KAUST Visualization Core Lab: Going Beyond Immersive Visualization in the Laboratory

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Abstract

This article gives an overview of the KAUST Visualization Core Lab (KVL) and discusses recent success stories highlighting different ways of going beyond traditional immersive visualization constrained within laboratory settings. With its shift towards few large-scale systems and more HMD systems, KVL uses frameworks to easily port applications between CAVEs and HMDs to maximize their benefits. KVL adapted to provide AI expertise to users, often finding unique research opportunities in immersive visualization projects that are rich in image data. KVL continuously innovates in immersive storytelling, and works with domain scientists to create research communications experiences that can engage and benefit the wider community. While some of the lessons presented here are not necessarily groundbreaking, the goal is to share how KVL continuously learns, adapts, and innovates to remain relevant in an ever-changing research landscape, in hopes of inspiring other labs.

Index Terms: immersive visualization, AR, VR, CAVE, tiled display, AI, immersive data-driven storytelling.

1 Introduction

The KAUST Visualization Core Lab (KVL) [9] is one of the ten core facilities in King Abdullah University of Science and Technology (KAUST) [10] located in Thuwal, Saudi Arabia, and established in 2009. As a core facility, it provides training, scientific expertise, and state-of-the-art facilities in the field of data visualization and data science to the university, and sometimes to government and industry collaborators. The research capability of the lab is based around its facilities and staff scientists. When KVL was established in 2009, it started with a heavy focus on immersive visualization with many large-scale systems such as CORNEA - a six-sided CAVE system (Fig. 1-left), two semi-immersive CAVEs (Fig. 1-right shows a decommissioned one), and three high-resolution tiled display walls. While these facilities served the research community well, the evolving research landscape and challenges of maintaining expensive large-scale systems led to the shift to fewer large-scale systems and more simple AR/VR HMD systems. At the moment, the lab hosts one semi-immersive CAVE system, two tiled display walls, and several AR/VR HMDs with development workstations. The technical specifications of these systems are described in later sections. In addition to changes in visualization systems, KVL also evolved into having staff data scientists to address the growing demand for AI research in data visualization and analysis workflows and beyond. Currently, KVL consists of three visualization scientists covering information and scientific visualization (visual analytics, HPC and in-situ vis, image segmentation/analysis, immersive analytics, large-scale data visualization), and two data scientists (machine learning and deep learning). This unique composition allows cross-learning and cross-collaboration between the team members resulting in unique research projects, some of which are described in the next sections.

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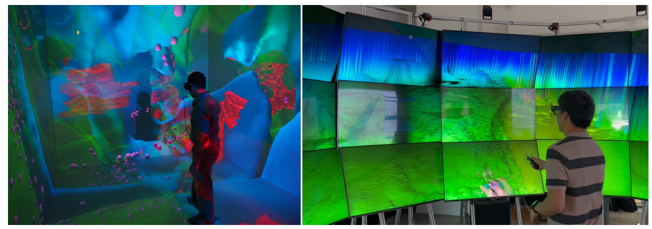

Figure 1: KVL decommissioned a six-sided CAVE (left) and a semi-immersive CAVE (right) system to focus more on COTS AR/VR.

These gradual changes in visualization systems and staff composition eventually paid off, resulting in a series of successful projects with multiple publications with collaborators. This paper describes some of these success stories and the adjustments as well as ideas implemented by KVL that led to them. The hope is to provide some insights and lessons that other labs might find useful in their own journey.

2 Going Beyond Immersive Visualization in the Lab

In this section, we share some of the recent success stories of KVL with some **insights and lessons learned** as well as the relevant **technical details**.

2.1 Beyond CAVEs: HMD & CAVE Portability

CAVEs are effective at immersing a group of users in a shared VR experience, but their use-cases are limited to in-house scenarios within the lab premises only, and finding impactful projects that utilize them can be challenging. Like many other immersive visualization labs, KVL has transitioned to having a mix of fewer large-scale systems (CAVEs and tiled displays) and many smaller commercial off-the-shelf (COTS) HMD systems. For similar labs, we recommend having a way to easily switch or port VR applications between CAVE and HMD systems in order to always hit two birds with one stone, i.e., providing the benefits of both CAVE and HMD to users using one code-base with minimal extra time and effort. This is exemplified in KVL's recent CPV-VR project.

