CAMERA BASED TEXTURE MAPPING:

3D APPLICATIONS FOR 2D IMAGES

A Thesis

by

NATHAN CHARLES BOWDEN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2005

Major Subject: Visualization Sciences

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Approved as to the style and content by:

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ABSTRACT

Camera Based Texture Mapping: 3D Applications for 2D Images. (May 2005)

Nathan Charles Bowden, B.E.D., Texas A&M University

Chair of Advisory Committee: Prof. Karen Hillier

This artist's area of research is the appropriate use of matte paintings within the context of completely computer generated films. The emphasis of research is the adaptation of analog techniques and paradigms into a digital production workspace. The purpose of this artist's research is the development of an original method of parenting perspective projections to three-dimensional (3D) cameras, specifically tailored to result in 3D matte paintings. Research includes the demonstration of techniques combining two-dimensional (2D) paintings, 3D props and sets, as well as camera projections onto primitive geometry to achieve a convincing final composite.

To Mom and Patrick

ACKNOWLEDGMENTS

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CHAPTER I

INTRODUCTION

Since the advent of motion pictures, filmmakers have endeavored to transport the viewers to fantastic worlds, different times, and far away places. Tools and techniques for achieving these illusions have evolved during the short history of the cinematic art form such as miniature sets, stop-motion animation, computer generated characters and environments, among many others. Matte paintings are one of the oldest and most effective special effects. These highly detailed paintings have a tradition that stems from hundreds of years ago. In the theater flat planes of wood and canvas were painted to add depth and realism to a stage set; during the Renaissance master artists created the most realistic art of their time using newly developed proficiency in perspective, perception, light, shadow, and color.

A successful matte painting is one that is never noticed. It is a two-dimensional image which is seamlessly integrated with other shot elements, creating a composite. Chris Evans, an Industrial Light and Magic (ILM) matte painter, aptly described matte painting as a magic trick: "The magician moves his wand to divert attention while the other hand does the trick. With the matte artist, the live-action plate is the diverting, moving wand, and the painting is the trick hand."

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This thesis follows the style and format of *ACM Transactions on Graphics.*

This technique earned its name from its characteristic blank space, the matte. Before the advent of digital compositing, the combination of film elements with matte paintings was typically achieved one of three ways: latent image compositing, "in-camera" glass shots, and projection. In the last case, projectors were used to shoot previously filmed elements on top of the painting (front projection), and/or behind the painting (rear projection) through a transparent matte, which were finally re-filmed together.

1.1 Value of Matte Painting

Although there are many different ways matte paintings are created and used, all attempt to accomplish the same goal of controlled illusion. They are used when the size and scope of the filmmaker's vision exceed the ability (financially or otherwise) to build a set or find an adequate location. Thus the first and perhaps most immediate reason to use matte paintings is cost. Matte painters are bound by nothing but personal imagination and skill with the brush; anything they can paint effectively exists on screen. While model makers and set designers can physically build environments that can rival the final output of even the most skilled painters, the cost in terms of dollars and manpower typically exceeds the resources needed for a single painter to complete the same shot.

The value of this technique is especially demonstrated when the screen time of ambitious shots are so short in duration they do not justify tremendous expense and man-

power that practical sets and on-site locations demand. Usually the relative screen time of a given matte painting on screen never exceeds a few seconds it is used to quickly establish a vista or locale. Longer shots give the viewer more time to scrutinize a matte painting on screen, consequently making the illusion more difficult to sustain. Other shortcomings of this tool include, but are not limited to, accurately matching a painting with other shot elements, limited camera movement, and an overall lack of shot flexibility when compared to live action sets.

1.2 Artistic Intent

This artist's area of research is the appropriate use of matte paintings within the context of completely computer generated films. The emphasis of research is the adaptation of analog techniques and paradigms into a digital production workspace. The purpose of this artist's research is the development of an original method of parenting perspective projections to three-dimensional (3D) cameras, specifically tailored to result in 3D matte paintings. Research includes the demonstration of techniques combining two-dimensional (2D) paintings, 3D props and sets, as well as camera projections onto primitive geometry to achieve a convincing final composite.

CHAPTER II

HISTORY

2.1 Brief History of Norman Dawn

The story of matte paintings began in Paris during the 1890's with the first public screenings of motion pictures. No stranger to illusion, magician turned filmmaker Georges Méliès used huge paintings as backgrounds for his sets and employed mirror tricks cultivated from his stage performances as some of the first "special effects" in his groundbreaking films. Méliès' work and tutelage inspired Norman Dawn, widely regarded as the father of matte paintings. At the age of 12, Dawn was using a camera obscura as a projection mechanism for sketching environments. He would often change locations but remain working on the same sheet of paper, combining different elements of new projections into a final composite drawing.

While working as a still photographer in1905, Dawn was assigned to photograph a building which unfortunately had a light pole obstructing his composition. "A photoengraver named Max Handsheigl suggested to Dawn that instead of going through a laborious retouching of a photo, he mount a sheet of glass between camera and building, paint a tree over the offending pole, and photograph glass image and building together (see Figure 1). It was an old still-photography technique that predated cinema, but a revelation to Dawn" (Vaz and Barron 2002). This simple yet ingenious solution

became the basis for set of artistic techniques that would go almost unchanged for nearly a hundred years.
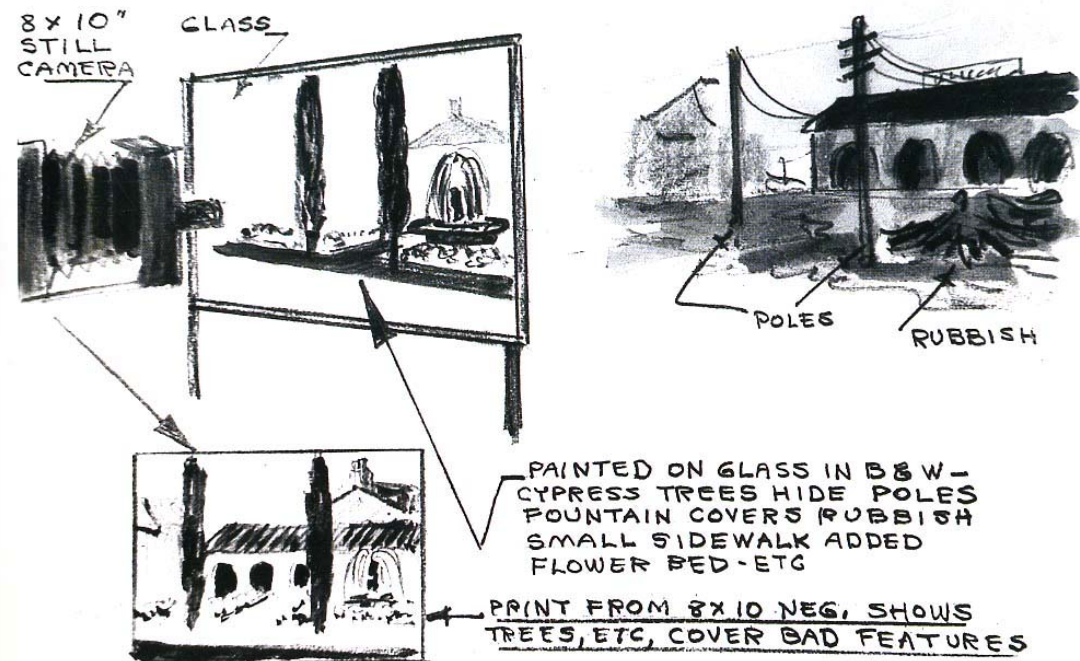
Figure 1. Norman Dawn. Glass Shot Setup Illustration. 1905 (from Vaz and Barron, 2002).

While working on the film *California Missions* in 1907, Dawn set up his camera, composed a shot, and set up a pane of glass in front of the camera and proceeded to paint "restored" Spanish missions over the existing remains (see Figure 2). When he wasn't literally fighting other filmmakers (competition was so fierce physical altercations often took place), he was constantly going back and forth from the painting to the camera to

make sure that the painting was blending as seamlessly as possible with the "practical" site. By all accounts this was the first time that this technique was ever used for a motion picture.
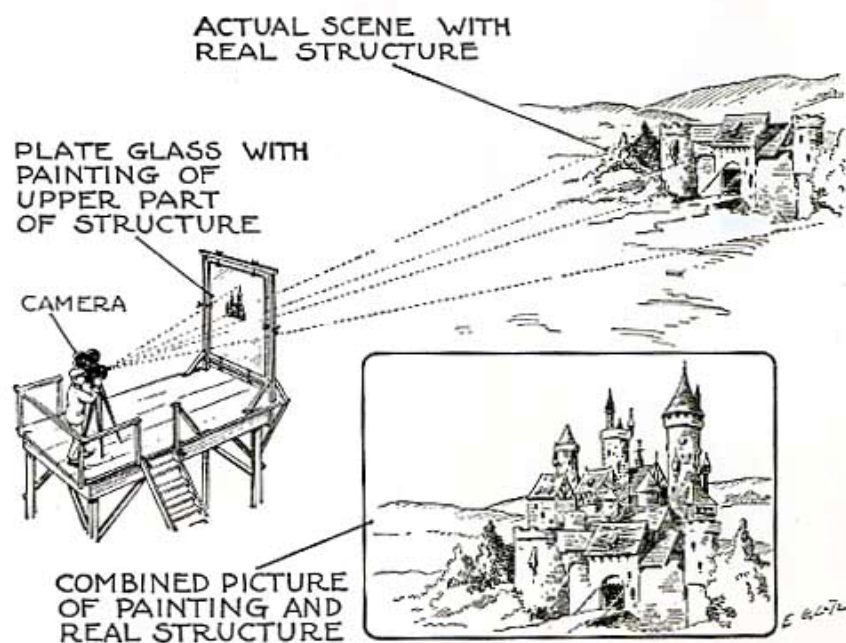
Figure 2. E. G. Lutz. Glass Shot Setup Illustration. 1927 (from Vaz and Barron, 2002).

