

# The Performative Mirror Space

Rachel Jacobs<sup>1</sup>, Holger Schnädelbach<sup>1</sup>, Nils Jäger<sup>2</sup>, Silvia Leal<sup>3</sup>, Robin Shackford<sup>3</sup>, Steve Benford<sup>1</sup>, Roma Patel<sup>1</sup>

<sup>1</sup>Computer Science, University of Nottingham, Nottingham, UK

<sup>2</sup>School of Architecture, Loughborough University, Loughborough, UK

<sup>3</sup>Independent Creative, Nottingham, UK

[rachel@i-am-ai.net](mailto:rachel@i-am-ai.net), [holger.schnadelbach@hsaa.eu](mailto:holger.schnadelbach@hsaa.eu), [n.jaeger@lboro.ac.uk](mailto:n.jaeger@lboro.ac.uk), [silvia.leal77@gmail.com](mailto:silvia.leal77@gmail.com),

[robin@littlebighead.com](mailto:robin@littlebighead.com), [steve.benford@nottingham.ac.uk](mailto:steve.benford@nottingham.ac.uk),

[roma.patel@nottingham.ac.uk](mailto:roma.patel@nottingham.ac.uk)

## ABSTRACT

Interactive mirrors, typically combining semi-transparent mirrors, digital screens and interaction mechanisms have been developed for a variety of application areas. Drawing on existing techniques to create interactive mirror spaces, we investigated their performative qualities through artistic discovery and collaborative prototyping. We document a linked set of design explorations and two public, site-specific experiences that brought together artists, communities, and HCI researchers. We illustrate the abstracted interactive mirror space that practitioners in the performance art, theatre and museum sectors can work with. In turn, we also discuss six performative design strategies concerning the use of physical context, movement and narrative that HCI researchers who wish to deploy interactive mirrors in more mainstream settings need to consider.

## CCS CONCEPTS

• **Applied computing~Performing arts** • Human-centered computing~Mixed / augmented reality

## KEYWORDS

Art; Design; Mirror; Performance; Storytelling

## ACM Reference format:

Rachel Jacobs, Holger Schnädelbach, Nils Jäger, Silvia Leal, Robin Shackford, Steve Benford, Roma Patel. 2019. The Performative Mirror Space. In *2019 CHI Conference on Human Factors in Computing Systems Proceedings (CHI 2019)*, May 4–9, 2019, Glasgow, Scotland, UK. ACM, NY, NY, USA. Paper 400, 15 pages. <https://doi.org/10.1145/3290605.3300630>

\*Article Title Footnote needs to be captured as Title Note

†Author Footnote to be captured as Author Note

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than ACM must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from [Permissions@acm.org](mailto:Permissions@acm.org).

CHI 2019, May 4–9, 2019, Glasgow, Scotland UK

© 2019 Association for Computing Machinery.

ACM ISBN 978-1-4503-5970-2/19/05...\$15.00

<https://doi.org/10.1145/3290605.3300630>

## 1 INTRODUCTION

This paper presents a process of artistic activity and HCI research that integrates and extends existing techniques for designing interactive mirrors with narrative and performance strategies, exploring the design opportunities within the 'performative mirror space' – described here as a theatrical space that exists in front of and inside a mirrors' reflection. Through the design of a series of collaborative, public interactive experiences, a diverse team of researchers and communities led by two artists in the UK and Brazil have come together to explore the opportunities and challenges for designing interactive mirror experiences from an artistic perspective. The underlying *Invisible* project follows in the footsteps of similar work that brings together artistic process and HCI research over the last 20 years [1, 2, 3]. *Invisible* followed two interwoven threads: 1) A research process of building a series of interactive mirror prototypes, that we describe here as the 'performative mirror space'. 2) Artistic experimentation inviting two communities to collaborate in the process of developing the 'mirror space' and building co-produced narratives created for this space. Building on existing knowledge of the 'combined space' within interactive mirrors [4] we explored how interactions can occur in front of and within the reflection of an interactive mirror to create a unique environment for the type of performative, playful and theatrical interactions developed by the artists and communities taking part.

In this paper we provide a detailed description of an exemplar, practice-focused exploration of how the performative mirror space can be developed to create collaborative, narrative based mixed reality performances. This leads us to make two contributions aimed at two audiences: 1) A grounded illustration of the abstracted, interactive mirror space, which 'sets the stage' for performance, most relevant for practitioners creating performative interactive mirror experiences in

performance art, the theatre, the museum and retail sectors, and in the home. 2) The discussion of six performative design strategies, where performances 'on the stage' created within the interactive mirror space include physical context, work with movement and the role of narrative. These strategies benefit those who work at the intersection of HCI research, the arts and exhibition design by providing an understanding of how to connect performance and interactive mirror space technologies. They also benefit a wider community of researchers: those developing enabling technologies (e.g. gesture, face tracking), and those who are conducting perceptual and cognitive experiments in HCI allowing them to investigate a wider range of contexts beyond single user interaction.

## 2 BACKGROUND

There has been growing interest in the use of augmented and interactive mirrors in a variety of settings such as museums, retail, and entertainment. These typically combine semi-transparent mirrors, digital screens and interaction mechanisms to create the illusion that physical actors and objects appear in the same place as virtual actors and objects. We refer the reader to Figure 14 for an overview of those aspects of interactive mirrors that are relevant for this paper.

In the commercial domain, interactive mirrors have created augmented versions of people, as avatars, in the context of the beauty and cosmetic industry [5,6,7]. Outside of this commercial context interactive mirrors have been used to allow people to dress as historical characters [8], explore interactions with virtual actors [9] and training people to learn physical movement [10]. Most of this work has focused on the technical implementation of interactive technologies (such as a Kinect) with a mirrored surface [9], focused on the person looking at the mirror [11,12] and how we might design digital interactions to respond to our reflections [13].

In contrast [4] map out an extended understanding of the nature and quality of the design space created behind the mirror within a volumetric space reflecting an increasing interest in mirrors in boxes [14], creating novel designs for health services [15], augmenting our selves, museums spaces and exhibits and for musicians. Similar to [16], [17] addresses some issues of the physical context of the mirror by using projections into the real world, as well as a screen moveable in relation to the mirror, to enhance the perception of a hybrid mixed reality environment. Some work has begun to look beyond the reflections of ourselves such as for enhanced digital displays in cars [18]

and [19] have explored the conditions of the real world where the mirror is placed, such as lighting and distance.

