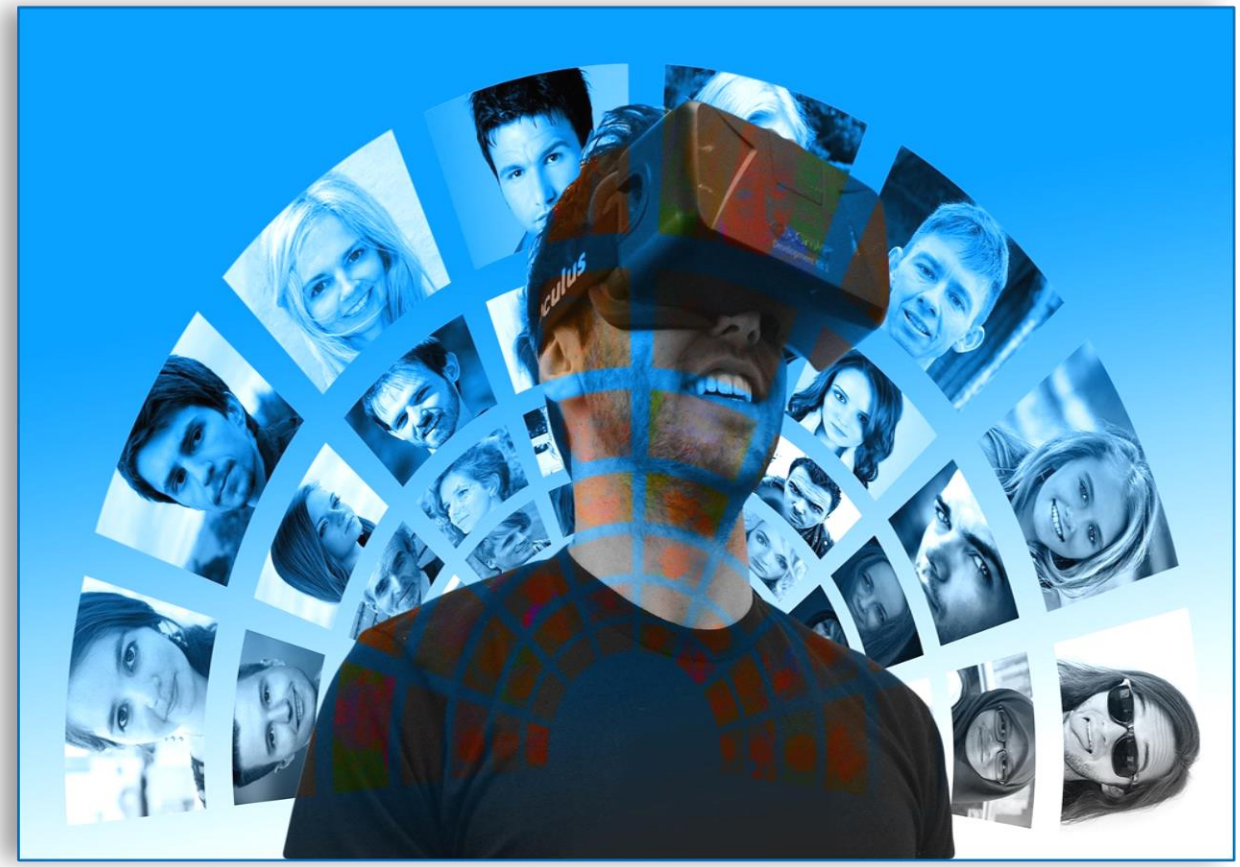
CALIFORNIA STATE UNIVERSITY
LONG BEACH
College of Engineering



Engineering the BEACH Metaverse

Expanding Educational Access and Engagement at Cal State Long Beach with AR/VR Technology

Table of Contents

1. EXECUTIVE SUMMARY

With a growing inventory of augmented reality and virtual reality facilities and equipment, as well as substantial faculty expertise, the CSULB College of Engineering (COE) is poised to further develop its AR/VR capabilities to achieve institutional goals and offer state-of-the-art learning experiences for students. The College welcomes collaborations with industry and other colleges and universities in the spirit of knowledge-sharing and advancement of AR/VR to develop new and more impactful techniques for teaching engineering and STEM concepts.

2. INTRODUCTION

University engineering programs are at a critical juncture, navigating an environment requiring new strategies to embrace challenges arising on a number of fronts. The nation's need for STEM graduates to remain internationally competitive creates continued pressure on universities to produce a substantial number of new graduates who are well-trained and represent the breadth of engineering disciplines. Now more than ever, engineering programs have an overarching obligation to foster greater diversity, equity, and inclusion to ensure that the faces of future engineers represent those within the society at large. In addition, access to engineering education must be extended in a meaningful way to students displaying a broad range of disabilities and different learning styles.

Against that backdrop is the need to increase engagement among engineering students. New materials and fresh learning experiences must be created that will appeal to a generation of digital natives and reinforce the College's core mission of providing hands-on learning experiences to students to supplement theoretical foundations. At the same time, those learning materials and experiences must effectively encourage students' understanding of core concepts and improve their educational experience.

Universities in general are witnessing a pedagogical revolution. In-person classes are no longer the only option. The temporary move to virtual learning during the pandemic has ushered in an enduring era of online and hybrid classes delivered on a variety of platforms. With the help of campus instructional designers, engineering faculty have been experimenting with novel learning modalities and platforms. In departing from traditional engineering classes, where concepts are taught via lab demonstrations or Powerpoint slides projected at the front of classrooms, engineering educators have opened themselves up to a range of exciting opportunities.

