

White Paper - Final

Engineering Content: Immersive Technology

Prepared for the U.S. Army Engineer Research and Development Center – CAD/BIM Technology Center

Introduction

Virtual reality (VR) is a computer-simulated environment that can simulate physical presence in places in the real world or imagined worlds¹. VR has captured the imagination of many when it appeared in movies, and has found several applications in architecture, engineering, medicine, chemistry, games, etc.

Even though it appeared to have a brilliant future, VR has suffered from a lack of low cost technology to make such immersive visualization within easy reach. Although many systems were producing very high quality renderings in an immersive way, most systems were extremely expensive. For instance, a Computer Aided Virtual Environments (CAVEs) that are available in the marketplace today, require dedicated facilities, hardware and trained operators. Such hardware is available, but often at a very high cost, often in the tens of thousands of dollars, sometimes-even millions. Since hardware loses value quickly in a world in constant evolution, it is difficult for many companies to justify such an expense. Consequently, VR has often remained underused.

Over the years, the market has evolved. A number of new, smaller and less expensive devices now make it easier to create VR experiences thusly within reach of the masses.

The purpose of this white paper is to examine different options for the creation of immersive and semi-immersive environments for the viewing of 3D engineering information. The options discussed in this white paper will rely on relatively low cost commodity hardware that is currently available or soon to be available in the market. It is our belief that these relatively low cost environments can provide similar value to the operator while preserving workflows and institutional knowledge used in today's visualization solutions.

Industry Trends

The primary driver in today's display and human interaction technology market is the gaming industry. The \$66 billion gaming industry presents hardware vendors with many opportunities for innovation in the field of human computer interaction. These innovations exist from large vendors such as Microsoft, Sony and Nintendo with several forms of motion sensor technology as well as smaller vendors such as Oculus VR

¹ See http://en.wikipedia.org/wiki/Virtual_reality

with their virtual reality (VR) headset technology. There are some exceptions, such as the relatively recent emergence of the tablet market, but the broader PC market has seen little innovation in human computer interaction beyond niche input devices.

The consumer entertainment market has provided innovation in the field of large format displays. Manufacturers in this market are also adopting motion control technologies for the control of these displays. These displays provide theater quality viewing and are readily available from major manufacturers at reasonable cost. These displays provide HD (High Definition) quality display in sizes of over 90 inches diagonal.

3D television has also received significant attention in the consumer market and is showing signs of success. Current technology requires the use of special glasses to 'create' the 3D experience. Technology that removes these limitations are emerging on the market but is not yet available. There are some complaints about the lack of content available that can take advantage of the 3D displays but adoption and further development in this area is expected to change.

Components of Virtual Reality

The setup of a VR system requires three main components: Data, Hardware and Software. The data is the information that is being visualized often needs to be prepared prior to experiencing or reviewing in a VR environment. The hardware is the set of components that provide the display and interaction tools and it is often the most expensive portion of the system, and is the main target of this white paper. The software bridges the Data and Hardware, enabling the display of the data on graphic surfaces, and navigation control(s) using hardware tools.

Data

Data visualization is the purpose of VR. To enable VR display, the data often has to be prepared, that is placed into a format that enables fast, high quality rendering. This required data format, in particular CAD models, may not be available in that format.

Data preparation for immersive environments can represent a large investment of time and computing resources. Data preparation can range from simple format conversion to complex data integration tasks. These tasks are typically tailored for a specific audience and purposed for an explicit presentation.

Engineering organizations require more from a visualization environment than simple graphical representations. Through graphical representations, one can understand spatial relationships but in most applications the ability to access the engineering information behind the graphical representation is the real value. Engineering attributes are critical to providing the complete representation of the design.

In any engineering organization, that uses design review tools, there will be existing workflows and processes for design review data preparation. These workflows will be a combination of the tooling and institutional knowledge learned from operating that tooling. An immersive display system should not significantly alter these processes because although the presentation mechanism is different the objectives and required information of immersive reviews are the same. Any system that offers immersive environments should leverage - and not replace - these existing workflows and processes. There is typically

significant intellectual property and institutional knowledge embedded in these processes that would be difficult to replicate.

