Challenges and Opportunities of Virtual Reality Painting Animation in Mainland China: A Case Study of Dark Tide

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Abstract
This article draws on the experience of producing the music video Dark Tide in Quill, a virtual reality painting software, to discuss the potential of integrating virtual reality (VR) technology into the animation industry workflow. Despite significant updates in VR content-creation technologies over the past seven years, many animation companies in Mainland China are reluctant to include these innovative technologies in their animation production workflows due to a lack of knowledge and drawbacks in the VR workflow. However, in light of uncertainty within the animation market and the commercial success of independent animation, VR painting technology could provide start-up animation studios with an alternative animation production workflow and production strategies for their future projects. Against this background, we examine the current advantages and limitations of Quill.

Keywords: VR Painting, Animation Industry, Quill by Smooth Step, Independent, Mainland China

1. Introduction to the Virtual Reality Painting Animation Software, Quill

At the Sundance Film Festival in 2017, a virtual reality (VR) animated short, *Dear Angelica* (Figure 1), became the highlight of this independent film event for its unique art style and innovative storytelling empowered by VR technology [1]. The short's art director, Wesley Allsbrook, along with her team who created the project, including its characters, backgrounds, and animation in an immersive VR environment, transformed the global animation industry's awareness of three-dimensional (3D) animation production. The animation tool that was used to create the short film's VR painting, Quill (now Quill by Smoothstep), will be the focus of discussion in this article.

Figure 1: Poster of Dear Angelica, 2017, directed by Saschka Unseld.

As an art design software, Quill was released in 2016. Supported by Oculus headsets, the software allows digital artists to immerse themselves in a virtual space and use controllers as "pens" to draw 3D models. This unique approach to art creation "satisfies makers' desire for simulating or depicting another world in its most full-body engagement sense and thus create illusionary experiences" [2]. At the outset, Quill only included a VR illustration function, similar to its counterpart, Tilt Brush (by Google). However, the extraordinary success of Dear Angelica indicated the future direction for Quill's technological development. In 2018, the animation function was added to Quill, which successfully supported the VR painting program's integration into the animation production pipeline. Artists within the industry continued exploring the creative potential of the software, and their efforts led to the development of several schools of art styles and techniques. For example, Goro Fujita's cartoon art style (Figure 2) is recognized for its simplified shapes and lively animation. His daily "Quillustration" artworks comprise characters and backgrounds created from basic geometric shapes and Quill's animation brush. In this way, Fujita can independently create a short but interesting loop scene in a minimum amount of time.

Figure 2: Daily Quillustration, 2022, created by Goro Fujita

Some Quill artists are dedicating themselves to using delicate and advanced art styles. For example, ex-Disney animator, Daniel Martin Peixe (Figure 3), will shift the shape of strokes by applying the grabbing tool in Quill to create characters that have close-to-realistic body proportions.
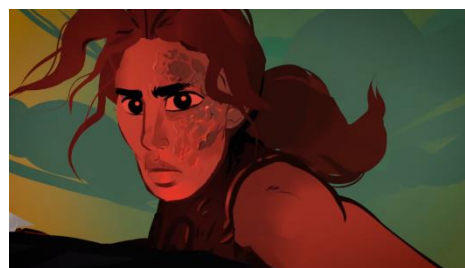

Figure 3: Screenshot of *Remedy*, 2020, created by Daniel Martin Peixe

Virtual reality artist, Léa Peirano, recreated famed Japanese anime scenes from Your Name (Figure 4) and *Spirited Away* in Quill to allow audiences to immerse themselves in these well-loved films. These cases indicate the remarkable capability of Quill in animation production and artistic style malleability.

Figure 4: Screenshot of Your Name fan art, 2022, created by Léa Peirano

Today, VR artists can communicate with other like-minded individuals via Discord hobby groups, such as "Virtual Animation," and create online teams to collaborate on animation projects remotely. Studio Syro, founded in 2020, is one of the most successful teams that benefited from this mode of collaboration. Although the artists of Studio Syro hail from all over the world and have no physical office (and had never met one another in person until October 2022), they nonetheless successfully unified their workflow by adopting Quill and taking advantage of the Internet transition services, for example, Google Drive. Their flagship VR series, Tales from Soda Island (Figure 5), comprises animated shorts created entirely in Quill, which were praised as "one of the most charming VR experiences" by editor Scott Hayden (2020) of Road to VR, a website focusing

on VR news and reviews.

Figure 5: Screenshot of Tales from Soda Island, 2020, directed by Dan Franke

Several Hollywood studios also adopted Quill as their main animation software in several unique animation projects, for example, *Namoo* (Figure 6), produced by Baobab Studios. The animated short was officially nominated at the 94th Academy Awards (2022) for Best Animated Short Film. It also won the Annie Award for Best Animated Special Production in the same year.

