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THREE-DIMENTIONAL PANEL ARRANGEMENTS IN AUGMENTED, VIRTUAL AND MIXED REALITY COMICS

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Abstract

Digital comics are commonly read on the screens of smartphones, tablets and personal computers. The popularity and widespread adoption of these devices have driven the development of apps, games and experiences utilising augmented, virtual and mixed reality technology. Alongside this rise in popularity, the digital mediation and hybridisation of the form of comics have allowed for the creation of comic formats designed to be read and navigated in three dimensions via these technologies.

This article provides a practice-based examination of the use of three-dimensional panel arrangements within digitally mediated comics. Case studies are provided from a range of prototypes that were created by the authors to explore the use of augmented, virtual and mixed reality in digital comic delivery. The design and analysis of these prototypes draws on existing theory and practice established around comics and their mediation in print, digital and architectural formats.

The article considers the use of tropes appropriated from the architectural and digital mediation of the comics' form. It highlights the ways in which narrative effect can be created by the relative position in three-dimensional space between reader and panel sequence. The tension between the fixed sequences of comics' narrative and the freeform exploration of three-dimensional space is also examined. Finally, the article examines how spatial depth impacts on the reader's experience of panel sequences and the layout and navigational challenges this raises.

Key words: Comics, Digital Mediation, Virtual Reality, Augmented Reality, Mixed Reality

Introduction

The form of comics began in the medium of print. In this medium, comics operate as an arrangement of simultaneously juxtaposed images on a "two-dimensional page that represents a three-dimensional world" (Kashtan, 2018, p. 182). Today, the form of comics is commonly read both in print and via digital display on the screens of smartphones, tablets and personal computers (Kashtan, 2018). While these screens share the two-dimensional nature of the page, their digital contents are more mutable and "inviting of change" (Murray, 1997, p. 154). The form of comics has gone through a period of change and hybridisation with other digital media, taking in elements of animation, gameplay and multi-cursal narrative (Goodbrey, 2017). At the same time, the widespread adoption of digital display has driven the development of apps and games that provide a more direct, three-dimensional visualisation of the world via augmented, virtual and mixed reality technologies. The growing popularity of these technologies has in turn led to further hybridisation of the comics' form, resulting in the creation of comics specially designed to be read and navigated in three dimensions.

This article provides a practice-based examination of the use of three-dimensional panel arrangements within digitally mediated comics. Case studies are provided from a series of prototype digital comics that make use of aspects of augmented, virtual and mixed reality in their delivery. These prototypes were created during two separate phases of practice-based inquiry, each initiated in response to the announcement of a significant new mixed reality device. Phase one consists of four prototypes created in 2015 in response to the Microsoft HoloLens. Phase two is currently ongoing and consists so far of one, longer-form prototype begun in 2023 in response to the Apple Vision Pro. The design and analysis of the prototypes draws on existing theory and practice established around comics and their mediation in print, digital, and architectural formats. Alongside this, the article also draws on aspects of the study of narrative space within videogames and digital media.

Phase one considers a variety of approaches to three-dimensional panel arrangement that draw on the use of tropes appropriated from the architectural and digital mediation of the comics' form. It explores the potential for the creation of narrative effect through the relative position in space between reader and panel sequence. Tensions are also examined between the fixed sequence of comics' narrative and the freeform progression inherent to three-dimensional space. Phase two builds upon the findings of phase one to consider, in more detail, how spatial depth impacts on the reader's experience of three-dimensional panel sequences and the layout and navigational challenges this raises. Drawing on the study of existing virtual reality comics and two prominent digital comic formats, it proposes a new design approach for mixed reality comics based on a three-dimensional application of the infinite canvas format.

Phase One

In 2015, Microsoft unveiled the HoloLens, described as the world's first "fully untethered, see-through holographic computer" (Godbold, 2015). The headset-based device was billed as enabling "high-definition holograms to come to life in your world, seamlessly integrating with your physical places, spaces, and things." (Godbold, 2015). To better understand the significance of these claims, it is useful to first consider the two related technologies of virtual and augmented reality.

Virtual reality (VR) is generally used to refer to three-dimensional, computer-simulated environments that we might typically view through a VR headset. The experience of depth is usually achieved by twin screens in the headset placed near each eye, with the user's pose and position tracked by the headset and translated into the virtual environment. Wearing a VR device is an act of immersion. The wearer becomes

"surrounded by a completely other reality … that takes over their attention … [and] whole perceptual apparatus" (Murray, 1998, p. 98). In contrast with VR, augmented reality (AR) experiences maintain the user's perceptions of their real-world environment. However, when this environment is viewed through an AR device such as a smartphone, it becomes augmented by additional computer-generated elements to present a combination of "real and virtual information" (Yoon, 2014, p. 7). The AR device maps the real world seen in the video feed and tracks its position and orientation relative to this view. Using this information, additional elements are overlayed on the live video footage to appear integrated into the view of the world presented on the screen.

By 2015, both virtual and augmented reality were starting to become established as consumer technologies. VR was still the more niche of the two, typically requiring an expensive headset tethered to a powerful personal computer to run. In contrast, AR could be experienced relatively easily, with apps available for many smartphones that allowed users to see an augmented view of the world via the phone's built-in camera and screen. With the introduction of the HoloLens, Microsoft were proposing a device that essentially merged aspects of VR and AR technology. The HoloLens could be worn like a VR headset that tracked the wearer's pose, position and view. But rather than use this information to immerse the wearer in a virtual world, it instead immersed them in an augmented view of the real world. The resulting mixed reality (MR) view provides the user with a much more seamless and immersive integration of computer-generated imagery and real-world surroundings.

It was the potential of the HoloLens as a device capable of enabling immersive MR experiences that first caught the attention of Daniel Goodbrey as a comic creator. At the time, Goodbrey had two major foci for his comics research and practice. The first concerned the ways in which the ongoing digital mediation and hybridisation of comics impacted on the key characteristics the form's operation (Goodbrey, 2017). While the second examined the challenges of architectural spatiality found in comics created as three-dimensional, gallery-based art installations (Goodbrey, 2016). The possibilities of an MR comic presented an irresistible merging of these two areas of focus that proved too enticing to avoid exploring in further depth.