In Bentley Systems ecosystem, an i-model² is used as a self-contained package for the transport and manipulation of engineering data. In most Bentley Systems applications, the creation of an i-model is a simple 'Save-As' operation from a design application. The resulting i-model will contain all the engineering information from the design application. This i-model can then be viewed immediately or can be further transformed as required by the user.

Additionally, an i-model can be augmented and transformed further by using tools such as i-model Composer™ and i-model Transformer™. These tools allow the user to prepare engineering models for visualization by optimizing the presentation and allowing the data to be transformed as required. These transformations can include filtering of unnecessary information as well as the augmentation of the model with information from non-CAD sources.

This results in a data preparation process for the purpose of immersive visualization that is nearly identical for all design review applications. This process can reuse existing workflows and knowledge to ensure the validity and integrity of the data that is being presented. This will also reduce the costs associated with specialized processes and the associated personnel and equipment.

Hardware

Immersive visualization requires two main elements: rendering and interaction. Generally, the larger the portion of the field of view the visualization hardware fills, the better the experience. The sense of the visualization experience can be dynamically altered by the resolution of imagery. Therefore, higher resolution imagery typically provides an enhanced experience. Interactivity is equally important. In order to feel totally immersed in an environment, a user must not only see the environment but the environment must change quickly as a result of movements in the physical world, and provide a way for a user to "click" on parts of the scene to query it. These two VR aspects are examined below.

Immersive Visualization Spectrum

There are several options in the marketplace for an immersive viewing experience. The appropriate solution will depend on the values and objectives of the organization. Any solution will be a set of compromises based on those objectives. These compromises may include cost, audience size, collaboration size, interaction and location scenarios.

The chart below (Figure 1) provides some guidance for each scenario described in this document based on overall effectiveness of the VR (immersiveness) and associated cost. All solutions are a compromise between cost and the depth of immersive realism.

² For more information on i-models see <http://www.bentley.com/en-US/Products/imodel/>

