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Surprise: Challenging design perceptions in immersive virtual reality environments? The case of designing a hospital project using a CAVE (Cave Automatic Virtual Environment)

Purpose - The purpose of this paper is to examine how the use of immersive virtual reality (IVR) impacts on the surprise aspects of designing.

Methodology - The empirical case is a new hospital in the UK wherein a CAVE (Cave Automatic Virtual Environment) type of IVR was used performing six design review sessions during bid preparation stage. Drawing from a former video-based study, we conducted follow-up discussions with the participants to access their perspectives on design surprises emerging from their engagement with the IVR. The study developed a reflective methodology, interviewing participants about their experiences of doing design in the immersive environment. Retrospective discussions were conducted in a data review format, through playing back video-clips of the IVR design sessions and asking the participants to reflect on their IVR design experience and on design surprises emerging from their engagement with the IVR.

Findings - The findings indicate that IVRs such as the CAVE are not only enhancing existing understandings of design, but also challenging the participants' understanding of the design as they experience the immersive version of it, provoking ruptures in current procedures and driving unanticipated changes to the design.

Originality/ Value - This qualitative study of surprise in design work using IVRs (for a real-life design project) brings new insights into emerging practices of designing using immersive technology such as the CAVE.

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Keywords: design practice, immersive virtual reality (IVR), design surprise, retrospective reflection

1. Introduction

*"Actually there are quite a few architects who when they go into built form at the completion of a project, are a little **surprised** at the body metric nature of the space, too big, too large, too high, too narrow, whatever it might be. Didn't think that was going to look quite that way, even though architects and designers are trained to do exactly that […]"*

(Project Lead, design team, interviewed in December 2012)

The above quote exposes a design practitioner's view on the surprise encountered when entering the built version of a design for the first time. Design practice is "frequently displaying surprising features that defy our understanding, descriptions, and planning capabilities" (Lanzara, 1999: p. 334) and is as "much about re-design, interruption, resumption, continuity, and re-contextualising as it is about design, creation, invention, initiation, and contextualising" (Weick, 1994: p. 6). This paper takes an interest in how/ if using immersive virtual reality (IVR) technologies might be impacting on the role of surprise emerging within design processes and on broader design practice.

The potential and use of IVR technologies in performing design has been extensively addressed (e.g. Zhang et al., 2020; Kahkonen, 2003; Whyte and Nikolic, 2018). The research interest in virtual reality (VR) and IVR has become an established trajectory of inquiry in the architectural design and built environment literature (Salama, 2019). The themes addressed in this literature range from immersiveness, experience, complexity, spatial perception and cognition, problem solving, decision-making, collaboration, user engagement, to value and cost or time. Overall, these studies suggest the potential of visualisation and collaboration environments to support the creation, communication, development and understanding of design through supporting and extending other design procedures (Whyte and Nikolic, 2018;

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Mastrollembo Ventura et al., 2020; Goulding and Rahimian, 2015). However, much of the literature focusses on developing/ testing technology in experimental studies, or examining the practical use of immersive technology using standard metrics. Much less examine the role of these technologies in 'real-life' practice situations, and seldom if ever address the way surprise and novelty impact both experience of these technologies, and of the designs they are representing.

Therefore this study asks: How might IVR be impacting on the surprise aspects of designing and on broader design practice? The paper addresses this question by taking a practice-based approach to examine IVR in a real-life design project through focussing on the actors and materials bound up in the situated design process and accounting for the participants' reflection on their design activities performed using the IVR. The empirical material is drawn from the early design of a new hospital project wherein design and contractor teams used a particular type of IVR, a CAVE (Cave Automatic Virtual Environment) set up in the Authors' University to demonstrate particular design requirements to the client and to perform design review meetings. The study builds on previous research (Author Ref) which studied the use and implications of IVRs for design activities by drawing on direct observation and video recording of design meetings held within the CAVE (Figure 1).

"It's totally out of perspective for me!" (E1)
"One, two, three...You CAN! You can see three beds!" (E2)
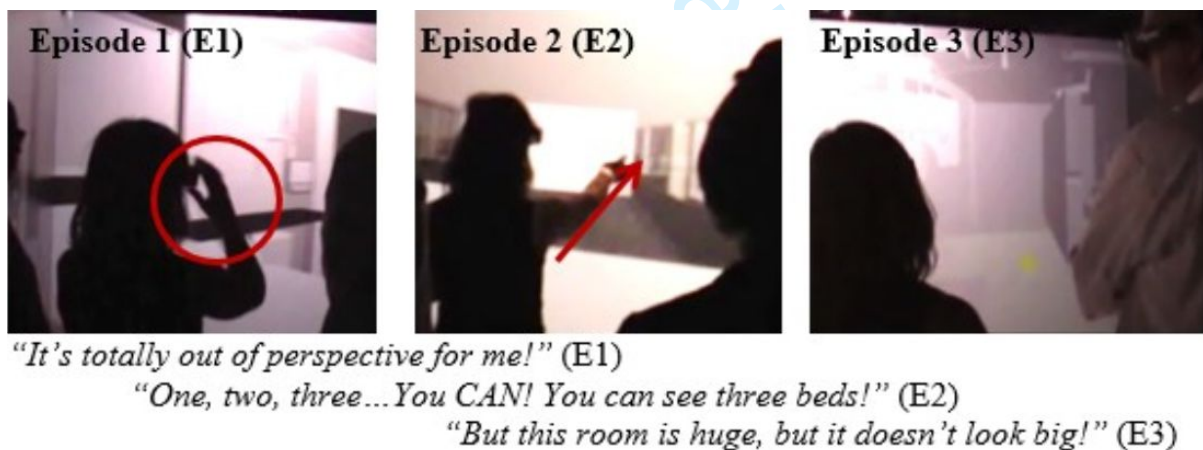"But this room is huge, but it doesn't look big!" (E3)

