Kintsugi VR: Designing with Fractured Objects

Asreen Rostami
asreen.rostami@ri.se
RISE Research Institutes of Sweden
Sweden
Department of Computer and
Systems Sciences
Stockholm University
Sweden

Kasper Karlgren
kasper@dsv.su.se
Department of Computer and
Systems Sciences
Stockholm University
Sweden

Donald McMillan
donald.mcmillan@dsv.su.se
Department of Computer and
Systems Sciences
Stockholm University
Sweden

Figure 1: Two participants taking part in each run of the sketched performance, interacting with different types of Fractured Objects as part of the performance. Photos courtesy of Noah Hellwig & Asreen Rostami.

ABSTRACT

This paper presents Fractured Objects for the design of virtual and mixed-reality experiences. Drawing on the qualitative analysis of three weeks of artistic activities within a residency program, we present six types of Fractured Objects that were used in sketching a mixed-reality performance. Building on these Fractured Objects, as they were articulated by the artists, we present speculative designs for their use in scenarios inspired by research within the IMX community. In discussion, we look to expand the concept of Fractured Objects by relating it to other design concepts such as Seamful Design and Wabi-Sabi, and explore the relationship to the temporality of interaction. We introduce Kintsugi VR with Fractured Objects, drawing on the concept of 'golden repair' in which the act of reconnecting fractured parts improves the resulting whole object.

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CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; **Mixed / augmented reality**; **Virtual reality**; • **Applied computing** → *Performing arts.*

KEYWORDS

Fractured objects, Kintsugi VR, Mixed-reality experience, Virtual reality, Artistic interaction

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1 INTRODUCTION

Progressively more media, games, and social experiences are being consumed through virtual and mixed-reality environments [15, 39, 52, 56]. The development of the tropes and tools for imparting information, constructing narratives, and eliciting emotion are still in flux. In this paper we draw on the understanding of the use of objects which appear – in some form – in both the virtual and physical representations of the experience developed by a professional artistic mixed-reality production team. Mixed-reality performances continuously represent some of the most novel design advances in the use of technology for immersive experiences. During design, development, and production of a novel interactive experience observed over the course of a three weeks artistic residency the artistic team defined a taxonomy of interactive object behaviours which both enabled and inspired the artistic process. This team brought together experimental interactive artists, developers, and included one of the authors of this paper in their role as an HCI researcher.

We contribute by analysing the process of artistic design, and presenting the ways in which ***Fractured Objects*** – objects used in the performance which deviate from the norm of 'digital twins' [21, 62] – are bound together. We define fractured objects as those that present the user with a shared experience between the physical and virtual environments, yet have differences in how they are interacted with or experienced in each. In effect, their nature is *fractured* between separate – yet connected – physical and virtual representations. These fractures are able to aid the participants ongoing understanding and immersion in the experience through the use of *narrative*, and *actuation*.

Using a performance-led research in the wild approach [5] as a subset of Research through Design (RtD), and drawing on the analysis of observations, field notes, and more than 26 hours of audio and video recordings of the design processes, we explore the way in which the artistic team designed and used six different types of *fractured objects* in the design of immersive, expressive interactions in VR. We use the term mixed-reality as an umbrella term to describe the performance that offers different perceptions of reality by making use of both virtual and physical environments within the virtual reality continuum [40].

Looking beyond mixed-reality performances, we continue our contribution by extrapolating design scenarios for virtual and augmented reality interaction in non-fiction virtual reality experiences, mixed media interactive narratives, and for educational purposes based upon these opportunities for binding fractured objects. In doing so, we discuss how fractured objects can be used by designers, artists and mixed-reality (MR) producers to move beyond designing digital replica's of the reality to a more opportunistic design approach that can benefit from fractured and misaligned [36] world in the design of immersive and meaningful MR experiences. Following on from this and by drawing on the Japanese traditional art of repairing broken pottery with golden adhesive, we introduce *Kintsugi VR* in which the fractured objects (and experiences) can be glued together with adhesives such as narratives and actuation that enhance the object. By including these fractured objects in the design, we expand on previous call on designing with 'aesthetics of fragmentation' in mind [32] as an approach for designing a mixed-reality experience that tries to connect imperfect and fractured pieces together to create novel and creative experience.

2 BACKGROUND

In this paper we draw on two strands of related work: the research within the field of HCI and IMX on designing artistic productions with VR, and the work on Immersive VR experiences.

2.1 VR & Artistic productions

One major focus area in studies of mixed-reality performances within HCI is how performing artists draw on their performing skills to appropriate the VR technology, and merge different elements of the physical and virtual worlds [48]. For instance, Rostami et al. [47] illustrates how in a VR-based performance, different group of artists and their professional skills and expertise are required to not only design the performative aspect of a performance, but also to deal with troubles of the technology, troubleshoot the technology failures during the live setting, and make the technology work during their performance.

While these studies present different layers and forms of realities within the performance and with respect to 360°videos, advances in VR technologies, enabled new opportunities of enhancing multiple realities within performances (e.g. *When We Meet Again* [16]). These technological advances provide not only new opportunities of expression for the artists [57], but introduced new opportunities of experiences for the audience members within the immersive experience [48]. In a recent work and with a more focus on designing an artistic immersive productions Striner et al. [52] describe how multi-sensory VR technology can be envisaged in designing new forms of immersive opera, and how it can provide an opportunity for the audience and performers to represent their bodies in ways that otherwise is not possible in the real world. These novel explorations also included different strands of research focused on, for example, how VR can influence the role of audience from viewer to active participant [30], and challenges and opportunities of incorporating VR with stage performances [29].