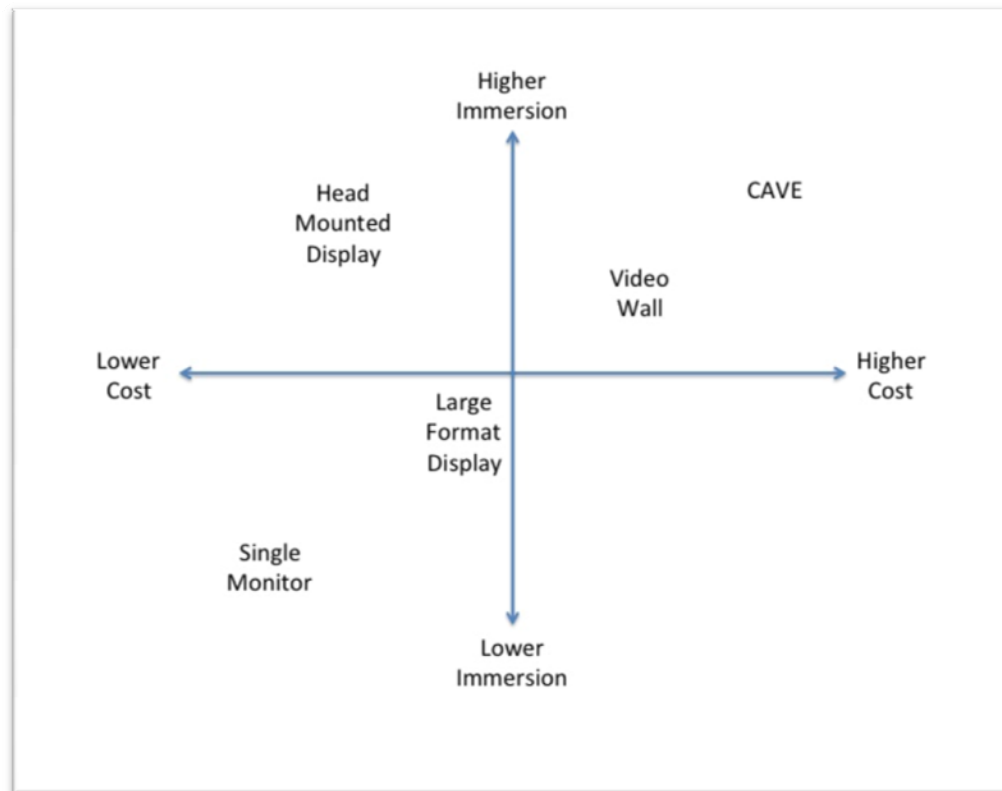


Figure 1 - Scenario Cost vs Immersion

Scenario 1 – Single Monitor/Workstation

The simplest and easiest to implement viewing solution is using a typical PC workstation with a reasonably sized display. This scenario provides a cost effective solution but also provides the least immersive experience. This solution is appropriate for one or two viewers depending on the display size (Figure 2).



Figure 2 - Various Monitor Display Sizes

A Workstation solution would consist of:

- One computer workstation
- One intermediate size display (27"-30" class)
- Typical PC input devices

The immersiveness of this solution will directly correlate to the size of the display available. The current 27 and 30-inch displays can provide some sense of immersion when viewed at typical viewing distances – a standard single maybe two-user review session. This solution clearly is not practical for groups larger.

It should be noted that newer high-resolution displays are capable of displaying ultra-high definition (UHD) resolutions. These displays require DisplayPort™ or Dual Channel DVI connections and cables to achieve the full resolution display.

This solution provides the lowest cost solution but also the lowest level of immersive visualization. Although it provides only limited immersiveness quality, computer gamers have used similar type computer monitors for 3D games for years. Gamers often feel quite immersed in the game, as the rendering quality, and speed of the interaction compensate for the limited monitor size.

User interaction in a workstation scenario would be accomplished through typical computer peripherals such keyboard and mouse. Alternative input devices such as 3D motion controllers are emerging in the market such as Leap Motion™ and the Creative Senz3D™. These controllers show significant promise but the available software to fully leverage what these devices might provide is still under evaluation. It is expected that these devices and associated software will continue to mature and become more relevant in the future.

Using this sort of visualization solution, ideally only one person has a viewpoint at any time – all the others view the model from a non-ideal position, which may result in model deformation. However, the hardware for this solution is readily available from various major manufactures and software applications such as

Bentley Navigator are offered commercially. There is an incremental cost of approximately \$200 to \$400³ associated with acquiring a larger display but the increase in monitor size is dependent on the organizations hardware standards.

Scenario 2 - Large Format Display

An extension to the workstation scenario is to further enlarge the display using consumer large format displays. This solution, using large format displays, is typically achieved in a conference room (Figure 3) or other dedicated space with a permanently mounted display. These displays are available in many different sizes and technologies.



Figure 3 - Typical Conference Room Installation

Flat panel displays, using LCD, LED or plasma display technologies, are available in sizes from 20" to 90". The largest displays tend to be based on recent LED technologies. Projector based displays can achieve larger sizes, over 159", but have environmental and spatial considerations. As these displays are projectors, they depend on line of sight from the projector to the screen. This prevents the image from being viewed directly in front of the screen for a front projection system. Alternatively, a rear projection screen can be used but these displays require additional facilities to serve as a projection room. No matter the display technology chosen, both technologies require the ability to control ambient light in the room to ensure the highest quality image.