Figure 1. Video study instances of design in the CAVE suggesting the idea of surprise

This paper is concerned with the participant's own reflections on design in IVRs, and especially the aspects of surprise as part of the design process. The following sections address this research interest by: firstly, examining how the idea of surprise is treated in the design and broader practice literature; secondly, by analysing particular design practitioners' reflection on their design surprises experienced using the CAVE as design setting; thirdly, by discussing the empirical findings in relation to both the literature on surprise and the research question set in the paper; and fourthly, by concluding that IVR enabled distinct types of design surprises through a more immersive experience of the designed spaces, resembling to visiting the built version of the design. The findings indicate that, using CAVE as design setting encouraged distinct design surprises –particularly focussed on the experience of the designed space, it challenged usual design procedures and understandings drawn on other less immersive media, it enabled noticing issues not previously observed and it drove new ways of making sense of and addressing the design.

2. Surprise in (design) practice

The aspect of surprise is scarcely considered in the literature on IVR for design. Some experimental studies (e.g. Rieuf et al. 2017) account for designers' surprise as emotion relating to experience of early design processes in immersive VR by drawing on psycho-physiology measures. Other experimental studies on architectural design education (e.g. Rahimian et al., 2014; Abu Alatta and Freewan, 2017; Maghool et al. 2018) indicate the potential of IVR to enable simulating unexpected events and to support learning by doing and stepping outside routine. Indeed, early research on VR and IVR broader applications highlights surprise as related to the sense of presence in VR (Slater et al. 1998) and suggests the potential of IVR to enable stepping outside routine and performing various disciplines activities in new and unexpected ways (Slater and Sanchez- Vives 2016). However, the previous work on IVR for design obscures the processes whereby practitioners perceive and address the surprise and challenge of designing in immersive settings in situations of practice, rather than in experimental contexts. There is, however, a well-established interest around the issue of surprise in areas including design cognition and creativity, organisational management and learning and use of technology/ information systems in organisational settings, as well as broader studies of social practices or psychology studies of social

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cognition, cognitive emotion and behaviour. Drawing on a broad identification of two main perspectives in this literature– 1) scientific rationality/cognitive and 2) qualitative/ experiential–, this paper next reviews how the issue of surprise is treated.

2.1 Cognitive treatments of surprise

Building on a cognitivist (information retrieving and processing) and cognitive psychology orientation, the first strand of studies treats surprise as connected to a degree of expectancy disconfirmation and as affective reaction to unexpectedness linked to 'causal thinking' and indicates surprise as central to sensory processing, adaptation and learning, attention and decision making (Reisenzein, 2000: p. 268). These studies aim for an abstract theorising of surprise by developing and/ or testing rational models of surprise preponderantly in experimental studies in controlled laboratory situations.

Within design, surprise is mostly addressed from cognitive and cognitive psychology perspectives and it is mainly discussed in relation to its impact on aspects of design creativity and on the perception and framing of design problems, or in terms of design strategies employed by designers to trigger users' surprise around their final design products.

For example, some studies on design creativity (Grace and Maher, 2015) consider surprise as a metacognitive (thinking about thinking) process and focus on the impact of surprise on design problems, goals, requirements formulation and relatedly on design creativity. Pointing the iterative nature of the process of problem and solution formulation and indicating the reasoning about the cause of surprise as relevant for changing design goals, this experimental work identifies taxonomies of surprise and responses to develop cognitive and computational models of surprise (programing computers to measure surprise). Other studies on improving design methods, tools and approaches to foster creativity (Becattini et al., 2015) focus on the cognitive processes emerging in relation to the perception of surprise around a new design product by treating surprise as constituted through human interpretation rather than as effect of measuring novelty. Such work raises attention to understanding users' reactions (cognitive responses) to surprising design products (Becattini et al., 2020). Other studies (Chen and Lai, 2014) address the impact of unexpectedness on the communication effect of design by taking

an information retrieving perspective focussed on emotional aspects. The role of non-routine contexts is also highlighted in relation to the impact of the design experience on creativity (Rahman and Jonas, 2010). Research on the role of emotions in design (e.g. Ge et al., 2021; Zhou et al., 2020) indicates the relation between designers' surprise as emotion experienced while designing and the design process/ thinking through increasing design-creativity, re-framing and design changes. Surprise as emotion in design is examined mostly in experimental studies through physiological measures (e.g. speech acoustics, electrodermal activity, automated facial emotion detection) and behavioural assessment, while rarely being considered as context dependant and examined through retrospective self -reports (Ge et al., 2021). Overall, most of these cognitive/ cognitive psychology studies draw on experimental work to develop/ test rational models of surprise based on measuring novelty and unexpectedness by using standard metrics.

In a different vein, Dorst and Cross (2001) develop a cognitive model of design creativity by connecting with reflective practice treatments of surprise as interruption of routine and as essential for triggering reflection in action. Stressing the role of surprise in stimulating framing and reframing, shaping and changing the view of the problem, these studies find that creativity is linked with the designers' identification of surprise in the 'problem space' which triggers their reflection, enabling the seeing of things in new ways and stimulating the process. This understanding accounts for designers' views of the terms and relationships underlying design activities, based on previous experience and knowledge. Similarly, Rodríguez Ramirez et al.'s (2014) study of designers' strategies for developing designs surprising to their users draws attention to designers' own perspectives to describe their intentions while designing surprising outcomes. Their situational analysis focusses on the behavioural, cognitive and emotional aspects of designers' experience informing their designing with the aim of eliciting surprise. However, they do not examine how designers themselves experience and address surprise occurring *during* design. On a similar note, Suwa et al. (2000) point out the situated nature of designing and draw attention to the role of representations (sketches in their example) to indicate surprise as unexpected discovery impacting on creativity. However, Suwa et al.'s (2000) focus remains on the cognitive aspects around these design surprises.

