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A 15-Year Retrospective on Immersive Visualization Lessons from the Applied Visualization Laboratory

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Changing the World's Energy Future

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Idaho National Laboratory

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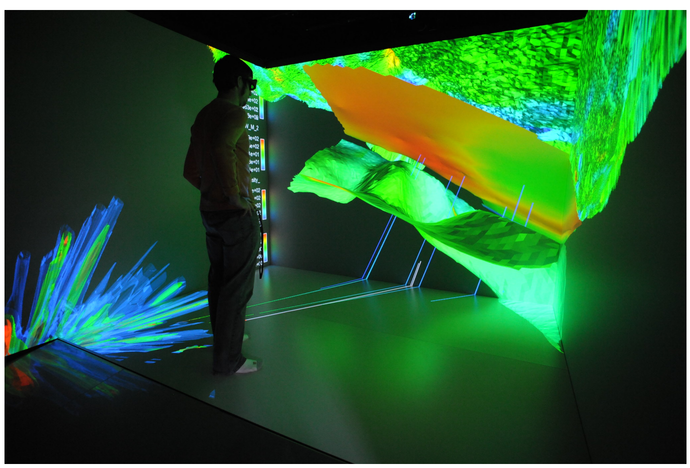

Figure 1: A researcher using the CAVE at Applied Visualization Laboratory to view and analyze subsurface model data to get a enhanced perception of the datasets.

Abstract

This article shares the experiences of operating an immersive visualization laboratory over a 15-year period. The paper discusses valuable insights into the lessons learned from various projects, including the challenges they faced, such as technical difficulties, user adoption, and opportunities, and practical solutions for overcoming them. One crucial element for successful immersive visualization projects is interdisciplinary collaboration. The paper presents the advantages of immersive visualization technology, such as improved data comprehension, enhanced communication, and increased engagement in complex scenarios. We present the dynamic realm of virtual and augmented truth (VR/AR) technology in the context of a immersive laboratory system. We spotlight rising trends inside the integration of VR/AR tools for visualization. We also present our experience in dealing with the hardware and software additives in an immersive VR/AR labs, dropping light on the demanding situations and successes encountered throughout everyday operations. Furthermore, it offers practical knowledge and guidance based on years of experience in the field, which can help you overcome challenges and achieve success in your project.

1 Introduction

Immersive virtual environments (IVE) are an instance of virtual worlds presented in an interactive medium such as virtual reality, that allows users to experience and interact with a virtual world as if they were physically in it (Sherman and Craig (2018)). In an IVE, users typically wear a headset or use a device that tracks their movements and allows them to move around and interact with the virtual world. They may also use handheld controllers or other input devices to interact with the environment and objects. IVEs can be highly realistic, with detailed graphics and realistic physics, or they can be more abstract, with simple graphics and exaggerated physics. Regardless of their style, IVE allows users to explore and interact with virtual spaces in a way that is impossible in the physical world (Schroeder (2002)). IVEs have gained widespread attention and adoption in recent years across various industries and fields, including education, training, research, entertainment, and product design. One key driver of this growth has been the development of increasingly sophisticated and realistic IVEs, thanks to computer hardware and software advances. This has made it possible to create more immersive and engaging virtual experiences, which in turn has led to increased demand for IVEs. Another factor contributing to the growth of IVEs is the increasing accessibility of IVE technology. Many IVEs can now be accessed via relatively inexpensive hardware such as headsets and controllers, making them more accessible to a broader range of users.

In terms of usage, IVEs are being used for a wide range of applications, including training, education, research, engineering, entertainment, and product design. For example, IVEs are being used to train pilots, surgeons, and other professionals, to study human behavior and cognition, to create virtual worlds for entertainment, and to design and test new products.

Overall, the current state of IVEs is one of rapid growth and development, with increasing demand and usage across various industries and fields. This trend will likely continue in the coming years as IVE technology advances and becomes more widely available.

With the ease of access and decreasing cost of commercial off-the-shelf (COTS) VR devices there is an on-going discussion between researchers and users on how these COTS would compare against the usability with the large immersive displays (like CAVEs). The immersive visualization requirements of researchers could be satisfied using COTS VR devices used in their offices. However, it is also essential to consider the specific needs and goals of the research, as well as the limitations of COTS VR devices.

One potential advantage of COTS VR devices is that they are often more portable and convenient than large immersive display systems, such as CAVEs. This can make them well-suited for use in smaller office environments or for researchers who need to take their visualization setup with them when traveling.

However, there are also several potential limitations to consider when using COTS VR devices for immersive visualization. For example:

- Visual quality: COTS VR devices may not offer the same level of visual quality as larger, more specialized immersive display systems.
- Multiple users: COTS VR devices are typically designed for use by a single user, whereas large immersive display systems can support multiple users at the same time.
- Computing resources: COTS VR devices may have limited computing power and may require a powerful computer to run demanding visualization applications.

Overall, it is important to carefully evaluate the specific requirements and goals of the research, as well as the limitations of COTS VR devices and large-immersive systems, to determine if they are suitable for satisfying the immersive visualization needs of researchers.

