7. International Immersive Projection Technologies Workshop
9. Eurographics Workshop on Virtual Environments
J. Deisinger, A. Kunz (Editors)

# Towards Virtual Reality for the Masses: 10 Years of Research at Disney's VR Studio

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**Abstract**
*The VR Studio was founded in 1992 to explore the potential of Virtual Reality technology for theme park attractions. This paper presents an overview of the VR Studio's history, from the location-based entertainment attractions developed for DisneyQuest, to research in using virtual reality technology for theme park design. The goal is to present many of the lessons learned during 10 years of building interactive virtual worlds. In particular, the paper will focus on the challenge of creating location-based virtual reality attractions for the mass audience.*

**Keywords:**
*Virtual Reality, location-based entertainment, interaction techniques, storytelling*

Categories and Subject Descriptors (according to ACM CSS): H.5.2 [User Interfaces]: Input devices and strategies; I.3.7 [Three-dimensional Graphics and Realism]: Virtual Reality

## 1. Introduction

The VR Studio is the Walt Disney Company's center of excellence in real-time graphics and interactive entertainment. The studio was founded in 1992 to explore the potential of Virtual Reality technology for theme park attractions. Early work included development of an interactive, head-mounted display (HMD) based attraction that immersed guests in the movie *Rocketeer*, and a single-user, HMD-based, interactive experience based upon the movie *Aladdin*.

The promise of this early work helped set the stage for the creation of *DisneyQuest*, Disney's indoor interactive theme park which opened in Orlando in 1998. The studio was responsible for the development of three of the main DisneyQuest attractions: Aladdin's Magic Carpet Ride, Hercules in the Underworld, and Pirates of the Caribbean: Battle for Buccaneer Gold.

The studio has also applied its expertise in the creation of interactive 3D environments to the design and visualization of theme parks and attractions. This includes work for Tokyo Disneyland, Disney's California Adventure, EPCOT, and the new Disney theme park currently under construction in Hong Kong. Time and time again the benefits of interactive 3D visualization have been demonstrated through designer walkthroughs, ride simulations, and 4D construction simulations.

Recently, with the advent of powerful consumer graphics systems, the VR Studio has turned their storytelling skills to the development of online gaming experiences for the home. Toontown Online (http://www.toontown.com) is the first massively multi-player online world designed for children ages 7 and older.

The goal of this paper is to give an overview of the history of the VR studio and to document many of the lessons learned during 10 years of building interactive virtual worlds. In particular, the paper will focus on the challenge of designing location-based virtual reality attractions for the mass audience.

## 2. DisneyQuest

### 2.1. History and Overview

The goal of this section is to present some of the lessons we learned building location-based entertainment (LBE) attractions for DisneyQuest, Disney's indoor interactive theme park. The high concept behind DisneyQuest was to give people a Disney theme park experience in their own neighborhood.

The first DisneyQuest facility opened on June 18th, 1998 in Orlando Florida. It contains more than 250 attractions in a 5 story, 100,000 square foot building. The DisneyQuest building is laid out like a conventional Disney theme park, with a central hub surrounded by differently themed lands. Instead of walking down Main Street, however, guests at DisneyQuest enter through a main lobby and ride to the heart of DisneyQuest on the *Cybrolator*; an elevator enhanced with synchronized computer graphics. From there guests are free to branch out into one of the four main areas: the Explore Zone, Create Zone, Score Zone, or Replay Zone.

Each DisneyQuest zone is themed differently; attractions in the Explore Zone, for example, are designed to be cooperative, goal-oriented adventures where guests explore exotic and ancient locales. Score Zone activities contain more head-to-head competition, while Create Zone activities are more about creativity and self-expression. The Replay Zone contains classic arcade games that have all been given a futuristic twist.

At its opening, DisneyQuest featured 6 high-end, virtual-reality based attractions:

- Aladdin's Magic Carpet Ride
- Cyberspace Mountain
- Hercules in the Underworld
- Invasion! An ExtraTERRORestrial Alien Encounter
- Ride the Comix
- Virtual Jungle Cruise

As part of a planned program of content renewal, Hercules was later replaced with Pirates of the Caribbean: Battle for Buccaneer Gold. As mentioned above, the VR Studio designed and developed Aladdin, Hercules, and Pirates.