Known as the "glass matte" technique, one of its limitations was that the paintings and camera had to be literally bolted down on location; the painting created on the spot. This issue was resolved years later with a technique Dawn called "original negative," which was inspired by director Edwin Porter's *The Great Train Robbery.* "Dawn used hand-cut cardboard mattes over his camera to block exposure of the areas of film reserved for the glass-painted image, which he could now create in the comfort of his studio. After rewinding the same roll of film with which he'd photographed the live-

action, he could then expose the finished painting, producing a single image effect" (Vaz and Barron 2002). From a production standpoint, this process provided a much easier means of compositing live action elements and matte paintings. However, the convenience of being able to produce the matte paintings offsite was marred by the possibility that the separate exposures might not line up properly, causing a jittering effect that Dawn called "weave." This issue plagued Dawn's *Story of the Andes* so much that it caused him to return to onsite glass mattes. It took three years for the camera precision technology, specifically the "registration needed to accurately line up the exposures," to catch up with the filmmaker's ambitions. This advance allowed him to return to the original negative technique (Vaz and Barron 2002).

The Bell and Howard 2709 motion picture camera featured precision registration pins, which allowed separate film elements to be accurately composited in-camera. This enabled Dawn to combine original negative and glass paintings into a new hybrid. Instead of painting the final image on the locked down, pane of glass on site, he merely painted a solid black matte. This was much faster than painting the final image and less cumbersome than using cut pieces of cardboard as mattes. The final paintings were created back at the studio using the same camera model featuring a custom "optical system, [which] allowed him to view the matte board on which he'd create his paintings while simultaneously viewing a strip of live-action test film in the camera aperture" (Vaz and Barron 2002). Another variation of this technique was featured in the 1924 film, *Master of Women*, while Dawn was working at the Louis B. Mayer film company. The final composite featured a dog team trekking through a glacial wilderness with a whaling

ship in the background. The first exposure on the film was the live-action footage, and the second exposure combined a miniature ship and a glass matte painting. This final composite succeeded in its own right as a special effect, but when viewed by industry mogul Marcus Loew through the optical setup at the studio, it prompted the acquisition of the Mayer company forming Metro-Goldwyn-Mayer (M.G.M.).

The following years brought both success and turmoil to Dawn, and the rapidly maturing film industry. In 1918 Dawn patented his technique of "cinematographic picture composition" and in 1921 he filed an extremely unpopular lawsuit against rival painter Ferdinand Earle and other parties who were yet to be mentioned for copyright infringement. Those parties not identified in the suit eventually became most of the major companies in Hollywood. The case went on until 1924, when it was dismissed. Dawn later disclosed that his employer had forced him to sell his patent to M.G.M. for $10,000; a price Dawn argued was far too low. After some "you'll never work in this town again if you don't" arm twisting, he acquiesced and sold the patent. M.G.M. made the technique publicly available, ending the legal controversy.

Dawn's contributions to the history of matte painting cannot be overstated. More often than once, it took technology a few years to catch up to his creativity and imagination. Ideas that were abandoned because of technological limitations, like rear projection (originally intended for Dawn's *The Drifter*) were realized to great effect years later. His pioneering efforts forged the basis for the analog matte paintings and compositing techniques used for the next 60 years. He also helped to inspire the paradigms for digital approaches that are used today.

2.2 Background of Painting Techniques

As previously stated, there were three standard methods of compositing paintings with live-action elements before the advent of digital compositing. The first, known as latent image compositing, uses black paint on glass to define the matte. When shot with a movie camera, the matte of the painting is not exposed because of its color. This provides a blank space on the film for the addition of live action sets, actors, or miniatures, which are shot separately and composited photo-chemically. In the case of "in-camera" glass shots, the second technique, the matte is defined by transparency instead of solid black. Panes of painted glass are arranged in front and/or behind a set; through the camera all these elements appear as one composite. For example, while filming stop motion animation for a jungle scene in the movie *King Kong*, there was one painting for the background, and another for the foreground which had a transparent matte. In the studio these two paintings were set up in front of the camera, and between the two there was a small table supporting a miniature stop-motion setup for Kong (see Figure 3). At any one frame the cameraman could look through the lens and see all three elements combined (see Figure 4).
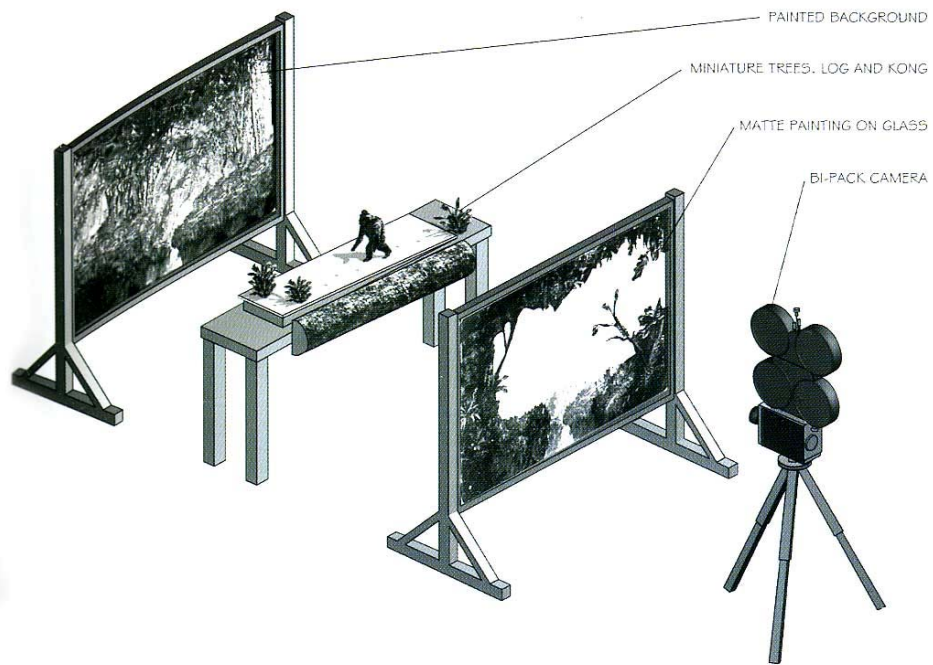
Figure 3. *King Kong* Compositing Setup.

Figure 4. King Kong "In-Camera" Composite.

Although there were other ways to achieve composites, these three techniques were the standard until the late eighties and early nineties, when George Lucas' special effects company Industrial Light and Magic (ILM) helped to revolutionize the art of matte paintings. ILM accomplished this by restoring the use of miniatures in conjunction with paintings as common practice while ushering matte paintings themselves into the digital age through the development of a series of computer aided painting tools.

One of the biggest limitations of matte paintings has always been the accommodation of camera motion. During the making of *Star Wars* in the late 1970's, ILM developed the motion control camera, which used a computer program to control the movement of a camera. The camera operator could repeat the same move exactly, allowing multiple models to be filmed separately and composited later. The idea was readapted in1980 by ILM effects cameraman Bruce Walters, using it to combine models and miniatures with matte paintings. Walters said "the rule for matte painting photography for a hundred years had been to never move the camera, to actually bolt it down (Vaz and Barron 2002)." The AutoMatte camera system worked in a fashion similar to the multiplane system pioneered by Disney, which moved panes of painted glass to create a parallax perspective effect. When the AutoMatte was used to film foreground models and multiple matte paintings for a single shot, the filmmaker was afforded more flexibility in regard to camera motion than previously available.

In 1985 ILM painter Chris Evans became the first artist in the matte department to use digital painting technology in the film *Young Sherlock Holmes*. Evans used a

Pixar Image Computer and in-house software to digitally paint out the matte lines of his

scanned painting for the final composite of a shot. This scene also featured the first

computer generated character used in a feature film: a stained glass knight that came to

life and attacked a live-action priest. In 1990 the digital manipulation tool that John

Knoll had developed with his brother Thomas at ILM was published by Adobe and made

commercially available as Photoshop. By 1992 ILM was no longer producing any oil

and glass paintings, and today Photoshop is arguably the most widely used professional

digital painting and image manipulation tool in the computer graphics industry.

CHAPTER III

STATE-OF-THE-ART

3.1 Multiplane Paradigm in a Digital Workspace

While Norman Dawn is credited as the father of matte painting, it was Walt

Disney's studio that pioneered multiplane animation. The state-of-the-art in 1937 was a

14 foot tall framing and camera system that was tremendously expensive and difficult to

both maintain and use. This system was developed to simulate a sense of depth by

literally separating foreground, middle-ground, and background. The basic idea behind

this technique used multiple glass paintings layered on top of one another. Each layer

was individually lit, painstakingly animated and blurred or focused frame by frame to

simulate camera motion and depth of field. Today, tools like Adobe After Effects

function on a similar paradigm. Within a given composition, elements can be layered on

top of one another and individually scaled, moved, blurred, otherwise manipulated and

key-framed with the click of the mouse.

3.2 Projection Paradigm in a Digital Workspace

In the past if a single plane 2D matte painting had to account for a camera move,

the shifts in perspective would be manually painted into the composition. The entire

matte painting would never been seen on screen, instead the camera would film it in

such a way that the camera perspective would correspond to the faux dimension and

perspective shifts of the painting. Projection mapping takes the idea of simulated

dimensionality and detail a step further by functioning as a virtual camera projector within a 3D environment. While this is a standard tool included in many of today's 3D software packages, there is limited documentation available as to how this method can be specifically used in the realm of 3D matte paintings. There is reference of image projection onto 3D geometry for use in digital matte painting which points to it being a common production technique. However, while the basic software tools may remain the same, how these tools are specifically utilized or modified remains predominantly proprietary, or at the very least not discussed in detail.