The arts have exploited mirrors to create powerful visual illusions. Tricks such as Peppers Ghost [20] and traditional fun fair 'hall of mirrors' create uncanny changes in perspectives that have long been used by visual artists and theatre makers. Janet Cardiff [21] and Paul Sermon [22] have used sound and image to create similar uncanny experiences that distort our sense of time and reality combined with camera, projections and audio. Whilst Giannachi's work on virtual theatres [23] and the 'archaeologies of presence' [24] explore how live-streamed performance can play with our sense of self, place and presence across mixed reality, these works have often been considered within the context of place, following a tradition of 'site-specific' art [25], that informs the work in this paper.

Mirrors have also been used since 1960's to today across scenography, cinema and architecture to distort our sense of scale, direction, distance and narrative, as shown by the design of Svoboda's Magic Flute [26]. In film and literature mirrors have been used as a device to play with our perceptions of the uncanny, transporting protagonists from real world narratives to other places, or to reveal elements of the unknown, such as seeing in to the future [27]. In architecture mirrored surfaces are used to blend buildings and environment [28], to enable specific interactions (e.g. dance studio mirrors), to encourage play and to enable street art [29].

It is important to note that mirrors also play an important role in our understanding of our sense of self [30, 31]. We begin to understand how our performative selves can guide how we take on roles, set a scene, become an audience to others, watch ourselves and equally enable others to become our audience [32]. Through playing with our reflection in a mirror we play with these theatrical and performative experiences, and how we perceive ourselves within the environment around us.

Despite the wealth of previous work and the performative role that mirrors 'naturally' have, there is no detailed account of how to put interactive mirror spaces to work in a performance context. Even though work in [4] generalises from individual interactive mirror techniques, potential producers in the relevant museum, theatre and performance art sectors cannot immediately draw on existing research to put interactive mirror spaces to work in live performance contexts. What role can the architectural context take? How can movement of

audience members and performance members be designed for? How can narrative be used to enable audience members and performers to use mirrors in their perception of self and that of others?

### 3 APPROACH

The collaborative process of the *Invisible* project involved using performing, visual art and theatre techniques combined with the techniques for designing interactive mirrors described in the literature. The two artists leading this process have been working together since 2009 on how to use interactive technologies to bridge environments and communities across the UK and Brazil [33]. This project involved two environments and communities, one in the UK and one in Brazil, with the view that the activities of sharing stories and building conversations between them will eventually enable interaction. For this context, the artists became interested in the possibilities of an interactive mirror that reflects the environment and acts as a doorway to another place to reveal that which you cannot see (e.g. a place's history) or to connect to another community.

Theatrical and contemporary art techniques were used as a device to explore what it means to play with our perceptions of the real world, the reflections of this world in a mirror and create digital content that interacts between and within these spaces. This included writing narratives that imagined the locations where the mirror might be installed and might transport the participant to, and considering the physical and sensory context of objects, bodies and place. Prototypes were constructed and tested together with a diverse set of participants being invited into this process, where being part of this creative network and participating in creative activities were the main aims of those participants. This is common in the extended network of collaborators that the artists work with. This process culminated in the development of two public presentations of the resulting mirror prototypes: (i) A small intimate performative game event and (ii) a larger scale static mirror installation as part of a busy public event.

### 4 EXPLORING THE MIRROR SPACE

We begin by presenting a series of performative explorations that were conducted in response to the artistic approaches of the artists and communities in the UK and Brazil and that drew on existing interactive mirror techniques. Our process was documented using

ethnographic techniques that included direct observation, photography, video and semi-structured interviews with the community participants, the artists and the event participants, mirroring previous work [3, 34]. The following draws on artists' intuitions emerging during the process, careful observations, the analysis of emerging themes (from recorded materials) [35], and from the authors drawing on previous work.

During the first phase of *Invisible*, the UK-based artist and team were in residence at a local arts centre. Two workshop sessions with a group of 9 self-selecting participants from the local community provided an opportunity to test, develop and experiment the set up and design of an interactive mirror. Initially, the workshop invited the participants to consider their bodies in relation to objects sent by the Brazil-based artist. This draws on work from artists Lygia Clarke and Helio Oiticica and the Neoconcrete and New Objectivity art movements from Brazil [36, 37], which proposes a collective physical, embodied and sensory starting point. The UK-based artist then introduced techniques for developing stories, visual narratives and performative experiences in relation to some of these objects and the workshop location. An interactive mirror, combining a large vertical screen, an overlaid semi-transparent mirror, Kinect tracking and a Unity backend were also presented.



**Figure 1. Participants playing and performing with objects**

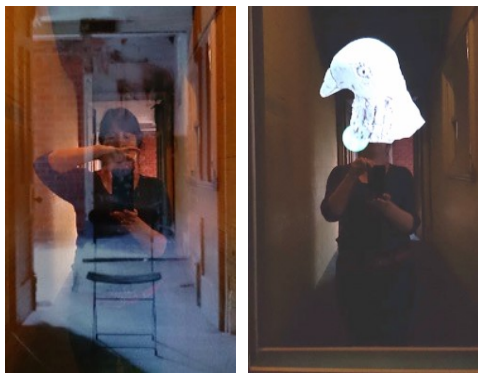
During the workshops, various narrative experiences were devised that combined objects designed by the participants appearing on the interactive mirror and simple haptic and full body interactions enabled by mapping the movements of a person in front of the mirror to the digital objects appearing on the screen behind the mirror, overlaid with their reflections. The interactive mirror was placed at the end of a dark corridor (see Figure 3). In what follows, we describe the explorations with this mirror.

*Exploration 1:* This involved photographing the corridor with a chair standing at its end from the perspective of a person standing behind the mirror looking down the corridor. The chair was then removed. The 'before' image appeared on the screen behind the mirror, overlaid with the reflection of the person standing

in front of the mirror. When this was presented back to the group, it was observed that several participants turned to see if the chair was there and all stated that they were confused as to whether the chair was there in reality. This image was also mapped to their body movements, creating a sensation of being able to expand the environment behind the participants as they moved.

*Exploration 2:* The next experiment involved transforming the reflection of the participant's body. A clay pigeon head was photographed and appeared on the screen overlaid on the reflection of the participant's head. This was tracked by the Kinect sensor as the participant moved. Each of the participants made their own clay heads to fit within the narratives they developed in the workshops. In each case the animal head appeared in front of the reflection, transforming the reflection of the participants body as they moved in front of the mirror.

