

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

Article

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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)

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1 2 3 4 **Surprise: Challenging design perceptions in** 5 6 **immersive virtual reality environments? The case of** 7 8 **designing a hospital project using a CAVE (Cave** 9 10 **Automatic Virtual Environment)** 11 12 13 14 15 16

17 **Purpose** - The purpose of this paper is to examine how the use of immersive
18 virtual reality (IVR) impacts on the surprise aspects of designing.
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20 **Methodology** - The empirical case is a new hospital in the UK wherein a
21 CAVE (Cave Automatic Virtual Environment) type of IVR was used
22 performing six design review sessions during bid preparation stage. Drawing
23 from a former video-based study, we conducted follow-up discussions with the
24 participants to access their perspectives on design surprises emerging from
25 their engagement with the IVR. The study developed a reflective
26 methodology, interviewing participants about their experiences of doing
27 design in the immersive environment. Retrospective discussions were
28 conducted in a data review format, through playing back video-clips of the
29 IVR design sessions and asking the participants to reflect on their IVR design
30 experience and on design surprises emerging from their engagement with the
31 IVR.
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40 **Findings** - The findings indicate that IVRs such as the CAVE are not only
41 enhancing existing understandings of design, but also challenging the
42 participants' understanding of the design as they experience the immersive
43 version of it, provoking ruptures in current procedures and driving
44 unanticipated changes to the design.
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49 **Originality/ Value** - This qualitative study of surprise in design work using
50 IVRs (for a real-life design project) brings new insights into emerging
51 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;

Mastrollembro 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).

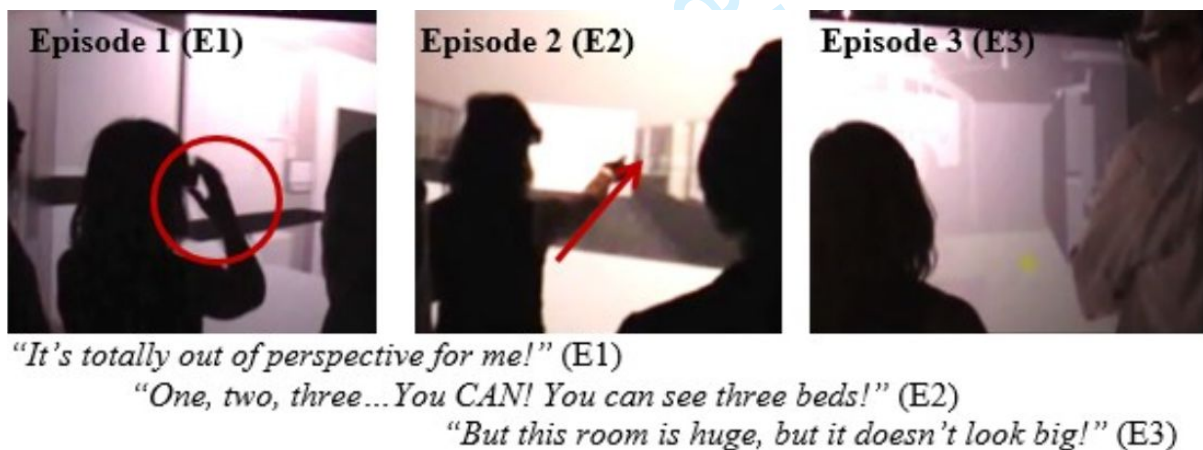


Figure 1. Video study instances of design in the CAVE suggesting the idea of surprise

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 psychophysiology 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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3 cognition, cognitive emotion and behaviour. Drawing on a broad identification of two main
4 perspectives in this literature– 1) scientific rationality/cognitive and 2) qualitative/
5 experimental–, this paper next reviews how the issue of surprise is treated.
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10 *2.1 Cognitive treatments of surprise*