Applied Visualization Laboratory (AVL) at Idaho National Laboratory houses a virtual environment from non-immersive to full-immersive. This lab was established in 2010 to support researchers, scientists, students, educators, and individuals from diverse backgrounds with a vested interest in the field of 2D/3D Visualization. Since its founding, the lab has consistently fulfilled this mission, offering a range of resources and services to aid in developing and advancing knowledge in the field of visualization. A virtual interactive demonstration of AVL space has been built to provide an overview of the lab https://virtual-tour-demo2.glitch.me/

This paper will present an overview of AVL at Idaho National Laboratory, including its current state, successes, workflow, sustainability of lab and challenges we have encountered.

2 IVE at Idaho National Laboratory

AVL is located at the Center for Advanced Energy Studies (CAES) (avlwebsite). AVL has eight team members to develop and maintain the lab. AVL hardware and software is mostly core-funded, occasionally a Principal Investigator will purchase hardware or software that stays with the computer lab. We also submit proposals to competitive internal and external research grants that will be used to support researchers. The environments that we create are through research projects that aim to utilize the hardware and software capabilities. AVL's drive towards gaining knowledge is demonstrated by its in-house research initiatives as well as working together with other research partners. Some of them are development of new VR technologies, advanced visualizations, and interdisciplinary applications. This commitment to academic discourse has led to numerous research outputs in scholarly publications. AVL's research contributions to the field are evident from notable publications such as Elliott et al. (2022), Khadka, Koudelka, et al. (2023), Khadka, Yang, et al. (2023), and Ritter et al. (2022). The concurrent adoption of application development and rigorous research makes IVL the leader in the areas of VR and visualization.

2.1 Hardware

Our lab has transformed in tremendous ways over the last 15 years of its existence. Our foundation was laid out in 2009, with installation of the CAVE. The following years were characterized by rapid change which kept software always ahead of technological progress. In this unique CAVE setup, VRUI software was used to visualize the data. It is also worth mentioning lab's proactive role in research grants, which have inspired innovations and broadened our investigative pursuits. Outreach and collaboration has been an integral component of our lab since we looked for these chances to work with the diverse group of interested users. Some demos (e.g. Advanced Test Reactor, LIDAR datasets) and presentations have become the hallmarks of our projects with their demonstrative character showing us the practical implications of our research.

Keeping update with the change in hardware technology is a vital aspect to AVL. VR/AR headset hardware lifecycles that can last up to a couple of years in the lab's operational framework. However, this period assumes the introduction of new hardware compatible with the needs of current or forthcoming projects. Likewise, projectors are also exchanged following their decommissioning period to maintain high standards and keeping pace with latest upgrades in software and apps. To be upfront with AVL's CAVE program update, its system refreshes are organized on an average of 8-9 year intervals which take into consideration the hardware and software advancements. In 2017 we updated the screens, projectors and sizes. However, it is prudent that the laboratory makes use of emerging technologies in an economical but foresightful manner. AVL has a four-panel Mechdyne CAVE system as a large-scale immersive visualization system (12ft X 12ft X 9ft). It uses ART system's DTrack eight-camera system to track a user's head and joystick movement. This CAVE system was refreshed in 2017 and can

Figure 2: A group of users at the AVL cave.

run both Linux and Windows. There are three IQ-Stations as a single-panel immersive display system in AVL. This IQ-Station was designed and developed in collaboration with Indiana University to provide a low-cost and immersive mobile system (Sherman et al. (2010)). AVL also houses HTC Vive Pro VR and Oculus Quest virtual reality headsets as a fully immersive display systems. We have Microsoft Hololens II, Magic Leap, and tablets to support the need for augmented reality visualization. We also have an Omni Treadmill as a tool to provide users with walking capabilities while training and interacting with the environments. AVL also has leap motion and haptic gloves as additional interaction tools to support user needs for immersive virtual environments.

Despite the fact that CAVE system has been the basic pillar of domain science applications in the AVL, the lab has realized the flexibility of VR and AR technologies, showcasing its willingness to study other immersive platforms. The lab has been flexible in adopting recent project such as VR headsets and AR devices demonstrating its adaptation capabilities to varied technological landscapes. Mostly, the choice between VR or AR headsets versus the CAVE is dictated by project specific needs such incorporation of real world aspects in virtual worlds or a need for personal portable experiences. For instance, VR headset provides a more immersive experience and access that is more personal at a time when users can interact with virtual environments individually. However, AR overlays virtual contents on physical world and offers unique opportunities for mixed reality apps. These choices speak to AVL's desire to customize technology solutions to the unique needs of each project, thereby improving the practicality and usefulness of immersive experiences in more applications.

2.2 Software

We utilize a variety of software to meet our client's needs and requirements. Currently, we use VRUI software (Kreylos (2008)) for scientific and LiDAR visualization in CAVE systems. We also work with Paraview and VTK for scientific visualization for non and full immersive-display systems (HTC Vive). We also use the Unity3D and UNREAL engines to develop engineering prototypes and training simulations. Furthermore, we use Blender for 3D modeling, ArcGIS for geographic data visualization, Meshlab for editing and processing 3D triangular meshes, and three.js/Aframe for 3D web-based visualization.