*Exploration 3:* The mirror hardware was then adapted, attaching the mirror to a wooden frame and moving it away from the screen. This created a similar effect to that described in [4], where the distance between participant and mirror and mirror and screen are equidistant. This added a type of 3D effect whilst extending the 'mirror space' to include a space (seen through the mirror) between the mirror plane and the screen. This was tested with a digital object - an image of a stone - that appeared on the screen behind the mirror. Responses recorded from the participants in the workshop suggested that the stone appeared to be floating somewhere in a space within the mirror.



**Figure 2. The chair and the pigeon head**

Video documentation observed several of the participants reaching out towards the stone trying to touch or hold it. They also played with shifting their body, and changing the distance to the mirror to gain a sense of the shape of the object.



**Figure 3. A participant reaching out to touch the stone**

*Exploration 4:* The participants were then invited to test the narratives they had devised and feedback their ideas. One of the participants brought a mask along as a prop to compliment his narrative experience. This created an additional performance element where the participant put on the mask and interacted with his reflection, overlaid with a digital mask appearing in the mirror. This was observed by the participants as creating an uncanny effect where it was unclear whether the digital or real mask had replaced their face.



**Figure 4. Reflection of participant's real mask overlaid onto digital mask**

Through these explorations the participants discussed both the technology and construction of the mirror, whilst raising some key questions about context and performative experience: (i) How we might play with where the mirror is located and the physical context of the mirror, instead of focusing on haptic interactions within the digital experience (ii) How to build a narrative experience that allows for more ambiguous, reflective 'slow' responses and interactions that engendered a greater suspension of disbelief (iii) How to integrate sensory, physical experiences using movement, gestures and overlaid digital objects in the mirror that evoke 'uncanny' responses (iv) How to explore textures - of objects, spaces and digital objects in 2D and 3D - using the whole body, sight and sound not just haptic interactions.

In parallel to these explorations the Brazil-based artist began collaborating with a community group that brought the *Invisible* project together with their own dance, movement and playful arts practice evolving from the



traditions of a local mask festival. As a result the group in Brazil supported the artists to devise two interactive narratives, which informed the key public events that took place in the UK, by providing images of traditional masks and games and songs that the group had developed, which were adapted for a 'performative mirror space' context.

## 5 BUILDING THE MIRROR PROTOTYPES

In response to the above, the research team developed a set of mirrored structures and experimented with how the narratives, songs and games might enable interactions within the mirror space created within these structures. As a result, two interactive mirror prototypes were built, each creating different forms of performative and theatrical mirror spaces: 1) *Mirror in a Suitcase*: A mobile mirror built into a vintage suitcase to be used as a prop within a broader performative experience to flexibly intervene in different environments. 2) *The Mirror Frame*: This focused on the interactive mirror as a space in it's own right that could either be installed in a specific environment or be built around an existing mirror.

### 5.1 Mirror in a Suitcase

To begin the design process, the Brazil-based artist sent the community in Brazil a suitcase to explore how they might respond and interact with it. The artist applied gold leaf to an old suitcase and filled it with a golden reflective surface and a number of tangible objects. While analogue only, this version allowed the physical handling of the artefact to explore the potential of a suitcase to intervene with the people and the environment where it was placed.

The group responded by sending back a film of the 'performed' interactions with the suitcase, from opening the package, to opening the suitcase and playing with the objects inside. Two key points of feedback then informed the further design stages: (i) the group did not consider the letter of instructions (which would have had technical instruction in the case of an interactive prototype), making it clear that they wanted to respond in a spontaneous and physical way; (ii) the group were physically rough with the suitcase, themselves and the props/objects contained within it, moving about with it and interacting with it from all angles. It was clear from these interactions that the suitcase worked as a trigger or prop for playful, performative responses from this group. As this suitcase was analogue and lightweight, the group were able to play in a physical and inquisitive way, moving freely around the room where they were located.



Figure 5. Experimentation with an analogue suitcase

This shaped our aim to build an interactive mirror that was small enough to be carried (and potentially to fit on a plane as hand luggage) with small, cheap, open source components so that it could be easily built and maintained in both the UK and Brazil. It should require only a very minimal amount of set up and instructions, with the aim that the final version would also be robust enough for the types of physical interactions that took place during the experiments with the analogue suitcase. The first prototype design involved a suitcase that would work in both portrait and landscape orientation so that it could be moved about and opened in a variety of different ways. This prototype was built using an old vintage suitcase with a monitor attached to the inside of the deeper section with a magnetised semi-transparent mirror flush with the top. A laptop was attached to the inside of the lid covered by a fully silvered mirror (see Figure 6).



Figure 6. Mirror in a suitcase

Interactivity was provided via a webcam using open source software (Processing and Open CV), and a bespoke template integrated with Processing provided simple options to 'choreograph' a narrative experience on a timeline. This first instantiation of the performance mirror space, combining lessons from the original four explorations and test with the analogue suitcase, allowed us to delve deeper into what kinds of effects and performances can be enabled, through the following explorations:

*Exploration 5:* The distance between the semi-transparent mirror and the monitor (which was set into the back of the suitcase at a distance of 9.75cm) provided opportunities to explore how people interact with the mirror space on a smaller scale. As the interaction sweet spot within the mirror space was very close to the mirror surface, it appeared to encourage people to get closer and take part in a more intimate performance with the mirror. Here the digital content was most likely to remain in front of their reflection although some people got close enough for the digital content to be level with and within their reflection.

*Exploration 6:* The suitcase contained one interactive (semi-transparent) mirrored surface and one standard fully silvered mirror. Opening the suitcase enabled the two mirror surfaces to be moved from a flat surface (both halves of the suitcase fully opened), to a variety of angles creating different effects of multiple reflections of each other. Distortions broke up the reflections and created different perspectives on the same reflection and the digital content. What was visible changed with each change of the object's location and the orientation of the ancillary mirror.

*Exploration 7:* The mirror in a suitcase was first tested in a wood, exploring how the interactive mirror would work outdoors, reflecting a specific environment and different angles (e.g. sky, leaves on the floor) as well as people in the environment. The digital objects appeared very faintly behind the reflections of the participant and the environment, creating subtle interactions between the reflections, the digital interactions and the real world whilst providing opportunities to explore the artists' original aim for an interactive mirror to respond to different locations.