The large format displays available in the market today are capable of displaying full high definition at 1080p resolution. As with desktop computer monitors, some models are capable of displaying ultra-high definition at 2160p and 4320p resolutions. These displays are also differentiated based on display

³ All costs stated in this paper are approximate and proportional based on the market at the time of publication. These costs should be considered estimates only and should not be used for budgeting purposes.

frequency, which will have very little impact in this scenario. Display frequency typically only becomes relevant with dynamic full motion video such sport programs. These displays typically use standard HDMI (High-Definition Multimedia Interface) connections.

This solution would consist of:

- One computer workstation
- One large format display (72"-90" class)
- Gaming controller

In order to provide the most immersive experience possible, the display should be as large as practical. For a typical size conference room this would be 72" or larger. Typical home theater installations recommend an ideal viewing location to provide a 20 to 40 degree field of view for the audience (Figure 4). This results in an ideal viewing distance of 1.2 to 2.5 times the diagonal size of the display. Using, for example, a large format display size of 60 inches, an ideal viewing distance would be 72 to 150 inches away. This would provide seating for approximately four people or standing room for approximately six. The ideal viewing area would increase proportionally to the size of the display.

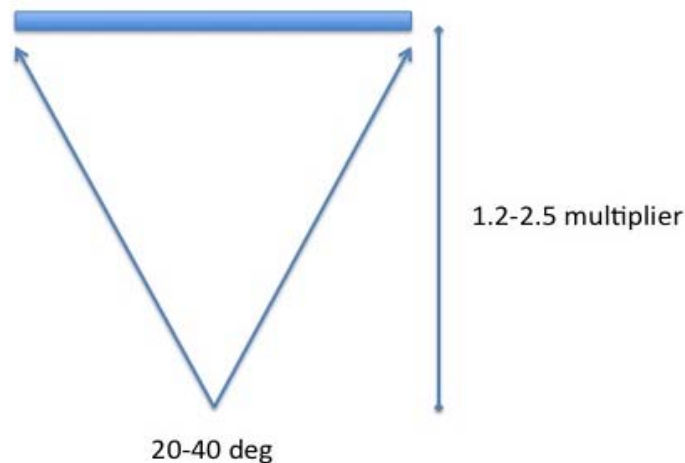


Figure 4 - Ideal Viewing Distance

In a conference room scenario the use of typical PC input devices may not be practical. It would be more intuitive to provide alternate input mechanisms such as a handheld game controller or a motion controller (such as Microsoft's Kinect™ device used with Xbox 360™). This type of controller would provide a more natural interface for those not experienced with the visualization software. Modern operating systems contain support for gaming controllers but not all applications have been developed to leverage these devices. The gestures and actions that control the visualization software will depend on the controller software being used.

Using a conference room setup, ideally, only one person has a viewpoint at any time – all the others view the model from a non-ideal position, which may result in model deformation. The passive viewers have no control, unless granted, thusly only one person in the room can navigate the model at any time.

The costs associated with this type of system can vary widely depending on the technology and display size. Flat panel displays can range from \$6,000 to \$10,000 for just the display. Projection based systems are less expensive for the projector and screen (\$4,000-\$7,000) but may have significant installation related costs.

Scenario 3 - Video Wall

To provide a more immersive environment or accommodate a larger audience, large format displays can be combined to create larger composite displays (Figure 5). These video wall displays are commonly seen in public for advertising or entertainment purposes. These arrays can provide a semi immersive display environment by filling the user's field of view dependent on the physical constraints of the space. Video walls can be installed on both a flat or curved surface. A curved installation will provide a modestly more immersive experience by surrounding the user but this type of installation will have constraints on size of the ideal viewing space.



Figure 5 - Video Wall Demonstration

This solution would consist of:

- Computer workstation(s) with one display output per screen
- Large format display(s) for video wall
- Video wall controller
- Gaming controller

Similar to larger format displays, the ideal viewing location is related to the size of the display. Using an example display made up of six 60-inch displays creates a composite display of approximately 166 inch diagonally. This creates an ideal viewing distance between 415 and 200 inches. This would provide seating room for approximately 18 people and standing room for approximately 25. When considering a curved installation the radius of the curve should be approximately the same as the ideal viewing distance (Figure 4).