2.3 Team Personnel

Our team comprising of eight members, including the manager, is led by the lab director who supervises the entire operations in the lab. This includes financial planning, project coordination, as well as various functions key in ensuring our lab's progress. Furthermore, the lab director formulates direction and aligns our efforts with larger objectives in the organization.

The system and hardware engineer works together with the lab director to keep the lab at the state of operation perfection. They are in charge of updating both hardware and software, hence facilitating the running of the lab. They are also the first to call in case some technical problem comes up.

The rest of our team includes skilled researchers in visualization. The combination of various expertise from scientific visualization to web3d, including virtual reality and augmented reality, serve as the foundation for our research. They are responsible for developing projects, undertaking thorough research in order to provide informative answers, and providing valuable mentorship to their colleagues in teams. Working in synergy, all of them work collectively, with each one providing their expertise thus propelling achievements and progress of our lab. This multidisciplinary team demonstrates the kind and level of staffing need to establish and maintain a dynamic and growing visualization lab. We generally have 4-5 major projects in a fiscal year.

3 Workflow

We have gradually started to incorporate scrum methodology (Schwaber (1997)) in our project workflow to ensure efficient project management and effective collaboration among team members. Scrum is an agile framework that allows teams to adapt to changing needs and priorities while promoting transparency and continuous improvement. Scrum-based workflows break the project into smaller tasks, prioritize them, and assign them to specific team members. We hold daily meetings to review progress and identify obstacles that need to be addressed. A sprint planning meeting is held to define goals for the next sprint, and a sprint review is conducted to assess progress and make any necessary adjustments. By implementing the Scrum methodology, we can foster a collaborative and iterative approach to project management while delivering high-quality projects on time and on budget.

Set project goals In the first phase, the goals of the project are outlined. Some of the questions that we explore in this steps are What problem are we trying to solve with the visualization? What are the key metrics we want to monitor? What do we want to learn?

Assemble a team Once we've set our project goals, it's time to assemble our team. Generally, it's the client, project manager and developers. Project manager or developers also act as a scrum master. This team members work together to visualize the creation.

Organize our sprints Once we have our team assembled, it's time to organize the first sprint. Breaking down the project backlog into smaller tasks, calculating the time and resource requirements for each piece of work, and prioritizing tasks for the first sprint is part of this process.

Run a sprint In this phase,the team starts working on their assigned tasks. The Scrum Master hosts daily stand up meetings to keep everyone updated on progress, identify roadblocks, and make adjustments as needed.

Demonstration and feedback At the end of each sprint, the plan is to present the work progress to clients and stakeholders. However, due to the nature of the project that we work on it is usually challenging to assemble all the team members. However, we usually schedule our work progress demonstrations based on the availability and then gather feedback on your visualizations and make any necessary improvements as we move towards next milestones.

The frequency of AVL usage depends on the size and type of various project types. Engagement in projects typically starts with an evaluation of project requirements so that resources are used specifically. At specific stages of the project, there are user facilities that are accessed, including the developing period of project prototypes, testing periods, and requirement demonstrations. Through the flexible usage model at AVL, users can benefit from the facilities' time frames as well their individual project requirements. Its flexibility allows for a dynamic collaborative setting which enables innovation and effective project development in the context of AVL's ecosystem. Therefore, the frequency of facility utilization depends on individual projects, and the latter shows the different needs and levels of development for each project.

4 Accomplishments

4.1 Engineering Designs

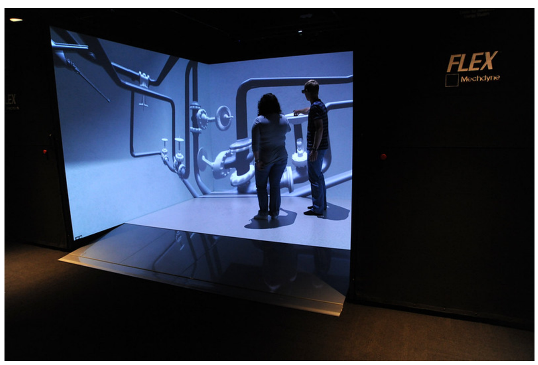

Figure 3: Users using large-immersive systems to inspect the engineering prototype design

For engineering design and prototyping, an IVE can be used to create a simulated world in which engineers and designers can test and iterate on their concepts without the need for physical prototypes. It can be more effective in the areas of aerospace, automotive, nuclear, and manufacturing, where construction of a physical prototype can be expensive and time-consuming.

Engineers in one of the our source recovery projects were initially reluctant to use the IVE for prototyping. For early design evaluation and review, they relied on traditional CAD software. We developed a virtual prototype to visualize the entire instruments for radioactive source recovery and process in the IVE. We invited them to view and interact with the virtual environment for radioactive source recovery process. They found several design imperfections and things to be considered for developing the prototype while being in the virtual prototype and interact. As a result of the immersive experience, the engineers went back and modified the design of the prototype with a better understanding of the spatial and physical limitations of their design. The use of IVE provided a reliable and trustworthy platform to conduct engineering design and prototype while saving time, cost, and increasing reliability.