**Figure 7. Testing the suitcase in a wood and Figure 8. Testing the suitcase in the sunlight**

## 5.2 Mirror in a suitcase public event

The prototype was then tested as part of a public event. The interactive mirror became a prop within a more extensive performance (based on the responses to the analogue suitcase from the group in Brazil) that involved a small group of people in conversation with the artist and

community in Brazil, who helped develop the content and game experience.



**Figure 9. Participants in the public event opening the suitcase and Figure 10. Holding a card overlaid on to the reflection**

This was an opportunity to layer the interactive mirror experience with other real world interactions using lighting, audio and analogue play. At first contact with the suitcase, a song was playing from the laptop inside. The sounds appeared to encourage the participants to touch and then open the suitcase and the mirrors were revealed. Digital content was triggered when the webcam recognised the presence of a participant's face. The digital content in the mirror appeared as an image of a hand holding a card (overlaid on the reflection of the participants as if it was their hand), asking them to play a game whilst 'walking differently' around the building (a game designed by the community in Brazil), using the mirror as a prop to augment the experience. The participants had put on real physical masks that they had created previously (see Figures 9 & 11). Once they had removed them on instruction, the participants had an opportunity to interact with their own reflection, in response to digital masks that appeared in the mirror alongside a spoken narrative in Portuguese and English.

The playful nature of this experience provided a context for mirror interactions in that specific location, similar to a treasure hunt. The elements of surprise and discovery appeared to fit well with the digital interactions with the masks and instruction cards held by an unknown person's hand that appeared in the mirror space. These triggers connected the participants both to the location they were in and the more abstract audio and visual narrative devised by the community in Brazil.

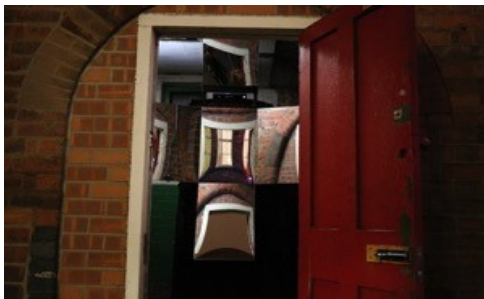
In a recorded feedback session the participants suggested there was an element of spookiness and other-worldliness about the interactions within the mirror space that contrasted with the rest of the experience, particularly when the digital objects appeared within the reflection in the mirror space. They also requested more opportunities for interactions and playfulness with the mirror integrated into the real world experiences. Observations of the way the participants interacted suggested that interacting with

a smaller mirror reduced the physical movements of the participants in the mirror space, whilst the way the suitcase moved, opened and closed allowed the participants to interact with the mirror in a more embodied and sensory way in the real world, reflecting the real world environments from different perspectives, angles and through more physical play.

### 5.3 The Mirror Frame Installation

The team then built the mirror frame to be installed in a fixed location and returning to using an interface designed in Unity, with Kinect tracking. It was designed to reflect the architecture and environment of the location as part of an immersive experience. The Mirror Frame involved multiple mirrored surfaces –made up of 5 mirrors in the shape of a cross. The centre mirror was interactive, combining a semi-transparent mirror and back screen. The frame was designed to look like a large Victorian era bellows camera with the odd looking mirror sculpture emerging from the cloaked frame. We set up a series of explorations into how this prototype extended our understanding of the performance mirror space and how the participants interacted within this performative context. The mirror frame was set up in a corridor of the arts centre, facing a doorway to the outside, creating mixed reflections of interior and exterior spaces, including the façade of the building opposite (Figure 11).

*Exploration 8:* The mirror frame allowed us to reflect the participants' peripheral vision of the ceiling or sky and the floor, as well as extending their view of what was to the side and behind them. This created interesting effects where digital objects appearing on the central screen were clearly not appearing in the other four surrounding reflections (see Figure 12).



**Figure 11. Five mirrors reflecting views into environment**

*Exploration 9:* The display was fixed at a distance of 70cm behind the screen and participants were able to move backwards and forwards in front of the mirror, into and out of equidistance of the displayed object (in the mirror).

This was particularly uncanny when the object was a mask tracked to the movements of someone's head.



**Figure 12. Digital mask appearing on participant**

Through these movements participants suggested a sensation was created whereby the digital object appeared to be moving in front of, within and behind the participant's reflection (Figure 12).

### 5.4 Mirror frame installation public event

The mirror frame was publicly shown at the arts centre as part of a larger public arts event. The narrative interface and performative experience created for this event allowed us to further weave stories and images about the environment in Brazil with stories about the environment where the arts centre was situated (in the UK). The narrative was built in Unity, played out from a PC and triggered by people via a Kinect, built into the mirror structure. As people walked towards the mirror, the Kinect tracked their movements and distance to the mirror, triggering the narrative to be played out within the mirror's reflection. The story was narrated by the artist based in Brazil, linking the underground world of sandstone caves that exists below the arts centre in the UK through manipulated reflections (similar to exploration 1), with a place on the other side of the Atlantic where masked people came to life through dance, music and play.

The event attracted 250 visitors, with approximately 50 people interacting directly with the mirror frame, another 100 people watching and interacting briefly as they walked past allowing us to observe how the interactive mirror worked in a public performance context, with larger audiences. People coming past the installation were at first seen peering at their reflections. When a mask appeared overlaid on the reflection of their heads, visitors moved about so that the mask moved from head to head between them. Once the visitors recognised what was happening, they began to play with passing the masks between their reflections. We observed several couples



who moved towards the frame slowly and tried to 'catch' the mask onto their heads.

People appeared to walk deliberately and tentatively towards the doorway with the mirror, as if they were walking down a path towards an unknown place. They moved backwards and forwards through the doorway in front of the mirror frame, playing with the architectural layout of the space in the real world, its reflections in the mirror space as well as the distance between their bodies and the screen. They were also seen moving, as if dancing side to side, this movement aided them to achieve different views of the real world environment, the reflections and the digital content (particularly the images of different landscapes such as the sandstone caves and Brazilian landscape), which were tracked to their body movement (as with Exploration 1). Other participants were seen to be walking past the mirror on their way to somewhere else in the building and briefly stopping to interact, particularly when Samba music was playing and images of dancing feet floated across their reflections, inspiring some people to deliberately join in the dance, watching their own dancing reflections merge with the dancing feet in the mirror. At one point (as with Exploration 3) a sandstone rock appeared in the mirror tracked to the centre of the participant's body. Many people again were observed reaching out to touch this object and to try and hold it. This was also encouraged by the narrative of the soundtrack, inviting them to 'feel the shape of it'.