Today the lines between texture artists and matte painters are rapidly blurring. In point of fact, projection painting is a means of texture mapping that is dependant on the camera's point of view. This technique is affectionately referred to as 2.5D, a moniker which aptly describes its nebulous existence between strictly 2D or 3D realms. Tools like Body Paint 3D and Deep Brush allow texture painters to work paint computer generated (CG) models in 3D space as through they were actual sculptures. When these tools are combined with software packages like Maya or XSI, and proprietary plug-ins, painters can achieve strikingly convincing matte paintings that seem to move and distort with the camera.

3.3 Painting in a Digital Workspace

Computer graphics tools, like Photoshop and Maya make the creation, implementation, and alteration of matte paintings faster than ever before. Painters can import reference computer models or frames from live action plates directly onto their

digital canvases; colors can be exactly matched with a click of a mouse instead of painstaking trial and error. These standard operations help digital matte painters develop and seamlessly integrate their work with other shot elements without the use of cumbersome analog optical systems. While these advances are a quantum leap ahead of the means Norman Dawn had at his disposal, matte paintings are still tremendously time consuming to create. Once completed, the greatest area of flexibility in terms of immediate change is color adjustment. Compositional modifications can always be added as separate layers in a digital painting or merely saved as a separate file. However, if the director decides to drastically change the camera view or make significant changes to an existing painting, a re-paint of the entire shot could be required.

The emphasis on pre-production is especially important in computer generated films, where everything that appears on film must be designed and fabricated from scratch. Storyboards, animatics (animated story boards) and pre-visualizations (primitive versions of 3D shots) for shots and sequences help directors view entire films in a quick and unadorned format. These pre-production tools allow directors to make editorial choices of shots well before they are assigned to the artists and technicians that will carry them to completion. In CG film-making, temporary stand-ins for props, characters, matte paintings, etc. are used to help block out shot elements like animation, camera work, and effects. When the decision to use a matte painting for a shot is made, a temporary painting created in a few hours can be used, instead of a final painting taking days or weeks to make. This allows to the director to make changes while keeping waste to a minimum.

CHAPTER IV

OVERVIEW

4.1 Methodology

This artist has designed a series of computer generated case studies to demonstrate various matte painting techniques. Some of these studies will showcase one technique exclusively while others show how several different techniques are used together for a single shot. 3D matte paintings have been created when analog paradigms alone failed to satisfy the objectives of a given shot. In order to explain why particular approaches were used or abandoned, each scene has be broken down into its individual elements and explained. The discussion includes the pre-production process, initial evaluation of where matte paintings could be used, testing, final composite, and final evaluation of a given shot.

4.2 Process

This artist has demonstrated techniques developed from analysis of existing work, which includes both traditional analog painting and state-of-the-art digital painting methods. Testing of these techniques has formed the basis of reasonable assumptions as to how they are used in 3D film making as well as how they can be expanded and improved for future research. For the purposes of this research, Alias/Wavefront's Maya has been used for all 3D production and Adobe's After Effects for 2D image compositing.

Different categories of matte paintings have been defined and explored including single-plane painting in addition to multi-plane painting, where two or more paintings are used to simulate motion and parallax perspective effects. This artist has also explored various ways of using projection-mapping (a method of applying two-dimensional image data onto three-dimensional geometry) to create 3D matte paintings. These techniques have been used alone or in conjunction with other methods to satisfy the requirements of a given shot. 3d matte painting techniques have been developed from analysis of previously published work.

This artist has mimicked analog techniques using digital tools. All paintings and multiplane elements have been created using digital painting / photo manipulation software like Adobe Photoshop and Corel Painter. These programs provide a robust painting engine, simulating real world painting and drawing tools. While both programs provide many standard brush types they also allow the user to create custom brushes; Corel Painter provides a myriad of canvas types and media, and Photoshop is the industry leader in photo manipulation tools. Paintings that do not consist of multiple layers have been referred to as "single plane" paintings; those that have at least one additional layer have been referred to as "multiplane" paintings.

Projected paintings have been created using the Maya camera system as a virtual slide projector. Instead of details being actually modeled, they have been painted and then projected onto simpler shapes. The projection camera(s) remain static while the separate "filming" cameras move and record each shot. The more the film camera

diverges in perspective from the projection camera, the more distortion becomes apparent.

4.3 Case Studies

4.3.1 Case Study 1 (ARC Shots 1-5)

The purpose of this animated piece was proof-of-concept for further research. This artist wished to demonstrate that matte paintings could be seamlessly integrated with 3D computer generated elements. Each shot was engineered so that one or more matte painting techniques could be used to accomplish the shot requirements. The main prop element used in each shot was a computer generated ship which was fully modeled and texture mapped. For this case study matte paintings were predominantly used to establish expansive exterior environments.

The five shots of the piece chronicle the journey of a small air-ship as it navigates through the sky and into a large canyon until it arrives at its final destination: a large island city in the middle of a canyon lake. This project began with a sketchbook page drawn in 2000 (see Figure 5). Beyond the ships themselves, the original concept also included giant whales that would pull ships through the air toward enormous floating cities. These extra ideas from the original concept were abandoned when the project was revisited in 2004 as a vehicle for thesis research due to the intended focus on matte paintings. Beyond initial notes and sketches, preproduction consisted of new conceptual designs for the ship and destination city, color concepts, and an overall plan of the canyon terrain. The plan was used to layout the position and animation of five

cameras and the ship during each shot. All five shots were first storyboarded and then those drawings were taken into After Effects and animated to create a rough animatic.
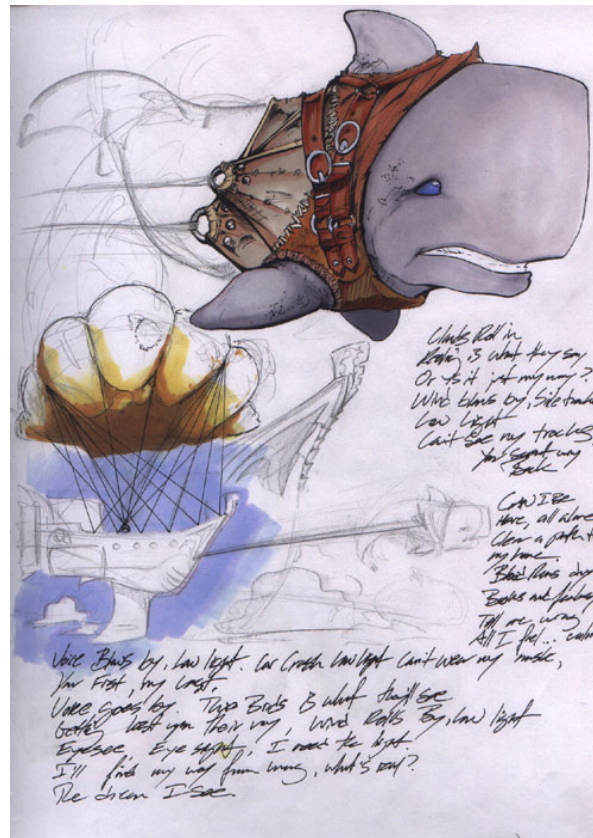

Figure 5. Initial Sketchbook Page Drawn in 2000.

The animatic was used to give an initial evaluation of which elements would be "practical" (modeled and textured) and which could be substituted using matte paintings. A rough primitive model of the canyon and the natural walls surrounding island city was modeled based on the plan drawing. Cameras and a sphere representing the ship were placed in the scene and animated, creating the initial layout pre-visualization in 3D. This

tool was used to evaluate how the shot elements would be created, but most importantly it was used as an editing mechanism. All camera work and ship animation was completed before any final paintings were created in order to keep the possibility of having to repaint a matte shot to a minimum.

4.3.1.1 Arc Shot 1

The opening shot for the piece required that the ship emerge from a volume of clouds and pass by a stationary camera. The main matte painting technique used for this shot was multiplane. Since there was no camera motion required for the shot the decision was made to use 2D cloud elements that were painted using Adobe Photoshop. These elements were then animated in Adobe After Effects. The background "sky" plate remained stationary while the cloud plates and vapor elements were animated to help simulate the volume and undulation of the clouds.

Figure 6. Shot 1 Storyboard Animatic.
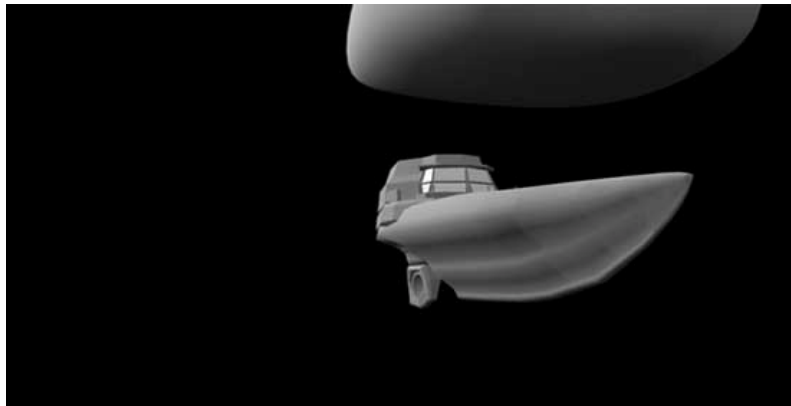
Figure 7. Shot 1 Color Cue.

Figure 8. Shot 1 Pre-Visualization.