Moving beyond artistic experiences with VR to the home media experiences, Geerts et al. [18] and Vatavu et al. [56] present potential scenarios of immersive Augmented Reality (AR) for TV viewers, such as when a physical TV can be removed from a living room as the augmented storyteller can appear in the viewers' living room without the need of any TV frame. In another example, Vosmeer & Schouten [57] and Speicher et al. [51] discuss how audio and visual cues can be used to manage the attention of participants in a VR experience, to keep them engaged and connected to the VR experience.

2.2 VR & Immersive Experiences

One of the most intriguing issues in using VR, from both artistic and research perspective, is how the sense of immersion and presence in VR is reinforced within the experience [36, 54, 57]. With respects to VR, immersion has been explored — mostly— through presence [50, 61]. This sense of presence, sometimes in the form of a shift in point of view, has been explored in both artistic [16, 57] and research studies. For instance, in *CHILDHOOD* Nishida et al. [43] provide an immersive experience from a child's point of view. In a notable exploration of immersion and sense of presence in VR, Cheng et al. [12] present TurkDeck, an immersive system which produces a haptic sensation in response to the user's act of touching an object in VR. This sensation connects the experience in VR to its physical representation (and vice versa) with the help of "human actuators". In another work, Ranasinghe et al. [45] have explored participants' engagement and sense of presence in the multi-sensory experience of a VR narration. Their study highlights how the use of thermal and wind stimuli can increase participant's engagement with the narrative compared to, for example, using only audio or visual sensation, potentially due to the novelty of the experience of these stimuli in interactive settings. With the same focus, Harley et al.[25]

have looked into mixed-reality experiences with VR, and how non-digital and sensory interactions (e.g. touch and smell) can create more opportunities for designers of such experiences. Although not in the form of performance, they suggest a number of narrative scenarios in which immersion does not simply emerge from the VR technology. Rather, it emerges from carefully curated play-driven interactions with the sensory environment. They argue that we can increase immersion throughout the whole experience by bringing back low-cost, real-world aspects and embodied qualities of an experience (e.g. feeling the wind on the skin) to a simulated VR experience.

3 METHOD

The design process described in this paper was part of the collaboration between the first author and a Swedish artist, Noah Hellwig to explore Rostami's concept of *friction* [46–48] with the goal of designing an embodied mixed-reality performance. Hellwig led the artistic exploration, design and choreography of the work and Rostami led and carried out the research aspects of the project.

The results presented in this paper are drawn from performance-led research in the wild [5] expanded with the self-situated performance research approach [53]. Performance-led research emphasises practice being led by artists and followed by the HCI researcher, whereas self-situated performance research accounts for the researcher's influence and knowledge of the design and performance. During the residency program, Rostami situated herself in the residency as a researcher in order to work closely with a group of performers and artists. The research contribution to the project included introducing the concept of friction [48] as a design resource, as well as establishing dialogue within the creative process of designing artworks while being "at the heart of design" [53]. This also included being part of the orchestrating team on stage and behind the scenes when required.

3.1 Data

The subjects of the data collection were, primarily, the 5 members of the project team over the course of the three week residency. This consisted of the first author of this paper who is an HCI researcher and four artists, including a professional theatre performer and curator, two professional choreographers and performers, and a game and VR designer. This range of expertise and backgrounds allowed for a combination of methods and techniques including brain and body storming [35], virtual reality design, performance design, improvisational theatre, game design, prototyping and sketching. The data also included recordings and observations of the participants taking part in the experience across 8 experimental runs. During the design process 13 participants (8 women and 5 men) experienced different iterations of the design. Three participants took part in the early version of the performance where the work was designed for a single participant experience (Figure 9), and ten participants took part in the final sketches of the performance that was designed for two-person experience (Figure 8).

Our data includes onsite observations, field notes taken throughout the design and development process, 993 minutes audio recordings of the team's everyday discussions, as well as briefing and debriefing sessions. 650 minutes of multi-angled video was also recorded of everyday design activities, and all the steps of sketching and staging the performances with both participants and audience members. For this study, these multiple sources of data provided the researcher "a way of triangulation and checking for different recall of events" [19] to articulate and reflect on the design process.

3.2 Qualitative Analysis

The subject of the analysis for this work is the *process of design* that led to the sketched performance, and as such each of the experimental runs was an iteration along the course of developing the interactions detailed below. We used on site observations and notes of participation to identify specific examples and incidents of interaction as a starting point. We then looked at the video material of these incidents, building an understanding of the situation. Through repeated analysis of the recordings informed by the first-person experience of the first author we focused on understanding examples and incidents of interaction as a starting point

In this way we extracted a corpus of 27 videos and 60 minutes of audio, distributed across the different stages of design. In focused analysis sessions, we paid a careful attention to the video material and watched all the video clips of the design process, to gain an overview. Each of these video clips were selected for illustrating how different object were described and used by the artists in both virtual and physical worlds, different strategies and methods that were used by the artists to create a meaning for each objects and the performance as a whole, or other behaviours that we felt were interesting. These were analysed in more focused data analysis sessions, and video clips were coded initially for the use of, for instance, virtual, physical, narrative, and coordination objects. Additionally we coded these clips based on the type of interaction that was required by the participant throughout the experience (e.g. embodied, physical or virtual), and different ways were these interactions were enabled by the artists and through the design (e.g. narratives, actuators). In-line with much HCI research we used coding as a process, rather than the product [37] – to help clarify and highlight opportunities for design. Through repeated analysis of the recordings informed by the first-person experience of the first author we focused on understanding how artists adapted the technology to design interaction within their sketches of the performance, how they related to the experience of immersion and presence, and how participants perceived different sketches of the performance and its interactions. This helped us to analyse the design process in more depth, resulting in the themes and the descriptions of the Fractured Objects.