CPV-VR is a VR experience that takes users on an underwater journey to discover the importance of coral reefs, the threats of climate change on corals, and the efforts of KAUST researchers and their collaborators to address these threats. Users are virtually transported inside the 3D reconstructed model of the Coral Probiotics Village (CPV) [17] - a coral reef that serves as a living underwater laboratory for KAUST researchers and incorporates 2D and 360 videos and interactive components for storytelling. This project, in collaboration with the KAUST Marine Microbiomes Lab [8], headed by Prof. Raquel Peixoto, was showcased at multiple venues, including the 28th United Nations Climate Change Conference COP28 [13], and the 2024 International Exhibition of

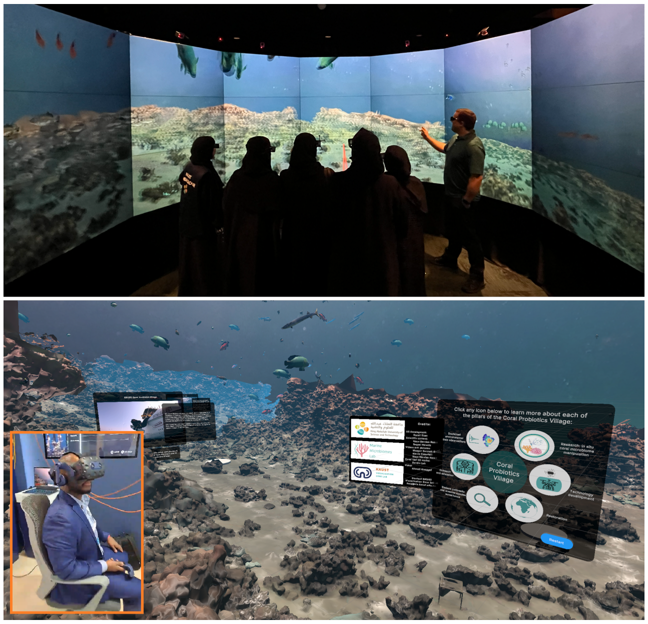

Figure 2: Having an easy way to port VR applications between CAVE (top) and HMD (bottom) systems can provide the benefits of both systems to users with minimal effort and cost.

Inventions in Geneva [6] where it was part of a Golden Medal winning entry. While having a VR application running on a CAVE system (Fig. 2-top) is useful for in-house events such as demos, tours, and community outreach, its more portable and simpler HMD-VR version (Fig. 2-bottom) can reach a wider audience, e.g., in conventions and conferences, leading to higher impact. Therefore, **having a way to easily switch or port VR applications between CAVE and HMD-VR systems can be quite beneficial** so that a single Unity code-base can be maximized for both systems.

Technical details: KVL's CAVE shown in Fig. 2-top is called CUBE VR System [7] and is a semi-immersive virtual reality environment featuring a 7 columns x 3 rows arrangement of BARCO OLS-521 Cubes (stereo HD LED systems), in a semi-circle configuration. The layout of the tiles is 180-degree concave and each planar column is rotated by 30 degrees. The VR HMD shown in Fig. 2-bottom is an HTC Vive Pro 2 tethered to a VR-capable laptop. The two applications use the same base Unity project with the CAVE version using the GetReal3D [4] plugin for tiled stereo display systems. The 3D model of the CPV coral reef was captured and generated in collaboration with Sandin Labs [11] from the University of California in San Diego. Agisoft Metashape [2] was used to reconstruct the 3D model from thousands of underwater photos of the reef. Due to hardware limitations, the resulting model extracted from the original 4 billion points was downsampled to 10 million triangles.