The ship element was composited on top of all the cloud elements except for one vapor element which remains above it to help add a sense of depth. Shot 1 was storyboarded to have the ship emerge as a dramatic revelation from the clouds (see Figures 6-8). Initial tests having the ship element merely change in opacity yielded poor results; the background clouds were unconvincing as a three-dimensional volume. The

flatness of the effect was emphasized by the dimension of the fully computer generated ship.

A solution was found by having the ship pass through a volumetric primitive sphere in the Maya environment (see Figure 9). When rendered this element showed the ship emerging from a sphere along its geometrical contours instead of the uniform reveal from merely a shift in opacity. This rendered pass was used as a composting matte applied to the existing ship element (see Figure 10). A volumetric shadow cast by the ship was also added to help the illusion of cloud volume.
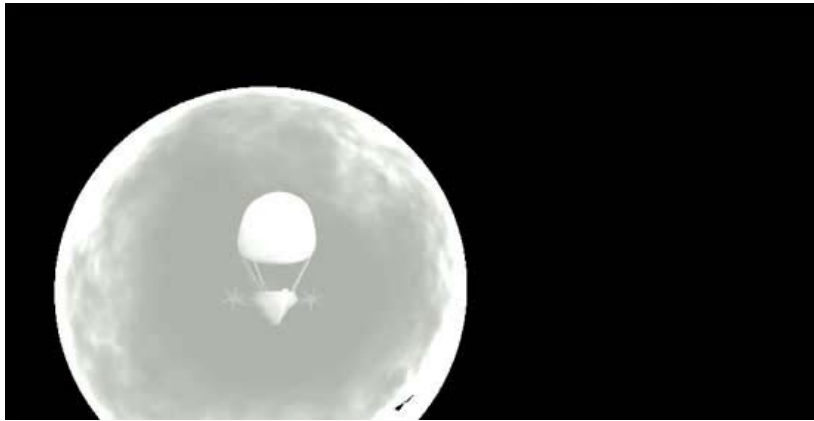

Figure 9. Shot 1 Volume Matte Frame.

Figure 10. Shot 1 Frame from Final Composite.

4.3.1.2 Arc Shot 2

This shot called for a vertical / rising camera move, establishing the terrain for the first time (see Figures 11-13). Computer generated grass was added as a foreground element and was blurred out of focus as it moved out of frame, revealing the canyon and the ships decent into it (see Figure 14). The grass was created on top of a simple N.U.R.B.S. plane which was modeled to represent the contours of a hill, and the Shot 2 camera was animated in the Maya environment to creating a rising crane shot. The background for this shot was a single plane painting which was had a translation animation in After Effects moving it slowly down the screen to match the camera move in Maya.
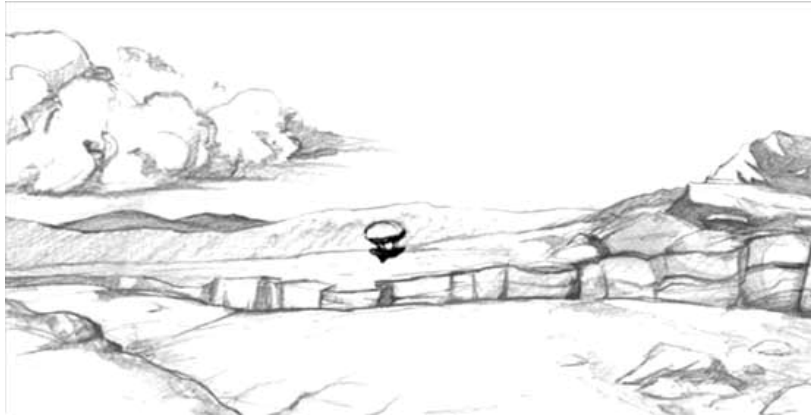
Figure 11. Shot 2 Storyboard Animatic.

Figure 12. Shot 2 Color Cue.

Figure 13. Shot 2 Single Plane Matte Painting.

Figure 14. Shot 2 Final Composite with Grass and Ship Elements.

4.3.1.3 Arc Shot 3

Shot 3 had no camera move, but it did have one specific parameter that would eventually lead to a breakthrough on another project. The shot called for the ship to descend into the canyon (see Figures 15 and 16). While having a locked camera helped,

the matte painting still needed to interact with the CG ship. Specifically, this artist

wanted to have the painting receive shadows cast from the ship run along the contours of
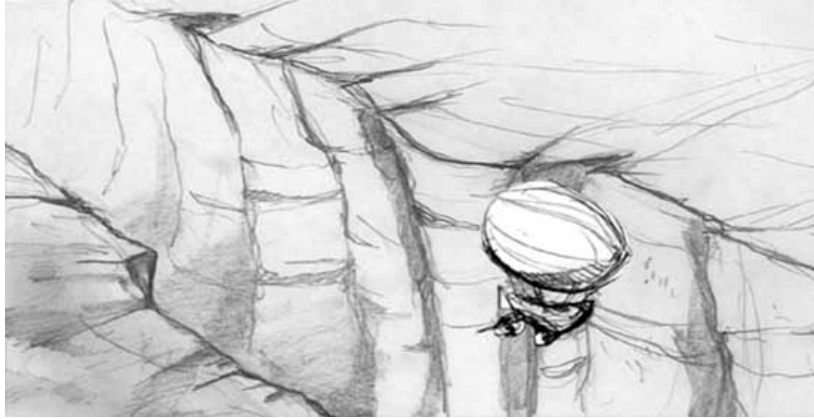
a painted canyon wall.

Figure 15. Shot 3 Storyboard Animatic.

Figure 16. Shot 3 Color Cue.

The effect was achieved by first modeling a primitive canyon wall using a

polygonal plain in Maya (see Figure 17). A wire-frame of the model was printed out and

traced with graphite on a light table, and then scanning the pencil drawing back into the

computer. The pencil image was first brought into After Effects as a background plate.

Next a sphere representing the ship was animated passing along the CG wall in Maya. A

pass was rendered of the sphere alone and another of just the shadow it cast on the wall.

These passes were then composited on top of the graphite background. The resulting

composite demonstrated a sphere traveling along a pencil canyon wall, casting a shadow

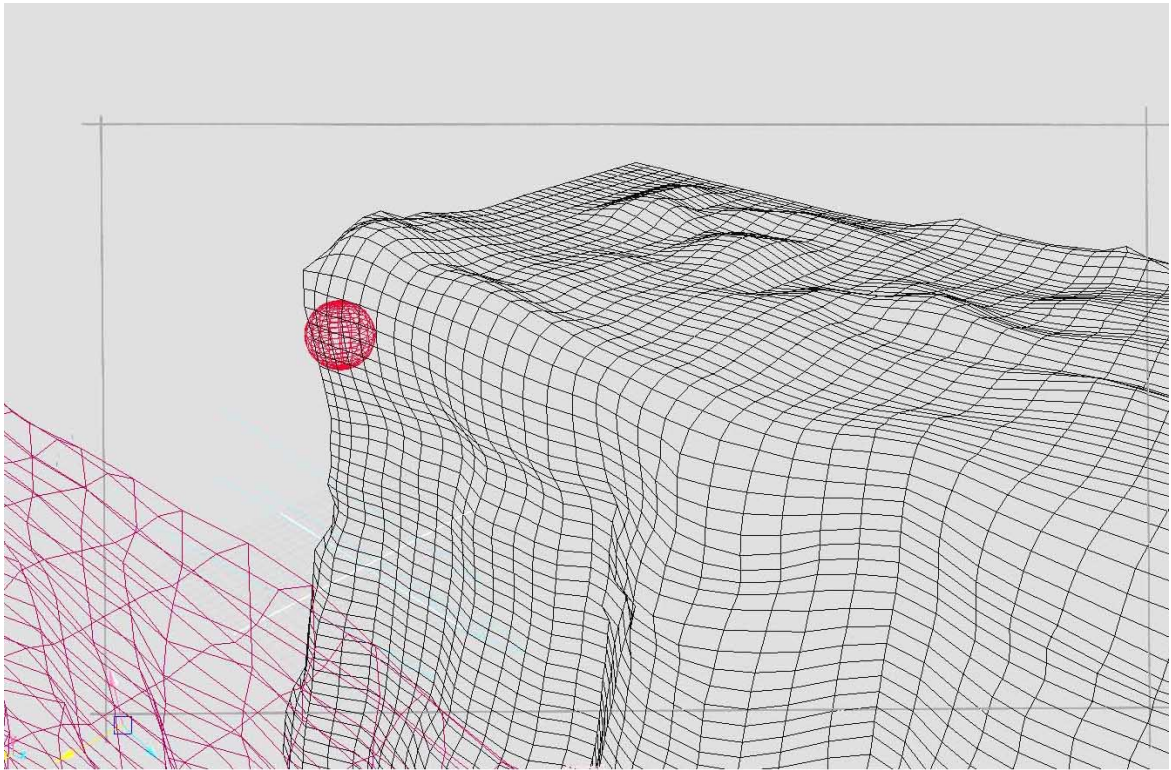that corresponded with the contours rendered in the drawing (see Figure 18).