### 5.5 Further explorations in the lab

These public events highlighted the potential effect of the environment where the mirror was placed on the entire experience to extend the performative mirror space, which warranted further exploration in a lab environment. In particular, the placement of the mirror frame in front of the doorway prompted us to think more about what is being reflected at different scales – closely surrounding the mirror, directly behind the participant and in the background or far distance of the mirror's reflection. The following explorations investigated this in more detail.

*Exploration 10:* To explore the influence of the background behind the mirror further, we added a large digital screen behind the participant (in front of the mirror), to control what would be reflected as background. Broadly, we tried the effects of displaying videos of different landscapes and then different artefacts. The background environments appearing to the participant to float behind them in their reflection in the central mirror,

allowed the experience to be transported to yet another place. In contrast, the strongest effects of displayed objects was how they appeared in the non-interactive mirror overlaid with the participants reflection, observed to be creating tricks of the eye, such as the impression that they were sitting on their shoulder.



**Figure. 13 Digital and real objects on an equidistant plane**

*Exploration 11:* The reflections of the doorway at the arts centre and the way participants walked through it to stand and 'perform' in front of the mirror anchored the experience in its location, appearing roughly at the same distance from the front of the mirror as the screen did from the back. In the lab we explored how participants moved through this 'equidistance plane' by deliberately placing multiple objects next to people so that they would appear next to their reflections, replicating the strong sense of this merging of realities within the mirror space.

## 6 THE EXTENDED MIRROR SPACE: SETTING THE STAGE

As highlighted throughout, a whole variety of interactive mirror technologies have been proposed to date. While integrations of such techniques have been discussed, most notably in [4], the performative context has not been systematically outlined. Drawing on the literature and our collaborative process, combining artistic and interactional explorations now allows us to begin the discussion of our work by describing and illustrating the emerging, extended mirror interaction space, as it is relevant for performance.

Each of our 11 explorations used semi-transparent mirrors as the central, interactive surface in front of a digital screen. The properties of the semi-transparent mirrors mean that only a proportion of the light available on the



### Mirror Space Explorations 1-11 in their Development Context

<p><b>1:</b> Display image of physical surroundings that is different from the actual surroundings.</p> <p><i>Parts of physical surroundings seem to disappear in the experience. People turning to check what they see in front of them and what is there behind them.</i></p>	<p><b>2:</b> Display a bright digital object on screen. Track that object with their head.</p> <p><i>Parts of the participant's body are transformed by digital content. People moving their bodies to explore the relationship of reflected body and virtual body.</i></p>	<p><b>3:</b> Increased distance between mirror and digital screen, which displays digital object.</p> <p><i>The digital object floating in 3D space. People reaching out towards the object, attempting to hold it</i></p>	<p><b>4:</b> A physical mask in front of a person's body is augmented with a digital mask on the screen.</p> <p><i>An overlay of body reflection, physical mask reflection and digital mask depiction. People tracked the physical mask and the system tracked that placing the digital mask.</i></p>
Yellow circle on screen   Fig 2	Blue Mask on screen   Fig 2	Distance mirror - screen   Fig 3	White physical mask   Fig 4

**Figure 14. Abstracted Mirror Interaction Space (Explorations shown are numbered in the figure)**

<p><b>5:</b> A small distance between screen and mirror (rather than no space at all).</p> <p><i>People explored the equidistance effect on a more intimate scale: getting very close, peering inside and making small head movements.</i></p>	<p><b>6:</b> Two mirrors, one interactive and one not. Flexible angle between those two mirrors.</p> <p><i>Flexibility in what is mirrored and multiple reflections related to each other: bringing together parts of the environments that do not appear together otherwise.</i></p>	<p><b>7:</b> The mirror in different surroundings, minimising the influence of digital display.</p> <p><i>The surroundings are foregrounded. The surroundings determine the experience.</i></p>	<p><b>8:</b> Multiple non-interactive mirrors pointing up/down, left/right.</p> <p><i>People seeing parts of the surroundings that do not appear in a flat mirror. Breaking people's expectations as only one mirror includes digital content.</i></p>
Not shown in graphic	Left hand mirror   Fig 6	Not shown in graphic   Fig 7	Nine mirror segments   Fig 11
<p><b>9:</b> Increased distance between mirror and screen: equidistance participants   mirror   screen.</p> <p><i>People moving forward and backward create the illusion of moving through digital objects on screen.</i></p>	<p><b>10:</b> Placement of digital screen in front of the mirror, allowing dynamic displays of content.</p> <p><i>Body augmentations appearing in non-interactive mirrors and background scenery interacting with reflections and digital content.</i></p>	<p><b>11:</b> Physical objects placed in the equidistant plane.</p> <p><i>Objects physically next to people appear next to their reflections. People can move in relation to physical objects. Providing a strong location anchor, especially when digital objects also appear.</i></p>	
Distance mirror - screen   Fig 12	Orange background	Red ball next to participant   Fig 13	

mirrored side is reflected and some light is transmitted from the other side. For the effect to work, there has to be a difference in light levels in the spaces separated by the mirror, the mirrored side being well lit, and the other side being comparatively darker. The virtual image of an object in front of the mirror appears at a location equidistant on the other side. The abstracted graphic below illustrates how an extended mirror space can be created when combining these effects. In the graphic, we make reference to each of the explorations that were conducted as part of our process. In this diagram a semi-transparent mirror divides an abstracted rectangular volume into two equal parts. The right hand part is kept dark. The left hand part is lit. An LCD screen is located in the darkened area at a distance behind the mirror and this is used to display the main interactive content. A secondary digital display is projected on the back wall in the well-lit room and can be used to display contextual visuals. Participants can freely move about in the left hand side of the room, while they cannot enter the right hand-side. The participant is surrounded by physical objects that they can physically interact with (e.g. move, wear). When looking towards the mirror, participants are seeing a multi-layering of reflections (virtual images of physical objects, people (themselves) and physical objects). These appear located in the darkened space alongside with whatever is displayed on the LCD screen. The participant's distance from the half-silvered mirror determines their spatial relationship to the elements appearing in that montage, and they can 'move through' the physical and reflected content by their movements in the real world.