Aladdin and Ride the Comix are HMD based attractions. Hercules and Pirates feature multi-screen immersive theaters (5 and 4 screens respectively) with stereo glasses. Cyberspace Mountain and the Virtual Jungle Cruise ride are single screen attractions combined with motion bases. Invasion surrounds the guests with 360 degrees of infinity optics. Four processor Silicon Graphics Infinite Reality 2 graphics computers drive all of the high-end attractions.

### 2.2. Location-Based Entertainment Design Constraints

The designs of all high-end DisneyQuest attractions are highly constrained by the unique nature of location-based entertainment.

All rides are short, typically 4–5 minute experiences. This means that, unlike a conventional PC game, there is very little time for teaching the guest how to use the attraction's controls and play the game. This is like the challenge of putting instructions on a video game cabinet where there is typically only room for 3 instructions, two of which are "Insert coin", and "Press start". It is imperative, therefore, that the ride's interface and game play be easy to learn. This is reinforced by the fact that, as a Disney attraction, the ride must be enjoyable by people of all ages. We cannot focus on adolescent males who are less intimidated by complex devices or game play.

Interfaces must also be simple because, to be economically viable, guests must be able to quickly load and unload the ride. There is no time to strap on cumbersome and fragile tracking devices or highly adjustable display devices.

As a result, interaction in these rides is primarily limited to navigation and targeting/shooting. The most complicated form of interaction is virtual swordplay in Ride the Comix. Usability is key – for a ride to be successful, one must focus on the guests natural skills. Control devices with real-world counterparts work the best (steering wheels, paddles, swords, cannons). Guests can apply real-world skills when using these devices, minimizing the need for additional training.

### 2.3. Aladdin's Magic Carpet Ride

*Aladdin's Magic Carpet Ride* is a four-person race through the world of Aladdin (figure 1). Wearing custom designed HMDs, competitors climb aboard motorcycle-like vehicles to begin their journey. Players become Abu, the monkey, and are charged with traversing Agrabah and the Cave of Wonders on Aladdin's flying carpet to find the Genie of the Lamp. Players compete against each other and the clock to see who can find the Genie first.

The DisneyQuest Aladdin ride is actually the third version of the Aladdin attraction developed by the VR studio. As mentioned above, one of the first attractions we built was also based upon the movie Aladdin. It was called "Aladdin Adventure!" Aladdin Adventure was an experimental prototype that was presented as part of the "Walt Disney Imagineering Labs" exhibit at EPCOT Innoventions in 1994 and at SIGGRAPH in Orlando that year. Aladdin Adventure allowed a guest to don a head-mounted display and fly around the streets of Agrabah, the fictional city from the movie. The goal was to make each guest feel as though they were the main character in a complete and satisfying personalized story, providing different opportunities (thanks to a variety of random story elements) to each guest every time they rode. Aladdin Adventure was extremely character based; it made extensive use of soft-skin character animation to enable the virtual characters to squash and stretch like their cartoon counterparts in the movie. More than 45,000 guests experienced the Aladdin Adventure exhibit at EPCOT. Results of extensive interviews, exit surveys, and data logging were presented by Pausch et al. in their 1996 SIGGRAPH paper: "Disney's Aladdin: First Steps Towards Storytelling in Virtual Reality". [1]

The second installation of Aladdin, "Aladdin's VR Adventure" was presented at Disneyland Starcade in 1996. It greatly expanded the number of environments presented to the guest and continued to explore the potential of non-linear narrative in a virtual environment.

All of the Aladdin installations faced numerous technological and design challenges, the most daunting of which were the limitations of the available hardware at the time.

When Aladdin Adventure was developed, for example, limitations in commercially available graphics hardware necessitated the development of a custom image generator called the Triclops, which consisted of three Silicon Graphics Onyx computers stacked into one refrigerator-sized tower (well before such configurations were offered commercially by SGI). To deliver a solid 60 Hz frame rate, the Onyxes were pipelined with each Onyx rendering every third frame at a rate of 20 Hz. By the time of the second Aladdin installation at Disneyland Starcade, optimizations in the rendering software allowed us to dedicate one Onyx per guest, producing three 60 Hz streams from a single Triclops.

To provide adequate field-of-view and resolution we designed and developed our own head-mounted display. This was a CRT-based HMD with 640x480 resolution and an 80 degree horizontal FOV. Though the use of CRTs resulted in much higher image quality, the resulting form factor was extremely front heavy and required a weight relief system. Figure 2 shows an image of the Aladdin HMD. Figure 3 presents an HMD schematic diagram.