11 Building on a cognitivist (information retrieving and processing) and cognitive psychology
12 orientation, the first strand of studies treats surprise as connected to a degree of expectancy
13 disconfirmation and as affective reaction to unexpectedness linked to ‘causal thinking’ and
14 indicates surprise as central to sensory processing, adaptation and learning, attention and
15 decision making (Reisenzein, 2000: p. 268). These studies aim for an abstract theorising of
16 surprise by developing and/ or testing rational models of surprise preponderantly in
17 experimental studies in controlled laboratory situations.
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26 Within design, surprise is mostly addressed from cognitive and cognitive psychology
27 perspectives and it is mainly discussed in relation to its impact on aspects of design creativity
28 and on the perception and framing of design problems, or in terms of design strategies
29 employed by designers to trigger users’ surprise around their final design products.
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35 For example, some studies on design creativity (Grace and Maher, 2015) consider surprise as
36 a metacognitive (thinking about thinking) process and focus on the impact of surprise on
37 design problems, goals, requirements formulation and relatedly on design creativity. Pointing
38 the iterative nature of the process of problem and solution formulation and indicating the
39 reasoning about the cause of surprise as relevant for changing design goals, this experimental
40 work identifies taxonomies of surprise and responses to develop cognitive and computational
41 models of surprise (programming computers to measure surprise). Other studies on improving
42 design methods, tools and approaches to foster creativity (Becattini et al., 2015) focus on the
43 cognitive processes emerging in relation to the perception of surprise around a new design
44 product by treating surprise as constituted through human interpretation rather than as effect
45 of measuring novelty. Such work raises attention to understanding users’ reactions (cognitive
46 responses) to surprising design products (Becattini et al., 2020). Other studies (Chen and Lai,
47 2014) address the impact of unexpectedness on the communication effect of design by taking
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3 an information retrieving perspective focussed on emotional aspects. The role of non-routine
4 contexts is also highlighted in relation to the impact of the design experience on creativity
5 (Rahman and Jonas, 2010). Research on the role of emotions in design (e.g. Ge et al., 2021;
6 Zhou et al., 2020) indicates the relation between designers' surprise as emotion experienced
7 while designing and the design process/ thinking through increasing design-creativity, re-
8 framing and design changes. Surprise as emotion in design is examined mostly in
9 experimental studies through physiological measures (e.g. speech acoustics, electrodermal
10 activity, automated facial emotion detection) and behavioural assessment, while rarely being
11 considered as context dependant and examined through retrospective self -reports (Ge et al.,
12 2021). Overall, most of these cognitive/ cognitive psychology studies draw on experimental
13 work to develop/ test rational models of surprise based on measuring novelty and
14 unexpectedness by using standard metrics.
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26 In a different vein, Dorst and Cross (2001) develop a cognitive model of design creativity by
27 connecting with reflective practice treatments of surprise as interruption of routine and as
28 essential for triggering reflection in action. Stressing the role of surprise in stimulating
29 framing and reframing, shaping and changing the view of the problem, these studies find that
30 creativity is linked with the designers' identification of surprise in the 'problem space' which
31 triggers their reflection, enabling the seeing of things in new ways and stimulating the
32 process. This understanding accounts for designers' views of the terms and relationships
33 underlying design activities, based on previous experience and knowledge. Similarly,
34 Rodríguez Ramirez et al.'s (2014) study of designers' strategies for developing designs
35 surprising to their users draws attention to designers' own perspectives to describe their
36 intentions while designing surprising outcomes. Their situational analysis focusses on the
37 behavioural, cognitive and emotional aspects of designers' experience informing their
38 designing with the aim of eliciting surprise. However, they do not examine how designers
39 themselves experience and address surprise occurring *during* design. On a similar note, Suwa
40 et al. (2000) point out the situated nature of designing and draw attention to the role of
41 representations (sketches in their example) to indicate surprise as unexpected discovery
42 impacting on creativity. However, Suwa et al.'s (2000) focus remains on the cognitive
43 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

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3 practitioners' reconsideration of existing assumptions built into practices (Lanzara 2009,
4 2016). Surprise is treated as a complex of "features that defy our understanding, descriptions
5 and planning abilities", addressed through a range of constructive activities globally
6 conceptualised as 'bricolage' i.e. encompassing "practical experiments, local readjustments
7 and repairs, extemporaneous improvisations" employed to respond to surprises, novelties,
8 and other puzzling phenomena interrupting/ rupturing repertoires of practice routines
9 (Lanzara, 1999: p. 334, 135).

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12 From a sensemaking perspective, surprise (particularly understood as interruption of routine
13 and/or as ambiguous event) is seen as "consequential occasion for sensemaking" (Weick,
14 1995: p. 105) and it is often discussed in relation to improvisation and making new sense to
15 restore interrupted activity (e.g. Weick, 1995; Sandberg and Tsoukas, 2015). Intersecting
16 with other areas of literature, this perspective acknowledges that interruption and recovery
17 (Weick, 2009) drive meaning of experiences and indicate the role of the repertoires of
18 previous experience.