4.2 Training

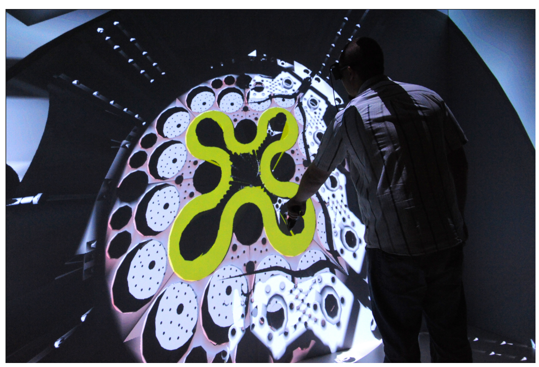

Figure 4: A user interacting with ATR core to understand its design.

Training is an essential component in the field of the nuclear industry. Firstly, the handling and operating of nuclear materials and facilities require a high level of technical expertise and knowledge. As a result, researchers and technical operators working in the nuclear industry must continue training to guarantee their job safety and efficiency. This includes training in nuclear reactor design, nuclear physics, radiation protection, and emergency response.

Advanced Test Reactor (ATR), the world's premier nuclear test reactor, provides nuclear fuel and materials testing capabilities for military, federal, university, and industry partners and customers. It periodically undergoes a maintenance overhaul. We have converted the 3D Computer Aided Design (CAD) model into an environment in our CAVE and developed interactions that allow us to virtually look inside the reactor and remove components or sections of the reactor for better viewing. This ATR virtual environment provides a co-located collaboration opportunity for the engineers performing maintenance work to train and understand the design and working mechanism of the ATR. We have received feedback that the use of large-immersive display systems for ATR visualization is far more effective than recorded videos and printed documents that have been used in the past.

4.3 Scientific Visualization

Our lab is dedicated to supporting the scientific community in its efforts to uncover new knowledge and advance their fields of study. By helping researchers to visualize and analyze their data effectively, we aim to enable them to make more informed and accurate conclusions about their research.

In one of our scientific visualization projects, we visualized graphite billet to analyze and understand the density, variation, and properties. The researchers had previously used a non-immersive 3D environment for visualization. They asked us to develop a 3D model using large-immersive display system to allow multiple people view the model collaboratively. They informed us that visualizing the graphite billet using the large-immersive display system provided a new dimension in understanding the essential components of graphite billet to conclude the experiments. They were able to navigate and be inside the graphite billet and conduct in-depth analysis. They also informed us that it would not be possible to do so using traditional tools for visualization.

4.4 Visual Analytics

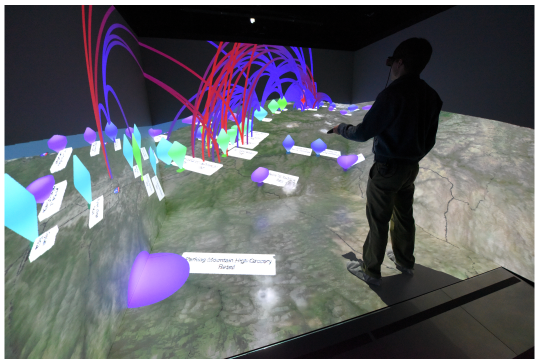

Figure 5: A user employing our large-immersive system for visualizing electric vehicle charging station usage.

Visual analytics can be used to examine massive volumes of data. It entails employing visualization techniques to explore, analyze, and communicate data. The usage of IVE for visual analytics has risen in popularity in recent years.

One of the most significant benefits of IVE for visual analytics is that it allows individuals to interact with multidimensional data and information in a more intuitive and natural manner. Oregon State University, for example, sought to examine EV charging statistics in order to plan the installation of new charging stations. Location, usage patterns and charging times per week are among those included in the data. Initially, the researcher tried to represent the data on a 2D background, but this did not work because the correlations between the variables are often unclear and the data is messy. Creating multi-dimensional images also takes time. To overcome these obstacles, researchers chose to visualize their data in IVE. They used his CAVE system to develop a 3D virtual environment that makes data exploration more natural and intuitive. The IVE makes it easier and faster for researchers to understand information, one can observe patterns and trends in data that are not readily apparent in 2D images. This allows you to make more informed decisions about where to locate new charging points based on usage patterns and other factors.

4.5 Lidar Visualization

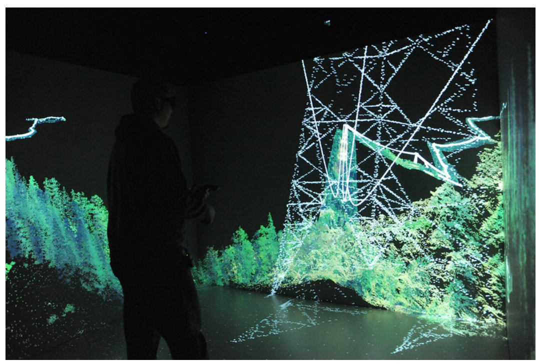

Figure 6: A user viewing a LiDAR scan of electric power grid.