**Figure 2** *Aladdin head-mounted display*

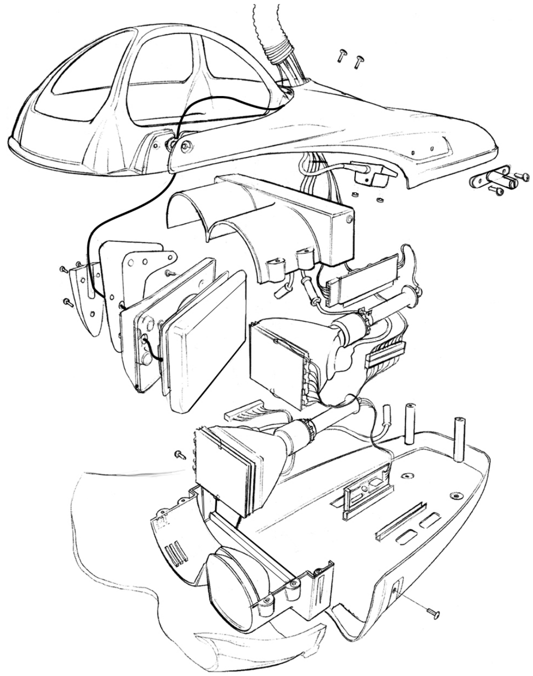

**Figure 3** *Aladdin HMD schematic diagram*

Since the majority of items in the environment were to be viewed from relatively far away (as the guest flew around on his carpet) we opted against creating a stereo HMD, choosing instead to create a biocular device (viewing a single image source with both eyes).

To encourage interaction in the shared virtual space we included microphones and stereo headphones in the head-mounted displays. This enables guests to share their experiences with friends and family members, resulting in much richer experiences for all.

To address operational and hygiene issues with the HMD we developed a removable helmet liner. By handing liners to the guest while they wait in the queue line we minimize idle time at the expensive virtual reality station. Guests can figure out how to don and adjust their helmet liner while waiting for their turn on the ride. Once they get to the VR station, a separate optics and display unit is quickly and easily snapped on top of the liner, allowing guests to quickly begin the ride. The liner has the additional advantage that it can be sanitized in between guests, reducing guest-to-guest contamination issues.

Finally, one of the biggest challenges we faced was coming up with an intuitive way for guests to fly a magic carpet; lacking a real-world counterpart it was difficult to create a set of controls that was intuitive and matched guests expectations. Figure 4 shows two views of the resulting Aladdin seat, which guests sat on like someone straddling a motorcycle. This design firmly grounded the guests with their weight supported on their buttocks, knees, and feet, and accomodated a wide range of heights. Based on the results of guest testing we disabled the ability to roll; guests would too easily get disoriented or lost. As a result of problems with motion sickness it was necessary to eliminate a proposed motion base.

### 2.4. Hercules in the Underworld

*Hercules in the Underworld* is a 4-player, 3D adventure where guests can choose to be Hercules, Meg, Pegasus or Phil (figure 5). As the characters, players run through the underworld picking up lightning bolts and searching for Pain and Panic (Hades' henchmen) who have hidden a cart filled with lightning bolts. Once guests have collected all the lightning bolts and found the cart, the characters race toward Hades' lair. Pegasus drives the cart as the other characters try to destroy Hades with the bolts.

Hercules takes place in a custom designed five-screen immersive projection theater (IPT). The theater is hexagonally shaped with screens only on five sides; the sixth is left open so guests can enter and exit the theater. To minimize the footprint of the theater and to maximize its angular resolution (for a given screen height) we turn the projectors on their side. This gives us an aspect ratio (screens taller than wide) that maximizes image quality and allows us to pack the theaters more closely together (figures 6 and 7).

**Figure 8** *Stereo glasses used for the Hercules ride*

Guests wear stereo glasses, but head tracking is not used. Images are rendered assuming an ideal eye point in the center of the theater. Though this results in images being distorted as the guest moves away from the ideal viewpoint, it generally is not disturbing (or even noticeable).

Due to SGI fill limitations, only the front three screens in the theater are in stereo. We felt that this was acceptable since the rear screens are primarily used to give the guests a sense of immersion and to provide vection cues in their peripheral vision. In addition, guests typically do not turn their heads very often to look at the back screens. To take full advantage of these peripheral cues we made sure to choose 3D glasses that were open at both sides (figure 8).

