to answer to the PLQs of the session and the related objectives. They also confirmed that it is correct *"to say that training is not always useful: it depends on the type of person (consider immersive sickness) and it is not beneficial to the goal of the meeting"* (Quote_T1). Moreover, *"the technology is evolving to streamline the process and your process map is going to be shorter. You will not need training with a new technology because the facilitator will be able to move you around even using head mounted displays"* (Quote_T3). Finally, *"the question is: where are we in the adoption maturity curve? A possibility for the future is that, as there is no need to train a client to join a video conference, there will be not the need to train them for using VR"* (Quote_T6).
- Phase 3b – introduction to the VR technology: advance VR users might not need an introduction to the VR technology, especially when VR sessions are adopted as a method to evaluate design intents multiple times and in various phases of the design process rather than in a single design review meeting. Moreover, *"phase 3 will reduce if you implement this process map in an entire project"* (Quote_T6) considering that there will be no need to introduce the technology every time if the same stakeholders are involved in multiple sessions. During

the first meetings using VR systems with participants who have not previous experience with virtual reality, instead, it is useful to let stakeholders be aware of the type of VR technology adopted (e.g., semi-immersive, fully-immersive), the reason behind this choice and the expected benefits. For example, *"semi-immersive VR is good for supporting communication: tell it to the participants if they ask why you are not going to use HMD devices"* (Quote_T1).

- Phase 3c – Description of the interactive workspace: before starting the VR session, stakeholders should also be informed about all the media and/or documents available to support them in the analysis of the design proposal. The idea that VR is not enough by itself for supporting design review meetings emerged, confirming previous studies (Whyte, 2002; Lather et al., 2018). As discussed by Bassanino et al. (2013), virtually-enabled collaborative workspaces offer "enhance communication and collaboration among project team members" adopting different visualisation and interaction techniques in design review meetings. Moreover, according to the different types of interactions that designers and clients want to allow during the meeting, various feature sets of IW should be planned (Lather et al., 2018) and *"a framework to guide the choice of the type of technology based on the needs of clients"* should be developed (Quote_T4).

5.2.4 Break 1 – Start recording audio and/or video

The first break was introduced in the *revised session protocol* as an intermediate step between the introduction to VR technologies and the following phase, when the attention of participants needs to be re-focused on the objectives of the meeting (Fig. 6).

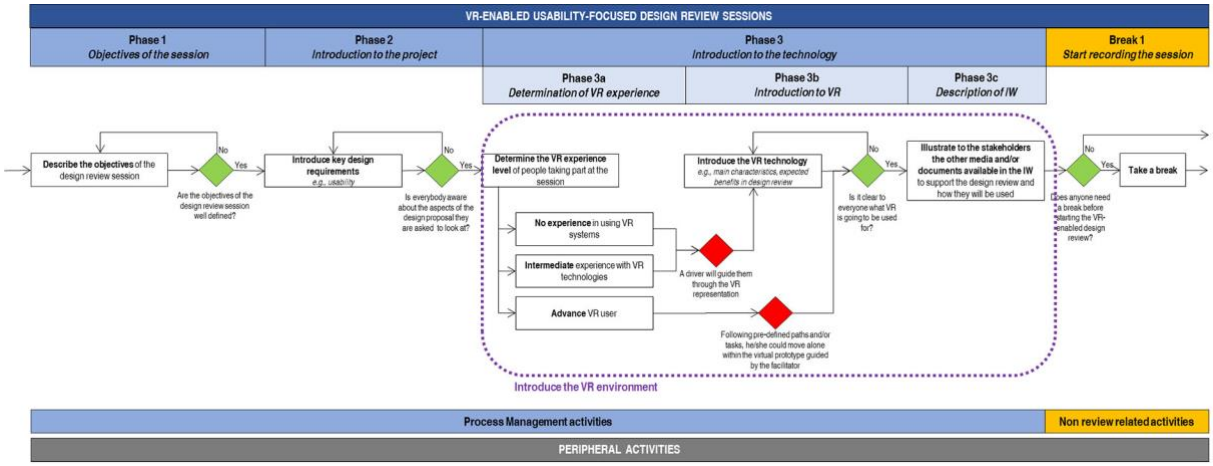

FIG. 6: VR-enabled usability-focused design review sessions: phase 1, phase 2, phase 3, break 1