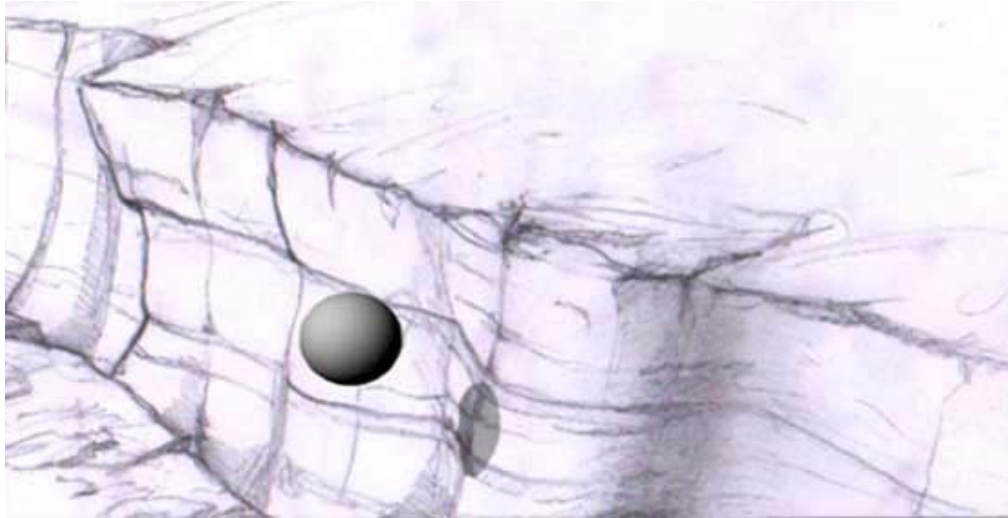Figure 17. Shot 3 Wire Frame Used to Trace Terrain.

Figure 18. Shot 3 Sphere Composite Test.

The process from the pencil test was repeated for the final matte painting. The 3D model was modified to create distinctive contours. This was lit and rendered; the resulting image was used as reference for the final painting. Using the setup for the proof-of-concept, the background plate was replaced with the newly created color version, and the sphere and shadow passes were replaced by respective ship and shadow elements (see Figure 19). While this shot succeeded technically, the static matte painting seemed a little unsettling. Eventually an animated shadow intended to simulate a cloud passing over head was added in the upper right hand of the frame (see Figure 20). This addition helped to alleviate the problem with the shot seeming too still, and it reminded this artist of Chris Evans' comments comparing matte painting to a sleight of hand.
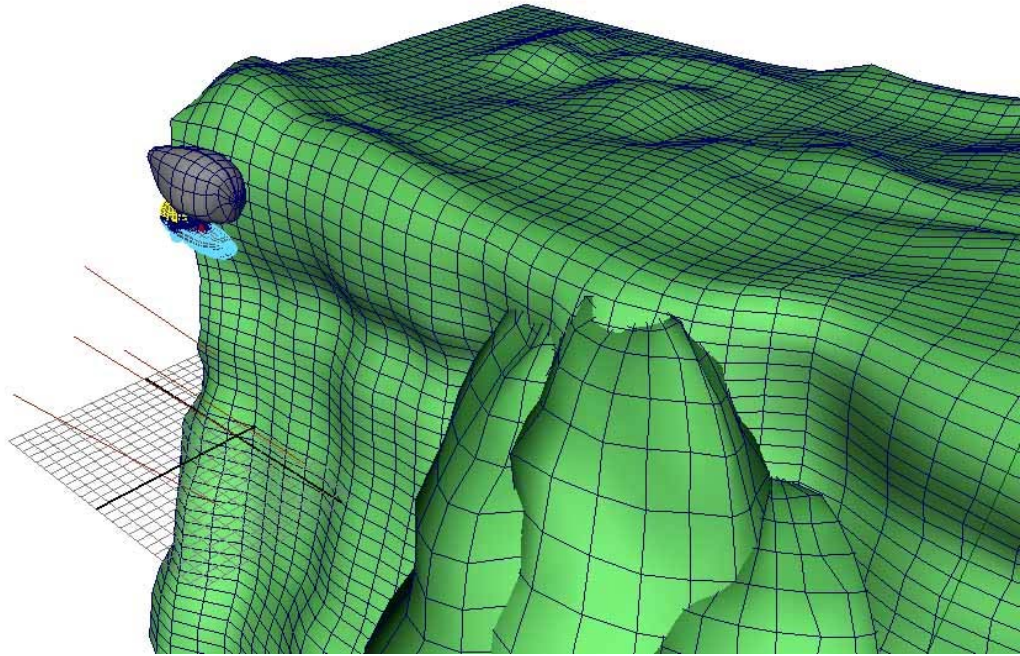
Figure 19. Shot 3 Modified Model for Final Painting.

Figure 20. Shot 3 Frame from Final Composite.

4.3.1.4 Arc Shot 4

This shot called for the camera to follow the ship as it meandered around a curve of the canyon, ultimately revealing the first view of the destination city. Initially both the canyon walls and the city itself where intended to be painted as flat planes and animated in such a way that the canyon walls revealed the city through a parallax perspective effect (see Figures 21 and 22). This shot was homage to the early Disney multiplane efforts. However when the jump was made from storyboard animatic to primitive 3D pre-visualization the approach was abandoned (see Figure 23). The dramatic degree of the camera move coupled with the 3D ship elements simply did not coalesce with the 2D style of flat planes merely moving apart to reveal the background.

Figure 21. Shot 4 Storyboard Animatic.
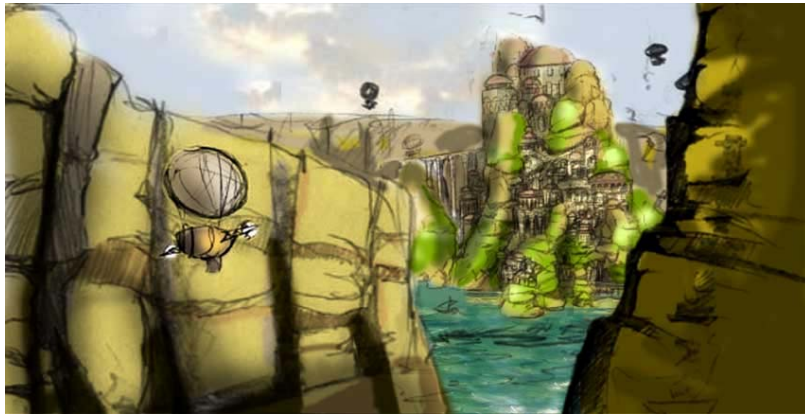
Figure 22. Shot 4 Color Cue.
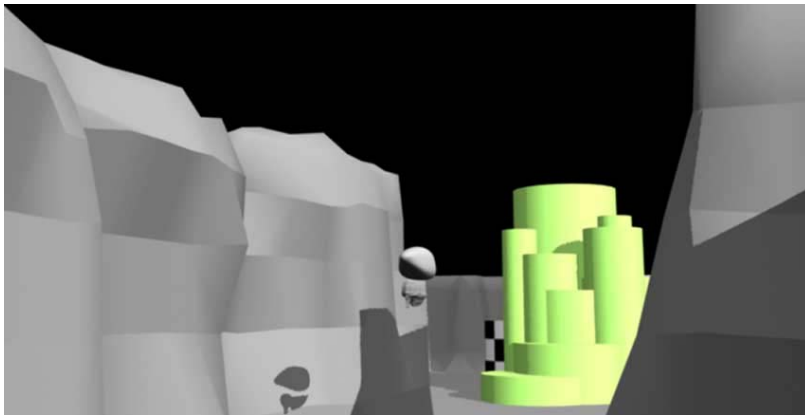
Figure 23. Shot 4 Pre-Visualization.

In order to satisfy this artist's requirements that each shot involve some form of matte painting, the decision was made to model and texture map the canyon walls as 3D prop elements, retaining the city and background as a single plane painting. A painting of the city was important for two reasons: cost (in terms of time) and screen time. A 3D model of the entire city would have taken too much time to model and texture map for a

3-4 second glimpse. These two criteria alone were textbook cases for a matte painting substitution.

In the next evolution of the shot 3D canyon walls revealed a single plane painting animated in After Effects moving left to right. While this effect was an improvement, it still lacked dimensionality or depth. In order to salvage this shot, the original parallax perspective approach was revisited, but this time it was focused on just the city and the canyon background behind it.

The matte painting was cut up into 8 slices, 7 for the city and the last for the canyon walls behind the city. Each slice was cut along the painted geometry of the city, starting with the buildings painted to represent the foreground elements; working with each progressive slice farther back in dimension. These slices were next brought into the Maya scene that contained the ship and canyon elements. The color and alpha channels where mapped onto single polygon planes and lined up in order and composed in front of the camera (which was oriented at the position of the last key-frame of the shot). When the camera was animated the 3D canyon walls revealed the city with a new degree of dimension achieved through the parallax perspective of 8 paintings on virtual pieces of glass (see Figure 24).

Figure 24. Shot 4 Final Composite.

4.3.1.5 Arc Shot 5

Shot 5This shot featured a sweeping camera move that ran along a curve, going behind a small portion of the city. Originally the small portion of the city was intended to be a painting that merely moved from right to left, ultimately revealing the approaching ship and a background matte painting (see Figures 25 and 26). However this shot was plagued by the same aesthetic problems with 2D flatness as shot 4. The decision was quickly made to model and texture map only the parts of the city that would be viewed in the shot and continue to resolve the background with a single plane painting (see Figure 27).
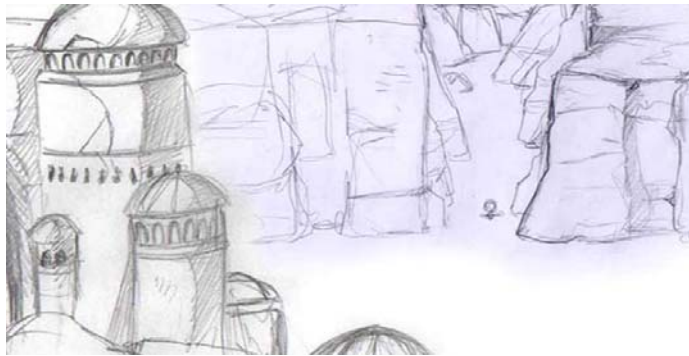
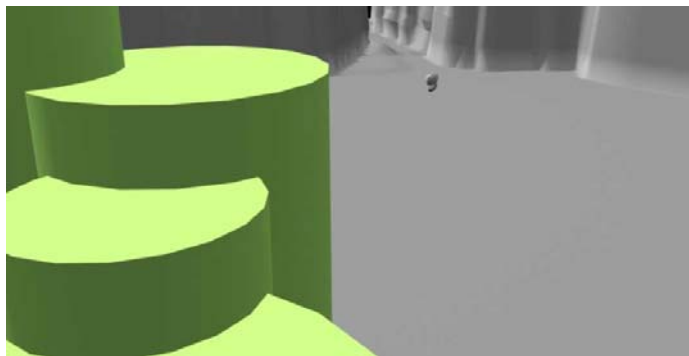Figure 25. Shot 5 Storyboard Animatic.