One of our biggest design challenges in Hercules was creating an intuitive interface for controlling a 3D avatar. Though we explored the possibility of giving guests complex devices such as tracked 6-DoF wands, we were forced to stick with conventional joysticks. Joysticks were the only devices we found that were almost universally understood by guests. The joysticks did, however, require considerable modification. After several commercial joysticks failed after just a few hours of guest testing, we were forced to build reinforced joysticks, complete with one-inch thick steel shafts running down the center.

Another big challenge was controlling a single viewpoint shared between four avatars. We wanted to give the guests the feeling that they were free to roam about the environment, while at the same time controlling the camera and presenting a good story. To do this we laid out the Hercules environments as a single, wide path. Guests were free to roam around within the confines of the path, but were kept moving along the path by means of a "Pusher", an invisible collision object that gently nudged stragglers forward. This is similar to the water skiing metaphor described by Galyean.[2] The camera watching the avatars was on a fixed track through the world, chosen by the show designer to be aesthetically pleasing. The avatars determined the speed at which the camera moved along the track; the camera staying focused near the center of a bounding sphere, or the "Bubble" as we call it, which surrounded the avatars' current position. With this system, guests were given a sense of freedom while the show designer could maintain creative control.

An additional benefit of using a fixed camera path in Hercules was that we could use an exact visibility solution; for every point along that path we exactly pre-computed all the polygons that were visible and only displayed those polygons. This was critical in enabling us to have environments that were as rich and complicated as possible.

## 2.5. Pirates of the Caribbean: Battle for Buccaneer Gold

*Pirates of the Caribbean: Battle for Buccaneer Gold*, the final ride we built for DisneyQuest, immerses guests in the world of the Pirates of the Caribbean theme park ride (figure 9). A crew of four guests boards a ship-themed motion platform, and enters a 3-D world of plundered towns, fortress islands and erupting volcanoes. Guests work together as captain and cannoneers on a five-minute journey that culminates in a final showdown with Jolly Roger and his Ghost ship to defend their pirate gold.

Pirates takes place in a four screen immersive theater built around the ship-themed motion platform. The ship has a real steering wheel and six physical cannons (figure 10). Guests wear stereo glasses and all screens are in stereo. The key advantage we had when building Pirates was that we could capitalize on the lessons we had learned building our other DisneyQuest rides.

We knew that time available during the ride was short, so we took full advantage of time the guest spends waiting in the queue line. We provide a richly themed queue line area that helps to set the mood for the ride and introduces some of the back-story (figure 11). We put a map outside the ride so that the guests can learn the layout of the land while they are waiting for their turn. We use clear glass entry doors to the theater so that guests can get a preview of what is coming and can begin to learn how to use the steering wheel and cannons by observing other guests in action (figure 12). Guests also spend their time waiting in line donning and adjusting their stereo glasses.

We had learned the importance of physical interfaces in helping to immerse a guest in an experience. As a result we designed the Pirates attraction to be as physically engaging as possible. Designed to hold four guests, the ship was laid out with three cannons on each side. The idea was that guests manning the cannons could run from side to side during the entire show with mom or dad in the driver's seat steering the ship and pointing out enemies. Show elements are deliberately placed on both sides of the ship to encourage the guests to run back and forth.

All interface devices take full advantage of the guest's real-world skills. Steering wheels and cannons are instantly recognizable and require little instruction. We were careful to trade off realism with fun, however, no real pirate ship could sail as fast, turn as quickly, and fire as rapidly as ours did. Though unrealistic, the design of our ship matched the guest's expectation. Were we to stage our sea battles such that they accurately reflected a real sea battle (which often would last for days), guests would be sorely disappointed.

Pirates also reflects a better understanding of the interactive story structure necessary to give a guest a satisfying and exciting experience. Earlier attractions we had built had been too linear and gave the guests insufficient freedom. Unconstrained action, on the other hand, can leave the guest feeling lost and unsatisfied. Pirates, therefore, was carefully crafted to be broken into three main sections: an introduction, where guests are given time to learn the interface and are given the back story; the main portion of the experience, where guests are free to roam about and explore; and an exciting conclusion, to give the guest a sense of closure.

Though guests are completely in control during the main portion of the show, we took several precautions to ensure some level of fun for all guests. In terms of visual design we created three large eye-catching elements (or "weenies" as they are known in the Disney design language): a fortress, an erupting volcano, and a burning town (figure 13). The purpose of these is to draw the guests to the interesting points of action in the world, like the castle in Disneyland is meant to draw people down Main Street.