Figure 6: Poster of Namoo, 2021, directed by Erick Oh

Other than animation production, Quill has also become an alternative in the independent gaming industry due to its quick modeling and multiple industrial standard formats output capabilities. Several independent developers have used Quill for game jams and some are even using the software for incoming projects, for example, *Bogdan's Cross* (Figure 7), by Federico Moreno Breser.

Figure 7: Photo Caption of Bogdan's Cross, 2023, Created by Federico Moreno Breser

Among the new challengers in the indie game industry that embrace VR painting technology, Funktronic Labs is a perfect example of a game developer adopting Quill as an auxiliary tool to speed up the design process. According to a report published on Meta Quest's blog page about Funktronic Labs in 2019, co-founder Eddie Lee, who created the popular VR gardening and adventure game, Fujii (Figure 8), noted that one of their artists, Tetra, "would develop concepts with Quill, and we would then synthesize 3D VR concepts into assets developed in Maya, which saved [us] a lot of time [3]."

Figure 8: Poster of Fujii, 2019, Created by Funktronic Labs

In conclusion, Quill is a 3D animation production application that is still primarily being used within a niche market. However, its unmatched approach to the creation of artwork has attracted independent creators who have become dedicated users in the development of their animations and games.

2. Virtual Reality Painting in Mainland China

In Mainland China, many animators still have the same impression of VR drawing software as they did in 2016 when Google introduced Tilt Brush. Some production teams might apply VR painting applications in the blocking stage. For example, artists used the VR sculpting application, Oculus Medium (Figure 9), to rapidly create art blocking to ensure the spatial arrangement of each object in a scene and to assist in decision making about the positioning of characters and mise-en-scène when working on an animated trailer for League of Legends called Kin of the Stained Blade [4]. Regardless, in most cases, animation studios in Mainland China have not yet adopted VR painting technology into their workflow.

Figure 9: Screenshot of the Behind-the-Scenes Process of *Kin of the Stained Blade,* 2020, Posted by Wuhu Animator Space

In terms of independent animation, because of the steep learning curve and the high demand for employees skilled in working with traditional 3D software (e.g., Maya and Blender), only a handful of independent animators in Mainland China can create 3D animation projects, and many of them have never heard of VR painting technology. Nonetheless, VR painting technology still receives exposure in Chinese media. In the era of short-form video, VR painting technology is widely applied in performance creation. Alice the Little World (Figure 10), a content creator on Bilibili.com, is currently the most well-known VR artist in Mainland China. Alice the Little World adopts Open Brush, an open-source software based on Google Tilt Brush that is equipped with animated effects brushes. By combining rapidly developing image synthesis technology in mixed reality (e.g. LIV, a streaming application) with a simple dance performance, the artist can successfully "walk" into the virtual world she created and, accordingly, achieve the successful combination of reality and technology.

Figure 10: Photo Capture of *China-Chic Little Lions,* 2021, Created by Alice the Little World

In creative animation production, AMAO, a motion designer based in Shanghai, succeeded in creating an immersive animation, Shanghai Moments (Figure 11) using Quill. By designing the entire scene in a "Russian doll" structure and applying the directional opacity brush in Quill, AMAO was able to creatively illustrate a snapshot of daily life in a Shikumen building complex in Shanghai, including a clever sci-fi twist at the end of the animation, to create a small but intriguing immersive storytelling experience.
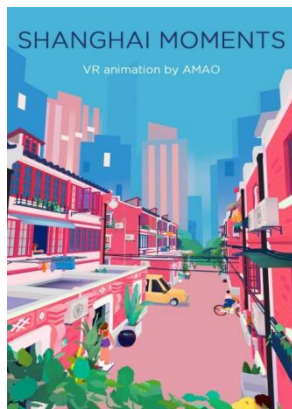

Figure 11: Poster for Shanghai Moments, 2019, Created by AMAO

In terms of the application of Quill, AMAO stated that she refrained from using virtual reality due to the emotional detachment that comes with cutting-edge technologies until trying Quill, which broadened her horizons [5]. From the perspective of the animation industry in Mainland China, however, the crude appearance of VR painting models and a lack of lighting features means that this type of software is unlikely to be popular in the mainstream animation market. As such, Quill is still viewed as an amateur application that cannot support commercial-level production.

As part of the "God Eye Project" which was held by TOPU International Animation Week to create music videos for outstanding independent musicians in China, our music video, Dark Tide (Figure 12), adopted long shots as its main narrative structure, which involved an enormous number of camera angle changes.

Figure 12: Screenshot of *Dark Tide,* 2022, Directed by Bowen Tan

If our animation approach in this project had adopted a hand drawing method, it would have been extremely difficult to maintain the high quality of the animation alongside complex changes in camera angles. Additionally, the lead artist, Toi, was well-known for her 2D graphic design, which could not be adapted to the realistic art style. Furthermore, we had a limited workforce and a strict production schedule in which to finish the project. Considering the high production efficiency and the accurate perspective function of Quill, we decided to adopt the Quill + Blender workflow, one of the mainstream production pipelines in the Quill community, to complete the project.