Figure 26. Shot 5 Pre-Visualization.

Figure 27. Shot 5 Before Final Texture Maps and Projections.

Shot 5 was revisited after the research and development of camera projection techniques in subsequent projects. This artist wanted to have the freedom of painting textures for the practical city elements as though they were 2D paintings; essentially not having to paint in U.V. space. The idea was based on the approach used to create the painting in shot 2: primitive reference geometry would form the basis of a matte painting that would line up and correspond with prop elements.

Projections in the Maya environment involved five parts: the image being projected, a perspective projection node, a camera that provided the vehicle for the projection, projection receiving geometry, and a surface shader that was applied to the projection receiving geometry (see Figure 28). Once the primitive geometry was modeled and a filming camera was set up with final orientation and animation, a new projection camera was created. The projection camera was oriented to correspond with the film camera's location and direction in X, Y, Z space. If there was no animation in the film camera, then the coordinates of the projection camera could match verbatim. However if there was going to be any animation in the camera involving panning or pulling back, the projection camera was pulled far enough back so that the projection was filling the frame of the film camera. Early testing with a camera animated along a curved path lateral to the geometry showed that the best results came when the orientation of the projection camera was set up based on the orientation of the film camera halfway through its animation cycle. This helped to alleviate distortion problems and projection artifacts such as the exposure of background geometry mapped with painted elements intended to correspond with foreground geometry.
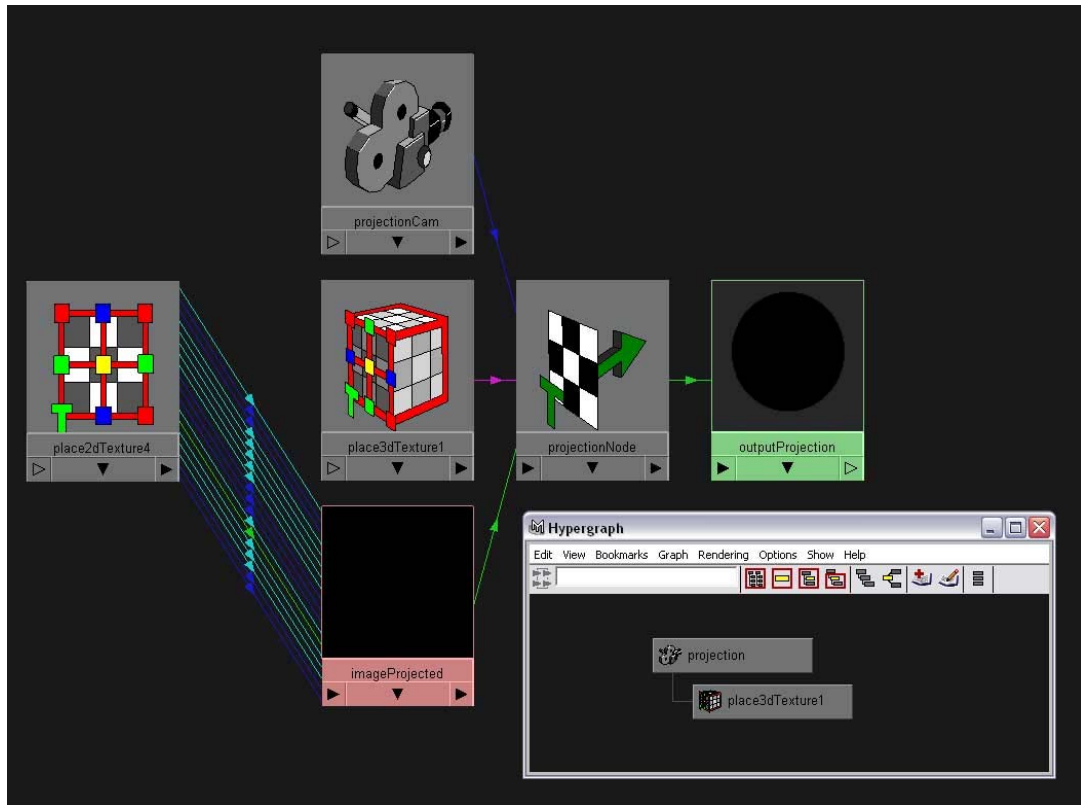
Figure 28. Projection Network in the Maya Environment.

These early tests in camera projections yielded two conditions that led to the best results. The first was that the geometry receiving projections should be as simple as possible and avoid any concavity in order to reduce or eliminate the incidence of background geometry erroneously mapped with projected painting elements from the foreground geometry. The second was there should be as little camera motion as possible. Unfortunately shot 5 shattered both these earlier conditions with a sweeping camera move that lasted nearly 15 seconds which traveled along the complex geometry of the practical city set.

A solution was found by using several small and localized projections instead of one large one (see Figures 29 and 30). This satisfied the previously stated conditions for successful projections because the duration of any particular projection was only a few seconds, the amount of camera motion was extremely limited, and the complexity of the geometry was isolated to small parts. Projection distortion and artifacts either occurred out of frame (film camera) or were obstructed by new foreground geometry as it entered the shot.

Figure 29. Shot 5 Composite of Localized Projections at the First Frame of Shot 5.

Figure 30. Shot 5 Final Composite Using the Projection Pass.

4.3.2 Case Study 2 (Untitled)

Case Study 2 was built on Arc Shot 3's idea of using primitive reference geometry to achieve 3D geometry / painting continuity. This was the first shot (outside of preliminary testing) produced by this artist using projection mapping as a means of applying a matte painting onto primitive geometry (see Figures 31-34). The technique was researched and developed primarily to help accommodate camera motion, but also out of the frustrations and shortcomings of the methods used in creating ARC shot 3.

To achieve geometry / painting continuity the projection camera was locked to the position and orientation of the film camera halfway through its animation cycle. An occlusion and key-light pass was rendered from this position as painting references. These were used to create a rough preliminary painting which was projected. This artist

discovered that since the painting was created from an orientation along the film camera path there were portions of the frames at the beginning and end of the animation cycle that the painting failed to cover. In order to solve this problem, the projection camera was pulled back and another test painting was created. This new projection was large enough to cover the film gate during the entire shot. Once the camera animation was finalized and the test projections were successful, a more detailed painting was created and projected.
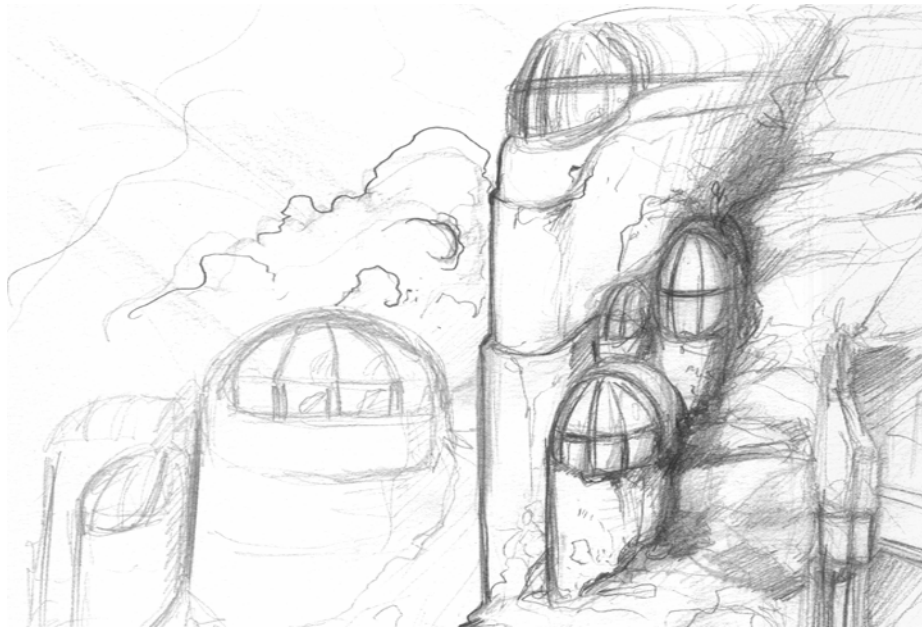

Figure 31. Case Study 2 Conceptual Sketch.
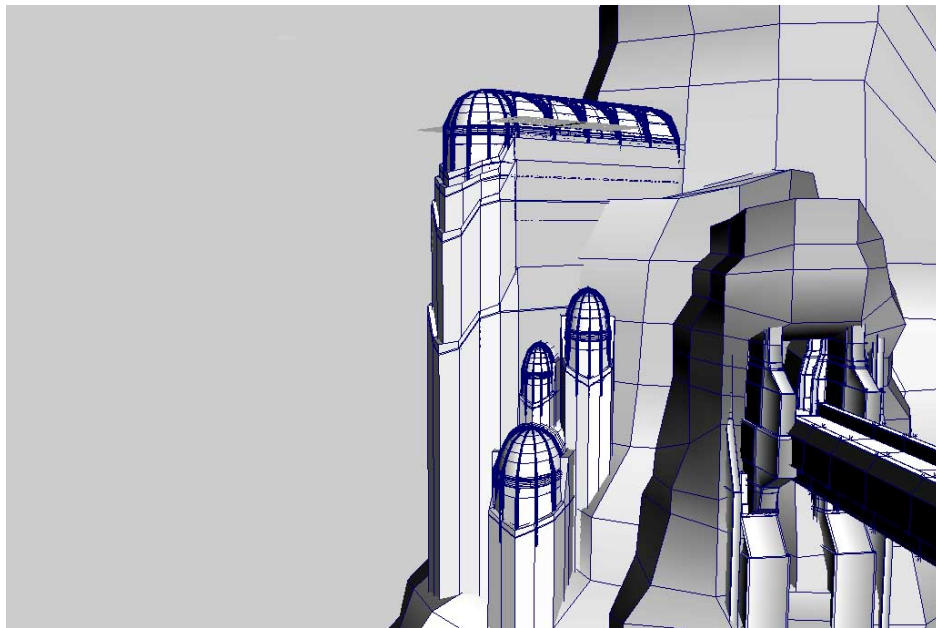
Figure 32. Case Study 2 Color Key.