If these fail to bring the ship to the action, we bring the action to the ship; enemy ships attack from behind, sea monsters rise up from the deep.


**Figure 13** Map of the Pirates world

If the pilot steers the ship too far a field, a sudden storm blows in which lifts up the ship and sets it back in the center of action. This effectively limits the range in which a ship can move without detracting from the feeling of unconstrained motion.

If the pilot fails to steer completely (or for some reason the group has no pilot) the ship automatically switches to autopilot, taking the crew to some of the more interesting sites of the world.

To give the guests a sense of closure we end the show with a cinematic transition to an exciting final confrontation; clouds roll in and Jolly Roger and his skeleton crew attack the ship. This ends the show with a literal bang that leaves the guests excited and eager to ride again.

## 3. Virtual Reality for Theme Park Design

### 3.1. Working with designers

As discussed in the last section, we have found virtual reality to be an effective medium for location-based entertainment experiences for the mass audience. We have also found that virtual environments can be valuable to a much more specific audience: the Imagineers of Walt Disney Imagineering (WDI). Imagineers are the people who design and build Disney theme parks and attractions around the world.

As part of our research here at the VR Studio, we have been exploring the effectiveness of virtual simulation and visualization for theme park design. Our primary challenge was finding ways to incorporate new virtual tools into the existing WDI design process. Our competition was a proud 50-year tradition of building physical models as a means of visualizing theme park designs.

Typically, in the course of designing an attraction, physical models will be built at several different scales: from 1:100th scale for visualizing an entire theme park or land, to 1:4 scale for visualizing an individual attraction (figure 14), all the way to 1:1 scale for working out design details of a ride vehicle or a section of a ride. These models are high-level-of-detail works of art; in addition to being beautiful, however, these models provide something that no virtual simulation has yet to match: simultaneous, zero-latency, perspective correct viewing by an unlimited number of viewers.

### 3.2. The Case for VR

Despite the numerous advantages offered by physical models, virtual simulations offer several important advantages over existing techniques. One key difference is the ability to make rapid modifications to existing models. Though it takes about the same amount of time to make a physical model of a theme park as it does a virtual one, changes to the virtual model can be made much, much faster.

Virtual models enable interactive sight-line evaluation, something that is difficult to do with physical models. In the past designers at WDI have used miniature cameras to fly through physical models, but such techniques are cumbersome and limited. Virtual models enable designers to quickly and easily identify problems very early in the design process. In the very first demo of an interactive visualization of Disney's California Adventure (DCA), for example, designers were able to identify "back of house" issues, cases where support buildings or other infrastructure, which shouldn't be visible to the guest, were visible from within the park. Identifying and fixing problems such as these early in the design process can translate into considerable savings during construction.

The ability to simulate complex behavior is another key advantage. We have used virtual simulations to allow designers to experience roller coasters before they were built (California Screamin' at Disney's California Adventure) and as a means of previewing complex new ride vehicles such as the free ranging vehicles used in Pooh's Hunny Hunt in Tokyo Disneyland. The ability to offer designers a first person perspective in an IPT is invaluable for ride timing verification; 2D and 3rd person ride planning tools are often misleading.

We have also been able to amortize the costs of building detailed 3D models by using them in many different ways: planning of special events (live shows), looking at crowd flow issues, and exploring rescue and evacuation scenarios.

Finally, virtual models make it possible to represent and communicate the spatial and temporal, or four-dimensional, aspects of construction schedules effectively. 4D models combine 3D CAD models with construction activities to display the progression of construction over time.[3,4] We have made extensive use of our IPT for visualizing many 4D models including DCA's Paradise Pier area, Hong Kong Disneyland, and the new Disney Concert Hall in downtown Los Angeles.

### 3.3. Lessons Learned

The single most important lesson we have learned working with designers is the importance of using an immersive theaters for virtual simulation and design visualization. Though we had previously tried using conventional monitors and head-mounted displays, it was not until we began using IPTs that our efforts really paid off. We believe this is true for several reasons.

First of all, the large number of simultaneous viewers in an IPT encourages interactive design sessions. Unlike a head-mounted display where participants are unable to see each other, designers in an IPT can make eye contact, observe body language and gestures. This makes communication, and as a result design sessions, in an IPT much more effective.