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

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

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3 1351). Unexpectedness may trigger changes in engagement with the elements involved in a
4 practice situation, shifting from being ‘transparently available’ (Yanow and Tsoukas, 2009)
5 to being brought under focus of deliberate attention.
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10 *The openness to perceive surprise in practice:* Another key idea shared in this strand of
11 studies is around the openness to perceive surprise as an important feature in social practices.
12 For example, from a practice-based perspective to organisational management and learning,
13 (Nicolini, 2012: p. 27) indicates the ‘practical wisdom’ as “non-inferential and non-deductive
14 form of knowledge” dependent on practitioners’ flexibility and openness to surprise and
15 improvisation. From a phenomenological perspective to reflective practice, Yanow and
16 Tsoukas (2009) discuss surprise as requiring a ‘degree of permeability’ (‘mindful openness’)
17 to allow perception of an event as surprising. From a reflective practice perspective, Schön
18 (1983) treats surprise as both trigger for, but also triggered by reflection and indicates that
19 “[...] the practitioner allows himself to experience surprise, puzzlement, or confusion in a
20 situation which he finds uncertain or unique.” (Schön, 1983: p. 68).
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31 *Repertoires of responses to surprise- a learning process:* The idea around ‘response
32 repertoires’ for dealing with interruptions connects with viewing organisational learning as
33 constituted through these enhanced repertoires of responses to ruptures in routines (Yanow,
34 2015; Christianson et al., 2009). From a sense making perspective to studying organisational
35 learning, Christiansson et al. (2009) note the role of rare events- conceptualised as
36 interruptions- in triggering learning through “exposing weaknesses and revealing unrealised
37 behavioural potential” (id.: 846). From this perspective, interruptions trigger learning firstly
38 by acting as audits of existing response repertoires and, secondly, by providing opportunities
39 to reorganise routines of interpreting, relating and restructuring. Similarly, the reflective
40 practice (e.g. Schön, 1995, 1983) approach argues that social practices become enriched
41 through reflective processes mobilised to engage with and address uncertain, conflicting,
42 puzzling situations of practice. Surprise encountered in practice may therefore impact on
43 further experiences through building up and shaping existing repertoires (Schön, 1983), an
44 ‘epistemic tool’ with potential for reframing knowledge (Lanzara, 2016: p. 8).
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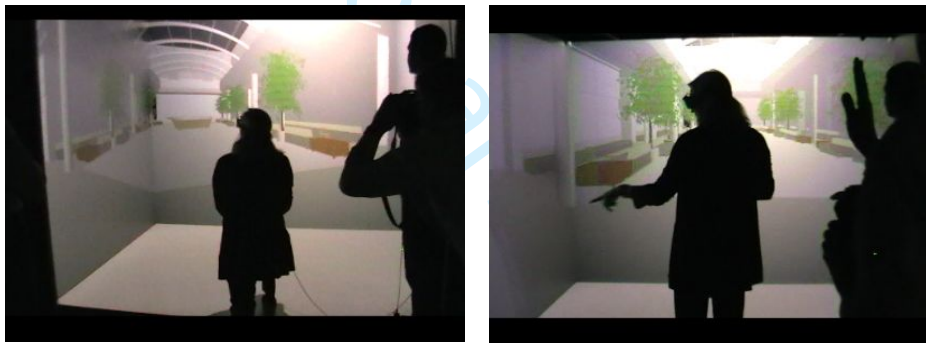
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3 *Surprise as method:* Beyond highlighting the role of surprise in performing social practices,
4 these studies also see surprise as an enhanced methodological route to inquire into the
5 dynamics and processes of configuring practice (e.g. Weick, 1992; Nicolini et al., 2003;
6 Ramiller and Wagner, 2009). Methodologically, practice is “better observed when some
7 “breakdown” occurs in an entrenched practice or when some substantial change requires
8 major realignments of the extant configuration of practice” (Nicolini et al., 2003: p. 26).
9 Hence, the importance of surprise consists in both its role as generative phenomenon essential
10 to practice and as a research means of grasping underlying mechanisms of practicing.
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19 Whilst there are differences in treatments of surprise, for instance between surprise as a
20 response (Bruner, 1986) or part of a series of events (Ciborra, 2002), or locating surprise as
21 an individual (Schön, 1983) or collective (Weick, 1995) phenomenon, there is an important
22 distinction between cognitive and qualitative approaches. The latter identify themes of
23 surprise as *generative phenomenon* in performing social practices; surprise as driving *shifts of*
24 *awareness*, the *openness/permeability to perceive surprise* in practice; the role of developing
25 repertoires of responses to surprise -relating to a *learning process*-; and the role of surprise as
26 *methodological means* to research into practice. This paper explores how these qualitative
27 accounts of surprise might be mobilised in design work using IVRs.
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37 **3. Methods**

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39 As indicated in the literature, surprise is an important aspect in design work (relating to
40 creativity, innovation, framing and re-framing etc.). This paper focusses on surprise to
41 understand the impact of IVRs on the surprise aspects of designing and on broader design
42 practice. Recognising surprise as an important aspect in design seen as a socio-material
43 process realised in situations of practice, this paper treats surprise as a situated phenomenon
44 and it examines how design practitioners make sense of and address surprise within design
45 processes performed using IVR and how this relates to broader design practice. Drawing on
46 this approach to surprise in design, this paper operationalises the research by examining a
47 situated use of IVR in design work through an empirical case of a real-life design project.
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3 The case study is based on a real-life project for designing a new hospital in the UK. One of
4 the requirements is that all patient accommodation is in single rooms, rather than traditional
5 wards. Single room only accommodation is rare in the UK, and so a key issue for the client
6 was ensuring that the rooms were of sufficient size. At the time of the research, the project
7 was still in bid preparation stage. The project team opted to augment the traditional design
8 and client engagement procedure with the use of an IVR environment - a CAVE¹ facility set
9 up in the Authors' University (Figure 2). This was to be used to demonstrate to the client that
10 the rooms were of an appropriate size and more generally to communicate the design of this
11 hospital project to the NHS client, to support reviewing key spaces in the hospital design and
12 to demonstrate how the design meets the requirements.
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34 Figure 2. Simulation of the hospital project using the CAVE at the Authors' University

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37 Building on insights of former research based on observation and video recording of six
38 design meetings performed using the CAVE, the methodology here draws on reflective
39 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).