Due to a lack of recognition regarding Quill in Mainland China, as this article previously stated, we received almost no support from experts and artists in the animation industry during the planning and production stages for Dark Tide. However, by searching for tutorials on YouTube and experimenting, we eventually established a reliable workflow that allowed us to finish the project by the start of TOPU International Animation Week in 2022, enabling us to share our production experience of Dark Tide to help artists gain better insight about VR painting technology. We also encourage creators who work with different media to experiment with the technology in their creative projects in the future.

3. A Comparison of the Production Experience Using Quill and Traditional Three-dimensional Animation Software
Ever since the first traditional 3D applications, e.g., Maya, were released, their complicated user interfaces (UIs) and the overwhelming use of specialized jargon have intimidated

newcomers within the art industry. When it comes to the animating stage, according to Pan and Mitchell (2020), artists usually create 3D character posing by adjusting keyframes using normal 2 degrees of freedom (2DoF) mouse interfaces on 2D screens, which represents the most time-consuming aspect of character animation. Motion capture is a plausible alternative that can overcome problems arising from the limitations of a 2D user interface but may fail to meet directors' expectations as a result of performers' physiology and can increase budgets for expensive equipment, large performance spaces, skilled actors, and laborious post-processing steps [6]. Therefore, professionals are increasingly interested in VR technology as a means of finding a straightforward and highly efficient operation interface that can replace redundant 2D UIs.

Quill has successfully simplified the user interface by integrating it into the VR dual controller system. The Quill designers categorized all the tools and parameter settings based on real-life painting habits into nine tabs and arranged them accordingly on an all-in-one virtual menu board floating above the "left hand" (left controller). If a user wishes to select a tool, adjust the timeline, or revise a parameter, they must move a cursor fixed on their "right hand" (right controller) to the menu board and then select the correct category or tool by "pressing" the virtual buttons on the virtual menu board. Following on, the computer executes the command and eventually sends vibration feedback to the user via the dual controllers to indicate completion of the command. Additionally, rather than the drop-down menu configuration, the Quill menu displays all the essential tools in a tab on the virtual menu board without further requirements for memorizing the locations of different functions. If a user prefers to put their menu elsewhere than on the "left hand", they can press the "grab" button on the right controller to enable moving the virtual menu board and then relocate it anywhere within the virtual space. In this way, artists can observe and create their immersive artworks in Quill without any hindrance from the UI.

For modeling, VR painting creators must pull the right controller trigger to draw several stroke models that will constitute the final model. In traditional 3D animation software, this is performed by users having to deform the basic model through extrusion, beveling, and other polygon adjustment techniques, to achieve a complete single model. The modeling methods and logic between VR painting and traditional 3D software are so different that the models created by VR painting encounter problems in shading and rendering in traditional 3D animation software, which will be discussed later. Shifting perspective is an advantage of VR painting applications as a result of the 6 degree of freedom (6DoF) tracking, which is supported by most VR goggles currently available on the market. Creators can press their right grab button on the right controller when no object in Quill is selected, then push the right joystick on the right controller while walking within the real world to move to the desired position within a virtual space. Similarly, the modification of selected model sizes and locations can be accomplished by grabbing the selected objects and pushing the right joystick in coordination with the movement of the right hand. Compared with mouse clicking and dragging, movement and controlling adjustments to the physical body in VR are much more convenient and efficient, and the operational logic closely matches how people think when they need to take hold of something in real life. Interaction design based on natural human behaviors can lower the learning threshold, thus enabling animators to quickly become acquainted with Quill. In addition, observing models in a 3D environment than seeing them on a screen is more straightforward, which will be helpful for VR content production.

To date, the best and most complex function of Quill is its animation capabilities. Quill has two sets of animation options: cel animation and keyframe animation, and both are applicable to the timeline, similar to Adobe Animate. Two separate function key arrays are laid out based on the two different animation systems on the same timeline interface in the same menu tab. Quill has also introduced exclusive functions to the timeline interface, including real-time recording, a preview spawn area, and looping clips. These functions also increase the number of function buttons, which makes the animation tab appear somewhat disorganized compared with other tabs in Quill. However, as our production progressed, we discovered that all of the function keys embedded in Quill were practical and able to manage almost any situation efficiently. Bowen's experience of producing a 30-second looping animation of a little boat struggling in a raging ocean for Spylent's short-form music video, Fisherman in the East Sea (Figure 13), will be discussed as an example below.

Figure 13: Screenshot of Fisherman in the East Sea, 2023, by Bowen Tan

Since the client needed the animation finished within 12 hours, Bowen decided to activate the real-time recording in Quill to create animation rapidly. By doing so, Bowen could simulate a boat navigating through a storm by "grabbing" the boat with his right controller and moving it around while the animation is playing. The whole process is similar to kids playing with toys.