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2.2. Qualitative driven studies of surprise

Contrasting this generally abstracted and more quantitative understanding of surprise, other work treats surprise as situated, by turning attention to the practice as performed in everyday life. Surprise is inherently realised in situated social and material interaction and stressing the connection between knowing and doing instead of focussing on the cognitive aspects. These studies build on various theoretical standpoints including practice-based approaches, reflective practice, or sensemaking perspectives. These studies intersect in treating surprise as socio-materially generated in practice situations and recognise the role of surprise as a generative phenomenon through driving practitioners' attention to and reconsideration of the underlying mechanisms of practice.

From a reflective practice perspective (Schön, 1983), surprise is central in performing (design) practice by triggering reflection and action to address and engage with unique, conflicting, uncertain, puzzling situations of practice by mobilising appreciations drawn on existing repertoires through both individual and collective conversation with the materials. Surprise is discussed as triggering 'new ways of seeing things' and leading to 'questioning assumptions that had been built into practice' (Schön, 1992: p. 131,136). The practitioner's ability of responding to 'surprise', contradictory, unfamiliar states perceived in the 'back-talk' of a design situation, is mediated through 'seeing' the situation in new ways, in association with familiar elements of previous experiences, which guides the process of shaping the situation by employing action and driving further accomplishment of practice.

Similarly, from a phenomenology oriented practice-based approach to change in organisations, the issue of surprise as breakdown is treated as means to encounter the 'world' suspending, even if briefly, usual attitudes and expectations (Ciborra, 2001: p. 28). Applying this perspective to study the use of technology in organisations, Ciborra indicates the processes of bricolage ('make do') and improvisation employed by practitioners to "find fixes to the plans and deal with surprises" (Ciborra, 2004: p. 20) and points out the phenomenon of drifting i.e. "deviating from planned purpose for a variety of reasons often outside anyone's influence" (Ciborra, 2001: p. 4). This kind of phenomenological approach indicates situations of discontinuity and disruptions related to the use of novel technologies and points out

practitioners' reconsideration of existing assumptions built into practices (Lanzara 2009, 2016). Surprise is treated as a complex of "features that defy our understanding, descriptions and planning abilities", addressed through a range of constructive activities globally conceptualised as 'bricolage' i.e. encompassing "practical experiments, local readjustments and repairs, extemporaneous improvisations" employed to respond to surprises, novelties, and other puzzling phenomena interrupting/ rupturing repertoires of practice routines (Lanzara, 1999: p. 334, 135).

From a sensemaking perspective, surprise (particularly understood as interruption of routine and/or as ambiguous event) is seen as "consequential occasion for sensemaking" (Weick, 1995: p. 105) and it is often discussed in relation to improvisation and making new sense to restore interrupted activity (e.g. Weick, 1995; Sandberg and Tsoukas, 2015). Intersecting with other areas of literature, this perspective acknowledges that interruption and recovery (Weick, 2009) drive meaning of experiences and indicate the role of the repertories of previous experience.

From various practice-based approaches- reflective practice, phenomenology or sensemaking perspectives-, these qualitative studies treating surprise as situatedly generated through practice experiences and highlighting the role of surprise as generative phenomenon in further performing social practices share a number of common ideas as described below.

Surprise in practice: shifts of awareness. These studies intersect in discussing surprise as enabling practitioners' shifting from subsidiary to focal awareness around the practice elements, leading to (re)opening (reflective) inquiry (e.g. Yanow, 2015). From a sensemaking perspective, 'jolts', surprises and other types of disruptions drive interpretations and "expose tacit, taken for granted assumptions" (Weick, 1992: p. 101). In various ways, these studies indicate the idea that through surprise 'elements' of practice taken for granted may be questioned, through a change of focus of awareness and attention. Surprise provokes a new types of awareness- more focal forms of attention employed to address disruptions: "When routine practices are interrupted by surprises, these disturbances produce a caring, a mattering –an affective state- that focuses awareness and attention" (Yanow and Tsoukas, 2009: p.

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1351). Unexpectedness may trigger changes in engagement with the elements involved in a practice situation, shifting from being 'transparently available' (Yanow and Tsoukas, 2009) to being brought under focus of deliberate attention.

The openness to perceive surprise in practice: Another key idea shared in this strand of studies is around the openness to perceive surprise as an important feature in social practices. For example, from a practice-based perspective to organisational management and learning, (Nicolini, 2012: p. 27) indicates the 'practical wisdom' as "non-inferential and non-deductive form of knowledge" dependent on practitioners' flexibility and openness to surprise and improvisation. From a phenomenological perspective to reflective practice, Yanow and Tsoukas (2009) discuss surprise as requiring a 'degree of permeability' ('mindful openness') to allow perception of an event as surprising. From a reflective practice perspective, Schön (1983) treats surprise as both trigger for, but also triggered by reflection and indicates that "[…] the practitioner allows himself to experience surprise, puzzlement, or confusion in a situation which he finds uncertain or unique." (Schön, 1983: p. 68).