As one example of what can be achieved, one particular performative situation is depicted. The person on the left located at Phy B looks at the half-silvered mirror. They are sufficiently lit to appear in the mirror. To them, their reflection appears at an equidistant location on the other side, at Vir B. The red physical object that is placed beside them appears beside them in their reflection, as it is located at the same distance from the mirror. The green object placed behind them, also appears behind them in their reflection. The digital image on the back wall screen behind the participant appears to surround them - appearing at the virtual back wall.

The digital screen located on the right has been placed at the virtual equidistance plane, so that objects displayed on it, appear next to the reflections of the physical side. This creates the illusion of people, physical and displayed objects appearing in the same place. Projected on the back

wall, the graphics appear to surround the participant in their reflection. Changing the lighting on the person and physical objects makes them appear and disappear in the reflection and the same applies to varying the brightness of the images on the screen and back wall. The equidistance planes become staging places for physical objects to be placed (as with the doorway at the arts centre) and for virtual objects to appear on the digital screen.

## 7 THE PERFORMATIVE MIRROR SPACE

When we look into a mirror, our experiences of 'self and other' literally come into 'play'. Our engagement with the mirrors' reflection is not simply a moment of self-recognition, but also a moment of connecting our selves with the world in that specific context, including how we respond to other people, objects or movements reflected in the mirror. Much of the previous work on interactive mirrors focuses on the technical strategies for creating illusions and different forms of physical interactions within mirror spaces. Comparatively little is understood about how to put these strategies to performative use, while designing technology for performativity has been explored in other contexts, for example in [38], which details strategies to encourage participation, the importance of context and in-situ developments and the potential for transitions between different performance frames. This work does not consider the importance of narratives across specific mixed realities spaces, including interactive mirror spaces, however. In what follows, we detail six performative design strategies that emerge specifically around the use of interactive mirrors focusing on the role of *physical context*, *movement* and *narrative*.

### 7.1 Inclusion of physical context

While the importance of use context is well established in HCI [38, 39], mirrors come with their own interactional challenges, such as the key components of light and distance [4]. As mirrors reflect the physical space, objects and actions around them, context becomes an unavoidable element of any interactions with the mirror. In our work this has led to challenges and opportunities, revealing the importance of place in terms of architecture, time of day, other people and objects, and light and distance.

#### (1) Develop in and embed the physical context

Our work, e.g. shown in exploration 9, demonstrates how the architecture of the place where the mirror is situated

becomes a key element of the performative mirror space. Here, the doorframe and opposite building were reflected in the multiple mirrors that made up the mirror frame installation. At the beginning of the experience an image of the building opposite at an earlier (lighter) time of day appeared within the central mirror, thus playing with the user's sense of time and place.

Considerations of the place, time and physical context of where and how the mirror is placed are fundamental to the design of the interactions. The explored effects would have been very difficult to predict and choreograph through sketches and drawings, or rehearse in a lab context, making developments in the place where the performance is due to occur vital. This requires physical prototypes with mirrors that can easily be fixed in place, oriented and relocated, allowing the free exploration of views generated by audience members and performers. In this way, moving beyond the technical focus on creating illusions, practitioners and researchers need to deeply embed interactive mirror spaces into the places that they are created for.

### ***(2) Multiple mirrors, topologies and transitions***

In our explorations multiple spaces were linked into the experience, and the mirror space acted as a 'doorway' to another mixed reality space created within the mirror. The narrative acted partly as pointer back to the real world, and to suggest another distant place in Brazil through the appearance of the masks, the soundtrack and the questions that appeared written on paper (Figure 10).

Moving beyond the focus on a single mirror surface and setting and working with these wider topological contexts - of multiple physical, mirrored and virtual spaces - allows practitioner and researchers to create multi-layered narratives across a mixed-reality network of spaces. This can either inform a larger promenade performance [40] (as with the suitcase) or create a site-specific performance contained within the mirror space (as with the frame). By extension, this work will involve multiple mirrors often in proximity to each other, where mirrored views are even harder to predict. Creating work in this space, one needs to consider multiple mirrors, multiple associated mixed reality spaces and the possible transitions between them.

## **7.2 Working with Movement**

Plascencia et al. [4] describe in depth how to technically create a series of illusions across the mirror space. Yet, throughout this work the hand movements and wider presence of the users is described as another 'object'

within the display. Our explorations emphasise whole body movements and how these become performances both for the performer to experience as reflections of themselves, and for others to watch and interact with.

### ***(3) Working with body movements and viewpoints***

The importance of movement to the ways that the performative mirror space was constructed was also reflected in our explorations; in the ways that multiple visitors interacted with each other by passing masks between each others faces, whilst others also watched from afar. It was also reflected in the way that people reached out to 'feel the shape' of the rock in the public event (exploration 9), considering how users might move to perform in response to these objects.

How to best create such illusions can be illustrated by returning to Fig.14. Moving between Phy A and Phy C results in the person's reflection moving between Vir A and Vir C. When the screen and physical objects remain stationary, it appears to the participant as if they were moving through the objects. Graphics displayed on the screen on the right hand side can appear in front, behind and inside participants from their perspective. Specifically designing for the effects of the viewers' movements is essential to the use of interactive mirrors in performance. While it cannot be controlled, designing for play with a person's viewpoint, body movements and use of props (not just their hands) are central to the interaction.

### ***(4) Working with moving mirrors***

Another way in which this interactional topology can become adaptive involves the movement of elements of the mirror, or the mirror itself. The suitcase mirror allowed for playful, intimate and flexible interactions, as its location and orientation could easily be changed and what is reflected of its environment was highly adaptive. While the movement of the actual mirror-spaces by performers can be choreographed, those by audience members become less predictable and explorative as shown first by the suitcase test in Brazil and then by the suitcase mirror event in the UK.

This strategy can be used to make the performative mirror space into a dynamic part of a wider performance, which is handed over to the performers and audience members as part of an embodied experience of performing in and with the mirror space, in comparison to [10]. The mirror suitcase has the potential to move to different places and contexts, requiring an even greater flexibility of both the physical and interactive design of the mirror. This allows

the performative mirror space to be revealed whenever and wherever the suitcase is opened.

### 7.3 The role of narrative

Narratives, across each of the explorations, invited the users movements to be transformed into performative acts that in turn weaved the objects and environments in the virtual world (the digital content) and the real world (the physical context) together. This created a coherent performance experience within the mirror space that suspends disbelief - beyond the trick of an illusion.