The first phase of this exploration began as a practice-based research collaboration within the University of Hertfordshire's Games and Visual Effects Research Lab (GVERL). Joining Goodbrey on the project were fellow GVERL members, David Tree and Doros Polydorou. Goodbrey acted as the comic artist and writer on the project, while Tree contributed 3D modelling and VR development skills, and Polydorou brought in expertise in AR and 3D projection for live performance. Together, the team created a series of four experimental prototype comics over a period of months in 2015. Although never made available to a wider audience, the internal testing of these prototypes amongst the design team allowed for valuable developmental insight to be gained. While the catalyst for the project had been Microsoft's announcement of the HoloLens, the device itself was not widely released until a year later in 2016. As such, the GVERL prototypes were developed using pre-existing AR and VR technology. This allowed for the testing of a range of different approaches and techniques that in the future could be applied to the creation of MR comics.

Before discussing each of the prototypes in greater detail, it's useful to consider some fundamentals of what a comic is and how it operates. In Goodbrey's prior research he identified a model for the form of comics that drew upon the work of a range of major scholars in the field (Cohn, 2013; Groensteen, 1999/2007; Hatfield, 2009; Hague, 2014; McCloud, 1993; Miodrag, 2013). The model identifies seven key characteristics of the form. These can be summarised as:

1. Space as time. Comics use arrangements of images in space to represent arrangements of moments or events in time;
2. Simultaneous juxtaposition of images. Comics place images in spatial juxtaposition to each other, such that two or more images may be viewed simultaneously by the reader;
3. Closure between images. The reader of a comic derives time, meaning, and motion out of sequences of static, juxtaposed images through the process of closure;
4. Spatial networks. Sequences of images form part of a larger spatial network of narrative and aesthetic interrelations that exists between all the elements in a comic;
5. Reader control of pacing. The pace at which the reader absorbs the information in a comic is controlled by the reader and determined by the pace at which they read and navigate the comic;
6. Tablodic images. The images in comics exhibit qualities of the tableau, in that they are deliberately composed, framed, and illustrated to represent key moments of narrative meaning;
7. Word and image blending. Although sometimes wordless, comics typically use a blend of words and images in spatial juxtaposition to convey meaning to the reader (Goodbrey, 2017).

The model provides a conceptual division of what are often overlapping and interconnected processes. It is not intended as an exhaustive list, and not all instances of the comics' form will necessarily display all seven characteristics. Indeed, different formats of comics across print and digital media can often be found to place each of these characteristics into greater or lesser emphasis. However, each of the four GVERL prototype comics were designed to deliberately incorporate all seven key characteristics. This enabled us to better examine any potential tensions in the usual operation of the form that might be introduced by the incorporation of augmented and virtual reality elements.

A typical print or digital comic features panels arranged on flat, two-dimensional planes. The artwork contained in each panel is similarly 'flat' and two-dimensional, although may often create an illusion of three dimensions within the depicted story world (Gavaler, 2022). An illusion of depth is not limited only to a panel's contents but may also be present in the depictions of the panels themselves. Gavaler (2022) notes that panels may be illustrated to "appear to overlap or rest atop the background of another image" creating a sense of "pseudo-depth" in panel compositions (p. 64). In contrast to these illustrative approaches that create pseudo-depth, MR comics allow for a simulation of actual spatial depth between panels, via the use of three-dimensional panel arrangements. Consideration of the ways in which such arrangements might problematise the usual reading and navigation of a comic quickly became a central element of our research. Alongside this sat a drive to explore the potential for AR and VR approaches to introduce new storytelling tools capable of operating successfully alongside the pre-existing characteristics of the form.

The first of the comics introduces the protagonist that would go on to feature in all four of the prototypes. This was Jack Fighter, a pulp-influenced investigator of the unknown, who was intended to provide a humorous connective thread through each of our experiments. The first comic, *Jack Fighter Versus Dreams Themselves* (GVERL, 2015a), begins with an introductory text that would also reappear with minor variations across each of the subsequent comics: "Through years of vigorous training, Jack Fighter honed his mind to journey beyond the bounds of space and time! Now Jack explores the very edges of reality, as he plumbs the depths of dreams themselves!" (GVERL, 2015a)

Dreams made use of a traditional print comics page laid out in a nine-panel grid (Figure 1) with AR then used to extend the sequence of panels off the page and into a simple

Figure 1 *Page Layout from Jack Fighter Versus Dreams Themselves (GVERL, 2015a)*

three-dimensional panel layout. At the time of the comic's creation, AR was already in use with other printed forms (Kashtan, 2018, p. 139) and beginning to see some use with comics. However, such uses in comics were primarily to provide "ancillary and/or Easter egg" information rather than elements "crucial or necessary" to the narrative (Yoon, 2014, p. 11). The aim with our prototype was to explore incorporation of augmented three-dimensional elements directly into both the comics' form and narrative. To read and interact with the AR elements of *Dreams*, the page must be placed on a table and viewed through a smartphone running an AR app. A QR code in the top left corner of the comic is used by the AR app to load the data associated with the page and then the page itself acts as a registry image which the app recognises in order to sync the 3D panel layout to the correct location on the physical page (Figure 2).

The comic's narrative features Jack Fighter falling asleep during the act of meditation. His dreams are then represented by the AR panel sequence which extends from above the sixth panel on the page. Hague describes the use of a common narrative trope in comics where a character is "presented as having an additional, even metatextual awareness when they come to operate outside of the two-dimensional limits" (2014, p. 56) into which they are bound. In a traditional print comic this might be shown by depicting a character moving outside of their containing panels, with the art and text implying that the character can now see the rest of the page's layout. *Dreams* employs a variation of this trope, with the page representing the two-dimensional reality to which Jack is bound, while the 3D arrangement of panels documents his exploration of a dream state that exists outside of the page.