This is also considered by the authors as an appropriate timing to start recording (video and/or audio) the meeting in order to later analyse what happened during the session. It is the opinion of the authors that recording could be useful for collecting comments on both the design proposal and the use of the VR systems and thus supporting the next meeting and design activities. Moreover, one of the industrial experts has also argued that they *"record audio and video more and more because it helps writing the notes. Moreover, using a screen"* they *"can record audio and video and collect these records in the cloud"* where all the members of the team can access and consult them (Quote_T6). It has been thus decided to include this phase in the session protocol in order to support the separation between peripheral activities and core ones.

5.2.5 Phase 4 - Managing the expectations of stakeholders

From the case study emerged how, for effectively running a VR-enabled design review meeting, there is the need to clarify some aspects of the VR representation and how it was developed in order to support stakeholders in the analysis of usability-related aspects of the design proposal. The talks with experts have confirmed the need for this phase, highlighting the key role of these activities in managing the design review process and to align the perspective of all the stakeholders involved in the analysis. Moreover, this phase is an explanation that the design team provides to the participants at the design review meeting about how the VR representation was prepared in order to answer to the Plain Language Questions driving the entire design review process. As stated by one of the industrial experts, in fact, *"Plain Language Questions and the explanation of the related level of detail are always useful (during design review meetings) to guide the client to understand what you mean and what there is and*

there is not in the model. Phase 4 is actually talking about something very important at every session: what am I looking at? What can I trust? What can I comment on? The statement "Declare the Level of Detail" contains a lot of important information" (Quote_T6). In particular, the activities proposed in this phase are not strictly VR-related but they *"are needed also without implementing VR technologies: very clear preambles are absolutely important at every meeting"* (Quote_T6). Moreover, both the industrial and the academic experts agree saying that *"there is the need to manage the expectations of people using the VR system: sometimes they have no expectations at all, while in other cases they have too many expectations regarding the level of detail of the visualisation and the navigation through the VR environment"* (Quote_T5). In particular, when end-users are involved *"it is important to calibrate their expectations (...) in order to prevent them from being distracted by a lack of detail"* (Quote_T2).

As proposed in the new evolution of Phase 4 (Fig. 7), it is possible to move to the core activities of the design review session only after a quality control gateway establishing that all the participants are ready because it has been ensured that everyone has understood the goal of the meeting and is thus ready to provide feedback on the design proposal as represented in the VR environment in a manner that is consistent with the design phase, the type of design review and the related and necessary level of geometrical detail, information and realism.

5.2.6 Phase 5 – The VR session

One of the main comments regarding Phase 5 highlighted how the process map describing the activities to perform during the VR session would have needed to be more structured, including decision gates; also wording have been finally refined (Fig. 7).