Concurrently, Quill automatically generated the keyframes in the boat layer to record the boat's position and displacement. After finishing the animation, Bowen baked the keyframe animation of the boat into a new layer of cel animation and then turned the recently created cel animation layer into a looping sequence by applying the "looping clips" function. For the fisher on the boat, Bowen used the grabbing tool to create several animated cel frames of clothes waving in the layer including the fisher, and then combined this layer and the boat layer under the same animation folder. By creating keyframes in the folder layer, Bowen could move the boat and fisher layers at the same time to create the overall movement of the boat (Figure 14). Furthermore, the animation of child objects could be played alongside the animation of parent objects, which helped him to create a miniature yet detailed animated scene within 12 hours.

Figure 14: A Screenshot of the Real-Time Recording Function in Quill, May 2023

In contrast, a traditional 3D animation application workflow will be too varied because artists must be able to manage several time-consuming stages that cannot be skipped, including texturing, lighting, rigging, and rendering, making it impossible to finish a project quickly. Overall, Quill is a powerful animation tool that is suitable for selected small and urgent projects.

4. Production Workflow of Dark Tide
Toi is an independent designer and modern artist who excels at the deconstruction of art. Using streaks and geometric figures, Toi successfully reassembles time and space into a two-dimensional (2D) expression to depict the tracking of an ordinary girl's daily life in the modern world from her peculiar perspective (Figure 15).

Figure 15: Artwork by Toi, 2020

In *Dark Tide*, we adopted optical art methods, created characters with both 3D and 2D body parts, and applied image design techniques when creating the scenes to recreate Toi's simplified but imaginative world. In terms of animation software, we used Quill, which was useful for adjusting optical illusions, which was achieved by selecting and moving the models. The city scene (Figure 16) at the very beginning of the animation is discussed below as an example.
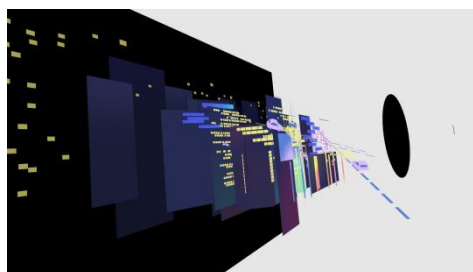

Figure 16: Behind-the-Scenes of Dark Tide in Quill, 2022, by Bowen Tan

We set up a camera from the timeline tab and arranged its movement in the virtual space beforehand. Then we took out the monitor UI from the virtual menu board and placed it in a convenient area in the virtual space, enabling us to see the scene from the camera perspective. In this way, we could structure and adjust the city and the cars' looping animation to align with the

storyboard through the camera angle. Although our production method was similar to traditional stop-motion animation production, Quill enabled us to save a significant amount of production time because the keyframe and looping animation function was powered by computers during the creation of dynamic backgrounds.

Despite saving time, recreating Toi's art style was still a huge challenge for Quill. Toi's artworks are greatly influenced by formalism, which is an abstract and obscure approach to artistic expression. Formalism gives rise to difficulties related to creating an emotional connection with an audience because it lacks the "imperfectness" reflected by "reality" that can be used to connect them with an artwork's inner world. To disrupt the monotony and stiffness brought about by the "perfectness" of regular composition, Toi employs grainy and uneven coloring, similar to the color inks used in early magazine printing, to instill "imperfectness" in her artworks, which allows the audience to intuitively establish a connection with her work because they can associate what is presented with physical objects, such as comics, magazines, and other types of print they are familiar with in real life. However, Quill's strokes appear to be color blocks without any texture on a 2D screen and, as such, there was no way for us to create strokes with "imperfect" textures in Quill as a means to reflect reality. Additionally, Toi's minimalist art style also prevented us from including design elements in scenes to make the video more interesting. It was a significant challenge for us to find a solution that allowed us to add textures to the models without sacrificing the simplified 2D art style. Because Quill has no shading function, we needed to include 3D animation software and a rendering engine in our workflow.

Initially, we planned to apply Redshift, a popular rendering engine among Quill artists in the virtual animation community, to render our animation. Redshift is a graphics processing unit (GPU)-based biased rendering software with built-in ray-tracing technology. In an article related to a series of Overwatch cinematic trailers (Figure 17) by Jeff Chamberlain et al. (2017), Blizzard Entertainment revealed that their production team had created "an entirely new, cost-effective animation pipeline" based on Redshift, which "allows rich, high-quality content to be created in a fraction of the time traditionally associated with pre-rendered workflows [7]."

Figure 17: Overwatch Cinematic Trailer, Reunion, 2018, Produced by Blizzard Entertainment

High efficiency is not the only selling point of Redshift. The powerful renderer is also known for its high degree of freedom of customization to satisfy a wide range of demands of various art styles. However, we had to abandon this solution after several attempts due to Bowen's poor computer configuration. At the time, Bowen only had an entry-level graphics card (GTX1650), which could not handle the real-time rendering and resulted in several system collapses during our tests. Considering our strict schedule, we had to opt for a lightweight rendering engine to avoid any further technical issues.