Figure 33. Case Study 2 Primitive Geometry Used for Painting Reference.

Initial testing of the projection technique was extremely successful, however once the camera motion was introduced, some of the geometry had to be modified. When the there was no camera motion at all, it made no difference, projection-wise, how complicated the geometry was. As soon as camera motion was introduced many projection artifacts were clearly evident. After further testing this artist discovered that the most successful results occurred when the geometry was convex relative to the camera. In hindsight, a multiple projection set up would have provided more freedom for camera movement, however that technique had not yet been developed.

There were two objectives of Case Study 2. The first was to project a detailed matte painting back onto the simple geometry on which it was based. Additionally, the projection setup had to accommodate a camera move. Although the model used for painting reference and projection reception was not ideally suited to a single projection with extensive camera motion, it did succeed in satisfying the stated objectives. The final composite for this shot included the principal prop set which received a single projection, and a multiplane painting background. Volumetric lighting effects were achieved by animating brush stokes in After Effects and these were combined with fog elements to help add motion and visual interest to the shot (see Figure 34).

Figure 34. Case Study 2 Frame from Final Composite.

4.3.3 Case Study 3 (High Genus)

Case Study 3 was created to further illustrate how 3D models could be used as

the basis for 2D paintings. Before the Photoshop and other digital painting tools, analog

matte painters were known to paint directly on top of large photographic prints. Some

would literally cut and paste different photo elements of models, props, and

environments, creating a collage which they would use as their canvas. The matte painter

would then add painted elements to create a seamless composite.

This artist wanted to demonstrate this idea by embellishing a high genus model

with painted details. An ambient occlusion pass was taken of the high genus 3D model

and brought into Photoshop, where the final painting was created (see Figures 35 and 36). This reference plate was initially intended to be used as a projection and involve a 3D camera move. However due to the nature of the model, all camera motion was abandoned due to an inordinate amount of projection artifacts found in early testing. A single 3D projection on the model was ultimately used, but only a single reference frame was rendered in the Maya environment. That frame was brought back into Photoshop, where the final composite was completed (see Figure 37).

If this case study is ever revisited as a 3D matte painting with some degree of camera motion, this artist can make several suggestions on how it could be accomplished. These assumptions are based on the experience accrued from this research. First, all projections should occur on zero-genus meshes. The high genus model used in this case study was chosen for aesthetic value, however initial testing generated many projection artifacts that were a direct result of its many geometrical facets. In order for this particular model to accommodate both painting projections and any lateral camera motion, many localized projections would have to be used. The incorporation of foreground texture-mapped prop elements would also help add depth and dimension to the overall composite. In conclusion, the amount of work needed to adapt this model for use as a projection receiver clearly indicates what a poor candidate it is for this technique. A better and infinitely more flexible solution would be to conventionally U.V. map and texture this model; perhaps using a single plane painting for detailed background elements.

Figure 35. Case Study 3 Conceptual Illustration.

Figure 36. Case Study 3 Occlusion Reference.

Figure 37. Case Study 3 Final Composite.

4.3.4 Case Study 4 (Room for One)

This case study was developed to demonstrate the simplest case scenario for camera-projected matte paintings. The objective of this case study was to project a painting on as few polygons as possible. An abandoned empty room was chosen as the subject matter for the set. This artist wanted the viewer to assume that the room's geometrical details like the window sills, molding and door where completely modeled and texture mapped. In order to maximize this idea, a single cube was used as a projection receiving model; ultimately only 4 faces of the cube were used (see Figure 38).
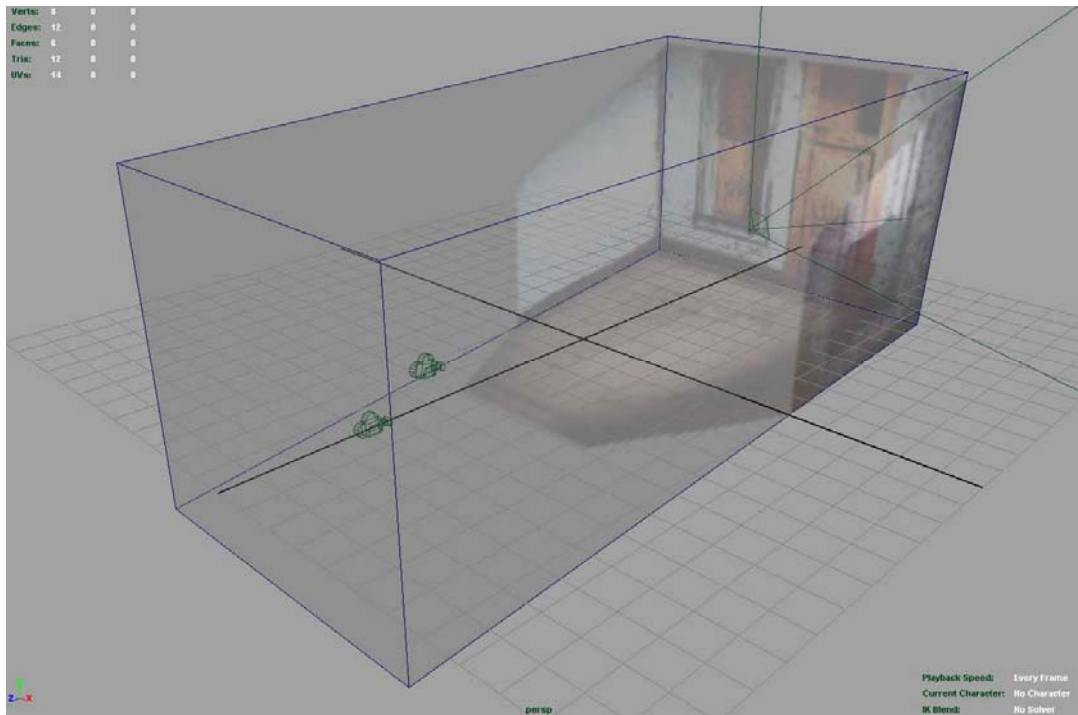
Figure 38. Case Study 4 Projection Receiving Cube.

The projection camera was set up in the cube using a reference projection, and the vertices of the geometry were adjusted to match the projection. Vertices on the projection end of the box were moved to line up "in camera" with the corners of the painted room, while the vertices behind the camera where adjusted so that the cube edges lined up with the vanishing horizontals of the one-point linear perspective painting. Camera motion was limited due to the simple nature of the model and the limited range of coverage from the single projection. The camera motion that *was* achieved helped to add dimension and interest to the shot. The final composite was entirely "in camera" using 4 polygonal faces and no CG lighting at all (see Figure 39).

Figure 39. Case Study 4 Frame from Final Composite.

4.3.5 Case Study 5 (Weathered)

This case study began as a photo collage from a series, and was never intended to be a 3D matte painting (see Figure 40). The 2D image was created in Photoshop using a black and white photograph of this artist as well as color photo texture reference. Testing for the photo series also included texture mapping a 3D model generated from a laser scan of this artist's face. However the results achieved at the time were poor and inconsistent with the other 2D pieces in the series. Ultimately the 3D direction for creating these collages was abandoned in favor for a strictly still-photography and

Photoshop approach. "Weathered" was revisited in this research because this artist

wanted to see how far he could push camera motion from a single projection.

Figure 40. Case Study 5 Original Photo Collage.

Although a 3D scan of this artist's face still existed, it was initially deemed too

complicated to succeed as a projection receiver (see Figure 41). Instead of using the

scan, early tests used a slightly modeled polygonal plane mesh, roughly the 3D

equivalent of relief sculptures. These tests were successful only in achieving extremely

limited camera motion. Tests involving simply texture mapping the planes achieved

similar results. Case Study 5 was nearly abandoned until this artist decided to do some

testing with the "high poly" 3D scan of his face.