#### *(5) Spectacle of the self*

In 1967 DeBord declared society was increasingly becoming a spectacle or performed representation of our social lives [41]. Much has been said since about how the 'spectacle' of our lives has increased with the emergence of interactive and ubiquitous technologies, particularly in reference to selfie culture, snapchat and other forms of social media [42]. In the case of interactive mirror technology the 'user' is transformed into a 'performer' through their interactions within the narrative context of the mirror space. An example can be seen here with the role of the masks in both versions of the mirror that enabled the audience to dress up in the real world (as with exploration 4) and the virtual world as a way of building visual and embodied performative narratives around the users interactions

Practitioners and researchers can draw on these forms of 'dressing up' and other ways to transform the reflection of the self, which has been shown to be an effective way to engage users in other interactive and reflective experiences such as photo booths, photo apps [8,16] and interactive mirrors used for health and beauty applications [15]. Designing for the transformation of the reflection of the user allows people to enter into a role or alternative version of themselves and therefore 'perform narratives' in this role.

#### *(6) Suspension of disbelief and the performance frame*

Mirrors have been used universally in fairy tales, myths and as theatrical devices to represent doorways to other places, for remotely viewing someone in another place and or time, reading the future, and then finding out what is on the other side. These narratives are typified by the classic British children's book *Alice Through the Looking Glass* [43] but are also found all over the world – from the European folk tale of *Snow White*, to the Brazilian myth of *Vitoria Regia* and the Japanese stories of the *Mirror of Matsuyama* [27,44]. The design of the narrative and

performative elements of both the Suitcase mirror and the Mirror Frame relied on these universal narratives to suspend the audience's disbelief and draw them into the performative experience of the interactions within the mirror space, played out through a combination of visual images, illusion, audio narratives and song designed to draw audiences into walking towards both the mirror in the suitcase and the Mirror Frame,

Creating the performance frame around the interactive mirror space is a key device to encourage interaction, get participants to reveal another world within the mirror and join other people who are part of the displayed narrative. Integrating narratives that encourage participants to play with the mirror space itself as well as props, in particular the masks, enables them to explore their awareness of themselves and others and encourage them to be less inhibited [45] as shown in these explorations by the participant's movements in front of the mirror, playing with the masks and sometimes even dancing and singing in response to the digital content. By employing these narrative devices designed to take the audience on a journey to another place and time, the audience is able to initiate their own performative and narrative engagements within the interactive mirror space

## 8 CONCLUSION

Drawing on the extensive artistic exploratory process described in this paper, we have illustrated how the abstracted interactive mirror space that provides the background for performative work to occur is created. Practitioners in the performance art, theatre and museum sectors can directly make use of these illustrations to set the stage for performances with and within interactive mirror spaces, making this technology-focused knowledge directly accessible to that audience. With this background in place, we then provided six concrete design strategies that HCI experts in research and industry, who already understand interactive mirror technologies well, can draw on. By engaging with the physical context, movements and narrative as an integral part of the design, the interactive mirror is transformed into more than an illusionary trick. As shown in our work, the performative mirror space can weave interactions together into a coherent and meaningful experience that is embodied by the user as a performer within it.

## ACKNOWLEDGMENTS

We would like to thank all our workshop participants and the Flor de Pequí collective at Guaimbê, Pirenópolis and the Fundo



de Arte Goias (Brazil). This work has been supported by the University of Nottingham through the Nottingham Research Fellowship ‘The Built Environment as the Interface to Personal Data’ and by the UK Engineering and Physical Sciences Research Council (EPSRC) through the grants ‘Living with Digital Ubiquity (EP/M000877/1)’ and the ‘EPSRC Centre for Doctoral Training in My Life in Data (EP/L015463/1)’.