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3 their CAVE design experience and the implications on the design process. This was aimed to
4 allow the participants' reflection on how they experienced particular episodes and describe
5 their understanding and reasoning behind the events. The method connects with Schön's (e.g.
6 1992) argument on the role of reflection-on-action outside of the situation as retrospective
7 thinking on previous actions and understandings through observing and describing. A
8 retrospective data review format was developed, both playing back video-clips from the
9 video data set and revealing the researcher's interpretation around what was happening
10 during the design sessions.
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19 The discussions were conducted nine months after the last CAVE design session and they
20 consisted of four individual interview sessions (30-60 minutes) with participants having
21 various roles in the design team: visualizer (REVIT modeller), project director, lead interior
22 designer and lead medical planner. The interviews were initiated by playing back video-clips
23 selected from the video data both to refresh the participants' memory and to enable their
24 retrospective reflection (Jewitt 2012) on the design events they had experienced in the
25 CAVE. The research followed the University's ethical procedures regarding the participants'
26 consent, confidentiality and data protection. Informed by the previous video-based study
27 (documented in Author Ref) by taking into question the findings indicated by the video
28 analysis, this paper draws on designers' retrospective reflection on both the CAVE
29 technology and on its use in design practice and it focusses on the participants' views on the
30 surprise and challenge encountered in the immersive simulation of their models and on the
31 impact of the CAVE on broader design practice. The interviews were recorded, transcribed
32 and analysed with a focus on understanding the design surprise emerging in the CAVE by
33 examining the participants' interpretation of the phenomena.
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47 The empirical material is structured along the reflective practice (Schön 1983) process of
48 reflecting before, during and after an experience. Following this structure, Section 4 describes
49 the interview data by focussing on the participants reflection on: their expectation from the
50 CAVE design sessions; their experience of surprise in the CAVE; and the impact of this
51 design experience on further developing the hospital project outside the CAVE.
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3 Subsequently, Section 5 discusses the relation between the interview-based findings and the
4 themes identified in the qualitative literature on surprise.
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9 By drawing on a situated approach to designers' experience of surprise when designing a
10 real-life design project in a particular technological setting (CAVE as a type of IVR), the
11 empirical findings indicate a close and detailed understanding of the situated use of the
12 technology by the particular group of design practitioners. Whilst the empirical findings are
13 limited to the particular situation/the case (dependant on the characteristics of the technology,
14 of the project, and the particular design participants perspectives at that moment in time),
15 insights of the study may be meaningful to better understand the use and impact of IVRs such
16 as the CAVE in other design situations.
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24 **4. Findings**

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27 This section describes the empirical material with a focus on surprise. The empirical vignettes
28 from the interview data are structured along the participants reflection on: their expectation
29 from the CAVE design sessions; their experience of surprise in the CAVE; and the impact of
30 the CAVE design experience on further developing the hospital project outside the CAVE.
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36 *4.1. Expectation from the CAVE design sessions*

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38 The participants shared a perception of surprise in relation to realisation of design intentions,
39 mostly with regard to spatiality of the layout in reference to design assumptions based on
40 previous work. The IVR was seen as a way of checking design discrepancies and avoiding
41 possible design surprises later in the process.
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47 *"[...] my main purpose of going to the CAVE [...] was to check the representations of [...]*
48 *elements within the model [...]and [...] that there weren't any major [...] discrepancies*
49 *between what we thought the spaces were going to be like and [...] what [the contractor]*
50 *thought the spaces were going to be like."* (Visualiser)
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3 “[I had] to make sure that what I needed to have inside the building [medical equipment and
4 workflows] fitted within [the] architectural envelope.” (Medical Planner)
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9 The participants’ reflection indicates that the ‘mattering’ (e.g. Yanow and Tsoukas, 2009)
10 associated with the perception of surprise connects with their roles in the project and their
11 focus of concern in using the CAVE: the body metric nature of the space (for the Project
12 Lead), the representation aspect of the design, in terms of consistency between the designers’
13 and contractors’ assumptions and intentions on the appearance of spaces (for the Visualiser),
14 or the ‘fit’ of the hospital equipment and activities workflows in the proposed architectural
15 envelope (for the Medical Planner).
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23 The following sections describe the participants’ reflection on how surprise was actually
24 experienced in the CAVE design sessions and how the CAVE design experience impacted on
25 further developing the design project.
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30 4.2. Experienced surprises in the CAVE design sessions