4 THE PERFORMANCE

The outcome of the residency was an experimental performance designed by Noah Hellwig, a Swedish artists and performer based in Stockholm, Sweden. During the performance, two participants can take part by wearing HTC-Vive[1] HMDs and interacting with objects in both the physical and virtual spaces, using HTC-Vive trackers and controllers (Figure 1). The performance is led by a team of three to four including: one or two stage performers, a live narrator and a system controller[2].

[1]https://www.vive.com/

[2]More information about the commercial and final version of the performance is available on the artist's website: https://www.noahhellwig.com/#/frictional-realities/

Table 1: Summary of the six different types of fractured objects and examples

Name	Description	Example
Recreated	A physical object recreated in VR	A physical book mapped (size and location) to a similar book in VR (Figure 2)
Mismatched	A physical object mapped to a completely different object in VR	A vase mapped to a virtual snake in VR (Figure 3)
Phantom-VR	A phantom object in VR	A physical figurine without an equivalent in VR, as is the central monkey in the set seen in (Figure 4).
Untouchable	A phantom object in the physical world	A virtual cat without an equivalent in the physical world (Figure 5).
Visually Adapted	A modified physical object in VR	A wooden figurine mapped to a larger, offset figurine in VR (Figure 6).
Physically Modified	A VR object modified in the physical world	A glove in VR mapped to a physical glove with balloons attached to it which are not included in the VR representation (Figure 7).

Upon arrival on the performance stage, both participants are asked to wear HMDs, close their eyes and lay down on the floor. Each participant is placed on their own side of the stage, and they hear the voice of the narrator in the physical room. Participants are invisible to each other in VR, unless they cross over the virtual wall between them, and physically move into the other's space. They are invited to interact with different elements of the performance (e.g. physical and virtual objects and the environment), with each other, and the stage performer. During the performance, the narrator delivers exposition, comments on participants' actions by recounting (and sometimes judging) their movements or mistakes, and relates those actions to the story of the performance. The performance ends when all the narrator's tasks have been performed by the participants.

The VR part of the experience was built in Unity using the SteamVR plugin, and 3D objects were designed in Maya, and wired HTC Vive devices together with four controllers were used to interact with objects. In terms of space, the production team had access to a 20*20 meter rehearsal space however, however due to limitations of HTC Vive tracking system, the actual performance area was 4.5*4.5 meter. The underlying artistic concern behind the performance was to play with participants perception of reality and sense of presence within the experience of an immersive VR performance.

The project was supported by the Swedish National Touring Theatre (*Riksteatern*) in Stokholm, Sweden. The grant covered the salary of four artists (excluding the HCI researcher), and gave access to a rehearsal and performance venue for three weeks, in the form of a residency program.

5 RESULTS

This section presents the themes from the analysis of the design and experience of the interactions throughout different iterations of the performance presented above. Throughout the analysis we demonstrate how the production team made use of VR technology to create a mixed-reality experience. In doing so, we describe how *fractured objects* were designed in the VR space to connect the physical and virtual worlds together, followed by describing how these fractured objects were 'glued' together with the help of *narrative* and *actuation* to enhance the sense of presence and to create a meaningful experience.

In visually presenting these concepts and to better communicate the difference in physical and VR presentation of these objects we use the following conventions: The physical world is represented in black and white and hand sketched. The virtual environment is represented in colour with photo-realistic objects[3]. Objects in both worlds are shown with the coloured photo-realistic representation overlaid with a sketched outline.

5.1 Fractured Objects

Aiming to merge the physical and virtual environments, artists first proceeded with creating a digital replica of physical objects in a virtual environment. In doing so, they created a digital replica for several objects available to them on stage, such as books, figurines, chairs and tables. These digital replicas not only resembled the physical object in terms of shape and size, but were also mapped to the same physical location using VR trackers. While these did not go as far as the complex modelling of Digital Twins used in a more complex product or scientific work [21], the simple model used here of matching location and orientation met the needs of the artists. Some objects were dynamic, tracking the location and orientation, and others which were not expected to be movable by the participants were manually sized and situated.

In one static example, artists **Recreated** a physical table in VR, where its size and location was mapped to a similar table in VR. With this approach, a participant could physically interact with an object, while observing the result of this interaction in the virtual environment. Such a design provided the artists an opportunity to create an 'aligned' and 'synced' interaction between the physical and virtual world, connecting the physical presence of the objects and ultimately their participants to the virtual one [36, 48].

While these experiments helped the artists to familiarise themselves with the technology and move forwards, the digital objects were not a perfect replica of their real version. In fact these objects were *fractured*, with the VR and the physical object diverging across a number of fault lines; for instance the texture and the material of the recreated physical object was not well represented in the virtual environment resulting in breaking the sense of reality of the VR object for participants. In the following example, a participant explains what was "off" in the experience of standing on a physical chair mapped to a virtual chair, in relation to his visual-kinaesthetic experience of exploring the fractured VR object:

> *"If I want to be picky, the chair [that I touched] wasn't aligned with what I saw [in VR]... standing on the edge [of the chair] the edge was a bit off... it was still cool."* (**P3**)

Soon after the first sketch, artists started to explore different VR experiments in an attempt to manipulate the sense of reality beyond simulation. This was done through several iterations of designs that,

[3]It should be noted that the VR environments we envisage using do not require photo-realism, this is simply to provide contrast in the figures here.