A projection camera was setup with the scanned model in the Maya environment to correspond with the orientation of the original film camera and this artist in real life. The camera and model orientation were both adjusted until a rendered frame from Maya matched the original 2D collage. Tests recording slight camera motion from this position quickly showed projection artifacts. However, the success of the overall effect was impressive enough to continue pursuing this direction. Most of the projection artifacts were resolved by simplifying the model. These changes involved lowering the overall polygonal detail and modifying vertices to reduce the amount facets in the model (see Figure 42). Creases of the nostrils and lips were reduced or removed entirely using the smooth parameter in Maya's sculpting toolset (see Figure 43). As these changes were made, the range of camera motion increased.
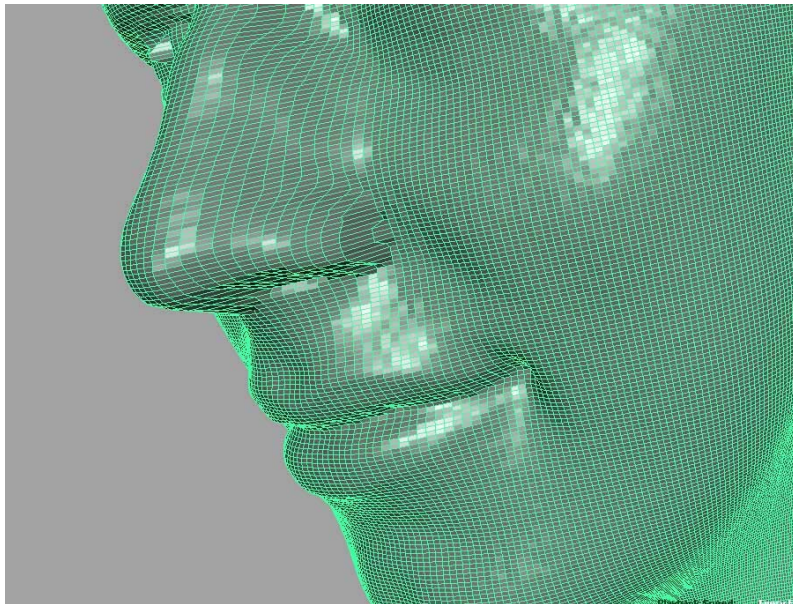

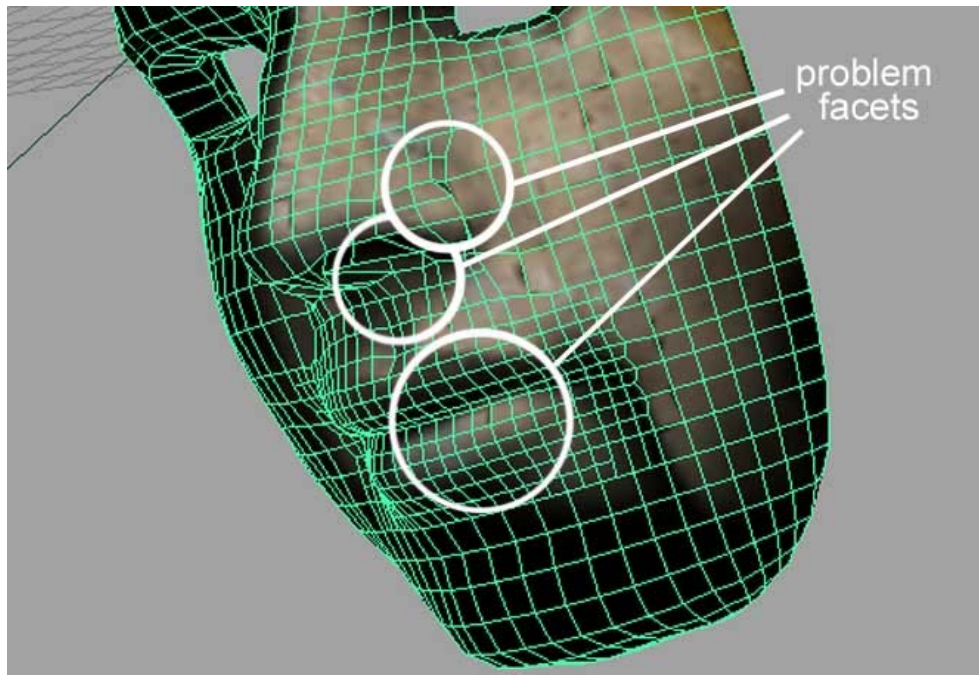Figure 41. Case Study 5 Original Polygon Density.

Figure 42. Case Study 5 Lowered Polygon Count with Remaining Problem Facets.
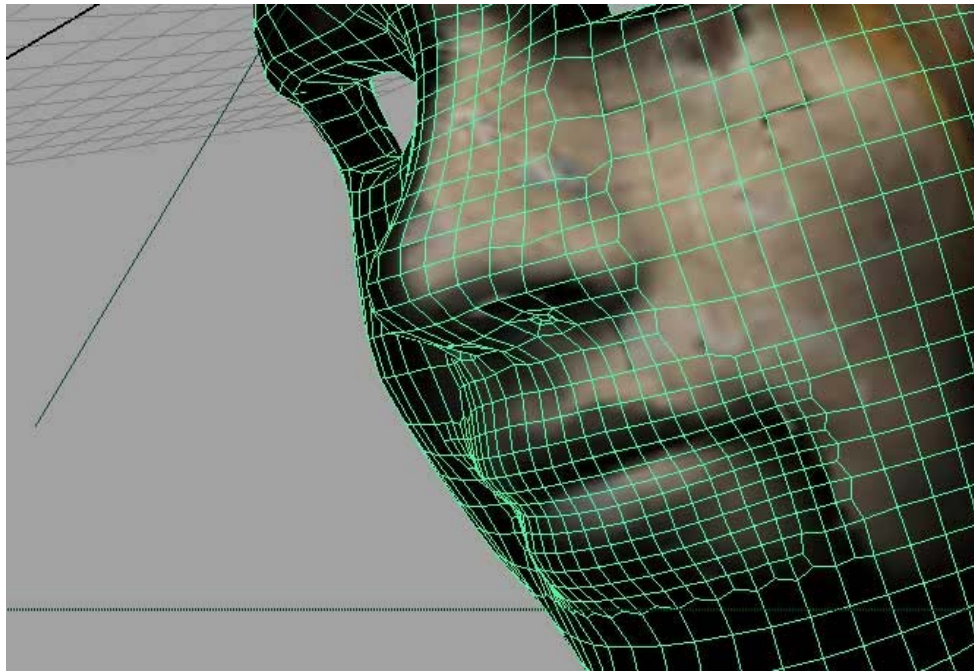

Figure 43. Case Study 5 Final Model with Facets Smoothed.

The camera animation began with a close up shot facing the front of the model and followed a curve pulling back and down until the film camera lined up with the projection camera (see Figures 44-46). This was the greatest range of motion using only one projection achieved by this artist during the course of this research. It was primarily accomplished by having a generally smooth model with curves convex to the camera, but also by having the camera move begin so close to the model. All remaining projection distortion occurred either out of frame or was "strategically" in dark shadow.

Using the existing set up, a specular map was created using the original collage, and projected onto the model. After a few tests using a single light, a specular pass was rendered and composited onto the color pass in After Effects. The specular-roll-off effect added dimensionality and faux detail to the final composite.

Figure 44. Case Study 5 Final Composite (Frame 0 of 600).

Figure 45. Case Study 5 Final Composite (Frame 300 of 600).

Figure 46. Case Study 5 Final Composite (Frame 600 of 600).

CHAPTER V

CONCLUSION

5.1 Discussion of Results

The history of matte paintings demonstrates their use, either alone or in conjunction with other shot elements, varies according to the demands of a particular shot. It also shows that there are distinct parallels between analog and digital painting techniques. The effectiveness of a given painting has always been directly dependant on the painter's ability to seamlessly integrate brush strokes with "practical" film elements. However, today's digital imaging tools make that process easier and offer more freedom than ever before.

The best candidate for a matte painting is a shot element that would consume resources disproportionate to its time on screen. For example, in traditional filmmaking this could be illustrated by constructing massive sets, which are only seen once on screen for establishment purposes. In virtual filmmaking the parallel is the same, however instead of carpenters and painters, there are modelers and texture artists. With computer generated films there is also the added factor of render time. Polygon counts, dynamic effects, texture map resolution, and countless other factors all add to the overall time and cost required to render a single frame. Any shots that can be rendered in full detail using a fraction of the time to render serve to free up those resources for other shots in the pipeline which must be achieved "practically."

With a practical set, a filmmaker can film the same shot from multiple angles, changing camera location at a moment's whim. The advantage and power of matte paintings are ultimately bound to the fact that they must be painstakingly created based on the particulars of individual shots. First and foremost there is the issue of camera orientation. The painter's canvas *is* the camera, therefore shot in which this painted element will be incorporated will ideally require little to no camera motion. As a result, the filmmaker does not have the degree of camera freedom found elsewhere in production. Instead a filmmaker desiring to make effective use of matte paintings should relegate experimentation and shot changes to the preproduction process, using simple paintings or stand-ins to help make final decisions. However, as this thesis has demonstrated, techniques like multiplane and camera projection can be used to accommodate limited camera motion.

5.2 Implications for Future Research/Creative Work

This artist would contend that the future of matte paintings should involve a mechanism for interpolating from one position to another. A perfect linear perspective drawing is only "perfect" from the exact orientation from which it was created. If the artist takes a step from to the left or right, the image seems distorted compared to the reality ahead. Matte painters are plagued by the same issue because they are also abstracting a 3D environment onto a 2D plane. A few seconds of motion on film appears correct, but in actuality it's merely 30 abstractions per second that record a new perspective for every change in position

The foremost problem that occurs with matte painting during camera motion is maintaining consistency from camera position "A" to position "B" without appearing flat and lifeless against the change happening around it. The multiple projection techniques described in Case Study 1 / Shot 5 is this artist's attempts to bridge that gap. What is ultimately being suggesting is a hybrid of the key frame animation paradigm and traditional painting. A tool that could allow matte painters to create key frames, say at the beginning, middle, and end of a camera movement, and automate the creation of paintings in between. In order for such technology to be useful in a production standpoint, they would have to equal the results using "practical" means while still maintaining the time and resource advantages of existing matte painting techniques. Until such technology exists, shots that requiring camera motion can certainly utilize a combination of modeling / texture mapping as well as the 2.5D matte painting techniques outlined in this research.

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