31 4.2.1. Surprise around the technology

32 The Medical Planner’s reflections indicate the disruption caused by the technicalities of the
33 environment: “it was exciting but it was a bit daunting” and points the source of breakdown
34 in the distorted viewing perspective, relating to the technology: “you have an expectation
35 [...] but [...] the perspective of what I was looking at was completely wrong”. At first, the
36 CAVE was perceived as unusual and surprising in reference to participants’ repertoires: “it
37 was a bit daunting because, it’s something new and you have an expectation”. This indicates
38 a tension between the expectations drawn on previous work and repertoires of usual
39 representations (like REVIT/ CAD models visualised on computer screens) - “this space that
40 I’ve designed, this was my layout” - and the CAVE version of the model as perceived from
41 the participant’s viewing perspective: “what I was looking at was completely wrong”.
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3 Alongside noting the disruption caused by an unfamiliar technology and representation, the
4 participants reflected on the use of the CAVE on a more frequent basis, suggesting
5 familiarisation with the specific procedures of navigating and using the model:
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10 *“Initially, there was an instantaneous reaction about something which was new and that we*
11 *hadn’t seen before. But in the fullness of time [...], that newness is off [...]* Wow, that would
12 *be really powerful, [...] so imagine you looking around a design [...] and suddenly you’re*
13 *somehow saying this is not quite right, that needs to be resolved in a different way. [...] So*
14 *that would be very powerful.”* (Project Lead)
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21 This suggests through repeated experiences designers would familiarise with the technical
22 particularities of the setting and suggests that a more routine way of performing design in the
23 immersive environment would lead to diminished novelty. These insights also highlight the
24 envisaged potential impact of the CAVE on design practice through to better enabling
25 designers’ noticing design surprises over technical or representational unfamiliarity,
26 supporting discovery of new issues about the design.
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33 *4.2.2. Surprise around the design*

34 *Visibility requirements*

35 The participants’ comments indicated their perception of surprise around their design as
36 experienced in the IVR simulation. For example, the CAVE model revealed surprise around
37 the design conformity with the clients’ requirement on visibility of patients’ beds from the
38 nurses’ station area.
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46 *“[...] one of the big issues was observation of the bedrooms from the staff base and that [the*
47 *CAVE] was really good validation of our design because we could see more beds than we*
48 *thought we could so that was very exciting.”* (Medical Planner)
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53 By enabling the participants’ discovery that they *“could see more [beds]”*, this is a case of
54 surprise not as interruption, or disconfirmation but instead as excitement through discovering
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3 an unexpected realisation of previous design intention. The participants' view on the CAVE
4 design experience shows that surprise occurred not only as unconfirmed expectation, but also
5 as unexpected confirmation.
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10 Surprise emerged through designers' exploration of their design within the CAVE also
11 connected with their increased awareness of the actual use of their design, driving reflection
12 on the clients' requirement and leading to reframing:
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17 *"I remember saying [to clinicians] you've given us this criteria [...] to see 60% of the rooms*
18 *from one single point, and I said [...] is that really necessary, [...] do people really stand like*
19 *that? And I just walked one step one way, one step the other way and I said, if I did that I can*
20 *see a lot more. So is it such a concern?" (Project Lead)*
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26 The Project Lead's reflection on the surprise around the visibility requirement connects with
27 surprise as relating to an affective state, a 'mattering', a 'caring' (e.g. Yanow and Tsoukas,
28 2009) focusing awareness in this case on the client's requirement and on the actual usability
29 of the designed space.
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35 Overall, the participants' view on the surprise experienced around visibility requirements
36 shows that in this case surprise enabled: 1) excitement through discovery of their design's
37 unexpected conformity with the requirement; and 2) inquiry into the requirement itself, and
38 relatedly a 'caring', a 'mattering' about the use of their design and increased awareness of the
39 actual usability of the space, and reconsidering the requirement together with the client.
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46 *Spatial size and relation with the equipment*

47 The participants' view on their surprise encountered around the size and equipment in the
48 operating theatre indicates a breakdown of realisation of design intention - although designed
49 of sufficient size, the room in the CAVE looked overcrowded populated with equipment. For
50 the Visualiser, the surprise emerged around the representational impact of the equipment in
51 the operating theatre, enabling reflection on the representation and driving changes to the
52 model: *"looking at it [the operating theatre] from that [the CAVE] perspective [...], seeing*
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3 *the equipment and how crowded rooms were [...] was a way of us saying [...] it's better if we*
4 *strip some of it out so they [the client] can understand the space better."*
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9 For the Medical Planner, the surprise perceived in the unsatisfactory relation between the
10 spatial size and equipment in the operating theatre enabled her attention on the actual use of
11 the space, leading to questioning and reframing the client's requirement: "[...] *we were*
12 *concerned that there was so much [equipment] in that space that it wasn't necessarily*
13 *workable despite [...] that they had asked for everything in there."*
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19 The CAVE design experience challenged existing understandings and procedures by not
20 confirming expectations of former design intentions and assumptions based on previous
21 experience (the size of the operating theatre), or by revealing new issues about the design
22 (unexpected discovery of their design conformity with the visibility requirement).
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28 *4.3. Impact of the CAVE design surprises on further developing the design* 29 *project outside the CAVE* 30 31