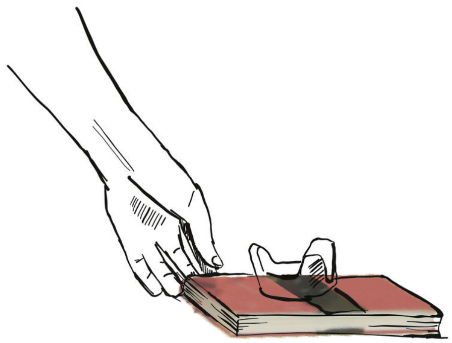

Figure 2: Recreated object – the book is recreated in VR, a tracker is used to map the physical book the virtual one.

Figure 3: Mismatched object – the vase is mapped to a snake in VR.

instead of attempting to hide or correct the fractures, used and even widened the gaps between the virtual and physical objects – all the while maintaining a meaningful and understandable connection between them for the participants. The *fractured objects* we describe here are those in which the fracture between the representations are either intentionally created for or, where they are inherent in the technological representation, deliberately employed in interaction.

This exploration resulted in the artists articulating a taxonomy of six types of object mapping between the virtual and physical, providing them with opportunities to create fractured tangible and sensory interactions (see Table 1).

These six types of fractured objects and fractured interactions associated with them emerged from artists' exploration of VR technology and through familiarising themselves with the potentials of VR. These objects were articulated in design sketches and acted out and explained to the group. For example, a sense of loss and surprise is projected to be engineered when a series of recreated objects were interacted with, but one of supposed meaning (a photograph of a deceased relative) was presented as an **Untouchable** object which upon reaching for it was intangible yet visible to the participant in VR. Similarly, a **Phantom-VR** object was described as touching and feeling a physical figurine while wearing a HMD, but missing the representation or equivalent of that figurine in VR.

In another example, **Mismatched** objects were described as physical objects with completely different representation in VR or vice versa; for example, holding and interacting with a physical book that is represented as a flowerpot in VR. Additionally, a **Visually Adapted** was described by the artists as an object that exists in both virtual and physical worlds, but the virtual version of the object is enhanced in some way:

> *For example you are handed this [physical] cylinder, the cylinder exist in VR but it also has something on top of it in [VR] like balloons, so it's more than just a cylinder, but the cylinder is there [on the table].* (**GW, Theatre performer and curator**)

In contrast the **Physically Modified** object was described as a VR object that exist in the real world but with some significant differences:

> *For example a bunny exists in VR, it is alive in real world and has a physical string attached to it [that is not visible in VR]. (**GW, Theatre performer and curator**)*

These sketches were – at this point – isolated examples which were not contextualised in any story-line, yet a number of them relied upon narrative to maintain immersion (to some extent) and convey meaning and purpose in the fracturing of the objects being interacted with. The artists saw that there was a deeper opportunity to build narratives not just around the objects' fractures, but to build them into the narrative exposition itself for greater experiential potency.

5.2 Narrative Glue

In an effort to bring more meaning to the interaction with these objects, the artists moved from designing from the perspective of the technology to focusing on employing their skills in acting and story telling to create meaning in a technology-driven design [27, 41]. One of the artists led the process by asking each member to build a sketched performance with a narrative incorporating a combination of these six types of objects and interactions with them. In these sketches the narratives were used as 'glue' to connect

Figure 4: Phantom-VR object – the middle figurine is not seen in VR

Figure 5: Untouchable object – the cat is only in VR

different pieces of these fractured experiences together and to create a meaning for the interaction with these objects.

In one example, the story required a co-present experience of two participants wearing HMDs and playing role of two fictional characters called *Alpha* and *Beta*. Following the narrator's voice (played by a performer) these two characters could interact with each other – to some extent – in the physical and virtual environment. In one scene the narrator asks the characters to perform some tasks, making them to interact with fractured objects:

> *... Alpha and Beta stood up and walked over to the table ... They stood there for a while, letting their curiosity grow until they couldn't keep their hands from exploring the endless possibilities that could potentially be presented on the table ... They chose one figurine and named it 'Bill' ... Alpha and Beta decided to put Bill on the pedestal...Bill frowned while Alpha and Beta attempted to do so, knowing this was in fact an impossible task... Alpha and Beta left Bill to his destiny and decided to walk over to the ball ...* (**Narrative extracted from the sketched performance**)

In the vignette presented above, the narrator asks the two characters to find a table (**Recreated** object) and locate different 'clues' provided on the table for them in order to move forward and "meet" each other in a dedicated space within the VR arena. For instance they are asked to find a figurine called 'Bill' and place it on it's pedestal. The body of Bill is a **Recreated** figurine, and the pedestal is an **Untouchable** object. This meant when participants attempted to reunite the two pieces of the statue and place the figurine on it's pedestal, the figurine fell through the virtual pedestal to the physical ground. In this scene the the two characters are intentionally unable to complete the task presented by the narrator, this was seen as a technique to engender frustration, anger and the sense of distrust – these were seen to be emotions often aimed at novel technologies but less in the artistic space. Artists used the misalignment provided by a fractured object as a resource rather than a limitation, to put the interaction in the context of a more narrative-driven experience by creating a story line around anger and distrust.

In another scenario a VR figurine would appear if participants find and touch the physical figurine in the real world (**Phantom-VR**). Subsequently, if over the course of the narrative participants did not follow the narrator's instruction the size of the VR figurine would continually increase – resulting in a giant VR object and a small physical object (**Visually Adapted**) – in order to shift participants' attention towards narrator's instruction.