## REFERENCES

- [1] Steve Benford, and Gabriela Giannachi. 2011. *Performing mixed reality*. MIT Press.
- [2] Carl DiSalvo, Kirsten Boehner, Nicholas A. Knouf and Phoebe Sengers. 2009. Nourishing the Ground for Sustainable HCI: Considerations from Ecologically Engaged Art. CHI '09: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM Press, 385-394.
- [3] Rachel Jacobs, Steve Benford, Mark Selby, Michael Golembewski, Dominic Price and Gabriella Giannachi. 2013. A conversation between trees: what data feels like in the forest. In: CHI '13: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 129-138.
- [4] Martinez Plasencia, Diego, Florent Berthaut, Abhijit Karnik, and Sriram Subramanian. 2014. Through the combining glass. In Proceedings of the 27th annual ACM symposium on User interface software and technology, 341-350.
- [5] Chueh Min Cheng, Meng Fang Chung, Ming Ouhyoung Yu, Ouhyoung, Hao-Hua Chu an Yung Yu Chuang. 2008. Chromirror: a real-time interactive mirror for chromatic and color-harmonic dressing. In CHI'08 extended abstracts on Human factors in computing systems, 2787-2792.
- [6] Daniel Saakes, Yeo Hui-Shyong, Noh Seung-Tak, Han Gyeol, and Woo Woontack. 2016. Mirror mirror: An on-body t-shirt design system. In Proceedings of the CHI Conference. Human Factors in Computing Systems, 6058-6063.
- [7] ASM Mahfujur Rahman, Thomas T. Tran, Sk Alamgir Hossain, and Abdulmotaieb El Saddik. 2010. Augmented rendering of makeup features in a smart interactive mirror system for decision support in cosmetic products selection. In Distributed Simulation and Real Time Applications (DS-RT). IEEE/ACM 14th International Symposium, 203-206.
- [8] Ana Javornik, Yvonne Rogers, Ana Maria Moutinho, Russell Freeman. 2016. Revealing the Shopper Experience of Using a "Magic Mirror" Augmented Reality Make-Up Application. In Conference on Designing Interactive Systems. Vol. 2016, 871-882.
- [9] Lucía Vera, Jesús Gimeno, Inmaculada Coma, Marcos Fernández. 2011. Augmented mirror: interactive augmented reality system based on Kinect. In IFIP Conference on Human-Computer Interaction, 483-486.
- [10] Fraser Anderson, Tovi Grossman, Justin Matejka and George Fitzmaurice. 2013. YouMove: enhancing movement training with an augmented reality mirror. In Proceedings of the 26th annual ACM symposium on User interface software and technology, 311-320.
- [11] Microsoft Research Labs. 2012. Hololector Retrieved Monday 8, 2012. <https://www.microsoft.com/en-us/research/video/hololector/>
- [12] Carlos Hitochi Morimoto. 2001. Interactive digital mirror. In Computer Graphics and Image Processing. Proceedings of XIV Brazilian Symposium, 232-236.
- [13] Kaori Fujinami, Fahim Kawsar, Tatsuo Nakajima. 2005. AwareMirror: A Personalized Display Using a Mirror. In International Conference on Pervasive Computing, 315-332.
- [14] Holger T. Regenbrecht, Elizabeth A. Franz, Graham McGregor, Brian G. Dixon, Simon Hoermann. 2011. Beyond the looking glass: Fooling the brain with the augmented mirror box. Presence: Teleoper. Virtual Environ. 20 (6).
- [15] Ming-Zher Poh, Daniel McDuff, Rosalind Picard. 2011. A medical mirror for non-contact health monitoring. In ACM SIGGRAPH. Emerging Technologies, Article 2.
- [16] Ana Javornik, Yvonne Rogers, Delia Gander, Ana Moutinho. 2017. MagicFace: Stepping into Character through an Augmented Reality Mirror. In Proceedings of the 2017 CHI Conference on Human Factors in Computing, Systems, 4838-4849.
- [17] Kim, Hanyuool, Issei Takahashi, Hiroki Yamamoto, Satoshi Maekawa, and Takeshi Naemura. 2013. MARIO: Mid-Air Augmented Reality Interaction with Objects. Entertainment Computing, 5 (4).
- [18] D. J. O'farrell, R. L. Veldman, K. Schofield, inventors. 1998. Vehicle mirror digital network and dynamically interactive mirror system. Donnelly Corporation, assignee.
- [19] Keita Ushida, Yu Tanaka, Takeshi Naemura, Hiroshi Harashima. 2002. I-mirror: An Interaction/Information Environment Based on a Mirror Metaphor Aiming to Install into Our Life Space. In Proceedings of the 12th International Conference on Artificial Reality and Telexistence (ICAT 2002), 113-118.
- [20] Manfred Pfister, 1991. *The theory and analysis of drama*. Cambridge University Press.
- [21] Janet Cardiff. 1999. In Real Time. Retrieved 18 September 2017 from <http://cardiffmiller.com/artworks/walks/realtime.html>
- [22] Paul Sermon. 1992. Telematic Dreaming. Retrieved 18 September 2017 from <http://www.paulsermon.org/dream/>
- [23] Gabriela Giannachi. 2004. *Virtual theatres: an introduction*. Routledge.
- [24] Gabriela Giannachi, Nick Kaye, Michael Shanks (Eds.). 2012. *Archaeologies of presence: Art, performance and the persistence of being*. Routledge.
- [25] Miwon Kwon. 2004. *One place after another: Site-specific art and locational identity*. MIT press.
- [26] Joslin McKinney, Philip Butterworth. 2009. *The Cambridge introduction to scenography*. Cambridge University Press.
- [27] Angela Carter (ed.). 1993. *The Second Virago Book of Fairy Tales*, Virago Press.
- [28] Peter Pichler. 2014. The Mirror Houses. Retrieved on 21 Sept 2018, [https://www.archdaily.com/577551/the-mirror-houses-peter-pichler-architecture?ad\\_medium=gallery](https://www.archdaily.com/577551/the-mirror-houses-peter-pichler-architecture?ad_medium=gallery)
- [29] Kurt Kohlstedt. 2016. Mirrored Street Facade Art Turns Pedestrians into Acrobats. Retrieved on March 10 2018 from <http://weburbanist.com/2013/01/27/mirrored-street-facade-art-turns-pedestrians-into-acrobats/>
- [30] Jacques Lacan. 1949. The mirror stage as formative of the function of the I as revealed in psychoanalytic experience. In *Reading French Psychoanalysis*. Routledge, 119-126.
- [31] Phillipe Rochat. 2003. Five levels of self-awareness as they unfold early in life. *Consciousness and cognition*, 12 (4), 717-731.
- [32] Erwin Goffman. 1959. *The presentation of self in everyday life*. Garden City.
- [33] Rachel Jacobs and Silvia Leal. 2018. Digital participation through artistic data interventions. In Michael Dezuanni, Marcus Foth, Kerry Mallan and Hilary Hughes. *Digital Participation through Social Living Labs: Valuing Local Knowledge, Enhancing Engagement*. Elsevier.
- [34] Robyn Taylor, Guy Schofield, John Shearer, Jayne Wallace, Peter Wright, Pierre Boulanger, Patrick Olivier. 2011. Designing from within: humanaquarium. In: 29th Annual Conference on Human Factors in Computing Systems (CHI).
- [35] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative research in psychology*, 3 (2), 77-101.

- [36] Ricardo Basbaum. 2001. *Arte Contemporânea Brasileira: texturas, dicções, ficções, estratégias*. Marca d'Água Livraria e Editora Ltda.
- [37] Glória Ferriera, Cecilia Cotrim. 2006. *Escritos de Artistas*. Rio de Janeiro: Zahar
- [38] Jennifer G. Sheridan, Nick Bryan-Kinns. 2008. Designing for Performative Tangible Interaction. *International Journal of Arts and Technology*. Special Issue on Tangible and Embedded Interaction.
- [39] Lucy Suchman. 1987. *Plans and Situated Actions: The Problem of Human-machine Communication*. Cambridge University Press.
- [40] Antonia Wilson. 2015. The Drowned Man: An interview with immersive theatre masters Punchdrunk. Creative Review. Retrieved 18 September 2017 <https://www.creativereview.co.uk/the-drowned-man-an-interview-with-immersive-theatre-masters-punchdrunk/>
- [41] Guy Debord. 1992. *La Societe du Spectacle*, Edition Gallimard, Paris.
- [42] Yongjun Sung, Lee Jung-Ah, Kim Eunice, Marina Choi Sejung. 2016. Why we post selfies: Understanding motivations for posting pictures of oneself. *Personality and Individual Differences* 97, 260-265.
- [43] Lewis Carroll. 1865. *Alice's Adventures in Wonderland*, Macmillian.
- [44] F. Hadland Davis. 1917. *Myths and Legends of Japan*. Dover Publications
- [45] Paloma Alarcó and Malcolm Warner. 2007. *The mirror & the mask: portraiture in the age of Picasso*. Yale University Press.