Repertoires of responses to surprise- a learning process: The idea around 'response repertoires' for dealing with interruptions connects with viewing organisational learning as constituted through these enhanced repertories of responses to ruptures in routines (Yannow, 2015; Christianson et al., 2009). From a sense making perspective to studying organisational learning, Christiansson et al. (2009) note the role of rare events- conceptualised as interruptions- in triggering learning through "exposing weaknesses and revealing unrealised behavioural potential" (id.: 846). From this perspective, interruptions trigger learning firstly by acting as audits of existing response repertoires and, secondly, by providing opportunities to reorganise routines of interpreting, relating and restructuring. Similarly, the reflective practice (e.g. Schön, 1995, 1983) approach argues that social practices become enriched through reflective processes mobilised to engage with and address uncertain, conflicting, puzzling situations of practice. Surprise encountered in practice may therefore impact on further experiences through building up and shaping existing repertoires (Schön, 1983), an 'epistemic tool' with potential for reframing knowledge (Lanzara, 2016: p. 8).

Surprise as method: Beyond highlighting the role of surprise in performing social practices, these studies also see surprise as an enhanced methodological route to inquire into the dynamics and processes of configuring practice (e.g. Weick,1992; Nicolini et al., 2003; Ramiller and Wagner, 2009). Methodologically, practice is "better observed when some "breakdown" occurs in an entrenched practice or when some substantial change requires major realignments of the extant configuration of practice" (Nicolini et al., 2003: p. 26). Hence, the importance of surprise consists in both its role as generative phenomenon essential to practice and as a research means of grasping underlying mechanisms of practicing.

Whilst there are differences in treatments of surprise, for instance between surprise as a response (Bruner, 1986) or part of a series of events (Ciborra, 2002), or locating surprise as an individual (Schön,1983) or collective (Weick, 1995) phenomenon, there is an important distinction between cognitive and qualitative approaches. The latter identify themes of surprise as *generative phenomenon* in performing social practices; surprise as driving *shifts of awareness*, the *openness/ permeability to perceive surprise* in practice; the role of developing repertoires of responses to surprise -relating to a *learning process*-; and the role of surprise as *methodological means* to research into practice. This paper explores how these qualitative accounts of surprise might be mobilised in design work using IVRs.

3. Methods

As indicated in the literature, surprise is an important aspect in design work (relating to creativity, innovation, framing and re-framing etc.). This paper focusses on surprise to understand the impact of IVRs on the surprise aspects of designing and on broader design practice. Recognising surprise as an important aspect in design seen as a socio-material process realised in situations of practice, this paper treats surprise as a situated phenomenon and it examines how design practitioners make sense of and address surprise within design processes performed using IVR and how this relates to broader design practice. Drawing on this approach to surprise in design, this paper operationalises the research by examining a situated use of IVR in design work through an empirical case of a real-life design project.

The case study is based on a real-life project for designing a new hospital in the UK. One of the requirements is that all patient accommodation is in single rooms, rather than traditional wards. Single room only accommodation is rare in the UK, and so a key issue for the client was ensuring that the rooms were of sufficient size. At the time of the research, the project was still in bid preparation stage. The project team opted to augment the traditional design and client engagement procedure with the use of an IVR environment - a CAVE[1] facility set up in the Authors' University (Figure 2). This was to be used to demonstrate to the client that the rooms were of an appropriate size and more generally to communicate the design of this hospital project to the NHS client, to support reviewing key spaces in the hospital design and to demonstrate how the design meets the requirements.

Figure 2. Simulation of the hospital project using the CAVE at the Authors' University

Building on insights of former research based on observation and video recording of six design meetings performed using the CAVE , the methodology here draws on reflective discussions with the participants involved to access their views on the surprise emerging in

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[1] The CAVE (Cave Automatic Virtual Environment) is a multi-person, full scale IVR environment, in which graphics are projected stereo onto the walls and floor. It offers the user (equipped with 3D stereo glasses and a head mounted tracking device with location sensor) an active stereo and real-time interaction with a life-sized 3D model. One user's movement in the space of the CAVE is being tracked and perspective rendering is displayed responsively. The CAVE at the Authors' University has three vertical projection screens (3m by 2.2m) and a floor projection screen (3m by 3m).

their CAVE design experience and the implications on the design process. This was aimed to allow the participants' reflection on how they experienced particular episodes and describe their understanding and reasoning behind the events. The method connects with Schön's (e.g. 1992) argument on the role of reflection-on-action outside of the situation as retrospective thinking on previous actions and understandings through observing and describing. A retrospective data review format was developed, both playing back video-clips from the video data set and revealing the researcher's interpretation around what was happening during the design sessions.

The discussions were conducted nine months after the last CAVE design session and they consisted of four individual interview sessions (30-60 minutes) with participants having various roles in the design team: visualizer (REVIT modeller), project director, lead interior designer and lead medical planner. The interviews were initiated by playing back video-clips selected from the video data both to refresh the participants' memory and to enable their retrospective reflection (Jewitt 2012) on the design events they had experienced in the CAVE. The research followed the University's ethical procedures regarding the participants' consent, confidentiality and data protection. Informed by the previous video-based study (documented in Author Ref) by taking into question the findings indicated by the video analysis, this paper draws on designers' retrospective reflection on both the CAVE technology and on its use in design practice and it focusses on the participants' views on the surprise and challenge encountered in the immersive simulation of their models and on the impact of the CAVE on broader design practice. The interviews were recorded, transcribed and analysed with a focus on understanding the design surprise emerging in the CAVE by examining the participants' interpretation of the phenomena.