A video wall controller that splits and distributes the video signal would coordinate the display of the various screens. These controllers are typically used for live video and other analog video sources.

Computer generated displays can be particularly sensitive to scaling of display resolutions resulting in image artifacts. The controller should be evaluated for this use case to determine if it provides adequate image quality. An alternative control configuration would be to use the rendering software to ensure each display displays the proper viewpoint. The rendering software would have to specifically support this paradigm in order for this to work properly.

The cost of a video wall display will depend on the cost of the individual displays and the technology used to distribute the video signal. A video wall controller based solution using six-60" displays described above could be in excess of \$20,000 with additional installation charges. Video wall installations typically cost between \$20,000 and \$90,000. A software-based solution may be slightly less but would require specific software support. In both cases, a dedicated computer workstation would be required to drive the display.

Scenario 4 - CAVEs

CAVEs are probably the most popular immersive virtual reality environments. These environments have several advantages over viewing models on a standard monitor. They have a greater feeling of immersion because the image fills the user's entire field of view. These environments can provide a feeling of true three-dimensional interaction with the use of tracking technologies to adjust the display based on lateral and rotational movements of the viewer. Remarkably, these environments can provide 1:1 display scale. This human scale display contributes to the sense of immersion as items appear at the same scale they would in the physical world (Figure 6).



Figure 6 - CAVE at University of Michigan

Other advantages of the CAVEs include the ability for the user to be completely surrounded by his environment. The most sophisticated CAVE environments will provide imagery surrounding the viewer, on all six sides. The use of motion controller technology can allow the user to interact with the model,

typically by using a “magic wand” or similar device. The motion controller technology typically used in CAVEs tends to be very lightweight and unobtrusive.

CAVEs are not without their disadvantages. CAVE installations can require very large dedicated facilities; some that offer floor and ceiling imagery can require three stories of clear space to accommodate the projection equipment. Several users can participate in a CAVE simultaneously; however, typically only one user can be in control of the system at any given time. Support of remote collaboration in a CAVE environment will be dependent on the application running the environment. As CAVEs tend to be proprietary, remote collaboration capabilities may be limited. These systems characteristically require large amounts of compute power as a result of the different viewpoints displayed simultaneously to surround the user. In addition, only one user can have perfect viewpoint at any time – all the others have incorrect viewpoints, which can alter perception.

CAVE environments can be very expensive to acquire and operate. Costs can range from \$100,000s to over \$1,000,000. Due to the complexity of these environments, many times trained and dedicated IT resources are necessary to operate the VR. Data preparation tasks increase due to the VR complexity, as these systems tend to rely on proprietary tools and formats.

Scenario 5 - Head Mounted Display

Head Mounted Display (HMD) is a device worn by the user on the head (Figure 7). For Virtual Reality use cases, these devices typically have two small displays that cover each eye. Additionally, these devices can be equipped with sensors that track the user's movements. For instance, some devices are equipped with an orientation sensor that measures the user's head orientation. Orientation data can then be used to control the orientation of the display of the virtual world. The full field of view and response to the user's natural motion provides the user the feeling of immersion in the virtual environment. An additional external position tracking system can be used to track the user's body movements. This provides an even more immersive experience, as the movements of the user in the physical world produce an equivalent navigation in the virtual world.

Recent advances in gaming technology have led to the development of new low cost devices that could be used for developing such VR systems. Displays such as the Oculus Rift™ and the castAR™ are interesting devices that are currently emerging onto the market. These displays along with input devices such as 3D motion controllers could provide the basis for an individual VR system.



Figure 7 - Oculus Rift HMD

The system would consist of the following hardware components for each viewer:

- One computer workstation
- A gaming HMD, for immersive visualization
- A 3D game controllers

The computer would run visualization application, such as Bentley Navigator™, which would be displayed on the HMD. Navigation would be controlled using HMD orientation sensor, or a 3D game controller. The hardware costs of such a system is incremental over a typical workstation. HMDs such as the ones mentioned about cost approximately \$200-\$400.