Previous research [48] described how consistency in the story and interaction can help the participants to better suspend their disbelief and engage with a performance, and experience immersion. In the examples presented above, artists engaged with narrative to 'glue' different types of fractured objects together and to the narrative. The combination of narratives and performative elements employed by the narrator helped the fractured experience to be part of a meaningful and understandable story line. Such an approach also helped the artists to provide 'consistency' of imagination [42] to the participant's, connecting participants' actions and reactions to the experience. Additionally, by using narratives as a glue to connect a story to these fractured objects participants were encouraged to "build belief" [42] rather than to 'suspend their disbelief' in order to accept a fractured experience without a meaning. In examples provided above, adherence to the narrative instructions was the 'glue' that provided meaning and context to understand the interactions with the fractures in the object and how that fracture was changing over time, and help the participants to 'stay' within the story world.

5.3 Actuated Fractured Objects

To better review different iterations of the sketched performance as a whole, artists held smaller showcases of their design with fractured objects. These showcases helped the team to understand how the designed interactions within the story world were perceived by the participants.

Throughout these showcases artists realised that, sometimes, the combination of narrative with fractured objects would not fully work as expected, and the objects require extra manipulation by artists to help the participants better experience the sense of immersion and presence. For instance, while the physical and virtual

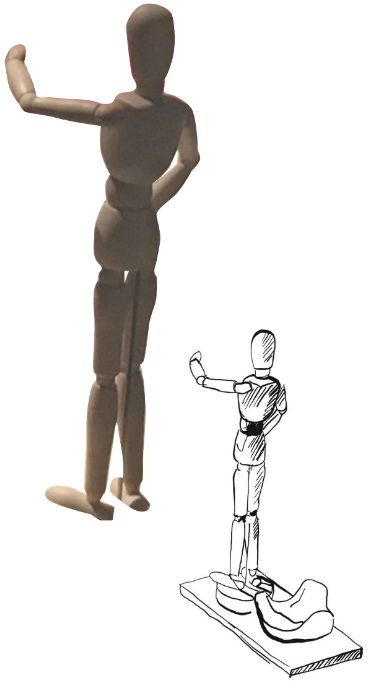

Figure 6: Visually Adapted object – the figure is scaled up in VR

Figure 7: Physically Modified object – the glove is physically 'modified' through balloons

objects were available for the participants to interact with directly, these objects had to be moved and manipulated by the artists themselves both in the virtual and physical environments (Figure 8). The actuation of fractured objects provided another way to 'glue' different elements of the fractured experience together and repair the fault lines between the virtual and physical through artistic merit.

Figure 9 shows a scene from one of these showcases. In this example, the balloon string was the fractured object used to build the interaction. This was a **Physically Modified** object, in that the string attached to a balloon in the VR was available to grab in the physical, but the texture was modified to be metal rather than fabric. The sensation of a balloon pulling the string held in your hand was added to bridge this gap through the participant gently pulling on the metal string in line with the ongoing scene. In this example, and with careful temporal coordination between the participant actuating the string and the system controller triggering the associated movement in VR, the physical string is pulled, so that the balloon in the VR creates the illusion that it is pulling against the participant with the virtual wind.

These explorations also included 'gluing' participant's action in VR to its reciprocal reaction in the physical world. For instance, in another scene when a character, *Alpha*, was exploring the table a performer decides to drop an object from the table to the ground. This was designed to imply a clumsiness in the participant's actions, connecting participant's interaction with a fractured object (**Untouchable**) to a physical reaction:

> [Participants are interacting with different objects on the table]
> *Narrator: Alpha was impatient and clumsy and before they knew it, they had knocked something over.*
> [The stage performer intentionally knocks over an object, creating a sense of illusion for the participant as if they have knocked it over themselves.] (**Narrative extracted from the sketched performance**)

In this example, the performer's manipulation of the participant's action and reaction was 'glued' to the experience and narrative, to help them connect the physical world of the experience to the virtual one in an attempt to create a sense of immersion and presence within the experience. Artists explained that, without careful timing and co-ordination so that the object would be dropped slightly earlier or later than it was planned and scripted within the narrative, the experience could become meaningless. In such an occasion, missing the cue – whether it's a live performer or the VR designer – could not only break the flow of the experience, it could also break the sense of immersion and presence that artists have carefully designed for.

6 DESIGNING WITH FRACTURED OBJECTS

We extended our analysis of the design process of the artist, to further situating the findings in a more exploratory design ideation. Following an iterative sketching and discussions among the research team, in this section we propose three speculative mixed-reality experiences built around fractured objects. Through employing this

Figure 8: The performer (right) is manually actuating a fractured object (in this example a box) in an attempt to manipulate participants' action.

Figure 9: A Participant is pulling the physical string. This action creates the illusion that the balloon in VR is pulling against the participant with the virtual wind.

approach, we aim at clarifying the analytic points through reformulating and testing the key concepts behind the six identified fractured objects. This helps us to provide results to a wider IMX audience by speculating different ways in which these objects can create extended value in designing future mixed-reality experiences [17, 33, 44].