2.2 Beyond Tiled Displays: AI Assisted Image Segmentation

High-resolution tiled displays are typically used to investigate large-scale data (images, volumes, meshes), allowing users to see a high-resolution overview as well as very fine details with minimal panning and zooming effort. While many users leverage tiled displays for image and volume rendering for the sake of data visualization and data-driven storytelling/presentations, many of these users often require automatic image segmentation in their workflows, e.g. to isolate objects or regions of interest for analysis. To address this increasing demand, **KVL added AI assisted segmentation as a service, providing added value to users and leading to increased collaborative research projects**. Fig. 3 illustrates one of KVL's example success stories where the lab helped leverage deep learning techniques to automatically segment mitochondria, myelin, and glycogen granules in high-resolution electron microscopy images of mice brain tissues. A poster titled "Electron Microscopy of Brain Tissue Fixed by Focused Beam Microwave to Preserve Glycogen" was presented by Maria Fernanda Veloz-Castillo in the 2025 Gordon Research Conference on Volume Electron Microscopy [5]. A full paper is currently underway to present the final results.

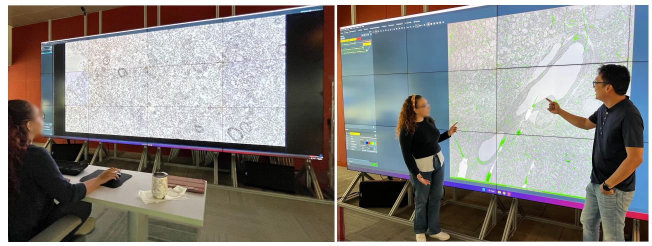

Figure 3: High-resolution tiled displays (left) combined with AI-assisted image segmentation (right) can add value to many users.

Technical details: The tiled display shown in Fig. 3 is called Zone 1 [7] and is a 24.9 Megapixel, 12-panel display wall in a 4 columns x 3 rows arrangement featuring 55" NEC ultra-narrow bezel LCD panels, each with a resolution of 1920 x 1080 pixels. Zone 1 uses NVIDIA Mosaic technology for managing the tiled display driven by a single workstation, enabling easy use of scientific applications on the facility. For data visualization, image segmentation and analysis, KVL provides and supports Amira/Avizo [3] software, among others. Amira/Avizo allows users to easily train and use deep learning models (typically U-Net based architectures) for image segmentation without the need for programming or prior technical AI background.

2.3 Beyond Immersive Visualization: AI-Driven Research Projects

While KVL started as a purely immersive visualization laboratory, it has evolved over the years to have a unique staff composition, which includes two data scientists who often have independent AI-driven non-visualization research projects. **Having data scientists allows the lab to sometimes find and develop AI-driven research opportunities from immersive visualization projects**. This often happens in visualization projects that involve large amounts of image data which can be used for training deep learning models that can automate time consuming or complex workflows. For example, working on the CPV VR experience described earlier led the KVL to work closely with the domain scientists in which they developed Coral-CAT [16] - a semi-automatic AI-based tool for color-based assessment of coral health from underwater photos. This application uses deep learning models for automatically segmenting corals in underwater photos and subsequently performs automatic color adjustments and analysis to correctly asses the level of bleaching in corals.

Another example, illustrated in Fig. 4 (a,b), is a project that started as a mixed reality visualization of 3D foraminifera reconstructions from computed tomography (CT) data. Foraminifera or forams are single-celled aquatic organisms that form calcareous shells, which fossilize abundantly and serve as key indicators of Earth's past environments and climate [15]. In collaboration with student Ali Al-Ibrahim, who scanned several specimens, KVL extracted 3D models of the forams and used them in an interactive HoloLens 2 application that allows users to investigate internal structures using a clipping plane that can be manipulated intuitively