LIDAR (Light Detection and Ranging) is a remote sensing technology that uses laser pulses to measure the distance to an object or surface(Collis (1970)). LIDAR data can be used create 3D models of real-world objects that can be further developed into a virtual environment. It can create highly detailed 3D models of real-world objects and environments that are utilized in decision-making, training, engineering, and education applications.

We have conducted LiDAR scans of buildings, rooms, outdoor environments, and equipment. In one particular project we were asked to scan and develop a 3D model of a portion of building that had been constructed in the early 40s and the blueprints for this part of the building could not be located. The scan was used to develop a 3D model that could be added to the engineering drawings of the rest of the building. This scan was then used to precisely locate and measure rooms, ducting, electrical conduit, and water lines for a proposed remodel project. After we combined the existing digital building model with the scan, we developed an environment that we displayed in our CAVE for project managers to view for better planning.

4.6 Education and Outreach

Figure 7: A group of K-12 students using large-immersive system for DNA protein visualization. This is a part of AVL's outreach and education program.

IVE can be a valuable tool for education and outreach programs. In a way that traditional visualization approaches might not be able to, these technologies can offer immersive and interactive experiences that captivate audiences and impart knowledge.

Our lab regularly provides demos to students for experiential learning opportunities and also excites them toward a STEM career. These demos are designed to be engaging and interactive, providing a dynamic and immersive experience to the students. We have experienced that these demos increase students' curiosity and encourage questions about their careers, projects, and opportunities. We provided demos to over 1300 viewers in fiscal year 2022. This volume of viewers provides us the opportunities to interact and engage with diverse groups of individuals for potential collaboration and support.

5 Sustainability of Immersive Visualization Laboratory

Immersive Visualization laboratories can play an important role in various fields including science, engineering, and the arts. They use the most advanced technology to create and analyze visual representations of data, simulation, and design. However, to ensure the sustainability and success of the visualization lab, it is essential to establish sustainable practices. In this section, we'll explore some of the factors that contribute to the sustainability of an immersive visualization lab based on our 15 years of experience at AVL.

5.1 Financial sustainability

In order for an immersive visualization lab to be sustainable in the long term, we need to build a strong financial foundation. This means creating a business model that generates enough revenue to cover our costs, including salaries, equipment and maintenance. A sustainable business model is crucial for several reasons. First, it allows us to provide consistent service to our customers. A stable source of income allows us to invest in the latest technology and equipment, hire professional staff and maintain the facilities to the highest standards. Financial sustainability not only ensures a high level of service, but also helps demonstrate the impact and value of the laboratory. If we can demonstrate that we are financially stable and generating revenue, it will communicate to customers and stakeholders that our lab is a valuable asset to the community. This can lead to more projects, collaborations and partnerships, which in turn can help us grow and expand our services. Of course, achieving financial sustainability is not always easy. It requires careful planning, budgeting and strategic decision making. We need to be aware of our expenses, monitor our funds and make necessary adjustments to stay within budget. Ultimately, ensuring financial sustainability is a critical factor in ensuring the lab is successful and able to serve customers and community for years to come. By focusing on this factor, an immersive visualization lab can build a strong foundation to demonstrate our impact and value, attract new clients and projects and invest in our employees, equipment and facilities.

5.2 Technical sustainability

To ensure the sustainability of an immersive visualization laboratory, it is very important to stay abreast of the latest technological developments. Regular hardware and software updates are necessary to provide advanced services to customers. This means we have to invest in new equipment and software to keep up with the latest trends in the industry. This shows our commitment to provide the best possible service and create added value for our customers. We are also able to differentiate ourselves from competitors who may not invest in the latest technology, giving us a competitive advantage. But it's not just about having the latest technology, we also need to have the knowledge and expertise to use it effectively. That's why we invest in ongoing education and training of our employees to ensure they have the skills and knowledge to make full use of our technology. It is also important to consider the costs of investing in new technology. Although this can be expensive, we know it is an investment in the sustainability and growth of our lab. By providing the best possible service and staying at the forefront of development, we are able to attract new customers and retain existing customers. In general, technical sustainability is a critical factor in the sustainability of an immersive visualization laboratory. By investing in the latest technology and continuous training of our employees, we can create value for our customers and differentiate ourselves from our competitors, leading to sustainable growth and success.

5.3 Staff retention

An IVE lab is only as good as its people, and retaining skilled and experienced staff is critical to its success. If the staff has the experience and knowledge to provide quality services, customers are more likely to return and recommend the laboratory to others. Therefore, it is important to consider staff retention as a factor in the sustainability of the IVE. Offering competitive salaries and benefits is one way to attract and retain top talent. In addition, providing opportunities for professional development, such as attending conferences or courses, demonstrates that the laboratory is invested in the growth and development of its staff. Not only does this help retain current employees, it can also attract new talent to the organization. Creating a positive work environment is another critical factor in employee retention. Employees who feel valued, appreciated and supported are more likely to stay with the organization long-term. This can be achieved through effective communication, providing opportunities for employees to participate in decision-making, and providing a positive work-life balance. It also demonstrates the value and impact of the laboratory and its commitment to staff and clients.