32 These surprises emerging in the CAVE provoked interruption of the routine performance of
33 the process and enabled designers' reflection on the medium, on their understanding and on
34 the ways of addressing these unsatisfactory issues perceived in the design. The designing
35 process built up on such disruptive aspects, through participants' making sense of and
36 addressing these surprises to accomplish their practice. The participants' discovery of
37 unexpected issues about their design drove changes to the design and affected the process:
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39 "to see the spaces in the CAVE [...] was very useful and we certainly used that experience in
40 our thinking later on in the process." (Visualiser).
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48 The designers' reflection revealed how the experience in the immersive environment affected
49 their further process of developing the project outside the CAVE:
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53 *"We made changes (to the design) as a result of having experienced the CAVE and that's*
54 *perhaps something that wouldn't have happened had we not had the benefit of being in the*
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3 CAVE. So my corridor that was a bit too low and narrow would have stayed a little bit too
4 low and narrow and we wouldn't have necessarily known." (Medical Planner)
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9 The participants noted the potential of the immersive environment to enable noticing design
10 issues which could not be previously perceived using other media and pointed the impact on
11 the particular design development. The Visualiser noted that "*when you have a different*
12 *perspective on something, you think of things in a different way.*". The participant's comment
13 infers the distinctiveness of the CAVE design experience, which suggests that, through
14 challenging and surprising previous understandings and assumptions, the CAVE enables new
15 ways of seeing.
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23 The participants' retrospective insights indicate the connection between the particularity of
24 the CAVE- as enabling a more immersive simulation of the design, resembling visiting a real
25 building- and the impact on the design process by enabling noticing design issues (e.g. the
26 depth of space, the spatial experience of the too low and narrow corridor) which could not be
27 previously noticed using other media (e.g. the underlying CAD model):
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33 "*It was very helpful to actually see things that we felt needed changing before it was actually*
34 *built. And you couldn't, even with the 3D BIM model, you still can't see depth [...] the CAVE*
35 *felt much more immersive*" (Healthcare Lead)
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41 These findings indicate the design surprises in the CAVE as enabling new ways of making
42 sense of the space and seeing things in new ways, impacting on the process through
43 informing further design decisions. Particularly, the participants pointed out the potential
44 brought by the immersiveness of the CAVE through enabling noticing design aspects which
45 needed to be changed during design rather than building stage.
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50 51 **5. Discussion** 52

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54 The empirical material was described in terms of the reflective practice (Schön 1983) process
55 of reflecting before, during and after an experience. The interview-based findings (Table 1)
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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	
<ul style="list-style-type: none"> ▪ 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 	<ul style="list-style-type: none"> ▪ Distorted viewing perspective ▪ Model navigation procedures ▪ Envisaged familiarisation with the technology through repeated experiences 	<ul style="list-style-type: none"> ▪ 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 	<ul style="list-style-type: none"> ▪ 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,