Inspired in part by a review of previous work at IMX around virtual reality and multi-sensory experiences which uncovered work on video journalism [6, 28], haptic feedback [1, 15], and engaging with suspenseful narratives in VR and 360°video [34], in the following sections we present design for contexts outside mixed-reality performances. We propose three different experiences and scenarios from the fields of non-fiction virtual reality experiences, mixed media interactive narratives, and to educational purposes. This post-production design activity follows the tradition of scenario based design for HCI research popularised by Gaver et al. [17] and in Virtual Reality by Harley et al. [24, 25] in a combination of textual description and exemplifying sketches [38, 44]. As such, the images presented in this section follow the same conventions as the examples of Fractured Objects, through separating the depiction of physical objects (represented by the drawn sketches) and the virtual objects (through the use of photos and colour).

6.1 Designing with Narrative Glue

The integration of virtual and mixed-reality with traditional practices of video journalism has long been of interest to the IMX community [6, 28] due to the opportunities it presents to immerse and emote. We suggest that expanding the interactions available to participants [18] and taking advantage of the opportunities designing with fractured objects presents, can ensure that designers are able to harness users' "appreciation for works that offered them meaningful agency and interactivity" [20].

This suggested experience is envisaged as part of a Virtual Reality Non-Fiction (VRNF) experience designed to highlight the future impacts of climate change in a domestic setting. In this exemplar, shown in Figure 10, participants' perceptions of their mundane use of their home water tap is used as a medium to add weight to the narrative around changes to their life at home.

When turning on the tap and wearing the HMD the user sees the water flow slowly stop due to a fictional future 'drought regulation'. As the user is watching their water slowly stop flowing (Figure 10, **a**), they are grounded in the reality as it is today with their other senses able to hear, feel, and smell the water still flowing. In this envisaged scenario, the narrator then explains both why the water has ceased to flow and guides the user in understanding how the fractures in the experience of the **Visually Adapted** tap and the running water highlight and enhance impact of the projected loss. Such as the time bending speculations – exemplified by the 'high water pants' of Biggs et al. [7] – where the fracture between present and future is felt but not seen, this design provokes by creating an experience where the future is seen but not felt. Without narration such an experience may be interpreted in many ways, not least of which would be an error in the rendering of the composite or virtual world, but the projected narration here binds differing representations of the virtual and physical tap giving them meaning and purpose.

6.2 Designing with Actuation

Inspired by the research into adding haptic feedback to media presentations [1] and social VR settings [15], we iterated on designs that connected the haptic feedback presented to the user and built

Figure 10: Washing hand in projected drought

upon the fractures between the fidelity of physical feedback technology is able to provide when compared to the fidelity available in the design of visuals.

Some of the most advanced haptic feedback systems in use are those developed for the training of physical skills in situations where there is risk, either to the subject of the manipulations or the manipulator, due to inexperience of the trainee. In the rendering of articulated simulacra of physical bodies, such as the training apparatus developed to give veterinary students the tactile experience of reaching inside a horse [8] or a cow [3] to aid in the identification and diagnosis of physical ailments, there is an understandable goal of a realistic physical experience through the movement of certain parts of the object. However, even with such high fidelity custom built devices users reported notable differences between inserting one's arm into a simulated cow rectum and the real thing [2]. That said, several studies have pointed out that fidelity of experience is independent from the learning outcomes of simulation-based training [23].

By embedding such a training simulator in a VR environment we not only gain the opportunity to render more of the projected environment of use, but also provide an opportunity to expand the use the feedback abilities of the haptic device in its training capacity. While keeping the physical sensations the same, we can expose renderings of the internal organs of the animal – a set of **Mismatched** objects where the physical internal actuators of the device are linked to the VR organ models (Figure 11). Either side of this fracture could also be exaggerated to aid in the learning process, visually altering the size or presentation of the organ as it is engaged with to aid internal navigation, or altering the felt size and behaviour of the object to place emphasis on certain physical properties over others early in the training phase. This also highlights that while the artists who we studied only employed human actuation for physical objects, the fractures can be evident in mechanically controlled and manipulated objects represented in a virtual space as well.

In a situation closer to the inspiration of haptic feedback in social VR, we can envisage the same interaction techniques used in combination with haptic gloves[4] or haptic body suits[5] to train the user to connect the haptic devices' approximation of the physical interaction they are experiencing in the virtual environment – be that a 'high five' or a hug shared between avatars – to the expected sensations if the same action was to happen in the physical environment. Using a combination of **Visually Adapted** and **Physically Modified** interactions to acclimatise a user to ever-less exaggerated versions of the interaction until they are able to 'feel' it as intended

[4]https://teslasuit.io/blog/teslasuit-introduces-its-brand-new-vr-gloves/
[5]https://teslasuit.io/the-suit/