The empirical material is structured along the reflective practice (Schön 1983) process of reflecting before, during and after an experience. Following this structure, Section 4 describes the interview data by focussing on the participants reflection on: their expectation from the CAVE design sessions; their experience of surprise in the CAVE; and the impact of this design experience on further developing the hospital project outside the CAVE.

Subsequently, Section 5 discusses the relation between the interview-based findings and the themes identified in the qualitative literature on surprise.

By drawing on a situated approach   to designers' experience of surprise when designing a real-life design project in a particular technological setting (CAVE as a type of IVR), the empirical findings indicate a close and detailed understanding of the situated use of the technology by the particular group of design practitioners. Whilst the empirical findings are limited to the particular situation/the case (dependant on the characteristics of the technology, of the project, and the particular design participants perspectives at that moment in time), insights of the study may be meaningful to better understand the use and impact of IVRs such as the CAVE in other design situations.

4. Findings

This section describes the empirical material with a focus on surprise. The empirical vignettes from the interview data are structured along the participants reflection on: their expectation from the CAVE design sessions; their experience of surprise in the CAVE; and the impact of the CAVE design experience on further developing the hospital project outside the CAVE.

4.1. Expectation from the CAVE design sessions

The participants shared a perception of surprise in relation to realisation of design intentions, mostly with regard to spatiality of the layout in reference to design assumptions based on previous work. The IVR was seen as a way of checking design discrepancies and avoiding possible design surprises later in the process.

"[…] my main purpose of going to the CAVE […] was to check the representations of […] elements within the model […]and […] that there weren't any major […] discrepancies between what we thought the spaces were going to be like and […] what [the contractor] thought the spaces were going to be like." (Visualiser)

"[I had] to make sure that what I needed to have inside the building [medical equipment and workflows] fitted within [the] architectural envelope." (Medical Planner)

The participants' reflection indicates that the 'mattering' (e.g. Yanow and Tsoukas, 2009) associated with the perception of surprise connects with their roles in the project and their focus of concern in using the CAVE: the body metric nature of the space (for the Project Lead), the representation aspect of the design, in terms of consistency between the designers' and contractors' assumptions and intentions on the appearance of spaces (for the Visualiser), or the 'fit' of the hospital equipment and activities workflows in the proposed architectural envelope (for the Medical Planner).

The following sections describe the participants' reflection on how surprise was actually experienced in the CAVE design sessions and how the CAVE design experience impacted on further developing the design project.

4.2. Experienced surprises in the CAVE design sessions

4.2.1. Surprise around the technology

The Medical Planner's reflections indicate the disruption caused by the technicalities of the environment: *"it was exciting but it was a bit daunting"* and points the source of breakdown in the distorted viewing perspective, relating to the technology: *"you have an expectation [...] but [...] the perspective of what I was looking at was completely wrong"*. At first, the CAVE was perceived as unusual and surprising in reference to participants' repertoires: *"it was a bit daunting because, it's something new and you have an expectation"*. This indicates a tension between the expectations drawn on previous work and repertoires of usual representations (like REVIT/ CAD models visualised on computer screens) - *"this space that I've designed, this was my layout"*- and the CAVE version of the model as perceived from the participant's viewing perspective: *"what I was looking at was completely wrong"*.

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Alongside noting the disruption caused by an unfamiliar technology and representation, the participants reflected on the use of the CAVE on a more frequent basis, suggesting familiarisation with the specific procedures of navigating and using the model:

"Initially, there was an instantaneous reaction about something which was new and that we hadn't seen before. But in the fullness of time [...], that newness is off [...] Wow, that would be really powerful, [...] so imagine you looking around a design [...] and suddenly you're somehow saying this is not quite right, that needs to be resolved in a different way. [...] So that would be very powerful." (Project Lead)

This suggests through repeated experiences designers would familiarise with the technical particularities of the setting and suggests that a more routine way of performing design in the immersive environment would lead to diminished novelty. These insights also highlight the envisaged potential impact of the CAVE on design practice through to better enabling designers' noticing design surprises over technical or representational unfamiliarity, supporting discovery of new issues about the design.

4.2.2. Surprise around the design

Visibility requirements

The participants' comments indicated their perception of surprise around their design as experienced in the IVR simulation. For example, the CAVE model revealed surprise around the design conformity with the clients' requirement on visibility of patients' beds from the nurses' station area.

"[...] one of the big issues was observation of the bedrooms from the staff base and that [the CAVE] was really good validation of our design because we could see more beds than we thought we could so that was very exciting." (Medical Planner)

By enabling the participants' discovery that they *"could see more [beds]"*, this is a case of surprise not as interruption, or disconfirmation but instead as excitement through discovering

an unexpected realisation of previous design intention. The participants' view on the CAVE design experience shows that surprise occurred not only as unconfirmed expectation, but also as unexpected confirmation.

Surprise emerged through designers' exploration of their design within the CAVE also connected with their increased awareness of the actual use of their design, driving reflection on the clients' requirement and leading to reframing:

"I remember saying [to clinicians] you've given us this criteria [...] to see 60% of the rooms from one single point, and I said [...] is that really necessary, [...] do people really stand like that? And I just walked one step one way, one step the other way and I said, if I did that I can see a lot more. So is it such a concern?" (Project Lead)

The Project Lead's reflection on the surprise around the visibility requirement connects with surprise as relating to an affective state, a 'mattering', a 'caring' (e.g. Yanow and Tsoukas, 2009) focusing awareness in this case on the client's requirement and on the actual usability of the designed space.