5.4 Collaboration and partnerships

Collaboration and partnerships are key to the sustainability and success of a laboratory. By collaborating with other organizations and entering into partnerships, the laboratory can involve new clients and projects, expand its knowledge and resources and provide opportunities for joint research and development. Collaboration with other organizations allows the laboratory to enter new markets and reach a wider customer base. Through partnerships, the laboratory can offer its additional services, offering clients a more complete package. This can lead to increased revenue and a more stable customer base, contributing to the long-term sustainability of the lab. Furthermore, collaboration can also expand a laboratory's expertise and resources. By collaborating with other organizations, the laboratory gains access to new technologies, skills and knowledge. This can help the laboratory stay up-to-date with emerging trends and advancements in the industry and provide specialized services to clients. Collaborations with academic institutions can lead, for example, to joint research projects that can advance the laboratory's understanding of the field, lead to new inventions, and lead to publications and presentations that demonstrate the laboratory's expertise and impact.

5.5 Community involvement and Outreach

Community involvement and outreach is an important factor in ensuring the sustainability of a lab. Community engagement can take many forms, from participating in local events and workshops to providing educational opportunities to local schools and universities. We regularly provide STEM education demos, mentorship to high school students, and also recruit students for internship. These activities allow us to increase awareness of the lab's work and build relationships with the people and community we serve. By showing our value and impact, we can also attract new customers and foster collaboration that will help us continue to grow. By interacting with the community, we also have the opportunity to learn about their needs and perspectives, which can help us adapt our services to better serve them. This not only benefits our customers, it also strengthens our reputation as a valuable community resource. Community engagement and outreach is an important factor in the sustainability of an IVE. By building relationships, raising awareness and tailoring product and services to the needs of the community, we can ensure that our laboratory remains a valuable and important resource for years to come.

5.6 Flexibility and adaptability

To survive and thrive, an IVE lab must be able to adapt to changing customer needs and market trends. Being able to be flexible and adaptable is critical to a lab's sustainability because it helps attract and retain customers. When an IVE lab can adapt to a client's specific needs, it shows the client that the lab is invested in their success. Clients appreciate working with a lab that meets their unique needs and are more likely to return for future projects if they feel the lab understands their goals and can provide customized solutions. In addition to responding to customers, it is also important to adapt to market trends. As new technologies and tools emerge, the IVE lab must be prepared to incorporate new solutions both in terms of hardware and software into their services. This capability shows that the laboratory follows the latest trends and is committed to providing its customers with the best possible solutions. Flexibility in services and product development and pricing models can also help an IVE differentiate itself from its competitors which aids in sustainability of the lab. The ability to be flexible and adaptable is critical to the sustainability of an imaging laboratory. By demonstrating a commitment to customers and the latest market trends, the lab can stand out from the competition, build a strong reputation and attract new customers.

5.7 Marketing and branding

Developing a strong brand and marketing strategy is an important factor in the sustainability of a laboratory. This requires the creation of a unique brand identity that differentiates the laboratory from competitors and helps create a positive image. A strong brand identity can be achieved in a number of ways, such as a unique logo, color scheme and message that reflects the values and services of the laboratory. This identity must be consistent across all communication channels, including the website, social media and promotional materials. A well-planned marketing strategy can help communicate the laboratory's services, values and expertise to potential clients. This involves identifying the target audience and adapting messages and activities accordingly. For example, an IVE lab specializing in energy data analysis and visualization might target organizations and industry that prioritize sustainability and energy impact. Marketing activities can be different, such as email campaigns, social media and advertisements. Public relations such as media and press releases can also increase awareness and credibility of the laboratory's services and expertise. With a strong brand and marketing strategy, an IVE can differentiate itself from its competitors, create a positive image and attract new customers. This, in turn, can help sustain the laboratory's operations and demonstrate its impact and value to the community. However, it is important to note that marketing and branding should not be the sole focus of an imaging lab's activities. Providing quality services, maintaining strong partnerships and collaborations, and investing in staff development are also key factors in demonstrating sustainability and efficiency and value.

6 Challenges and Solutions

6.1 Unfamiliar / Unaccustomed

Although the usage of an immersive virtual environment using virtual reality (VR) technology has increased, some individuals are still afraid to utilize VR devices for visualization. This hesitation may be due to various factors, such as the expense of VR equipment, the chance of feeling motion sickness or other undesirable consequences, or a lack of awareness about how VR might be utilized for visualization. Furthermore, some people may be apprehensive about privacy or feel uneasy when wearing a VR headset or gadget. Addressing these issues and educating people about the benefits and applications of VR technology may be beneficial in encouraging more usage of VR for visualization.

6.2 Standard Software in CAVE Systems

The CAVE VR system has numerous advantages, but because of the difficulties in running software on the system, scientists and researchers could be unwilling to utilize it. These issues could have to do with the system's incompatibility with particular programs or its difficulty being properly set up. Therefore, researchers and scientists may think about utilizing different VR systems that offer a more streamlined software experience. It's crucial to remember that the designers of the CAVE VR system are always striving to enhance the user experience and resolve any issues.