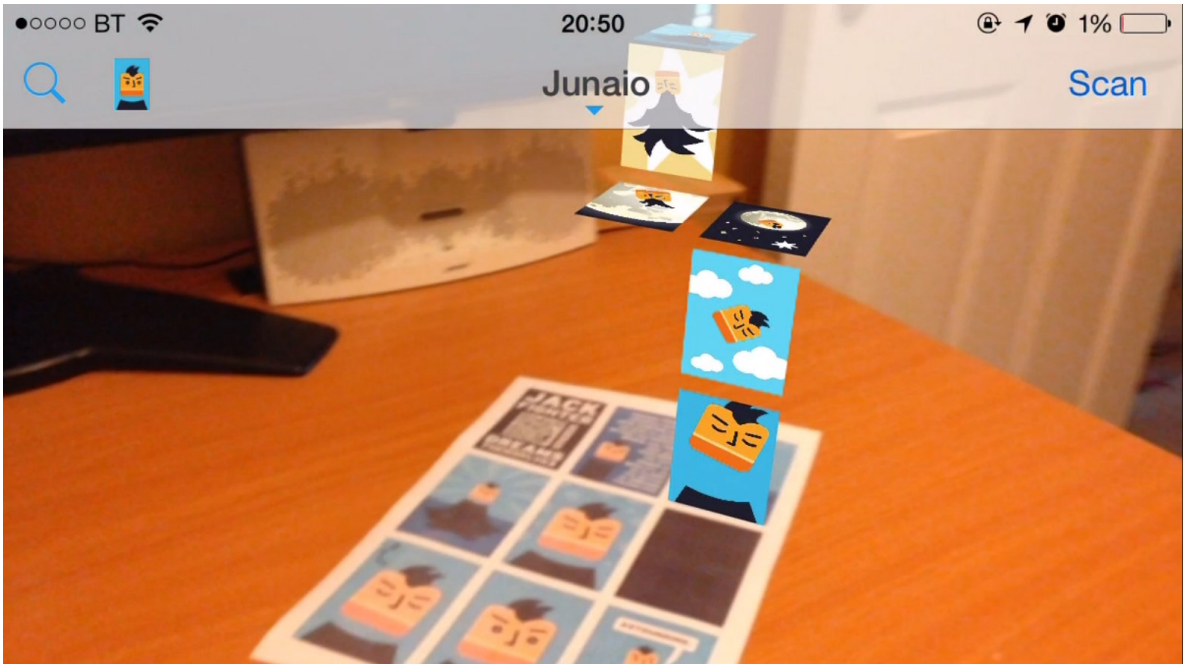

Figure 2 *Screen Capture of an AR Viewing of Jack Fighter Versus Dreams Themselves (GVERL, 2015a)*

Figure 3 *Page Layout from Jack Fighter Versus The Portal Of Mystery (GVERL, 2015b)*

The AR elements of *Dreams* were arranged using the AR development software Metaio Creator and viewed on a smartphone via the associated Junaio AR browser app. An issue we encountered with this software was that because the comic page acted as a registry image for the app, the page had to always remain at least partially visible to the smartphone's camera. If the reader moved the camera fully away from the page to follow the trail of AR panels, all the AR panels would immediately disappear. This imposed limits on how we could arrange the AR panels to ensure they could all be viewed without losing sight of the original page. The relatively small dimensions of the smartphone screen and the need to keep the page in view also necessitated keeping the content of each panel simple enough to be easily understood when viewed at a small size. To achieve this, a highly abstracted cartoon style was employed for the artwork, and the use of word and image blending was restricted to the page and kept absent from the AR panel sequence.

Our second comic, *Jack Fighter Versus The Portal Of Mystery* (GVERL, 2015b), took a similar approach to *Dreams* in its layout and use of AR. The comic is again based on a printed page that features a nine-panel grid, with a QR code in the first panel used by the Junaio app to load the associated AR data. The panels on the page depicted Jack Fighter reaching into a mysterious floating portal that fills the middle panel of the page (Figure 3)

Viewing the page via AR reveals an animated 3D model of an arm extending out of this middle panel, with smaller panels animated to move in circles around the arm (Figure 4).

The use of 3D modelling in *Portal* recalls the use of the way sculptural elements are employed in architecturally mediated comics (Goodbrey, 2017). Architecturally mediated comics, sometimes also referred to as "gallery comics", are a type of art installation in which comics are "made specifically for exhibition" within the physical space of a chosen locale (Gravett, 2013, p. 131). Looking at and reading most traditional print and screen-based comics allows "the mobility of both the object and its spectator" (Hague, 2014, p. 53). In contrast, the fixed position of the comic on the table in *Portal* and the addition of the three-dimensional AR elements imply a more sculptural experience that is "intended for viewing from multiple angles and… cannot be taken in fully without this requirement being met" (Hague, 2014, p. 53).

Figure 4 *Screen Capture of an AR Viewing of Jack Fighter Versus The Portal Of Mystery (GVERL, 2015b)*

The animation of the hand and arm raised some initial debate amongst our team as we considered whether the animation should begin by depicting the movement of the hand as it first emerged from the portal. Ultimately, we decided not to show this moment through animation and instead rely on the reader to infer this moment as having taken place between panels four and five through the process of "closure" (McCloud, 1993, p. 63). Miodrag notes that "time in comics is fictive time" (2013, p. 118). It is a construction by the reader via the process of closure and the reader's interpretation of the spatial arrangement of elements on the page.

The introduction of actual time-based sequences with a fixed beginning and end can potentially be disruptive to these vital reader-derived processes (Groensteen, 2011/2013, p. 70). In *Portals,* we instead opted to use a looped animation of the already-emerged hand, gently swaying and flexing its fingers. This use of looped animation can draw parallels to the use of "polymorphic" panels in print comics that "show a single entity repeated in multiple positions of an action while remaining in a single encapsulated frame" (Cohn, 2010, p. 131). It works in the same way that animation is sometimes employed in digital comics to provide looping moments of time within individual panels that do not conflict with the main flow of time established via the wider spatial arrangement of a comic's panels (Goodbrey 2017).