3D Display Technologies

3D display technology is growing in popularity in the consumer market. Early versions of these displays relied on active 3D technology where the display alternates between displaying the left and right image of the stereoscopic image. The viewer then wears glasses that contain LCD or similar technology that acts as a shutter to allow each eye to view the appropriate image. Active 3D glasses tend to be more expensive because of the complexity and require a power source to operate the shutter mechanism. Passive 3D displays are gaining in popularity due to the glasses lower cost. These displays use polarization to display the stereoscopic image while the polarized lens in the glasses allows each eye to see the appropriate image.



Figure 8 - 3D Display with Glasses

Other 3D display technologies that do not require glasses are currently under research and have been demonstrated in prototype form. However, none are available at this time for purchase.

3D display technology can be used in all of the visualization scenarios discussed as long as the displays used support 3D technologies. 3D displays are available in sizes that are appropriate for workstation use as well as larger consumer displays, even the video wall solution. During the 2012 CES Show (Consumer

Electronics Show), LG Electronics demonstrated a large-scale video wall with 3D capabilities (Figure 9). 3D glasses were required as with most of today's 3D technologies.



Figure 9 - 3D Video Wall & 2013 CES

Future Options

Although fully immersive environments are specialty products at this time, it appears that these will become more mainstream in the future. These technologies will emerge in the consumer market based on the technologies described in patent applications and the direction of academic research.

Microsoft has recently filed patent application #20120223885 that provides an “Immersive Display Experience,” apparently a result of the Microsoft Research project IllumiRoom⁴ This patent discusses the creation of full room displays by using a primary display with peripheral images displayed on “environmental surfaces”. Although the patent does not discuss specifics of this technology, it is easy to assume that this is a potential for the “next generation projection system” for gaming. This would provide an immersive environment using the actual room as the projection screen.

This concept is similar to Infinity-by-Nine⁵, research prototypes produced at MIT. This prototype varies the amount of detail that must be provided to gain a sense of immersion. This research found that the amount of information and resolution drops significantly in the viewer's peripheral vision. This allows more computationally efficient degraded imagery to be used in parts of the display. The Microsoft patent alludes to using similar techniques. Market acceptance will dictate if these solutions become readily available.

⁴ See <http://research.microsoft.com/en-us/projects/illumiroom/>

⁵ See <http://labcast.media.mit.edu/?p=262>

Software – What to Look For

Visualization

The visualization software for an engineering environment must have its roots in engineering design review. The accuracy inherent in these packages requires significantly different systems as that of gaming engines. Today's engineering visualization solutions are optimized for the display of geometrically intense models. Many visualization solutions, with roots in the gaming industry, are optimized for simplistic geometry with complex imagery projected onto that geometry. This optimization technique works poorly with engineering models that are geometry driven.

Interaction

Navigation is a primary operation in any visual environment. The navigation of the model must be easy and intuitive for a user to become comfortable and productive with a tool. The gaming industry has provided several models for navigating 3D virtual environments.

Another important consideration is the ability to interrogate the model. Although a picture is a valuable way to communicate, the spatial relationships within a model along with the ability to interact with the model and ask questions about what is displayed provides the real value. Questions about the spatial relationships of the model such as "What is the distance between X and Y?" and identifying questions such as "Where is X?" and "What item is on the screen?" build viewer confidence when interrogating the model. Other, much deeper, questions are also important. Questions about the topology of a model such as "What is this connected to?" are asked to address concerns about the design. Access to construction and operational data can be invaluable to answer questions such as "What items have been delivered on site?" and "What items need maintenance this week?"

Collaborative Virtual Reality

The display scenarios described above could be extended to provide distributed capabilities so that individuals in different locations, each with their own system, could collaborate in the same virtual environment. This collaboration ability would be enabled by visualization software and would not require any additional hardware except for network connectivity.