6.3 Cost and Maintenance

Virtual reality systems might be difficult to deploy widely due to their high cost. Due to the unique hardware and software requirements, as well as the requirement for training and support, these systems sometimes have a high price tag. As regular updates and upgrades are required to keep the system operating effectively and to assure compatibility with the newest software and technology, maintaining a virtual reality system may also be expensive. For people and organizations, especially smaller ones with tighter finances, these fees can be difficult. Despite these financial obstacles, virtual reality systems are growing in popularity as the technology advances and their costs come down.

7 Trends in Immersive Virtual Environment

Figure 8: A demonstration of earthquake data using AVL's CAVE.

7.1 Market for VR and AR

It is anticipated that the VR and AR markets will expand in the upcoming years. The VR industry is anticipated to reach 20.9 billion by 2025, while the AR market is anticipated to reach 88.4 billion dollars by 2026, per a survey by MarketandMarket (MarketandMarket (n.d.-a, n.d.-b)). These trends show that there will be an increasing number of users in research and academics. VR and AR will increase their usage in many industries including healthcare, education, retail, and entertainment. This is a growing, fast moving marketplace with Oculus, HTC Vive, Microsoft, Google, and Apple being some of its key members. Still issues remain including costs of devices and concerns about privacy, but continuing research and development provides the potential for expansion. The trajectory of VR and AR market will transform the way people interact with digital and physical realms, bringing great opportunities for many business entities and individuals worldwide.

In contrast, augmented reality is used to enhance the shopping experience and provide interactive entertainment. Immersive virtual worlds are used more frequently in education to deliver dynamic and exciting learning experiences. This trend is anticipated to continue as teachers look for fresh approaches to teaching and engaging pupils. As designers and developers of VR/AR environments, we should be prepared to develop rich, interactive, and enhanced virtual environments to meet their requirements.

7.2 Adaptation

Immersive virtual environments are becoming more popular across various areas, including healthcare, education, the military, architecture, etc. As more business areas learn the advantages of employing immersive virtual worlds for training, simulation, and other uses, this trend is anticipated to continue. We may anticipate visual, haptic feedback, and artificial intelligence innovations as immersive virtual worlds get more advanced. The COVID-19 epidemic has increased the trend toward remote work, and immersive virtual environments provide a mechanism for distant teams to collaborate and communicate in a more immersive and dynamic way. Although virtual reality (VR) and augmented reality (AR) are sometimes grouped, we anticipate an increase in the use of AR, which integrates the actual world with digital aspects.

For example, in the health care industry, medical practitioners, including doctors and other specialists, there is an increasing trend of using IVE in virtual consultation programs that let patients chat with healthcare specialists long distance. Similarly, in education, virtual classrooms and collaborative learning experience will be used by the students and the educators so that they can engage themselves in immersive virtual spaces from different regions. Moreover companies in the architecture and design industry will increasingly use IVE for virtual project reviews and client presentations. This will help companies to communicate with their employees and the clients without physically being present. With more and more people working from home globally, the real world use of IVE will spread across different types of organization, facilitating communication and inter-connection.

7.3 AI/ML and IVE

There has been an increasing movement toward using artificial intelligence (AI) and machine learning (ML) in 3D visualization for pattern recognition, predictive analysis, and automated user interface support. The automated production of 3D models and visualizations using AI is one instance of this. By doing this, time can be saved, and analysts can concentrate on higher-level duties like evaluating the data and providing recommendations based on the findings. Another trend is utilizing ML techniques to find patterns in data that may not be immediately obvious when represented in 3D.

These algorithms can also be used to forecast outcomes for the future using data from the past. Additionally, there has been a increasing interest towards the use of natural language processing (NLP) to enable analysts to communicate with 3D visualization tools orally or in writing. Analysts may find it simpler to query the data and draw conclusions. In general, the application of AI and machine learning in 3D visualization aids analysts in more rapidly and precisely deriving insights from data and producing more accurate forecasts of future events.

The rapid advancement of generative AI has paved the manner for transformative developments throughout numerous industries, and its future applications are poised to reshape the panorama of visualization, interaction, and ideation. In the world of design, we can count on the emergence of sophisticated AI-powered gear which could generate dynamic and personalised visual content material based totally on person preferences, enabling designers to streamline their innovative processes and bring more engaging and tailored reports. Additionally, in the area of records visualization, generative AI algorithms may additionally play a pivotal function in automating the advent of interactive and insightful visible representations, imparting companies and researchers a greater intuitive way of interpreting complex datasets. Furthermore, as generative AI keeps to evolve, we can assume novel applications in human-pc interaction, wherein AI-driven structures will become extra adept at understanding and responding to herbal language, gestures, and different types of consumer input, fostering a more seamless and immersive consumer enjoy. Overall, the mixing of generative AI into those domains holds excellent promise for the destiny, promising to decorate creativity, efficiency, and person engagement in ways that had been as soon as idea to be past the world of possibility.