In our third prototype we wanted to create a larger and more immersive MR experience that would allow us to explore playful approaches to navigating through a comic. *Jack Fighter*

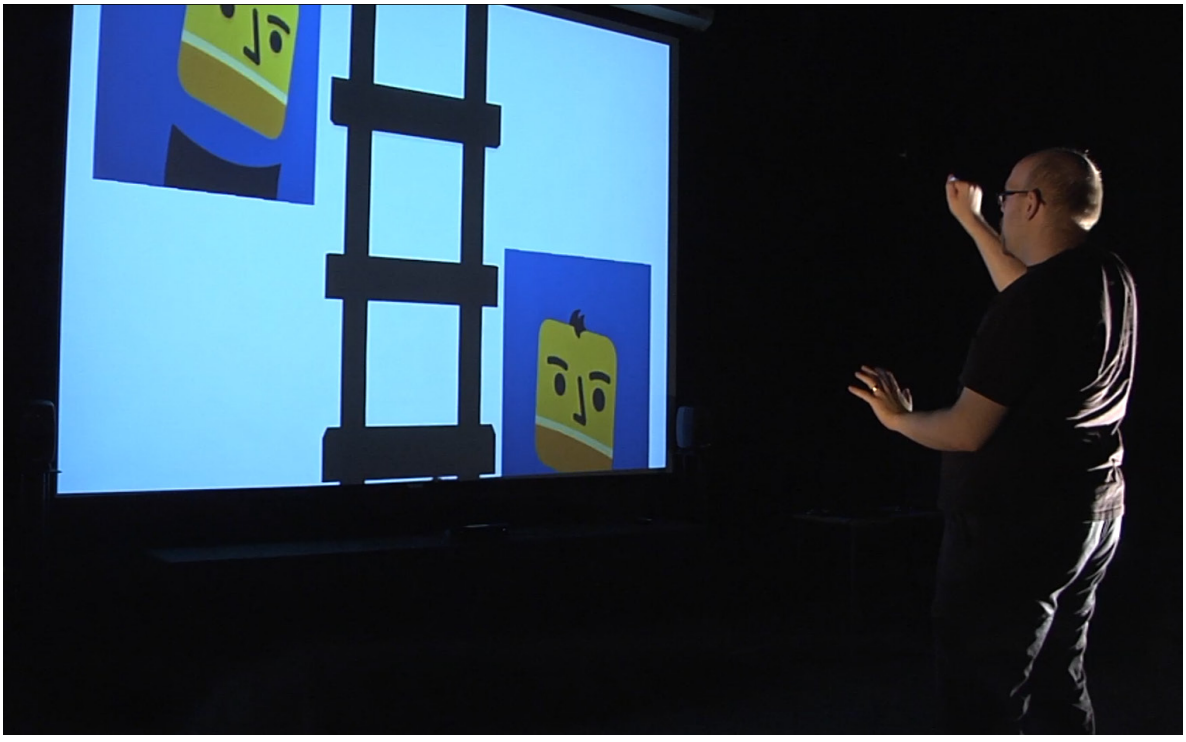

Figure 5 *Screen Capture from a Video of a Reader Navigating Jack Fighter Versus The Ladder Of Time (GVERL, 2015c)*

Versus The Ladder Of Time (GVERL, 2015c) operates as an installation piece, with the comic's panels projected on a large screen in a darkened room. The panels are arranged in two columns and depict a rapidly aging Jack Fighter in the act of travelling through time. In between the two columns is the image of a ladder. The reader stands in front of the screen and moves their hands and arms to mime the act of climbing the ladder. These gestures are captured by a Microsoft Kinect camera and then used to control the reader's progress through the comic, scrolling more of the ladder and more panels down into the projected view (Figure 5). This imparts the impression on the reader that they are climbing up the ladder to read through the comic.

In testing the comic amongst the team, we discovered this approach to navigation quickly became intuitive, providing a satisfying illusion of climbing the ladder to progress through the narrative. Parallels can be drawn between this approach and the use of "visual onomatopoeics" in digital comics, where the animated movement of a panel matches and emphasises the action depicted within the panel (Barber 2002, p. 22). In architecturally mediated comics, visual onomatopoeics can also be seen at work in arrangements of panels that either rise up or descend down a wall (Goodbrey 2016). Events depicted in the panels such as climbing a mountain or falling from a cliff can be mimicked by either the rising or descending of the panel sequence. To read these sequences, a reader must tilt their head to follow the panels downwards or upwards. This physical movement on behalf of the reader reinforces the dramatic nature of the acts depicted within the panels. In *Ladder Of Time*, we see a similar phenomenon that might best be described as gestural onomatopoeics. The navigational gesture of gripping and pulling on each rung of the ladder matches and emphasises the depicted narrative of a ladder being climbed.

It is interesting to note that the impact of the gestural onomatopoeics in *Ladder Of Time* was only successfully felt when climbing up through the comic. Attempts to reverse direction through the narrative and climb back down the ladder felt much less convincing, as descending a ladder is an activity led more by your legs and feet than your hands and arms. We also observed a reader's height to be a factor in their experience of the comic. The scale of the projected ladder felt more convincing for taller readers than shorter readers, who had their sense of climbing the ladder weakened by the need to reach slightly too high to grab each rung of the ladder. Notably, some readers also described repeated climbs of the comic as being physically tiring. This points towards an important consideration for the creation of longer MR comics that may need to factor in the potential for physical fatigue when employing more elaborate gestures as part of their reading and navigation process.

In our fourth prototype we aimed to again develop an immersive experience, focussing this time on the challenges of reading and navigating through more complex three-dimensional panel arrangements. *Jack Fighter Versus The Enigma Of Choice* (GVERL, 2015d) is a VR comic created using the Unreal Engine and designed for viewing via an Oculus Rift DK2 headset. The comic features an arrangement of panels in a corridor-like layout within a featureless white void (Figure 6).