Overall, the participants' view on the surprise experienced around visibility requirements shows that in this case surprise enabled: 1) excitement through discovery of their design's unexpected conformity with the requirement; and 2) inquiry into the requirement itself, and relatedly a 'caring', a 'mattering' about the use of their design and increased awareness of the actual usability of the space, and reconsidering the requirement together with the client.

Spatial size and relation with the equipment
The participants' view on their surprise encountered around the size and equipment in the operating theatre indicates a breakdown of realisation of design intention - although designed of sufficient size, the room in the CAVE looked overcrowded populated with equipment. For the Visualiser, the surprise emerged around the representational impact of the equipment in the operating theatre, enabling reflection on the representation and driving changes to the model: *"looking at it [the operating theatre] from that [the CAVE] perspective [...], seeing*

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the equipment and how crowded rooms were […] was a way of us saying […] it's better if we
strip some of it out so they [the client] can understand the space better."

For the Medical Planner, the surprise perceived in the unsatisfactory relation between the spatial size and equipment in the operating theatre enabled her attention on the actual use of the space, leading to questioning and reframing the client's requirement: *"[…] we were concerned that there was so much [equipment] in that space that it wasn't necessarily workable despite […] that they had asked for everything in there."*

The CAVE design experience challenged existing understandings and procedures by not confirming expectations of former design intentions and assumptions based on previous experience (the size of the operating theatre), or by revealing new issues about the design (unexpected discovery of their design conformity with the visibility requirement).

4.3. Impact of the CAVE design surprises on further developing the design project outside the CAVE

These surprises emerging in the CAVE provoked interruption of the routine performance of the process and enabled designers' reflection on the medium, on their understanding and on the ways of addressing these unsatisfactory issues perceived in the design. The designing process built up on such disruptive aspects, through participants' making sense of and addressing these surprises to accomplish their practice. The participants' discovery of unexpected issues about their design drove changes to the design and affected the process: *"to see the spaces in the CAVE […] was very useful and we certainly used that experience in our thinking later on in the process."* (Visualiser).

The designers' reflection revealed how the experience in the immersive environment affected their further process of developing the project outside the CAVE:

"We made changes (to the design) as a result of having experienced the CAVE and that's perhaps something that wouldn't have happened had we not had the benefit of being in the

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CAVE. So my corridor that was a bit too low and narrow would have stayed a little bit too low and narrow and we wouldn't have necessarily known." (Medical Planner)

The participants noted the potential of the immersive environment to enable noticing design issues which could not be previously perceived using other media and pointed the impact on the particular design development. The Visualiser noted that *"when you have a different perspective on something, you think of things in a different way.".* The participant's comment infers the distinctiveness of the CAVE design experience, which suggests that, through challenging and surprising previous understandings and assumptions, the CAVE enables new ways of seeing.

The participants' retrospective insights indicate the connection between the particularity of the CAVE- as enabling a more immersive simulation of the design, resembling visiting a real building- and the impact on the design process by enabling noticing design issues (e.g. the depth of space, the spatial experience of the too low and narrow corridor) which could not be previously noticed using other media (e.g. the underlying CAD model):

"It was very helpful to actually see things that we felt needed changing before it was actually built. And you couldn't, even with the 3D BIM model, you still can't see depth [...] the CAVE felt much more immersive" (Healthcare Lead)

These findings indicate the design surprises in the CAVE as enabling new ways of making sense of the space and seeing things in new ways, impacting on the process through informing further design decisions. Particularly, the participants pointed out the potential brought by the immersiveness of the CAVE through enabling noticing design aspects which needed to be changed during design rather than building stage.

5. Discussion

The empirical material was described in terms of the reflective practice (Schön 1983) process of reflecting before, during and after an experience. The interview-based findings (Table 1)

were drawn on the participants reflection on: their expectation from the CAVE design sessions; their experience of surprise in the CAVE; and the impact of the CAVE design experience on further developing the hospital project outside the CAVE. This section discusses the relation between the interview-based findings and the themes identified in the qualitative literature on surprise.

Reflective process

Before experience	During experience		After experience
Expectations from the CAVE design sessions	**Experienced surprises in the CAVE design sessions**		**Impact of the CAVE design surprises on further developing the design project outside the CAVE**
	Surprise around the technology	Surprise around the design	
▪ Checking conformity with design intention to avoid surprises later in the process ▪ Focus on spatiality of the layout ▪ Indicates the focus of concern of individual roles	▪ Distorted viewing perspective ▪ Model navigation procedures ▪ Envisaged familiarisation with the technology through repeated experiences	▪ Surprise as unexpected realisation of design intention (visibility requirement) ▪ Surprise as not confirmed expectation (spatial size and equipment in operating theatre) ▪ Surprise as noticing new issues about the design ▪ Surprise leading to inquiring the design requirement ▪ Surprise relating to 'caring'/ 'mattering' about the use and experience of the design	▪ Challenging previous understandings and assumptions based on other media ▪ Noticing new issues about the design ▪ Driving changes to the design ▪ Envisaged potential of the CAVE to enable surprise around the design even after familiarisation with the technology

Impact of the CAVE on design surprise

Relation of the CAVE to broader design practice based on other design media

Table 1. Summary of findings

Overall, these empirical findings on surprise support understanding the impact of IVRs (such as the CAVE) on the surprise aspects of designing and on broader design practice. The findings show that the surprise encountered by the participants in the immersive environment around both the newly experienced technology and the design played an important role in performing design review in the CAVE. The element of unexpectedness triggered not only constraints -subsequently addressed by the participants-, but it also enabled noticing new issues about the design and seeing the situation in new ways. The participants' reflection on using the CAVE on a more usual basis for design work indicated benefits but also suggested that a more routine way of performing design in IVRs may lead to diminishing novelty. These insights indicate the eventual extinction of surprise around the technology. However, whilst noting the effect of familiarisation with the technology through repeated experiences,

the findings also indicate the on-going potential of the CAVE in challenging designers'
previous understandings and assumptions about the design itself and encouraging generative
design surprises. By focussing separately on participants' views on their surprise around the
technology and around their design, the findings indicate that the element of surprise emerged
and played an important role within the both. Therefore, the study argues that even as the
immersive technology becomes familiar, surprise may still be central in orienting to the
design in the CAVE for performing work on new design projects.