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3 the findings also indicate the on-going potential of the CAVE in challenging designers'
4 previous understandings and assumptions about the design itself and encouraging generative
5 design surprises. By focussing separately on participants' views on their surprise around the
6 technology and around their design, the findings indicate that the element of surprise emerged
7 and played an important role within the both. Therefore, the study argues that even as the
8 immersive technology becomes familiar, surprise may still be central in orienting to the
9 design in the CAVE for performing work on new design projects.
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17 These findings indicate that the surprise perceived in the CAVE simulation of the design
18 enabled the participants to notice unintended consequences of previous design intentions,
19 and, in some circumstances, it did not confirm their expectations. Unexpected issues drove
20 changes on the design and affected the process. Therefore, the study complements the VR
21 literature by suggesting that using IVRs for design work not only supports daily practices
22 based on less immersive media and representations, but also challenges the designers'
23 understandings, provoking ruptures in current procedures, which need to be addressed by the
24 practitioners' reflection on and reconsideration of previous understandings and assumptions
25 based on other media, driving changes to the design.
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35 These findings also indicate the relevance of adopting a practice-based, situated approach to
36 examine the surprise phenomena by focussing on the particular participants' experience i.e.
37 their making sense of and addressing surprise in practice situations. By focussing on the
38 practicalities of using IVR in design, this paper contributes to the design and qualitative/
39 experiential literature on surprise by bringing empirical insights on the surprise emerging in
40 design work using IVRs, as detailed below.
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47 *Surprise as generative:* The study reinforces the central idea of the literature on surprise as
48 generative phenomenon in performing social practices. IVR encouraged discovery of new
49 things and noticing issues not able to be perceived using other media. Using the CAVE as
50 design medium enabled what the literature (e.g. Schön, 1983) refers to as "seeing the things
51 in new ways". The findings suggest that, through enabling a more immersive simulation of
52 the design, the CAVE enables distinct design surprises -particularly focussed on the
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3 experience of being in the designed spaces-, challenged assumptions and the potential of
4 seeing things that need to be changed before the actual building is built.
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9 *Surprise in practice: shifts of awareness:* The CAVE design surprises stimulated the
10 participants' awareness around and reconsideration of taken for granted constituents of their
11 practice. The CAVE design surprises drove inquiry into previous design procedures and
12 understandings by, for example leading to reframing the client's requirement, which shifted
13 from being transparently available to being apparent and under focus of scrutiny (as referred
14 to in the literature by, for e.g., Yanow and Tsoukas, 2009).
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22 *The openness to perceive surprise in practice:* The findings contribute to the literature idea
23 on the role of practitioners' openness to perceive and respond to surprise (e.g. Nicolini, 2012;
24 Yannow and Tsoukas, 2009; Weick, 1995) by suggesting that, although design practice is
25 generally allowing space for surprise, the use of the IVR environment may encourage a
26 higher *permeability to surprise*. The CAVE encouraged seeing things in new ways ("*When*
27 *you have a different perspective on something, you think of things in a different way*"), it
28 enabled noticing issues which could not be previously observed ("*my corridor would have*
29 *stayed a little low and narrow and we wouldn't have necessarily known*"), and it stimulated
30 attention to different design aspects, particularly related to the experience in the design
31 spaces: "*It was very easy to think about the building as a final building by using the CAVE. It*
32 *really felt like you were in the space... so it made it very easy to pull out observations about*
33 *the space.*". By supporting a more immersive experience of the designed spaces- resembling
34 to visiting the built version of the design (relating to awareness on distinct design aspects ,
35 particularly the spatial experience), the CAVE enabled a higher permeability to surprise, it
36 challenged usual design procedures and understandings drawn on less immersive media,
37 driving new ways of making sense of and changing design issues before the building stage.
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51 *Repertoires of responses to surprise: a learning process:* The findings also connect with the
52 idea around surprise as triggering learning through driving auditing of existing repertoires of
53 responses (e.g. Christiansson et al., 2009). This process of questioning previous
54 understandings and procedures is suggested by the empirical material through the
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3 participants' transition from initial intention of 'checking' if everything 'fits' with the client's
4 requirements and previous design moves to actually questioning the fit, the issues that have to
5 fit, the requirement itself, and their former ways of going about the designing process.
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8 Another way in which some studies (e.g. Christiansson et al., 2009) suggest that surprises/
9 interruptions connect with a learning process is by providing opportunities to reorganise
10 routine of interpreting, relating and restructuring current understandings and procedures. On
11 the particular project level, this aspect is suggested by the CAVE data through the
12 participants' making new sense and reframing of, for example, the client's requirement
13 around the equipment in the operating theatre or the visibility towards the patients' rooms.
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21 To some extent, the findings show the participants' awareness of the impact of the design
22 surprises experienced in the CAVE. This is indicated through participants' recognition of
23 changes brought by the CAVE design experience on the design process ("*We made*
24 *amendments to the design on the basis of the experience in CAVE*"), and through suggested
25 familiarisation with the technology –in terms of both using the CAVE (the '*newness*' of the
26 CAVE will be '*off*') and developing awareness around its potential for design work ("*that*
27 *would be really powerful*"). To a broader extent and relating to the literature on surprise and
28 particularly on the relation between surprise and learning (Lanzara, 2016; Christiansson et al.,
29 2009; Schön, 1995, 1983) these findings indicate that the impact of design surprises
30 experienced in the CAVE may span beyond the particular design episode by informing the
31 particular participants' further practice. In this sense, through newly shaped understandings,
32 shifted visions/ new ways of seeing, enriched repertoires, etc. which the particular
33 practitioners might not even be aware of, the surprises experienced in the CAVE design
34 process connect with a learning process. However, as noted by the literature (e.g.
35 Christiansson et al., 2009), this may be less about 'lessons learned' away from action and
36 more about skills acquired during action and the nature and impact of learning through
37 interruptions/ surprising events may not be apparent until subsequent interruptions (id.: p.
38 857). As suggested by a reflective practice perspective, a potential way to support
39 practitioners acquiring more from past experiences is by encouraging their retrospective
40 reflection-on-action as a way to stimulate their awareness of how they made use of the CAVE
41 as design medium and on how their ways of using it interacted with their approach to the
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3 designing process. This aspect may be interesting to be closer addressed in further work by
4 supporting designers' articulation of these insights in an explicit form to be purported by
5 "reflective transfer" (Schön, 1995) to future practice situations perceived as similar.
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10 *Surprise as methodological means to research into practice:* Connecting with ideas of the
11 qualitative/ experiential research on surprise as encountered and addressed in practice
12 situations, the study recognises the relevance of surprise as methodological means (e.g.
13 Nicolini et al. 2003) to understand the dynamics of design practice. Methodologically, the
14 participants' views on the design surprises encountered in the CAVE and their reflection on
15 the ways of addressing these surprises enabled insights into underlying mechanisms of
16 accomplishing design practice.
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24 *Surprise as response or as event/ experience:* Reflecting on the interest placed in the
25 literature on the response (e.g. Bruner, 1986) or on the experience (e.g. Ciborra, 2002)
26 aspects of surprise, this study indicates that, whilst design surprises in the CAVE emerged
27 partly as response to previous expectation - "violated presuppositions [...] of what is taken
28 for granted" in Bruner's (1986: p. 46) words, illustrated in the data through, for example, the
29 Medical Planner's comments: "*You have an expectation [...] but what I was looking at was*
30 *completely wrong*"-, these ruptures became interestingly configured as experience of the
31 designed spaces, shifting to challenged assumptions and reconsideration of what was taken
32 for granted. Design surprises in the CAVE were distinctively configured as what Ciborra
33 (2002: p. 121) refers to as "events [...] representing disjunctures, where existing frames
34 assumptions and values fall apart". The findings indicate the relation between the immersive
35 experience resembling to being in the designed space and the CAVE participants' shift from
36 initial intention and potential expectation of surprise around their design in terms of
37 'checking' if everything 'fits' with the client's requirements and previous design intentions to
38 actually questioning the fit, the issues that have to fit, the requirement itself, and their
39 previous ways of going about the designing process (e.g. questioning the client's
40 requirement: "*How do you even work like this?*").
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3 *Surprise as individual or as collective event:* Relating the empirical findings to the different
4 focus of the literature on the individual (e.g. Schön, 1983) or the collective, organisational
5 surprise (e.g. Weick, 1995), the findings indicate the surprise emerging in the CAVE as
6 connecting to both particular individuals' roles in the project and focus of concern -through
7 their attention on particular aspects around surprise and distinct strategies of addressing them-
8 and collaboratively reflecting on individual surprises and addressing the challenges, ruptures
9 and surprises as a group. For example, whilst for the Visualiser the surprise emerged around
10 the representational impact of the equipment in the operating theatre, triggering reflection on
11 the representation and driving changes to the model, for the Medical Planner the surprise
12 perceived in the unsatisfactory relation between the spatial size and equipment in the
13 operating theatre enabled her attention on the actual use of the space, leading to questioning
14 the client's requirement. However, the disruption was addressed through the design teams'
15 collaborative reflection, adjustments and repairs, driving changes to the design and further
16 discussions with the client.
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27 **6. Conclusions**