As the reader moves through the void, different sequences of panels can be read by looking either down, up, left or right. The narrative of the comic concerns Jack Fighter's dilemma as to which soft drink he should choose from a vending machine. The choice between "Diet", "Regular" or "eXtreme" (GVERL, 2015d) drinks branches the narrative along three different but similarly disastrous pathways. At the end of the comic these three branches reconverge, and it's revealed that Jack was merely imagining the worst possible outcome of each choice offered by the vending machine. He then opts to instead go and drink a glass of water.

In a more traditional page-based arrangement of a panel sequence, a reader will typically follow a path from panel to

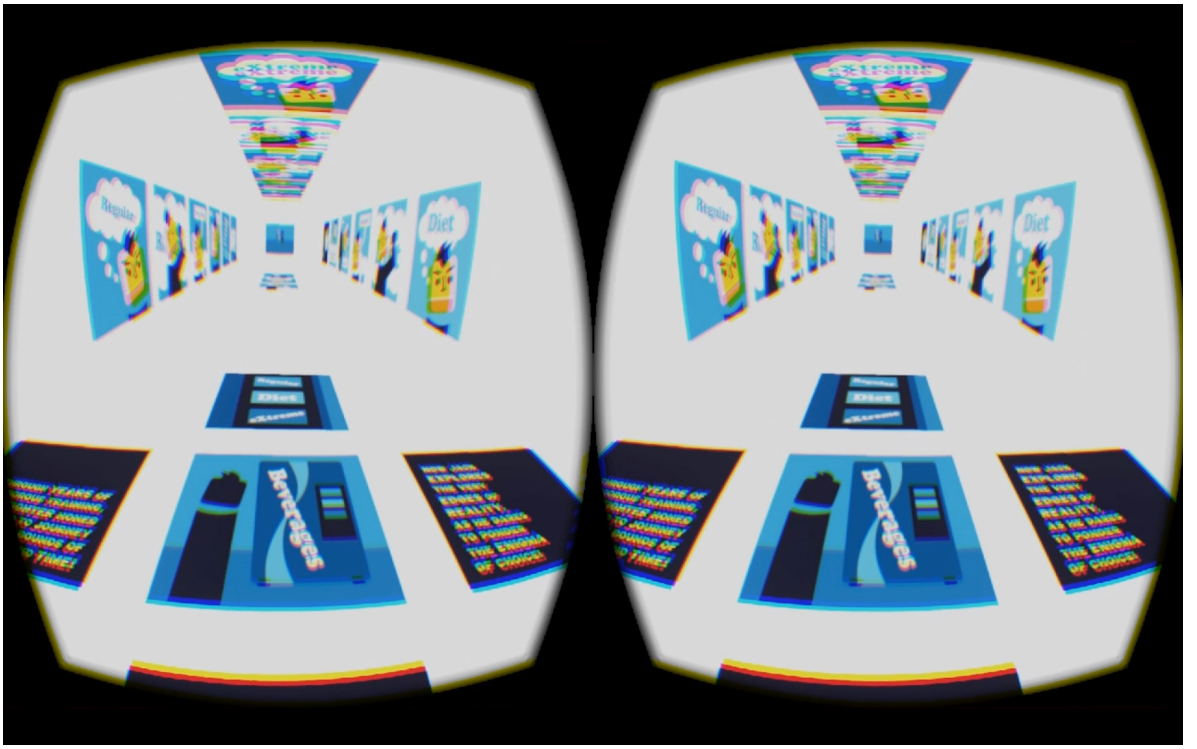

Figure 6 *Screen Capture from VR Headset Showing the Layout of Jack Fighter Versus The Enigma Of Choice (GVERL, 2015d)*

panel through the page that allows them to easily understand the narrative conveyed by the sequence. Nichols describes this path as 'the raster of reading' and notes that while "the raster varies depending on the cultural norms… in western culture it usually runs from left to right, top to bottom across the page" (2013, p. 304). In contrast to this fixed and culturally ingrained reading raster, Nitsche asserts that three-dimensional space "implies the option of a different turn at any moment, a new choice or a different perspective that outweighs traditional nodes and links." (2008, p. 28) For this reason, VR experiences tend to evoke "the viewer's natural tendency to explore" the virtual environment that surrounds them (Waliokar & Remedios, 2023, p. 158). A clear tension therefore exists between the freeform exploration inherent to three-dimensional spaces and the fixed progression dictated by the arrangement of panels in a set reading sequence.

To address this tension in *Enigma*, the compromise we reached was to allow the reader to look around freely but limit their range of movement to a straight line. This line was placed down the middle of the corridor of panels, with the reader able to control their movement forward and backwards along the line via the use of a hand-held game controller. The comic panels in *Enigma* were arranged at a fixed distance from the line of movement, giving us the ability to fine tune the distance at which each panel can be seen and read. The specific placement in space of each branching sequences in relation to the reader then became a point of consideration. In an architecturally mediated comic, "the relative position in space between reader and panel sequence can also be used for narrative effect" (Goodbrey, 2016, p18). We attempted to employ this technique in *Enigma* in the placement of the eXtreme sequence, which was arranged as a ceiling to the