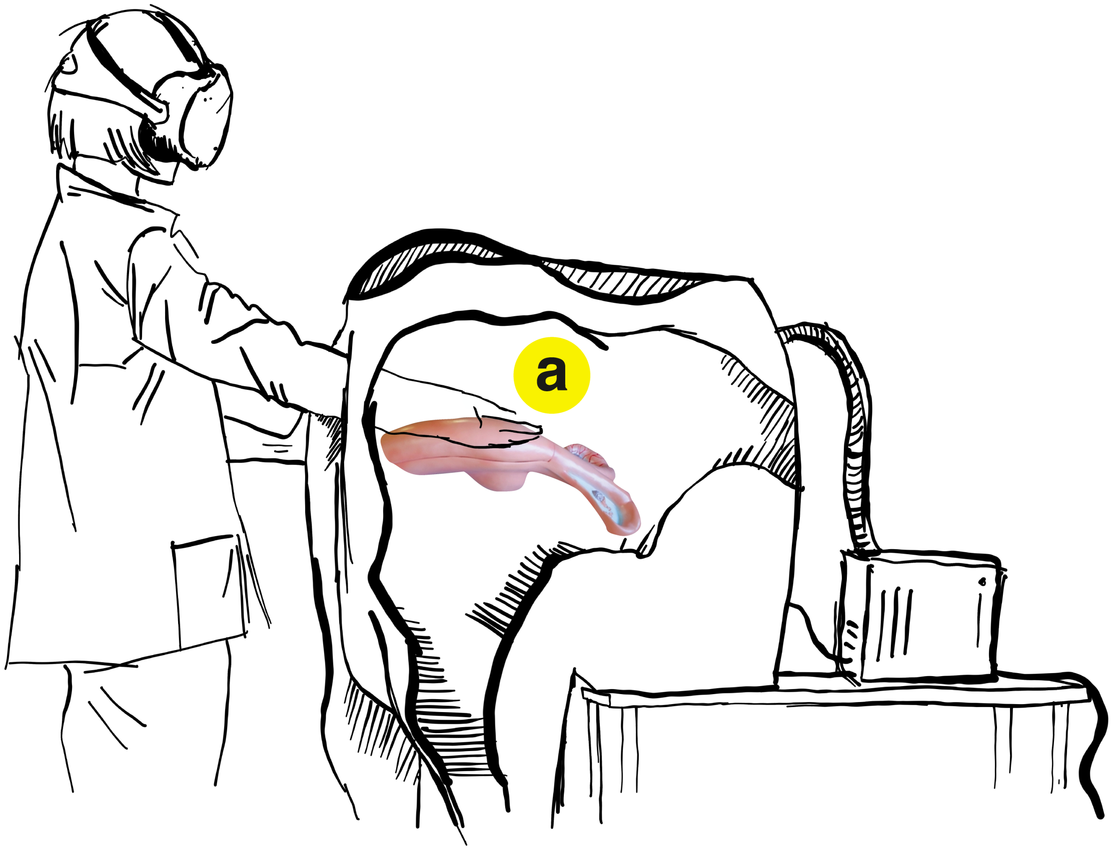

Figure 11: VR-enhanced haptic veterinary training device

by the designer of the experience while successfully understanding the feedback would be an interesting future research direction.

6.3 Designing with Misalignment

Drawing on the opportunities for VR and 360°video in engaging viewers in a suspenseful narrative [34], and employing game elements [31] to overcome some of the challenges Marques et al [34] reported, this design draws on the concept of an escape room experience as an embedded game-element within a larger suspenseful narrative drama.

The idea of implementing escape rooms in virtual reality, or augmenting them to take advantage of virtual and mixed-reality technology has been explored to some extent (e.g. [58, 59]). Following on from these ideas we envisaged the design of puzzle elements that could be used to draw the viewer of a VR or MR drama through the discovery and validation of information the protagonist would do to advance the plot.

This scenario is based around the traditional 'crime board' [13] element popular in detective fiction as seen in Figure 12. In a mixed-reality space this could be made available to the audience physically, whereas in a home or theatre setting this could be a static image on the screen.

Some of the audience would don HMDs before the crime board was presented to them. While the majority of elements on the board are **Recreated** in in the virtual environment, the task of the players would be to follow clues to find pairs of related objects which are misaligned [36]. In the example presented in Figure 12, the clues are split between the virtual and physical representations. The purely physical photo is **Phantom-VR** (Figure 12, **b**) which means it is not visible to those wearing HMDs, the purely virtual and **Untouchable** photos (Figure 12, **a**) are only visible to those wearing the headsets. The **Physically Modified** letter (Figure 12, **c**) shows slightly different details of the case depending on if the reader is viewing it in the physical world or through an HMD.

For each of the elements on the crime board, the audience members must discuss and connect them back themselves to the overarching narrative of the experience. By using the misalignment [36] between the two representations of the board, and designing the fractured objects and the nature of those fractures, the development team can ensure that the audience is 'with' the protagonist before moving to the next scene – ensuring a shared understanding through replicating the reasoning and allowing the audience to invest in the process of shared discovery.

Figure 12: Crime Board with clues fractured between VR and physical representations.

7 DISCUSSION

Drawing directly from the artists involved in designing and performing the mixed-reality performance [46, 47] we have presented this taxonomy of fractured objects in the light of the creation and experience of artistic mixed-reality interactions. However, as in the designs drawn from them we see this as a way of understanding – and utilising – of the normal natural differences between objects presented digitally and physically.

While there is a longstanding vision of recreating more and more complex aspects of the physical world in digital form to be experienced, replayed, and manipulated in various versions of the 'metaverse' [14, 22] currently replicating physical objects in virtual reality in aspects beyond their volumetric and visual properties is reserved for industrial and scientific applications, where the modelling necessary to create a 'digital twin' [21] can be justified. While consumer level hardware is increasing in fidelity rapidly in terms of bodily and object tracking [26], visual fidelity [49], and even physical sensory feedback [9] the ability to model physical objects for addition to the virtual world is still at a surface level. By that, we mean that while the technology for modelling objects is increasing in speed and fidelity, it is limited to the generation of a representation of the visual and volumetric model that can accurately reproduce what something *looks like* in the world but nothing about *how it behaves* in the world. The weight, texture, and how it is interconnected with other objects in the environment are necessarily lost when an object is represented by a 3D mesh with a photographic texture. In this way, for the foreseeable future all objects in a mixed or virtual reality environment will be fractured to some extent.