These findings indicate that the surprise perceived in the CAVE simulation of the design
enabled the participants to notice unintended consequences of previous design intentions,
and, in some circumstances, it did not confirm their expectations. Unexpected issues drove
changes on the design and affected the process. Therefore, the study complements the VR
literature by suggesting that using IVRs for design work not only supports daily practices
based on less immersive media and representations, but also challenges the designers'
understandings, provoking ruptures in current procedures, which need to be addressed by the
practitioners' reflection on and reconsideration of previous understandings and assumptions
based on other media, driving changes to the design.

These findings also indicate the relevance of adopting a practice-based, situated approach to
examine the surprise phenomena by focussing on the particular participants' experience i.e.
their making sense of and addressing surprise in practice situations. By focussing on the
practicalities of using IVR in design, this paper contributes to the design and qualitative/
experiential literature on surprise by bringing empirical insights on the surprise emerging in
design work using IVRs, as detailed below.

Surprise as generative: The study reinforces the central idea of the literature on surprise as
generative phenomenon in performing social practices. IVR encouraged discovery of new
things and noticing issues not able to be perceived using other media. Using the CAVE as
design medium enabled what the literature (e.g. Schön, 1983) refers to as "seeing the things
in new ways". The findings suggest that, through enabling a more immersive simulation of
the design, the CAVE enables distinct design surprises -particularly focussed on the

experience of being in the designed spaces-, challenged assumptions and the potential of seeing things that need to be changed before the actual building is built.

Surprise in practice: shifts of awareness: The CAVE design surprises stimulated the participants' awareness around and reconsideration of taken for granted constituents of their practice. The CAVE design surprises drove inquiry into previous design procedures and understandings by, for example leading to reframing the client's requirement, which shifted from being transparently available to being apparent and under focus of scrutiny (as referred to in the literature by, for e.g., Yanow and Tsoukas, 2009).

The openness to perceive surprise in practice: The findings contribute to the literature idea on the role of practitioners' openness to perceive and respond to surprise (e.g. Nicolini, 2012; Yannow and Tsoukas, 2009; Weick, 1995) by suggesting that, although design practice is generally allowing space for surprise, the use of the IVR environment may encourage a higher *permeability to surprise*. The CAVE encouraged seeing things in new ways (*"When you have a different perspective on something, you think of things in a different way"*), it enabled noticing issues which could not be previously observed (*"my corridor would have stayed a little low and narrow and we wouldn't have necessarily known"*), and it stimulated attention to different design aspects, particularly related to the experience in the design spaces: *"It was very easy to think about the building as a final building by using the CAVE. It really felt like you were in the space… so it made it very easy to pull out observations about the space.".* By supporting a more immersive experience of the designed spaces- resembling to visiting the built version of the design (relating to awareness on distinct design aspects , particularly the spatial experience), the CAVE enabled a higher permeability to surprise, it challenged usual design procedures and understandings drawn on less immersive media, driving new ways of making sense of and changing design issues before the building stage.

Repertoires of responses to surprise: a learning process: The findings also connect with the idea around surprise as triggering learning through driving auditing of existing repertoires of responses (e.g. Christiansson et al., 2009). This process of questioning previous understandings and procedures is suggested by the empirical material through the

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participants' transition from initial intention of 'checking' if everything 'fits' with the client's requirements and previous design moves to actually questioning the fit, the issues that have to fit, the requirement itself, and their former ways of going about the designing process. Another way in which some studies (e.g. Christiansson et al., 2009) suggest that surprises/ interruptions connect with a learning process is by providing opportunities to reorganise routine of interpreting, relating and restructuring current understandings and procedures. On the particular project level, this aspect is suggested by the CAVE data through the participants' making new sense and reframing of, for example, the client's requirement around the equipment in the operating theatre or the visibility towards the patients' rooms.

To some extent, the findings show the participants' awareness of the impact of the design surprises experienced in the CAVE. This is indicated through participants' recognition of changes brought by the CAVE design experience on the design process ("*We made amendments to the design on the basis of the experience in CAVE*", and through suggested familiarisation with the technology –in terms of both using the CAVE (the '*newness*' of the CAVE will be '*off*') and developing awareness around its potential for design work ("*that would be really powerful*"). To a broader extent and relating to the literature on surprise and particularly on the relation between surprise and learning (Lanzara, 2016; Christiansson et al., 2009; Schön, 1995, 1983) these findings indicate that the impact of design surprises experienced in the CAVE may span beyond the particular design episode by informing the particular participants' further practice. In this sense, through newly shaped understandings, shifted visions/ new ways of seeing, enriched repertories, etc. which the particular practitioners might not even be aware of, the surprises experienced in the CAVE design process connect with a learning process. However, as noted by the literature (e.g. Christiansson et al., 2009), this may be less about 'lessons learned' away from action and more about skills acquired during action and the nature and impact of learning through interruptions/ surprising events may not be apparent until subsequent interruptions (id.: p. 857). As suggested by a reflective practice perspective, a potential way to support practitioners acquiring more from past experiences is by encouraging their retrospective reflection-on-action as a way to stimulate their awareness of how they made use of the CAVE as design medium and on how their ways of using it interacted with their approach to the

designing process. This aspect may be interesting to be closer addressed in further work by supporting designers' articulation of these insights in an explicit form to be purported by "reflective transfer" (Schön, 1995) to future practice situations perceived as similar.