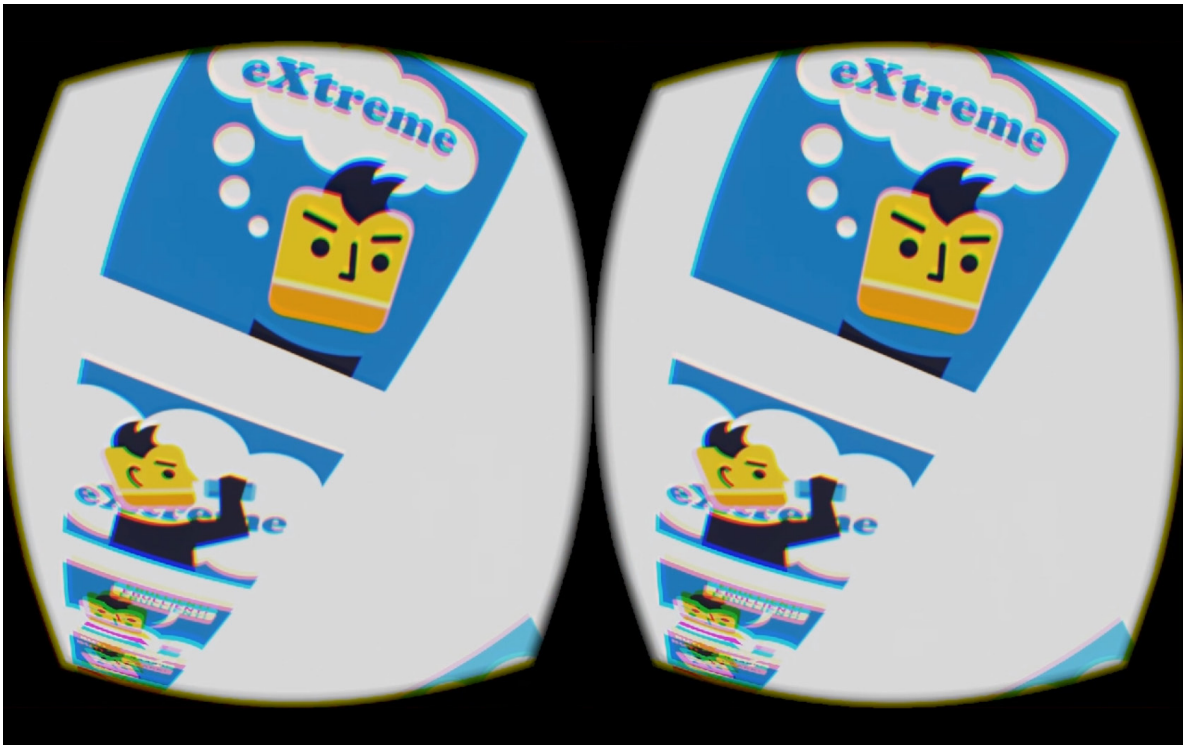

Figure 7 *Screen Capture from VR Headset Showing the 'eXtreme' Sequence from Jack Fighter Versus The Enigma Of Choice (GVERL, 2015d)*

virtual corridor of panels. Positioned thus above the reader and out of their usual line of sight, it requires a more extreme tilting of the head to read, mirroring the more extreme events depicted in the panels of the sequence (Figure 7).

The branching paths in the narrative were included to necessitate that the reader makes a conscious choice about where to look and which sequence of panels to follow. In this manner, we aimed to achieve a balance between freedom of view and fixed sequence of progression. During our testing this approach proved reasonably successful, although the process of returning to the beginning of the comic to follow a different branch of the narrative was at times a source of frustration. Our initial attempts to address this issue led to experimentation with more complex layouts of panels and branching pathways. To enable this, we worked on developing a system that could allow for forks in the line on which the reader travels. However, fully implementing such a system introduced a significant amount of further complexity into the project and, ultimately, we made the decision that this was outside the scope of our intentions for the prototype.

Through the development of our four prototypes, we were able to gain useful insight into a range of approaches that can be employed in the creation of AR, VR and MR comics. One common thread that emerged from our work was that, by seeking to engage with the unique aspects of three-dimensional panel arrangements in each comic, we were often also driven towards a deliberate problematisation of the acts of reading and navigation. Groensteen notes that in print comics, "readers generally set their own rhythm, with no constraints" to prevent this taking place (2011/2013, p. 70). By forcing the reader to

make extra effort to view and navigate each comic, we found this led to a disruption of the usual rhythms of reading that are common to more traditional comic formats (Goodbrey, 2017). While our prototypes were successful in presenting a range of novel storytelling opportunities, on some level they also prevented the reader from becoming fully engaged with both the act of reading and the story being read. It was this realisation that would go on to be of particular significance during the second phase of our research.

Phase Two

In 2023, Apple announced the upcoming release of their new MR headset, the Vision Pro. While the VR market has seen considerable growth across the last decade, MR devices did not initially see the same level of consumer uptake. Following its release in 2016, Microsoft continued to iterate on the HoloLens but focussed their efforts towards a more niche, "enterprise first" strategy aimed at governments and large corporations (Irwin, 2024). In 2024, Microsoft discontinued production of the HoloLens, ceding the market to Apple and their other main competitor Meta. Meta was a significant driver in the growth of the VR market and, with the release of the Quest 3 headset in 2023, they also had their own consumer-focussed MR headset on the market. It was this renewed competition in consumer-focussed MR devices that, in combination with the Vision Pro's initial marketing focus, became the catalyst for the second phase of our MR comic research.

Included in the marketing material released alongside the announcement of the Vision Pro was a clear focus on the device being used to facilitate acts of reading in an MR environment (Engadget, 2023). Primarily this is achieved via the use of virtual screens of text and images overlaid onto the real-world environment around the wearer. Our previous research had resulted in a series of prototypes that had deliberately problematised the act of reading in three-dimensional comics. But the Vision Pro invited us to consider an opposite approach. Could we develop an MR comic that prioritised the act of reading while still incorporating a three-dimensional arrangement of panels? To answer this question, we began by examining some of the popular formats in which comics are read on screen and the influence of these formats on the development of comics in VR. We were particularly interested in approaches to creating digitally native comics with long form narratives that required sustained acts of reading to consume. The two most notable and relevant formats we identified through our research were that of "panel delivery" (Goodbrey, 2017, p. 68) and the "infinite canvas" (McCloud, 2000, p. 222).