We have observed that IPTs help to externalize discussions during design sessions. Ironically a virtual representation helps to give designers something concrete to talk about when discussing design issues. Problems can be talked about in terms of "Look at that problem over there" instead of in more abstract, or even worse, personal terms ("Lets talk about your bad idea").

An IPT is a powerful communication tool, especially when working with non-designers. Unlike a detailed written description of a ride, attraction, or construction site, which may take hundreds of pages, a visual representation of a complex concept can be more easily understood.

Finally, IPTs are powerful sales tools, particularly when crossing international borders. Showing a virtual prototype helped to transcend language barriers and sell the concept of the Pooh's Hunny Hunt ride to the Oriental Land Company (the Japanese owners of Tokyo Disneyland).

## 4. Future Directions

Currently the VR studio is focusing its VR research on two areas of exploration: large scale immersive theaters and virtually augmented roller coasters.

Figure 15 shows the current prototype of our next-generation immersive theater. Design goals included wide field-of-view, passive-stereo viewing of pre-rendered and interactive content shown on a seamless wrap-around screen. The system consists of a 26 ft diameter, hemi-cylindrical (180 degrees field of view) polarization-preserving screen and six Christie Digital Mirage 5000 DLP projectors. For displaying pre-rendered content we use six DVS HD Station digital playback devices. For real-time content we use a PC Graphics Cluster consisting of six servers plus a master PC powered by 3D Labs Wildcat 6210 graphics accelerators. To explore the potential of combining high-quality pre-rendered content with interactive elements, we combine in real-time the pre-recorded output of the DVS system with interactive 3D elements generated by the graphics cluster using six RGB Spectrum SynchroMaster analog compositing units.

A big limitation of current virtual simulations is the lack of true g-forces; our Virtual Ride program is a direct response to this problem. Our goal is to augment a traditional roller coaster with virtual displays. Proposed designs include an LCD flat panel display with either reflective or refractive infinity optics mounted on the guest's shoulder restraint. This would allow us to present a wide variety of virtual settings while the guest is physically transported along the track. Design challenges include synchronization of the virtual images with the vehicle's physical motion, safety (designing displays that provide adequate head clearance on a turbulent, rapidly moving vehicle), and motion sickness.

## 5. Conclusions

The goal of this paper was to present many of the lessons learned during 10 years of developing virtual attractions for the masses. The most important include:

- Physical interfaces help to immerse guests in an experience.
- Facile controls are critical for guest acceptance; focus on the guest's natural skills.
- Take advantage of all available time, such as time spent in the queue line to maximize play with minimum time.
- Immersive theatres are important tools for virtual design

## Acknowledgments

I would like to give special thanks to Gary Daines, Jesse Schell, and Joe Shochet for their invaluable contributions to this paper. I would also like to thank all of the other members of the VR Studio, past and present, for their dedication, hard work, and creativity. As always, thanks to my wife Sandra for her unwavering support and my children Dylan and Coco (Lia) for the joy they bring to my life.

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**Figure 1** *Aladdin's Magic Carpet Ride*

**Figure 4** *Aladdin ride interface*


**Figure 5** *Hercules in the Underworld*

**Figure 6** *Exterior view of the Hercules IPT prototype*

**Figure 7** *Interior view of the Hercules IPT*

**Figure 9** *Pirates of the Caribbean: Battle for Buccaneer Gold*

**Figure 10** *Pirates cannons and steering wheel*


**Figure 11** *Entry to Pirates of the Caribbean queue line*


**Figure 12** *Map and glass entry door of Pirates ride*

**Figure 14** *Sample model from Pooh's Hunny Hunt*

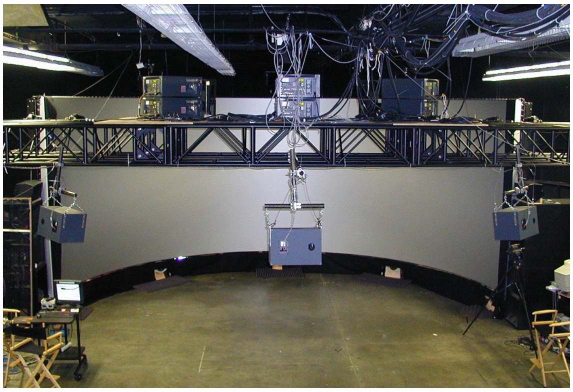

**Figure 15** *Seamless IPT prototype*