After careful research, we discovered Eevee. According to the introduction (2023) on the Blender official website, "Eevee is Blender's realtime render engine built using OpenGL [and] focused on speed and interactivity while achieving the goal of rendering PBR (physically based rendering) materials." Additionally, non-photorealistic rendering is Blender's prioritized development direction and, as such, its proficiency in cel-shading rendering is widely recognized by the industry compared with other 3D software. In addition, compared to Cinema 4D, Blender has much lower computer requirements, and we had a better experience using it than any other traditional 3D animation application due to its impressive system stability. Eventually, we decided to apply Blender to our animation production in relation to texturing, lighting, and rendering for the completed Quill animation.

After Eevee finished rendering the portable network graphics (PNG) image sequences, to add the "imperfectness" to our music video and unify the visual style, we decided to include After Effects in our pipeline for the perfecting touch because of its high efficiency comparing with 3D rendering engines, as recommended and implemented by the post-production special effects artist, Harry Chen, who is currently studying at the School of Visual Arts in New York City. This process improved the overall quality of Dark Tide and was approved by our producer.

In conclusion, the animation project was carried out according to the following procedures. First, animation and scenes were created in Quill and then output as Alembic files. Second, the Alembic files were imported into Blender for texturing, lighting, and mise-en-scène. Third, the PNG animation image sequences were rendered in Eevee. Fourth, the PNG image sequences were edited according to the storyboard, and the finished clips were again exported as PNG sequences (this was because most of the clips in the music video were long shots that were divided into several sections to be independently produced in Quill and Blender). In the final step, the integrated PNG sequences were imported into After Effects to add visual effects before exporting the final video.

5. The Usage Experience of Importing Quill Animation into Blender

Currently, Quill supports output into two mainstream interchange formats for 3D graphics, FBX and Alembic, both of which support read-in animation data. Before exporting the files, Quill users should bake the keyframe animation into cel animation to record the position and displacement information of objects for the interchange formats. This process can lead to additional editing on the models not being possible in traditional 3D animation applications, e.g., those involving rigging, liquids, and particles. We applied the process because our models did not follow the traditional rules of 3D character design in this instance, which made it difficult for us to create skeletons for the characters. Moreover, Bowen prefers using a stop-motion workflow to create character movement, which means Bowen had already completed the animation stage in Quill. Therefore, this limitation had little impact on the project.

In terms of the material, we strived to create 3D animation with a 2D feel, so for the majority of models, we applied vertex color and self-emitting shading to eliminate the shadow caused by environment lights to create a 2D-animation atmosphere. However, we added extra textures for storytelling purposes. For example, in the crypto sleep casket scene (Figure 18), we used noise texturing to simulate a stagnant fog effect that would indicate the frozen environment in which the younger sister was sleeping to let the audience gain a better understanding of the scene.

Figure 18: A Screenshot of the "crypto sleep Casket" Scene in *Dark Tide*, 2022, by Bowen Tan

We also encountered other technical problems in the Quill-to-Blender workflow. For example, at the start of the music video, Bowen created a translucent glass using the directional opacity brush in Quill. However, Blender failed to recognize the effect (to solve the problem, Bowen painted all the objects in the scene (except the glass) green and exported the same clip as a PNG sequence from Quill). Then, Harry Chen applied keying and motion tracking in After Effects to overlay the same glass rendered by Blender. In another case, overlapping strokes could be seen if their shading were semi-transparent, which could appear messy; this happened because the majority of shapes in Quill were created using multiple strokes overlaying one another. Regardless, Toi's conceptual art feel was satisfactorily maintained using Eevee. Using the "bloom" effect in Blender, individual self-emitting materials in the music video could create halo effects, bringing the visual expression to a new level and amazing the well-known Chinese independent VR artist AMAO, who stated, "I failed to realize that the music video [was] a Quill animation." Eevee being a stable and rapid rendering engine also significantly increased our production efficiency once our workflow had been proficiently implemented. Therefore, if a schedule is reasonable and a computer has the correct requirements, a 3D rendering engine can significantly enhance the quality of Quill animation.

5.1 The Advantage of Using Quill in Commercial Animation Production

A study conducted by Ho, Sun, and Tsai (2019, p.3) found that compared to 3D software, VR "enables immersion in a synthetic environment instead of viewing the environment from an external perspective." According to another research article published in Computers & Education, "VR learning environments are applicable to extending the use of animation and multimedia for learning [8,23]. Their research highlights a need for transition from conventional web-based multimedia learning to immersive, interactive, intuitive, and entertaining VR learning environments." Additionally, the intuitive design of VR painting operation can help students become acquainted with and subsequently proficient in their application within a brief period while minimizing feelings of frustration during the learning process to an extent. These advantages can help companies to subsequently save on 3D animator training costs.