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30 This paper has examined how IVR might impact on the surprise aspects of designing and on
31 broader design practice. Adopting a particular strategy of accessing design practitioners'
32 reflection on the use of technology and on their practice, this question was addressed by
33 looking at designers' views on their design surprises experienced using a CAVE type of IVR.
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40 The study indicates that, by supporting a more immersive simulation of the design, using
41 CAVE as design setting encouraged distinct types of design surprise, particularly focussed on
42 the experience of being in the designed spaces. The study showed that CAVE challenged
43 usual design procedures and understandings drawn on other less immersive media, it enabled
44 noticing issues not previously observed, and it drove new ways of making sense of and
45 addressing the design, supporting changes to the design before the building stage. The study
46 suggests that, although design practice is generally allowing space for surprise, the use of the
47 IVRs may encourage a higher permeability to surprise.
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3 The study argues that CAVE may be useful for design practice by triggering surprise not just
4 as a new technology and new way of visualising the design, but also on a more usual, daily
5 basis, through enabling a more immersive simulation relating to distinct ways of making
6 sense of the experience of designed spaces and connecting to challenged assumptions drawn
7 on less immersive media and procedures. Of particular relevance to design practice, these
8 findings highlight the role of surprise as design discovery in the CAVE, through leading to
9 design changes/ refinement and guiding the further process.
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17 These findings contribute to the design literature on surprise and extend current
18 understanding around the surprise and challenge in IVR design settings by highlighting
19 aspects around the actual impact of the situated use of IVR technology on design practice.
20 The study also enhances current understanding around and supports integrating the practical
21 consequences of using CAVEs in design activities by indicating that immersive technologies
22 might be useful for design practice and practitioners through extending and challenging
23 designers' own understandings of their previous work. Finally, the study demonstrates the
24 relevance of mobilising the idea of reflection-on-action facilitated through the use of video as
25 methodological means to access the participants' view on the use of the IVR and the surprise
26 emerged through their engagement with the technology through direct experience in situ.
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37 As in all research, there are limitations to this paper. Whilst the accounts of design surprises
38 presented in this paper unpacked design practitioners' views on the surprise phenomena
39 drawn on their design experience using an IVR environment to develop a real-life design
40 project, they are limited to the perspective of four design participants working on a particular
41 phase (design review, during bid preparation) within a particular project. It would be
42 interesting to also examine possible design surprise which might emerge using IVR settings
43 in other design stages such as early design as well as later, during detailed design and
44 construction. Further research could extend or challenge the findings of this paper by
45 exploring possible patterns of design surprises emerging across multiple situations of using
46 IVR for design work for other design projects, involving other design teams. Other future
47 work could investigate the impact of design surprises emerging through the use of
48 collaborative IVR on design stakeholders' engagement and focus on related implications
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3 around managing design users' / clients' expectations. Another interesting avenue for future
4 research would be to examine possible design surprise and the related dynamics of design
5 practice emerging through integrating IVR within design usual work and procedures.
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