Panel Delivery is an approach to creating digital comics that saw great use in the 2010s but has since seen something of a decline in popularity (O'Keefe, 2020). It involves the use of page-like groupings of panels which are displayed to the reader and then altered by either the removal or alteration of existing panels or the addition of new panels or panel sequences. John Barber, one of the original pioneers of panel delivery, describes the approach as creating a "malleable page" (2002, p. 63). Panel delivery comics retain the concept of the page as a grouping of panels into a single "design unit" (Hatfield, 2009, p. 139) and as such draw on the wealth of compositional tricks and tropes established in print comics. In printed comics, stories are built around the turn of the page, which allows creators to delay the delivery of punch lines and to craft moments of surprise or suspense within their narratives. However, in panel delivery the content of each page grouping is not treated as being permanently fixed in space. Moments of surprise and dramatic reveals are not limited only to the turn of the page but can instead be achieved at any point with the addition of a new panel to an existing grouping. In this way panel delivery can be seen to embrace the "plastic" and mutable nature of digital media (Murray, 1997, p. 154).

Infinite canvas comics originate from the work of Scott McCloud, who proposed the idea that "the monitor which so

often acts as a page may also act as a window" (2000, p. 222) onto a larger arrangement of panels. The format saw much experimental use amongst webcomic creators for several years but only more recently achieved mass levels of popularity via digital comic publishing platforms such as Webtoon. Vertically scrolling, infinite canvas comics are the default Webtoon format, with popular series now enjoying million-strong readerships (O'Keefe, 2020). In an infinite canvas comic, all the panels in the comic exist in a fixed spatial relationship on one large plane or canvas. The window of the screen is then placed under the reader's control, allowing them to navigate this plane to read the comic. Infinite canvas formats allow for the spacing between panels to be used for narrative effect. For example, greater distances that force the reader to scroll further can be used to control when certain images are revealed or to express shifts in the passing or perception of time. Branches in the flow of panels within the comic can introduce alternate pathways through a story and the overall shape formed by the arrangement of panels can be used to reflect or enhance aspects of the narrative.

Since our initial experiments in 2015, the increased popularity of VR devices has seen the release of several VR comic platforms, with three of the most notable being Madefire VR, Sphere Toon and ComX VR. The comics released for these platforms all take a similar approach in terms of their format. Rather than present the reader with a navigable three-dimensional space as we attempted with our *Enigma* prototype, the reader remains static with the comic extending out to fill their field of view and immerse them in the depicted world of the comic. In this manner, the comics can be seen to draw on cinematic approaches to VR, with the information most important to the narrative placed centrally within the180-degree field of view of the reader (Waliokar & Remedios, 2023). A panel delivery approach is then used to allow the reader to read and progress through the narrative, with changes being made to groupings of panels and the artwork displayed within and around the panels. The addition of animation to accompany the appearance of panels and changes in the otherwise static artwork makes the experience in some ways reminiscent of a giant three-dimensional pop-up book.

To capitalise on the VR nature of the reading experience, an emphasis is placed on the relative depth of different elements of the composition. Panels sit at different positions on the Z axis and artwork is separated out into its constituent 2D elements in such a way as to enhance the sense of foreground, midground and background objects existing at different distances from the reader. This emphasis on spatial depth in the artwork recalls earlier approaches to incorporating depth into print comics via the use of anaglyphs and their accompanying red and blue glasses. Hague notes that while historically this approach has been seen simply as a "gimmick product", in more recent years creators have begun to explore the potential "narrative and philosophical effects" of such three-dimensional compositions (2014, p. 56).

In terms of the reading experience, the approach taken by these VR comics is certainly more successful than that of *Enigma*. In hindsight, an error we made with *Enigma* was in thinking of it primarily as an architecturally-mediated comic translated into a VR environment that the reader is then forced to navigate and explore. The decision to instead keep the reader stationary and have the comic change around their position immediately eliminates many of the problematic aspects of reading in VR. The use of a panel delivery approach is also helpful in providing readers a more straightforward raster of reading that generally obeys the usual left to right, top to bottom reading path. However, while beneficial in this respect, panel delivery approaches also bring with them some negative aspects that are placed in greater emphasis by the additional spatial complexity of VR panel compositions.

In a page-based print comic, all the pages and panels operate as part of a spatial network (Groensteen, 1999/2007) with a fixed simultaneity of images between the panels on

each page. Nichols observes such print comics to have the quality of "flippy-throughiness" (2016, p. 97). This means that it is easy for the reader to navigate forward and backwards through the comic pages and there is a fixed, physical location to all the information in the spatial network of the comic. In contrast, a panel delivery approach weakens the fixed simultaneity of images and erodes the quality of flippy-throughiness so that there is no longer a fixed spatial aspect to the network of interrelations between each panel in the comic. As a result, the reader's understanding of the wider spatial network and their position within it becomes more difficult for them to manage. This provides an interruption to the usual rhythms of reading that are ideally established when comics are explored and read (Goodbrey, 2017). The addition of spatial depth and animation in VR adds even further complexity for the reader to negotiate and this further disrupts the establishment of reading rhythm.

In digital comics, infinite canvas approaches have previously been identified as a way to address some of the negative aspects of panel delivery (Goodbrey, 2017). The use of infinite canvas helps to address the issue of flippy-throughiness by giving all the panels in a comic's network a fixed spatial relationship to each other. While navigating the comic, the reader benefits from having a fixed panel configuration or shape to hold in their head. They also have full control over their progression and place within this configuration. This allows for rhythms of reading to build up that, while not exactly the same as those of a page-based print comic, better capture the spirit of how a traditional, multipage work is read. To date, the new wave of VR comics has primarily made use of panel delivery approaches in their translation of the comics page into three-dimensional arrangements of panels. But could a three-dimensional application of the infinite canvas instead point the way towards a better comic reading experience?

Discovering an answer to this question sat at the heart of the development of our latest comic prototype, *Grandmother Made Gods* (GVERL, 2023). While intended ultimately as an MR comic, as a prototype *Grandmother* was created using the Unreal Engine for viewing via a Meta Quest VR headset. This approach allowed us to test the key elements of the comic's operation in VR as a proof of concept without the additional hardware costs and expertise required to create a full MR prototype. The comic was written and illustrated by Daniel Goodbrey and implemented in Unreal by David Tree. The narrative of the comic is a story about the relationship between a woman and her grandmother. The grandmother in the story is described as having "made gods" (GVERL, 2023), although exactly what this means is left for the reader to determine. Within the story world of the comic, the gods in question are represented by portraits, seen both on the walls of the grandmother's home and as individual panels within the comic (Figure 8).