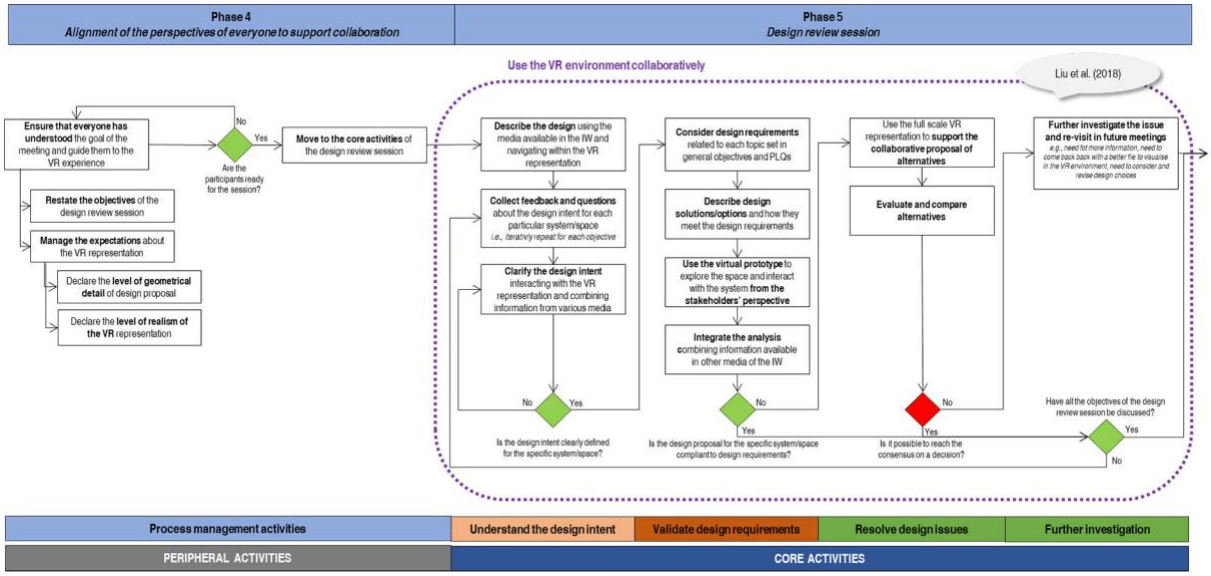

FIG. 7: VR-enabled usability-focused design review sessions: phase 4, phase 5

Literature comparison has been adopted as a method to modify Phase 5. As already said, the "process model for usability design reviews", named "Design Review Process Model – DRPM" (Liu et al., 2018), has been integrated within the session protocol because (1) it was developed specifically for usability-focused design reviews, describing the "communication and interaction dynamics" in design review meetings that involve clients and end-users as stakeholders in the occupancy phase of the building. Moreover, (2) the DRPM is defined as "agnostic, meaning it is applicable across diverse media that can be employed in the design review process" (Liu et al., 2018), such as "drawings, renderings, 3D models or VR models". The process model focuses on core design review activities, which are grouped in three cycles: cycle 1 - Understand the design intent, cycle 2 – Validate design requirements, cycle 3 – Resolve design issues. The structured of the three cycle have been maintained as well as the color-codes related to the stakeholders who are the main responsible for each group of activities (i.e., designers, reviewers, designers and reviewers as a collaborative unit). Moreover, as stated by an expert from the academia, *"there are many issues that cannot be resolved real time and they will need to be analysed in a later step"* (e.g., as well as the design progresses) (Quote_T7). For that reason, as also suggested by another expert from the industry "*a step to consider the need for future meetings should be also included"* (Quote_T5) in the case it is not possible

to reach a consensus on the design proposal regarding a specific system, space or other objective of the design review session. Moreover, it is necessary *"to see in the agenda where the decision is made and the agreement is reached"* (Quote_T6). Two types of gateway have been included: quality control gateways (i.e., in green) are necessary to move from one group of activities to the next one, while the decision gateway (i.e., in red) is necessary to highlight if a decision is taken during the design review.

5.2.7 Break 2 – Recovery from virtual reality sickness

The need for breaks to be included in the session protocol in order to face motion sickness, one of the main obstacles that affects, from the technological perspective, the implementation of VR systems in design review meetings, has been confirmed during the talks with both academic and industrial experts. "*The timing for taking breaks should follow the needs of the meeting"* (Quote_T5); they are *"helpful"* because they are proposed to *"avoid that the users get overwhelmed by this kind of technology experiencing cyber sickness"* (Quote_T8) (Fig. 8).