By presenting how our subject artists understood and worked with this lived reality of the creation of VR and MR experiences we aim to provide another lens by which designers of all genres of mixed and virtual reality can approach and employ these fractures instead of attempting to 'paper over the cracks'. In doing so we echo earlier calls in mobile systems development to employ Seamful Design [10, 11] to both expose the limitations of mobile infrastructures and employ them in the design of novel experiences [4] in the VR and MR space.

7.1 Fractured Temporality

However, as the modelling does get more complex in recreating the behaviours of physical objects on the path towards realistic reproduction further categories of fractured object will become available for design in the divergences between the physical behaviours and the virtual models' actions and interactions. One interesting type of fracture which, while not explicitly addressed by our participants, is evident in the technical challenge of ensuring that the virtual environment can be rendered and delivered to the HMDs quickly enough to allow people to move things and understand that movement is that of the temporality of action.

In our examples this fracture is limited to the delay or preemption of physical interaction with an object – the virtual artefact can either move before or after it or its physical counterpart is moved. This in itself presents interesting opportunities for the design of interaction, from allowing potentially destructive actions in a training scenario the time to be 'undone' before they impact the learning outcomes of a group of users, to exposing expected, optimal, or historical paths through a virtual interaction by starting the feedback for the calculated next action before the user initiates it.

As the modelling of object behaviour becomes more complex, the possibilities to (or, perhaps the expectation of experiencing) fractures of the temporal connections within and between objects will present themselves. Providing interaction designers the tools to manipulate when an object reacts to a particular stimuli, or emits another which would be input to a range of connected objects in a complex mixed-reality environment holds potential for more subtle nudges towards a desired path of interaction than the simple example of actuating the next step before it is reached, and more explanatory fail-safes for a learning environment by delaying and highlighting a chain of consequences as successive modelled objects progressively delay their reaction to a destructive action by the user.

7.2 Kintsugi VR

The recent advancement in AR/VR technologies has helped the designers to stitch and merge the digital and physical worlds together, giving them more and more tools to create ever more flawless immersive experiences within their mixed-reality projects. Yet, there are situations where, intentionally or otherwise, different seams and joints of these realities remain untouched and visible. That results in a fractured experience for the user.

In much of the previous research presented throughout this paper [10, 11, 32, 48, 60] as well as the data presented, we have discussed how systems designers or artists have benefited from the seams and fractions between the physical and virtual worlds though enhancing the fault lines to their benefits, rather than trying to remove those fractures.

In one example, Williamson et al. [60] use the camera view to expose the physical world around the passenger wearing an HMD and immersing themselves in a VR environment. This can be seen as a degradation of the immersion and fidelity of the virtual space, yet the security provided by allowing the passengers to maintain peripheral awareness from within VR while in the complex and unfamiliar physical environment of a passenger aircraft enabled the users to *further* their own immersion in the virtual environment. In another example, Rostami et al. [48] discuss how a group of artists use non-digital aspects of a performance (e.g. scenery props) as a source of friction, to connect the audiences' physical and emotional experience to the VR part of the performance. In this example, physical interactions between the performer and the audience in VR is established through fractured objects but seams are enhanced, rather than covered, through artists' preformative techniques to prime the audience and create a successful immersive experience with a 360°video.

By piecing together fractured objects and gluing them together with different techniques – be that an artistic exploitation such as the use of narratives or the technical design described in [32, 60] – a VR experience can be designed to offer misaligned yet novel and immersive experience to its users.

Borrowing from Japanese art of *Kintsugi* to repair broken pottery using lacquer mixed with gold powder, we suggest *Kintsugi VR*. Like broken pottery pieces, fractured objects in VR can be pieced together with the golden glue of artistic manipulation (through narrative and actuation) or seamful design to inspire novel opportunities of design for mixed-reality experiences.

This can be seen as similar to the concept of Wabi-Sabi as articulated for HCI by Tsanaki & Fernaeus [55], encouraging designers to embrace the imperfections and impermanence of all creations, however the specific focus of Kinstugi VR with Fractured Objects for the space between physical and virtual representations allows a more actionable set of concepts to be presented for use.

We encourage those designing any experience that builds upon objects that traverse the boundaries of the physical and virtual to look through the lens of Kinstugi VR and examine the fractures that the representational model encodes – not only in an attempt to invisibly stitch them together or to carefully direct attention in another direction, but open to the possibility that these may be 'golden' seams for novel interaction, the elicitation of emotion, and advancing narratives.

8 CONCLUSION

In this paper we have presented the concept of Fractured Objects as drawn from artists' development of a mixed-reality performance along with the results of a design exploration into their use in other genres of interactive experience. The concepts of **Recreated**, **Mismatched**, **Phantom-VR**, **Untouchable**, **Visually Adapted**, and **Physically Modified** items that exists at the point between the virtual and physical representations of such experiences were are described in relation to the *fractures* – inherent or designed – in the duality of their representation.

Managing the connections between the fractured parts of the objects are discussed in terms of representation, narration, and actuation being used to embed the fractures as integral to the interactions with and through the fractured objects. This led to the concept of Kintsugi VR, drawing on the Japanese concepts of Kintsugi and Kintsukuroi in which broken objects are repaired not only to return them to the state they were originally – but in employing the use of careful craftsmanship and precious materials are made more beautiful, valuable, and useful than they were before the break.

As we go forward creating more and more complex virtual and mixed-reality spaces to learn, play, and work within our exposure to fractured objects will increase dramatically. Our goal with this paper is to provide the conceptual building blocks to construct interactions that not only work within the technical and modelling constraints that such spaces will embody, but to build upon the nature of the differences inherent between dual virtual and physical representations to encourage and enhance those experiences.

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