In our previous prototypes, the narratives in each comic had been kept relatively short and simple, amounting to the rough equivalent of one to two pages if laid out for print. In contrast *Grandmother* told a much longer story, roughly equivalent to a nine-page print comic. This allows the reader to engage in a sustained act of reading over a longer period of time. In turn this gave us a much better opportunity to study and fine-tune the implementation of our three-dimensional infinite canvas reading experience. For the purposes of the VR prototype, a basic living room space was created in which the reader sits while reading the comic. The design of this room was kept deliberately simple to avoid the pitfall of the virtual environment drawing the reader's attention away from the content of the comic's narrative (Waliokar & Remedios, 2023). In the proposed MR version of the comic this virtual space would be replaced altogether with a live view of the reader's actual surroundings.

In our previous VR prototype, the readers moved themselves through space to navigate around a network of panels

Figure 8 *Panels from Grandmother Made Gods (GVERL, 2023)*

positioned in three-dimensional space. Taking note of the approach now used more widely in VR comics, in *Grandmother* the reader instead remains stationary. The network of panels flows towards and then past the reader, dramatically simplifying reading and navigation (Figure 9).

All the panels in the comic exist in a fixed spatial network with each other and move along a consistent path as they move past the reader. The position and shape of this path dictates the panels' relative positions to each other and their movement past the reader. In this manner, the reader is able to experience the spatially juxtaposed relationship between the panels they are currently reading and the next panels in the sequence. They can also easily navigate forward and backwards through the comic's spatial network using the Quest's handheld controllers.

This use of panels in a fixed spatial relationship coupled with a consistent and straight forward navigation approach allows for the reader to quickly achieve a consistent rhythm

Figure 9 *Screen Capture from VR Headset Showing the Panel Layout in Grandmother Made Gods (GVERL, 2023)*

of reading. Considerable time was spent during the development of the prototype on the fine tuning of this reading experience. Consideration was given to the shape of the path, how much of the panel layout would be visible at once and the distance at which panels can be easily read before they move past the reader and out of sight. Based on the experiences of the design team in testing the comic, we settled on a curving path for the panels to follow, descending from the ceiling of our virtual room (Figure 10).

To aid the legibility of the foreground panels, a slight colour fade was added so that panels appear more faded the further they are from the reader. To allow more of the arrangement of panels to be visible together at once, panels in the distance were also reduced to a slightly smaller size. They then scale back to full size as they move nearer to the reader.

Taken as a whole, our efforts with *Grandmother* achieved a much smoother experience that prioritises the act of reading within a three-dimensional arrangement of panels. With a consistent rhythm of reading established as the main focus of the comic, it was possible for us to then experiment further with ways in which the three-dimensional nature of the reading environment could be employed for narrative effect. During this experimentation, particular care was taken not to destabilise the success already achieved with the core

Figure 10 *Screen Capture Showing the Path of Panel Movement in Grandmother Made Gods (GVERL, 2023)*

reading experience. Ultimately, we arrived at a subtle but impactful addition to the comic. As the reader reads, the portrait panels depicting the gods within the story slowly accumulate as portraits on the walls of the room around the reader. Appearing towards the edges of the reader's 180-degree field of view, the portraits may not be immediately noticed by the reader as they appear. But by the end of the story these gods fill the walls of the reading environment. They represent a testament to the scope and strangeness of the grandmother's labour and provide an additional surprise for the reader to discover either during or directly following their reading experience.

Our work in phase two is still ongoing. The ultimate goal of the phase is the development of a general-purpose toolkit that comic creators can use to assemble infinite canvas comics for VR and MR environments. Having established a principal approach for the use of the infinite canvas in navigating a three-dimensional arrangement of panels, our next step is to develop a second prototype that further tests the limits of its application. The new prototype is still in the early stages of development but is intended to re-introduce some of the complexity of our phase one prototypes. It will feature a more complex arrangement of panels which move past the reader along a more varied and elaborate path. Our aim with this prototype is to strike a balance between a rich narrative use of three-dimensional space and a smooth, unproblematised reading experience.

Conclusion

The form of comics traditionally operates in two-dimensional arrangements of panels that represent a three-dimensional world. This article has examined a variety of approaches to using the form of comics to represent a three-dimensional world while also operating in a three-dimensional arrangement of panels. The position of these panel arrangements relative to the reader can be used for deliberate narrative effect. Sculptural elements, moving panels and loops of animation can be successfully incorporated as part of the arrangement. But the need for the reader to read the comic can place limits on panel positioning and the complexity of a panel's content. Novel ways to navigate a comic can be introduced that relate the reader's gestures to aspects of a comic's narrative. This makes the user more aware of the act of navigation and can potentially lead to physical fatigue during prolonged periods of reading. The more that acts of reading and navigation are problematised, the more it disrupts the ability of the reader to build up a consistent rhythm of reading.

Three-dimensional spaces invite a freeform choice of movement and exploration that may conflict with the fixed raster of reading usually required by a comic's narrative sequence. Navigating a three-dimensional arrangement of panels can require either the reader to move their position relative to the panels, or for the panels to move their position relative to the reader. Movement of the reader around the panel arrangement can lead to a more sculptural relationship between reader and comic but may also disrupt the formation of normal reading rhythms. Limiting the reader's movement and changing or moving the panel arrangement around the reader can help to better foster the establishment of a regular reading rhythm. With a stationary reader, existing digital comic formats such as panel delivery and the infinite canvas can be successfully adapted for use with three-dimensional arrangements of panels. While at present panel delivery is the more commonly used approach, this article has pointed toward the potential of the infinite canvas to provide a superior reading experience for longer form comic narratives.

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