7.4 Enhanced collaboration and communication

IVE will increasingly be used for remote collaboration and communication. We see this trend growing, with IVE being embraced for collaboration post-COVID era. Remote work is becoming more popular, and the use of IVE will make communication even more helpful. Companies such as Spatial, AltspaceVR, and Virbela are pioneering systems that allow users to have interaction in digital environments, facilitating dynamic collaboration regardless of geographical distances. In these environments, participants can have interaction with shared content material, avatars, and spatial audio, growing an immersive revel in that mimics face-to-face interactions. This trend isn't restrained to a particular industry, as agencies, instructional establishments, or even social gatherings increasingly more leverage IVE to bridge the distance between bodily distances. As the generation keeps to increase and person adoption grows, it's far predicted that IVE will become an necessary tool for collaboration, providing a nuanced and enriched alternative to traditional faraway communique techniques.

7.5 Enhanced interactivity

With the advancement of technology, we can expect an increase in the development of advanced sensors and input devices that can be easily used out-of-the-box within large IVEs. This technology, when used with IVEs, will allow for more natural and intuitive interactions, such as gestural control, haptic feedback, and even thought-controlled interfaces. For example, gesture instead of hand in-game actions could be used for making VR gaming more intuitive and interesting. The technologies can also be useful to the healthcare sector by providing thought controlled interfaces into the rehabilitation programs. Patients may utilize the thought to guide virtual simulations that could enhance therapy and help with physical or cognitive rehabilitation. Moreover, natural and intrinsic interactions in IVEs can make it possible to transform the conceptualisation of immersive learning as well within education. Haptics is a cool way of learning since it makes it possible for students to learn through touching and they are given feedback from the touch screen. Advanced sensors and human interface devices depict how it would be possible for people to interact with virtual worlds.

7.6 Advancements in education

Large immersive virtual environments that can facilitate co-location collaboration and training. The use of CAVE-like systems along with VR/AR headsets and mobile devices can offer a more engaging and effective learning experience compared to traditional methods, as individuals can assist each other in learning and conducting training. In the future, we can expect to see a wider use of these IVE technologies in classrooms, industries, healthcare, and other domains. As educational institutions will more frequently adopt IVE technology such as cave like systems into classrooms to enhance learning experience. This would involve students engaging in collaborative projects and simulations.

It would therefore become more active and interactive in terms of teaching and learning. Specifically, in manufacturing industries or where hands-on training is required like hazardous areas, virtual technology may be vital in providing safe but realistic simulations. Immersive training scenarios could be used to provide healthcare professionals an opportunity of riskless practice of difficult procedures in a virtual environment. Moreover, firms can leverage on IVE to have teams work together as if they exist within the same geographical location. With advancing technology, IVE systems are likely to become cheaper which may spur their widespread use in different areas. Generally, the projection sees a future where IVE technologies become essential instruments in education, industries, health, and so forth, changing the manner in which we educate, work, and cooperate.

7.7 Content and Variety

Both large-scale immersive virtual environments and VR headsets rely on steady streams of high-quality content to keep users engaged. Large environments and VR headsets are beneficial here as they can offer a variety of experiences, from roller coasters to interactive games to theater. They also can deliver content ranging from educational experiences to social applications to immersive storytelling.

In the approaching years, we will assume the advent of expansive digital worlds that cater to numerous pastimes and preferences. For example, topic parks would possibly make investments heavily in big-scale VR environments, imparting traffic an array of reviews consisting of digital curler coasters, interactive games, and immersive theater performances. Simultaneously, VR headsets are possibly to grow to be an increasing number of flexible, turning in content that extends beyond enjoyment. Educational establishments can also undertake VR technology to offer college students with immersive studying stories, starting from virtual discipline journeys to complicated scientific simulations. Social packages inside VR can also thrive, fostering new methods for humans to attach and engage in digital spaces. Additionally, the world of immersive storytelling is poised to enlarge, with creators leveraging VR headsets to move audiences into fascinating narratives. The consistent evolution and integration of extraordinary content across each huge-scale environments and VR headsets are poised to drive sustained consumer engagement, making VR a transformative pressure in various sectors.

Figure 9: A user using HTC Vive headset and OmniTreadmill for interacting in a vitual environment.

8 Final Thoughts

It is likely that large immersive display systems and virtual reality headsets will continue to coexist in the market to meet users' diverse needs and preferences. Large immersive display systems, such as CAVEs (Cave Automatic Virtual Environment) and other projection-based systems, offer a high-quality, immersive experience for groups of users. These systems are often used for training, simulation, and visualization applications, where the ability to see and interact with digital content in a large, shared space is important.

On the other hand, virtual reality headsets, such as the Oculus Rift and HTC Vive, offer a more personal, portable immersive experience for individual users. These devices are often used for gaming and entertainment, as well as for various other applications, including visualization, healthcare, education, and design.

Overall, both large immersive display systems and virtual reality headsets have their own unique strengths and limitations, and it is likely that they will continue to be used in parallel to meet the needs of different groups of users and applications.

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