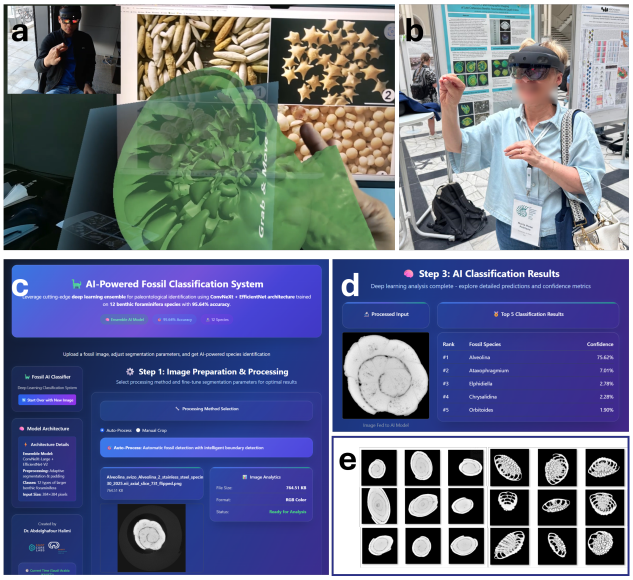

Figure 4: Immersive visualization projects (a,b) involving large amounts of imaging data (e) can often lead to AI-driven projects (c,d).

with 6 degrees of freedom. This work was presented as a poster entitled "Micro-CT and Holographic Imaging of Late Cretaceous Benthic Foraminifera in Saudi Arabia" at the 12th International Cretaceous Symposium [1]. Due to the abundance of imaging data (examples in Fig. 4-e), this immersive visualization project naturally led to ForamDeepSlice [18] - a deep learning framework for automatic classification of foraminifera species from CT images, shown in Fig. 4 (c,d).

Technical details: The HoloLens 2 application was developed in Unity based on the clipping plane template provided by the open source Mixed Reality Toolkit (MRTK). The 3D models of foraminifera used in the application were extracted from the raw CT image stacks of each foram specimen using Amira/Avizo using a simple workflow that consists of denoising, automatic thresholding for segmentation, and geometry extraction and mesh simplification.

2.4 Beyond Traditional Storytelling: Shared Mixed Reality Experience

Immersive visualization is a powerful tool for data-driven storytelling [19] due to the many possibilities to convey the message behind data as well as the impressive immersion that it provides. In addition to using existing approaches, **KVL also actively explores innovative and unique ways of data-driven storytelling**. An example of this is a project in which a mixed reality experience was shared and streamed to a projection screen during a live presentation at a big conference (Fig. 5). This particular example is a HoloLens 2 application that displays different animations of climate model simulation and emulation results, demonstrating the benefits of the research entitled "Boosting Earth System Model Outputs And Saving PetaBytes in Their Storage Using Exascale Climate Emulators" [14]. This research project eventually won the prestigious 2024 ACM Gordon Bell Prize for Climate Modelling during the International Conference for High Performance Computing, Networking, Storage and Analysis (SC24). The unique storytelling aspect of the presentation added extra wow factor to the already impressive research, leading to potentially more impact and memorability to the audience. The same mixed reality application was showcased at the KAUST booth during the conference and the desktop version of the application is also publicly available.

Figure 5: Sharing or live streaming the view from a mixed reality device can be a unique way to provide data-driven storytelling.

Technical details: The HoloLens 2 application development involves mapping the 2D output time series visualization of climate models generated by the research project's prototype into a 3D sphere inside a Unity project. During the presentation, the live view of the HoloLens was streamed to the presentation computer using VLC media player with the stream source set to the HoloLens api for live stream capture. This set up requires the HoloLens to be in the same wireless network as the presentation computer. In order to reduce chances of mistakes during the live presentation, interactions were minimized, and animations were automated in proper sequence according to the story/presentation.

2.5 Beyond Research Papers: Immersive Visualization for Research Communications and Outreach

While many of the immersive visualization projects developed in the lab typically aim to develop new techniques, algorithms, and applications that can be published, **KVL also works with domain scientists in developing immersive visualizations for research communications and outreach to give back to the community and attract new users**. For example, KVL developed a mobile-AR application that places a virtual giant coral situated in the real-world to educate the community about coral preservation efforts in the Red Sea (Fig. 6). This app was developed in collaboration with SHAMS [12] - a Saudi government agency for preservation of corals and turtles, and was presented at the 6th Saudi Environment Week in Riyadh.