Conversely, traditional 3D animation applications like Maya highlight the industrial division of labor that requires a vast expenditure of time and personnel. The leading current 3D animation software in Mainland China is Maya. However, according to Fan and Feng (2021, p.1), the animation industry in Mainland China "is still in its infancy, and its development is relatively backward [9]. The main reason is that there is no sustainable development model in the industry." Another study also notes that many animation companies "are still struggling to upgrade from contract studios to [research and development] activities [10]." According to the Brief Report on the Chinese Animation Production Industry, although China has a large anime market, the animation industry is still struggling [11]. Most animation companies are still suffering from long-term capital loss, and some very large animation companies only manage to break even. Only a minority group of Global Exchange Market listed (GEM-listed) animation companies represent tier-one corporations that can generate significant profits in China, e.g., Enlight Media. In addition, the overall competency gaps among different tiers of animation companies are enormous. Under harsh industrial circumstances, it is challenging to keep a Maya production team running in China. The problems of the animation industry in Mainland China were exposed by a

blockbuster animation series, The Three Body Problem (Figure 19), which was produced by YHKT Entertainment, a medium-sized 3D animation studio in China.

Figure 19: A Poster for *The Three Body Problem*, 2022, Produced by YHKT Entertainment

An online report noted that Chinese financial investors will keep forcing animation companies to hasten the progress of production once an animation project receives funding, which differs from animation industries outside China [12]. This situation has led to severe production problems in The Three Body Problem animation series. Several technical errors can be observed in almost every episode of the series, including texturing mistakes, missing shadows, and incorrect perspectives (in a 3D animation series). Furthermore, excessive product placement throughout the series also reflects an eagerness for quick profits, which the series' audience perceived negatively. In contrast, Yao-Chinese Folktales (2023) a collection of animated short stories produced by several independent animation teams and supervised by Shanghai Animation Film Studio, was a notable example that showed the potential direction of Chinese animation production. Among the eight episodes, except for "She Wolf" and "Null Island," which applied Photorealistic and cel shading CG rendering, respectively, six episodes applied traditional or artistic methods to create animation, including traditional hand drawing, paper cutting, and puppetry. The "Old Man Yang" episode (Figure 20) by Chen Liaoyu, Liu Kuang and Gu Yang even combined traditional hand drawing animation with modern cel shading animation, to successfully create a lovely Beijing hutong in the style of a children's art book. In light of the success of Yao-Chinese Folktales, finding a cost-efficient and flexible workflow could be a practical option for Chinese animation companies.

Figure 20: A Poster for "Old Man Yang", 2023

In terms of the experience gained while producing Dark Tide, we believe Quill to be a viable option for independent animation companies. Virtual space in Quill is a flexible environment that can be scaled or moved freely using controllers. Additionally, modeling in Quill is similar to drawing on paper, and thus very straightforward. Furthermore, several convenient tools are available, such as the grabbing tool, which can easily shift the shape of strokes to create complicated models or animation. Therefore, independent VR animators can independently finish the major steps of 3D animation production, even in a small workspace. Bowen's experience of creating Dark Tide can serve as a good example for supporting this. During the production

phase, Bowen lived in a small rental room of less than 10 square meters in Beijing, as is the case for most young people in China. Apart from a bed, wardrobe, and desk area, the only workspace he had in the rental room was no more than two square meters. Many people were hesitant to believe that VR painting could be achieved in such a small space because many digital exhibition halls generally comprise huge areas for VR display purposes. To their surprise, Bowen managed to finish the entire Dark Tide animation process using VR painting in that narrow rental room, thanks to convenient navigation in the Quill virtual environment and its easy-to-use tools. Moreover, the Alembic and FBX files exported from Quill can record the UV mapping, curve, mesh, and other model data, which provides users with convenience when rendering various stylized animations to meet different art style requirements.

Remote collaboration is also an achievable option for Quill's workflow. The project folders of Quill are not very big (up to 3 gigabytes only). Today's data transmission services, such as Google Drive and WeTransfer, can efficiently send files of a medium size to any drive with an Internet connection. During the production of Dark Tide, we successfully implemented a remote collaboration workflow. While working on a long shot during the beginning part, we sent the "beverage drinking" section to a well-known Chinese Vritual Reality (VR) artist, Bigz, and asked him to create a transition shot of two pipes entering into a glass containing a beverage. Once he sent back the project folders, no errors or data loss were observed, and we could even make further revisions to his project files. Thus, we believe Quill holds enormous potential for large-scale collaboration.

In summary, based on the uncertainty of the current animation industry in Mainland China, Quill could serve as a qualifying animation production software for small animation teams due to its high efficiency and flexibility. If specific teams incorporate the application into commercial animation production, it may lead to new possibilities within the animation market.