5.2.8 Phase 6 – Discussion

The discussion phase has been positively commented by the experts; some integrations have been also proposed (Fig.8). One of the industrial experts considered it as *"a great idea"* to support the improvement of VR adoption in following design review meetings (Quote_T3). Anyway, he has also highlighted a possible obstacle in relation to time management. In fact, he said: *"most people focus on the goal of the meeting, which is your phase 5. As soon as the assumed goals are achieved there is a disconnection of the engagement and a very little time for collecting the feedback, which instead are important to refine the way we present the steps of the VR experience"*. (Quote_T3)

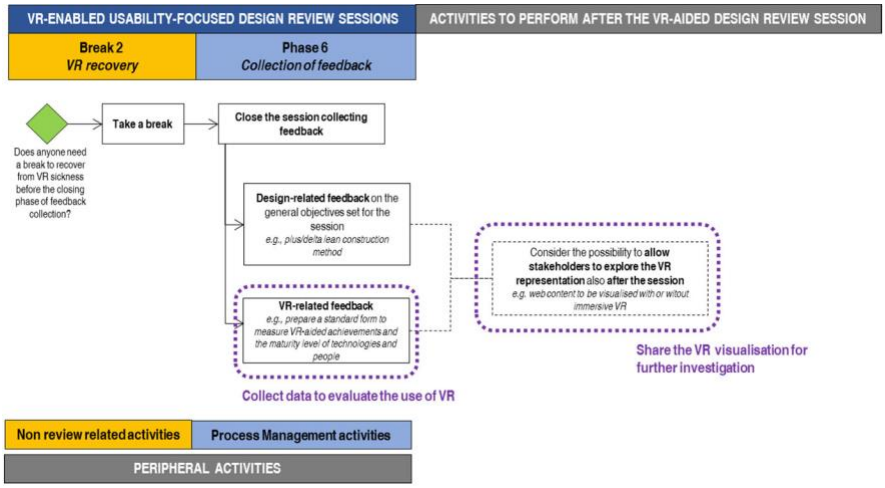

FIG. 8: VR-enabled usability-focused design review sessions: break 2, phase 6 and activities to perform after the VR-aided design review session

Moreover, an important aspect emerged: according to the experts, the feedback session should be split into two separate sections (Fig. 7). During this phase, in fact, it is possible (1) to close *"the design review with final feedback"* in relation to the previously defined objectives of the meeting (Quote_T6) and (2) to close the *"VR session and get feedback on what has worked or not"* in relation to the adoption of VR reality systems to support the analysis of the design proposal within an interactive workspace (Quote_T9). Splitting the feedback collection phase (i.e., Phase 6) *"in a part related to the design proposal and in a part related to the immersive VR technology and its effective use"* could be necessary *"especially for a number of years as VR becomes more mature"* (Quote_T6). Furthermore, an industrial expert suggested that standard forms could be used as a *"framework to measure the feedback on both the design proposal and the use of the virtual reality system"* in order to *"improve the next iteration and the next meeting"* (Quote_T3). An academic expert also suggested to *"refer to the Plus/Delta Lean Construction method to get feedback on the general objectives"* that have been set for the meeting (Quote_T9).

This type of approach could inform design firms and clients to understand whether they need to invest more or less in the technology, in training people and so on. Moreover, it could be a way to understand, measuring it, if VR actually allows the achievement of some results that it would have not be achieved through traditional representations. The experts supporting this idea somehow provide an evidence for the rising research trend according to which a more comparative and quantitative approach is needed in future research works in order to understand and quantify the impact of virtual reality on user performance as a necessary step to its wider adoption in the construction industry and, so, to justify investment (Paes et al., 2017; Khashe et al., 2018).

6. DISCUSSION AND CONCLUSIONS

As discussed in the research background, studies related to VR implementation in the AEC industry usually state general benefits for adopting immersive virtual environments for various purposes and use cases during the delivery process of a building facility. Most of them are empirical studies, usually based on case studies, in which the use of virtual facility prototypes, for example, provided "conditions for better collaborations among stakeholders" (Bassanino et al., 2010; Berg and Vance, 2017; Fernando et al., 2013), enabled "better spatial understanding in comparison to 2D and non-immersive 3D representations" (Paes at al., 2017), allowed the identification of design issues that would not be identified otherwise (Dunston et al., 2011) and represented building proposals in a closer way to the experiential-spatial human experience (Bullinger et al., 2010).