Figure 6: Mobile-AR is a low-cost option for immersive visualization that can be easily distributed and used by a large number of users.

In another example, KVL developed a virtual art exhibit where the artwork are derived from CT scanned scientific data of corals, insects, fish, and rocks, not only to educate the community about the power of CT scanning but also to promote collaboration between different scientific laboratories in the university (Fig. 7). This experience was part of a wider art exhibit co-organized with KAUST's Al Naimi Petroleum Enginieeering Research Center (ANPERC) which maintains one of the main CT machines in the university. The exhibit was well received and attended by school children, government representatives, and the wider KAUST community.

While HMDs like the HoloLens 2 device have been around for years, they still attract attention and publicity, which is helpful for

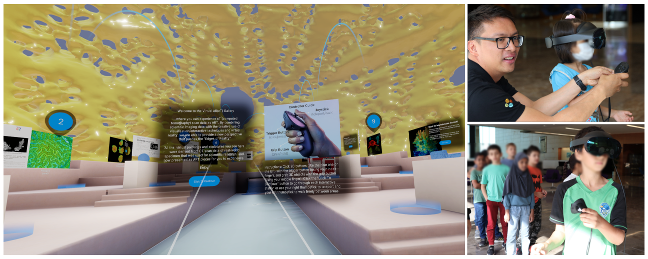

Figure 7: A VR museum is a user-friendly approach that allows users to freely explore points of interest according to their preferences.

reaching a wider audience and also for advertising the capabilities of the lab. We find that such applications often spark curiosity and initiates conversations that can lead to new projects and collaborations. In our example shown in Fig. 8, KVL developed a mixed reality application that shows a virtual F1 race car situated inside the visualization lab. This demo was shown and presented to Oscar Piastri during his team's visit to KAUST in 2025 where other KAUST collaborators also showcased their research contributions to the McLaren F1 racing team using the lab's larger tiled display.

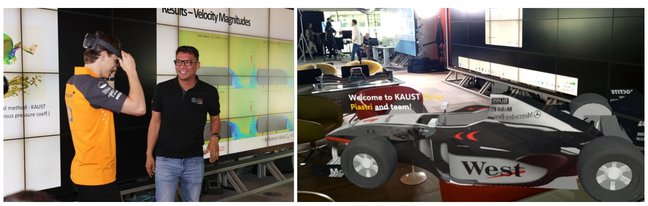

Figure 8: HMD-based demos still attract attention and publicity, which is great for advertising the lab and attracting new collaborators.

Technical details: The mobile-AR and VR museum applications shown in Fig. 6 and Fig. 7, respectively, were both based on project templates provided by Unity. The coral model was reconstructed from multiple underwater photos of an actual giant Red Sea coral via photogrammetry. In all these applications, interactions are kept as minimal and simple as possible to make them user-friendly.

3 Conclusion

This article provided an overview of the KAUST Visualization Core Lab as well as different ways it goes beyond the traditional immersive visualization constrained in large-scale lab facilities. In order to maximize the benefits of both CAVE and HMD systems, the use of frameworks that allow easy porting, such as Unity with GetReal3D, is recommended. The addition of AI capabilities in an immersive visualization lab can lead to unique project opportunities. While this is not necessarily easy, lab staff/scientists often have extensive backgrounds in computer science, image processing, and mathematics which can often serve as a good foundation for learning AI tools and techniques that can benefit their users. Furthermore, easy-to-use software for AI assisted segmentation, classification, and other tasks are becoming more and more prevalent and can be leveraged as well. KVL is always finding ways to facilitate immersive data-driven storytelling such as by using shared/streamed mixed reality experiences. Finally, KVL continuously works with domain scientists in developing immersive visualizations for research communication and outreach, in order to give back to the community and attract new collaborators. While KVL has been taking inspiration from other labs around the world, it has also been continuously learning, adapting, and innovating to remain relevant and to keep contributing in impactful research.

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