5.2 The Current Limitations of Quill

Presently, the biggest obstacle for Quill in Mainland China is the public recognition of VR technology. We checked the video view counts of China's leading VR artist, Alice the Little World on October 10, 2023, and observed the following numbers. The most viewed video of the content creator was VR Painting Creation – the China-Chic Little Lions, which had 1.48 million views in total. However, the view count of her other videos was mostly around 2,000. Even a celebrity collaboration special, Ultimate Crossover! Li Yugang x Fang Jinlong China-Chic Version Together for a Shared Future had only 251,000 views in total. Another famous Chinese artist on Bilibili.com, VR painter Kudo Albus, had only 522,000 views for her most popular video. Additionally, only five videos on her channel had more than 100,000 views, one of which is a hidden vlog ("Spring Festival VR Painting? Why Could I Use the Technology Developed by CCTV for Years? Open Source or Self Developing?", 2023) questioning CCTV's credit for inventing Open VR, an open-source application developed by the Icosa Foundation [13]. The view counts of other VR art content creators, such as Claudio the Escapist, Xiao Zhang_Bigz (Figure 21), and the Painter Mang Bo, are in the vicinity of 100s to 1,000s. As we previously noted, this indicates that mainstream audiences have little knowledge about VR technology. The media in China has also ignored this technology, resulting in the slow development of the VR industry in Mainland China, let alone the VR art community. If Bigz had ignored the video about Bowen's VR artwork on Bilibili.com, Bowen would have had little chance of finding a collaborator when he was in a desperate situation during the production of Dark Tide.

Figure 21: Xiao Zhang Creating VR artwork at the China International Import Expo, 7 November 2018

Artists in Mainland China have little knowledge about basic VR operating practices because most of them have never used VR technology before. In 2022, Bowen tried to introduce Quill to young Chinese artists who were experts in graphic tablet drawing at the TOPU International Animation Week but found that most had no idea how to press buttons on a menu board in a virtual space. Additionally, the cybersickness caused by VR also scared them away after experiencing VR painting technology, even though they agreed that Quill was a powerful tool for animation production. Moreover, VR painting tutorials remain scarce in Mainland China, as does the use of Quill. A series of Quill tutorial videos released by Rui Qi Design is the most comprehensive overview of the application in China to date, but the overall view count of the videos is only a few hundred, and the version of Quill used in the videos is long outdated. Taking these factors into account, VR painting in Mainland China remains a niche animation production technology, and it will be difficult to attract emerging artists to the field in the near future.

The redundant interchange process of traditional 3D applications is also a large problem for Quill. The application has no shading function at present, which requires users to export 3D graphic interchange formats to achieve more sophisticated post-production in traditional 3D animation software. However, this

process is fairly trivial and may sometimes be overlooked. If mistakes are made, such as forgetting to bake the keyframe animation layer, misplacing models, or using the wrong colors, creators will have to wear VR goggles to correct them in Quill and then export the interchange format files again for use in traditional 3D animation applications, which is time-consuming. Additionally, the workflow does not enable artists to view the outcomes of their projects when they are working in Quill, which makes it difficult to supervise projects. The process of exporting interchange formats can also distort models, which may subsequently appear different from what artists observe in Quill. As such, Quill retains significant potential for implementing further progress in its current phase.

5. 3 The Current Situation for Quill Outside Mainland China

The early prosperity of Quill animation studios, such as Studio Syro, So Meta Studios, and Parade Animation, was largely attributed to the investment of Facebook in VR content creation. Overall investment in the VR field declined soon after 2016, according to a Wendy Lee report (2019) because of the rudimentary hardware that was not ready for consumer use [14]. Quill nevertheless remains an excellent application with exciting potential, used by small animation or game design studios. Studio Syro, who still insists on creating high-quality animation projects entirely in Quill, collaborated with Very Cavaliere Productions and Meta to release their latest VR 360° animated short, Reimagined Nyssa – Volume I (Figure 22) at the 79th Venice International Film Festival (2022).
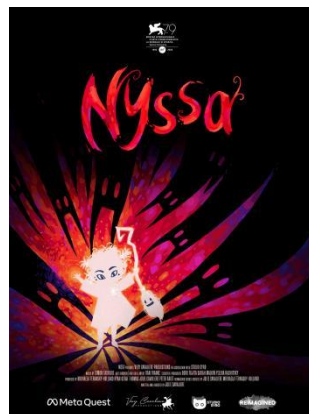
Figure 22: A Poster for *Reimagined Nyssa – Volume I, 2022,* directed by Julie Cavaliere

Almost at the same time, Lava machine released its new animated short, What Time Is It? (Figure 23) on the Meta Quest platform in July 2022.

Figure 23: Photo Caption from *What Time Is It?*, 2022

Before long, they released another animated short, Reincarnation Mall, on February 9, 2023. The two projects were both produced by implementing a Quill + Maya workflow. Meanwhile, So Meta Studios cooperated with the production company, Pureplay Entertainment, and the Amazon streaming platform (Amazon Prime) to create 2D hand-drawn-style Quill animation (Figure 24) for television.

Figure 24: A Work Example Posted on So Meta Studios' Facebook page, March 19, 2022

When discussing independent games, a three-person game studio, Peanut Button, created a point-and-click VR puzzle-solving game, The Secrets of Retropolis (Figure 25) entirely with Quill. The studio has also released a trailer in February 2023 for the second episode, Retropolis 2: Never Say Goodbye. In conclusion, Quill has been implemented as a primary production application in several successful commercial projects outside Mainland China, illustrating the feasibility of its workflow for the future of the entertainment industry.