However, despite the growing interest from the construction industry for virtual reality systems some obstacles and challenges still affect their effective implementation. Procedural challenges are usually reported in previous studies as observations from the development of case studies in which VR systems had been adopted. According to Whyte (2002) and Liu et al. (2014), the development of more mature workflows and processes for incorporating VR tools for the AEC industry could increase the industry adoption of immersive virtual environments. Within this context, the need for a structured approach emerged in order to ensure the promised effectiveness and value of VR systems in design review. This is the gap this study has addressed developing a session protocol to ensure the effectiveness of VR in usability-focused design reviews in which clients and end-users could be involved.

A preliminary step consisted in organising those challenges and providing possible solutions for them in a systematic way. Both the case study and the talks with VR experts have provided evidence for findings coming from previous researches. Moreover, the research activities described in this paper finally resulted in a comprehensive and structured session protocol for informing future researchers and professionals in those procedural challenges supporting them in their effective management.

6.1.1 Contribution of the study for research and practice

As a comprehensive summary of all the phases and activities that have to be followed for the effective implementation of VR systems in usability-focused design reviews, the VR-aided usability-focused design review session protocol fill a gap in the research on the adoption of virtual reality in the AEC industry, which was lacking a prescriptive and structured process to drive the effective use of this technology in collaborative meetings and decision-making processes. Its adoption, in fact, avoiding focusing more than necessary on technological aspects, is of extreme importance from a procedural perspective in order to obtain reliable results in design review sessions according to the objectives of the meeting, the phase of the process and the stakeholders involved. Moreover, the session protocol represents a valuable framework for future researchers investigating the same topic because it can be used as a flexible and extensible basis for both qualitative and quantitative research works.

Talks with experts have been used to validate the preliminary research results and extend the session protocol; moreover, they have also confirmed the contribution to practice of session protocol itself. It can be adopted by practitioners as it is, representing a reliable basis to guide them in the effective implementation of virtual reality systems in this phase of low maturity and, at the same time, growing adoption of the technology in the AEC industry. Moreover, practitioners can also modify and adapt the session protocol based on the specific needs of a building project. Furthermore, as the level of maturity in the use of the tool increases, practitioners can integrate the session protocol with additional activities to be performed as well as observations and procedural considerations to take into account, including results from their own best practises and further references, such as future technological advancements as well as future process management sources.

6.1.2 Limitations of the research

A series of limitations have influenced the development of the research project and its results, paving the way for future developments and studies. Research limitations concern both the application of the procedural guidelines and the extent of any generalisations to be made in the light of the methods used.

The research project does not consider the implementation of virtual reality systems in specific design processes (e.g., participatory design, user experience design, user-centred design) neither in relation to specific types of public procurement routes (e.g., integrated project delivery, design and build). The types of design review and the related objective (e.g., select options, validate design versions) have not been considered in particular as well. The session protocol, in fact, have been developed to be applied at a general level, referring to the minimum and prescriptive aspects to be considered when applying VR systems for usability-focused analysis in collaborative design review meetings in order to maximise their value when clients and end-users are involved.

From a methodological point of view, the research experience described in this study considers only a specific building type and operational requirements related to the functionality and effectiveness of internal spaces; findings need to be generalised in other settings and to be analysed in additional projects, where the procedural guidelines can be applied and further validated in actual contexts of application. The data set could be extended in additional research activities in order to finalise the results, eventually involving a wider panel of design stakeholders as a method to validate and generalise the outcomes of the study. Moreover, some restraints regarding the collection of audio and video recordings when minors were involved affected the data collection process during the development of the case study. Furthermore, it has to be noted that the immersive virtual environment was available for a limited time, during which it was possible to involve a certain number of stakeholders and to organise a limited number of session for data collection. Finally, the process of preparation of the VR-compatible version of BIM models required a considerable investment in time and resources because of (1) the visualisation packaged adopted at those time and the related capabilities and (2) some uncertainties in the setting the most appropriate level of detail for the VR representation in relation to the current design stage.