A collaborative virtual environment could be initiated with some or all participants in remote locations. The participants would enter the visualization application and connect to the virtual environment. The visualization application would be enhanced with a collaboration module, similar to what is found in collaborative games such as Activision's Call of Duty™ series and Mojang's Minecraft™. This collaboration ability will allow each participant to know each other user's position in the virtual model.

All users could start visualization from a common position in the model. They could remotely speak with each other, and view the same part of the model. For instance, a virtual environment participant could show a specific element to his colleagues by touching it with a virtual pointer, highlighting the element, and others would be informed by a visual cue in their field of view. Participants could see each other in the virtual model world through the representation of their avatar. Many real world actions, such as turning

around to speak talk with a participant, or pointing at something with your hand, could be reproduced using the controller device.

In this environment model rendering would be done locally, on each viewer's computer. The only data that would need to be transferred through the network during the visualization session is the participant's location, the ID of highlighted elements, and participants' voice.

Several remote viewers could therefore have a common visualization experience: some remote using a HMD running on their laptop, others in a CAVE, a few sitting at their desk viewing the model on their PC monitor, etc. All participants could review the same model and share comments, each one having a different level of immersiveness.

Conclusion

Virtual reality hardware has developed dramatically over the past few months. Recent advances have resulted in the production of hardware at a much lower cost that would make it possible to develop VR systems at a lower cost than it was previously possible. Several simple configurations using a large monitor, a large TV or a gaming HMD would make it possible for an individual to establish a VR for less than \$1000 in hardware. This means several sites could be equipped with VR hardware to do collaborative VR, for a reasonable price.

Software Considerations

The software that powers an immersive environment must primarily represent a realistic image on a display device. In addition to this functionality, it must also provide a view into the engineering information behind the image; the ability to 'simply view' an image on the screen is insufficient on today's complex engineering projects. The user must be able to interrogate the model to answer the complex questions about the design and construction or operational status.

The software and workflows to create such a complex data model can be as complex as the model itself. These work processes should leverage institutional knowledge whenever possible and should not require special processes for an immersive environment. These processes should be the same regardless of the eventual display mechanism.

The complexity of the information required for design review workflows all lend themselves to portable self-contained and self-describing data containers. This requirement is met by Bentley's i-model⁶ technology. This technology encourages publishing data such that it is consumable in downstream applications. These containers can hold aggregate information from many different sources of information.

The visualization software should also provide the opportunity for collaboration with remote persons. This collaboration should not be dependent on a specific display mechanism. The difference in display may cause the experience to vary amongst participants but allow the inclusion of remote expertise that would not otherwise be possible. Remote participants can reduce the need for travel resulting in significant cost savings for an organization.

⁶ For more information on i-models see <http://www.bentley.com/en-US/Products/imodel/>

Hardware Considerations

These various technology choices all have inherent advantages and limitations. In addition, no single technology will be suitable for all use cases.

Individual Use

The primary consideration when delivering a semi-immersive environment to individuals is typically cost. The use of workstations with large displays or fully immersive head mounted displays can help mitigate those costs by delivering a high level of functionality at a relatively low price point. As these technologies become more popular and demand increases, it is expected that cost will continue to drop.

Conference Room

Large format displays exist in many corporate conference rooms today. This commodity technology can be very effective when used for design review scenarios. This approach is both flexible and cost effective. Video walls should be considered for VR environments depending on the size and intended use of the space.

Showcase Facility

There are many considerations when creating a showcase environment. These facilities are typically purpose built and dedicated to the showcase task and can be quite large. The video wall approach can be quite effective in this environment as it provides a sophisticated and modern presentation. A video wall allows some flexibility as it can be used to display standard video and other video sources.

Disclaimer

The solutions and opinions in this paper are based on the state of the industry and market as of the time of publication. It does not imply any obligation on behalf of Bentley Systems to bring these solutions to market as a commercially available product or service.

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