Figure 25: A Poster for The Secrets of Retropolis, 2021, produced by Peanut button

Apart from the animation and game industry, educational institutions outside China are also implementing VR technology in classes. According to the Virtual Reality in Education Global Market Report, VR is currently being introduced to all levels of education, including K-12, higher education, and vocational training [15]. Furthermore, VR technology in the education market grew from $8.67 billion in 2022 to $11.95 billion in 2023 at a compound annual growth rate of 37.9%. Virtual reality painting is also included in the 3D animation curriculum and is viewed as an educational tool. Dustin Richard Clark, a high school teacher in the Melissa Independent School District (Texas) shared a four-minute Quill-animated short, Strays (2023) (Figure 26), independently created by his student in his 3D animation course with other VR artists on the Virtual Animation Discord channel. The scenes are visually engaging and the story is relatively complete, indicating Quill as being a good educational animation tool for facilitating teenagers' interest in art and animation [16].
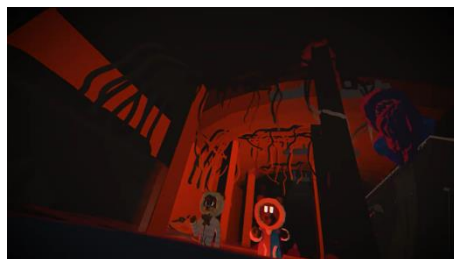

Figure 26: A Screenshot of Strays, 2023, directed by Aidan Mitchell-Johnson

6. The Outlook for Virtual Reality Animation Production Software

Since 2016, the so-called "inaugural year of the VR era," leading animation companies have also witnessed the exciting potential of VR animation software and have invested financially in the development of their internal VR software. In 2016, a group of Disney employees began their research into VR animation technology during their spare time and successfully persuaded the Disney administration to fund an application they called PoseVR. According to the official website of Disney Animation Studios (2017), the development team aimed to create a functioning, posable rig in VR to test assumptions about design and workflow for an experimental project to demonstrate the potential of VR as a tool for posing and animating CG characters [17]. PoseVR was introduced to Disney employees in 2017 and was immediately put into the production of the very first Disney VR animated short, Cycles (2018). Amid Amidi noted in his report (2018, para.6) that "Director Jeff Gipson has said in interviews that PoseVR was used to block out the animation in his short, and then that [same] animation was further refined

in Maya." The rapid transformation of PoseVR into a qualified production tool demonstrates the immense potential of VR technology [18].

Even so, PoseVR still has a long way from perfection. According to a manuscript of Disney research in Institute of Electrical and Electronics Engineers Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops, Disney's production team discovered a perceptual disparity between the director and artists when reviewing the same project from different perspectives, i.e., one in VR and the second on a 2D screen [6]. As a result, they created a mixed reality (MR) collaboration mode, based on the first-generation PoseVR, to allow multiple users to pose and animate characters in the same MR space. After introducing the new functions to Disney animators, the software development team was surprised to find that animators were able to engage in more natural communication with their coworkers in the MR space, leading to smoother and more efficient collaborations. Accordingly, an intuitive, stable, real-time, and immersive collaboration communication tool in MR can potentially increase overall productivity for not only independent creators but also corporations.

Cloud gaming is also a technical concept that may be able to augment the promotion of VR technology in the future. According to research, "VR games require intensive computational resources to render and display," which poses a large challenge for wearable headsets in terms of reducing their size, weight, and power consumption [19]. The most often adopted solution to date is linking VR headsets to personal computers equipped with high-performance GPUs via cables or WiFi. Mainstream VR headsets, such as Oculus Quest 2, are embedded with central processing units but they can still not support VR animation software that comprises complicated 3D graphics. Bowen has to carry his ITX computer and set up a workstation on-site if he has to relocate VR painting technology for specific activities, which is quite inconvenient. In contrast, a cloud gaming system can empower normal VR users to play blockbuster games without high-end PCs by sending the gaming data from headsets to a cloud server to process. With the promotion of the 5G network, VR painting technology may break free from the limits of a local server (personal computer). In the near future, multi-user MR collaboration software may have the opportunity to change the on-site production modes currently being employed.

Overall, VR painting software currently represents a new choice for small-to-medium-sized animation studios. With the help of VR tutorials and the development of Internet technology, we believe that emerging artists will increasingly adopt VR software to complete their projects independently. Meanwhile, VR artists are struggling to establish a sustainable commercial method for supporting ongoing production processes. They require support from the government and the animation industry because with the arrival of new XR products, for example, Apple Vision Pro, enhanced knowledge of 360° storytelling may be urgently needed.

Competing Interest Declaration
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statements
The data that support the findings of this study are available on request from the corresponding author, Bowen T. The data are not publicly available for now due to the submission rules and regulations of film festivals.

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