6.1.3 Future works

Despite the evidence provided by empirical studies in the field, one of the main future works, confirmed from both the literature review and the talks with experts, is the need to measure, by an appropriate framework, the actual added value contributed by the implementation of virtual reality systems in the design review process. Sacks et al. (2013), in fact, stated that the successful use of VR technology in other industries cannot prove its effectiveness for architectural and construction practises; anyway, this has not been rigorously tested yet. The session protocol proposed in this study represent a comprehensive basis and reference framework for quantitative research aiming at measuring the added value of VR systems, in terms of communication and analysis capability, in each phase of a digitally-enabled usability-focused design review meeting. For example, the adoption of lean methods such as the plus/delta process could be applied in the final phase of the procedural guidelines, the Phase 6 - Discussion, in order to collect feedback for continuous improvement and to measure the effectiveness of the tool on the specific design review process. Modifications in terms of stakeholders involved, types and number of design reviews, objectives of each session of analysis if compared with traditional processes could be proposed and analysed. Moreover, no guidelines are available to lead users to the selection of the most appropriate VR system based on their needs and expected user performance and interaction with the virtual facility prototype according to VR purposes and related uses. Current literature does not provide a framework for developing such spaces, as pointed it out in Castronovo et al. (2019), who has started to work in this direction.

Moreover, the different types of design processes (e.g., user-centred design, participatory design) should be also taken into account and the procedural guidelines could be adapted to each specific process considering the relevant activities and constraints. As far as process mapping is concerned, at this point of the research, the team decided to not include “actors” to the “activities” as it would make the process map too prescriptive and rigid. Therefore, the team wanted to make the process map to be flexible in the actors that could leverage it, so that it could be applied by a wider panel of stakeholders such as BIM managers, designers, and owner representatives. As additional research is performed, potential actors that could perform the activities of the process map could be suggested. The adoption of the Business Process Modelling Notation (BPMN) could facilitate future works to improve this and future process maps for VR adoption in building processes. The Information Delivery Manual

(IDM), as a documentation reference to capture business processes (ISO 29481-1:2016), also recommends the use of the BPMN symbols for the development of process maps and it should be taken into account in future works.

Furthermore, future research activities should investigate how cognitive processes in collaborative activities, such as design review meetings when multiple stakeholders are involved, change because of the adoption of virtual reality systems. The role of virtual prototypes in cognitive processes is much more investigated in other sectors such as cognitive and computer sciences (Paes et al., 2017); this should be evaluated in the construction industry as well in order to deeply understand the role of immersive virtual environments in collaborative processes. For example, the bi-directional dialogue between clients and design teams and how it changes because of VR systems and interactive workspaces should be investigated, as well as the more and more significant role of end-users in stakeholder engagement processes when soft landing strategies converge with pre-occupancy (i.e., usability-focused) evaluations and they are both supported by the possibility to explore a virtual facility prototype. The effect of an enhanced role of the occupancy evaluation on design practises and the results of a forward-thinking design approach, which is the core of an effective occupant engagement, in how a building performs when in-use should be further investigated as well. Especially in this case, psychological aspects related to the perception of spaces within an immersive virtual environment could have effects on the pre-occupancy evaluation and the validity of the perception of the users during the evaluation.

Finally, additional research should be related to the contractual aspects of VR adoption in design review meetings in relation to the validity of the VR representation and the use of VR systems in design reviews, considering both the level of information need for an effective and reliable VR representation based on the phase of the design process and the stakeholders involved in the analysis as well as the risk for possible discrepancies between the perception of the design proposal in the immersive environment and its actual result once the building is built.

These research gaps could represent important ideas for future research activities, supporting the industry in a more mature adoption of immersive VR technologies.

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