Surprise as methodological means to research into practice: Connecting with ideas of the qualitative/ experiential research on surprise as encountered and addressed in practice situations, the study recognises the relevance of surprise as methodological means (e.g. Nicolini et al. 2003) to understand the dynamics of design practice. Methodologically, the participants' views on the design surprises encountered in the CAVE and their reflection on the ways of addressing these surprises enabled insights into underlying mechanisms of accomplishing design practice.

Surprise as response or as event/ experience: Reflecting on the interest placed in the literature on the response (e.g. Bruner, 1986) or on the experience (e.g. Ciborra, 2002) aspects of surprise, this study indicates that, whilst design surprises in the CAVE emerged partly as response to previous expectation - "violated presuppositions […] of what is taken for granted" in Bruner's (1986: p. 46) words, illustrated in the data through, for example, the Medical Planner's comments: "*You have an expectation […] but what I was looking at was completely wrong*"-, these ruptures became interestingly configured as experience of the designed spaces, shifting to challenged assumptions and reconsideration of what was taken for granted. Design surprises in the CAVE were distinctively configured as what Ciborra (2002: p. 121) refers to as "events […] representing disjunctures, where existing frames assumptions and values fall apart". The findings indicate the relation between the immersive experience resembling to being in the designed space and the CAVE participants' shift from initial intention and potential expectation of surprise around their design in terms of '*checking*' if everything '*fits*' with the client's requirements and previous design intentions to actually questioning the fit, the issues that have to fit, the requirement itself, and their previous ways of going about the designing process (e.g. questioning the client's requirement: "*How do you even work like this?*").

Surprise as individual or as collective event: Relating the empirical findings to the different focus of the literature on the individual (e.g. Schön, 1983) or the collective, organisational surprise (e.g. Weick, 1995), the findings indicate the surprise emerging in the CAVE as connecting to both particular individuals' roles in the project and focus of concern -through their attention on particular aspects around surprise and distinct strategies of addressing them- and collaboratively reflecting on individual surprises and addressing the challenges, ruptures and surprises as a group. For example, whilst for the Visualiser the surprise emerged around the representational impact of the equipment in the operating theatre, triggering reflection on the representation and driving changes to the model, for the Medical Planner the surprise perceived in the unsatisfactory relation between the spatial size and equipment in the operating theatre enabled her attention on the actual use of the space, leading to questioning the client's requirement. However, the disruption was addressed through the design teams' collaborative reflection, adjustments and repairs, driving changes to the design and further discussions with the client.

6. Conclusions

This paper has examined how IVR might impact on the surprise aspects of designing and on broader design practice. Adopting a particular strategy of accessing design practitioners' reflection on the use of technology and on their practice, this question was addressed by looking at designers' views on their design surprises experienced using a CAVE type of IVR.

The study indicates that, by supporting a more immersive simulation of the design, using CAVE as design setting encouraged distinct types of design surprise, particularly focussed on the experience of being in the designed spaces. The study showed that CAVE challenged usual design procedures and understandings drawn on other less immersive media, it enabled noticing issues not previously observed, and it drove new ways of making sense of and addressing the design, supporting changes to the design before the building stage. The study suggests that, although design practice is generally allowing space for surprise, the use of the IVRs may encourage a higher permeability to surprise.

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The study argues that CAVE may be useful for design practice by triggering surprise not just as a new technology and new way of visualising the design, but also on a more usual, daily basis, through enabling a more immersive simulation relating to distinct ways of making sense of the experience of designed spaces and connecting to challenged assumptions drawn on less immersive media and procedures. Of particular relevance to design practice, these findings highlight the role of surprise as design discovery in the CAVE, through leading to design changes/ refinement and guiding the further process.

These findings contribute to the design literature on surprise and extend current understanding around the surprise and challenge in IVR design settings by highlighting aspects around the actual impact of the situated use of IVR technology on design practice. The study also enhances current understanding around and supports integrating the practical consequences of using CAVEs in design activities by indicating that immersive technologies might be useful for design practice and practitioners through extending and challenging designers' own understandings of their previous work. Finally, the study demonstrates the relevance of mobilising the idea of reflection-on-action facilitated through the use of video as methodological means to access the participants' view on the use of the IVR and the surprise emerged through their engagement with the technology through direct experience in situ.

As in all research, there are limitations to this paper. Whilst the accounts of design surprises presented in this paper unpacked design practitioners' views on the surprise phenomena drawn on their design experience using an IVR environment to develop a real-life design project, they are limited to the perspective of four design participants working on a particular phase (design review, during bid preparation) within a particular project. It would be interesting to also examine possible design surprise which might emerge using IVR settings in other design stages such as early design as well as later, during detailed design and construction.   Further research could extend or challenge the findings of this paper by exploring possible patterns of design surprises emerging across multiple situations of using IVR for design work for other design projects, involving other design teams. Other future work could investigate the impact of design surprises emerging through the use of collaborative IVR on design stakeholders' engagement and focus on related implications

around managing design users'/ clients' expectations. Another interesting avenue for future research would be to examine possible design surprise and the related dynamics of design practice emerging through integrating IVR within design usual work and procedures.

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