Navigating this evolving environment also requires engineering colleges to prioritize a dynamic range of partnerships and collaborations, both within and outside the university. Collaborations with other university departments and other universities will not only provide students and faculty with multidisciplinary experiences, but extend the academic and economic reach of collaborating organizations. Outreach relationships with local community colleges, and middle and high schools, are crucial for evangelizing engineering education to a new generation,

increasing the pipeline of potential engineering students, and expanding the student pool to more diverse groups. Establishing and maintaining strong industry partnerships is essential for eliciting valuable input on industry trends and engineering curriculum, and facilitating access to resources such as equipment and other gifts, internships, and professional development advice.

AR/VR is emerging as a common tool to help the CSULB College of Engineering and other universities address these pressing issues and achieve these goals. Already being embraced by faculty in many College departments, the technology has the potential to increase diversity and inclusion, open access for those with disabilities, enhance students' educational experiences, and provide a platform for collaborations between the College and other colleges, universities, and industry.

Long the domain of the videogame industry, AR/VR has recently become a viable option for education and training due to increased computer processing power, new software and hardware, more robust Internet connections, and declining prices of software and hardware. In AR, digital content overlays physical environments. In VR, users interact in artificial 3D virtual or sensory environments. Both are being increasingly used by universities to enhance educational offerings in a variety of areas.

AR/VR has strong appeal to visual learners, who make up nearly two-thirds of the population. Research shows that information absorbed visually has higher comprehension and retention rates. In engineering, visual representations are useful for conveying complex concepts and promote visual thinking, which is essential for creating and communicating designs and systems throughout an engineering student's educational and career journey.

With large technology companies staking out claims to expand into the metaverse, AR/VR is on its way to becoming mainstream, increasing students' expectations for immersive educational offerings. Facebook, which recently changed its name to Meta, will invest $10 billion in AR/VR products and services in 2022. Adobe, meanwhile, is expanding its Creative Cloud products for creating digital content and providing workflow platforms for AR/VR content creation.

3. CSULB COLLEGE OF ENGINEERING AR/VR CAPABILITIES

a. Equipment

i. Headsets:

- HTC Pro Eye VR headset (3 sets)
- HTC VIVE Cosmos Elite 3D VR system (4 sets)
- Magic Leap VR headset (1 set)
- Microsoft HoloLens 2 mixed-reality smart glasses (4 sets)
- Oculus Rift VR headset (4 sets)

ii. Sensing Systems:

- BCI 21-channel EEG cap (1)
- Emotiv Epoch 14-channel whole-brain sensing EEG headset (1 set)

- Myoware EMG sensors (1)
- Perception Neuron system (1, full-body, including hands and fingers)
- Rokoko system (1, full-body)
- Shimmer EMG, inertia measurement unit and skin sensing system (1)
- TDK, STmicro, and Xsens inertia measurement units (1)

iii. High-performance Computers:

- Alienware laptop (3, with high configuration)
- Dell High-end Gaming PCs (3, with i7 Core, Nvifda GeForce GTX, 512 GB, SSD Storage, 16GB RAM)
- Exxact High-end PC (1, with i7-7920X, 1080 Ti GPU, 256 SSD, 16GB RAM, 2TB SATA)

iv. Other Equipment:

- Laser scanner (1)
- Samsung 360 camera (1)
- Robot manipulators (2)
- Mobile base with holonomic wheels and Lidar sensor (1)

b. Facilities

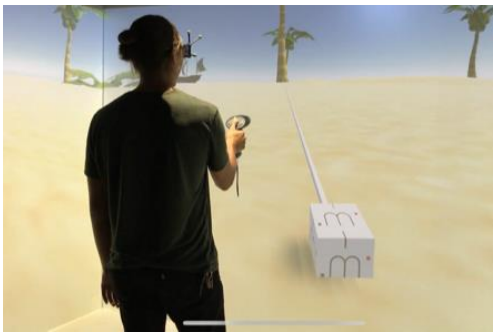
i. Beach CAVE Lab

The Beach CAVE Lab houses a Cave Automatic Virtual Environment (CAVE) immersive virtual environment system that facilitates interdisciplinary research in human-machine interaction in a dynamic environment. The system consists of room-size 4-panel displays with 8-camera real-time full body motion tracking. A CAVE-like system offers better presence through a greater field of view that can be shared with multiple users and allows an operator to interact immersively in a real user volume. The acquisition of the CAVE system was funded by a National Science Foundation (NSF) Major Research Instrumentation grant. The lab is overseen by CSULB Mechanical & Aerospace Engineering. (Contact: Drs. Panadda Marayong and Praveen Shankar)

Major equipment:

- VisCube M4 (Visbox, Inc., IL) CAVE VR system with front-projected 4-panel displays (12’ W x 8’ D x 10’ H)
- ARTTrack real-time full body motion tracking system
- Fully-integrated graphics workstation

ii. Human Performance and Robotics Lab



The Human Performance and Robotics Lab's research projects range from musculoskeletal modeling to robotic control. HPRL has received grants from DENSO, the NSF, and the National Institutes of Health and collaborates with various departments and institutions to engage in interdisciplinary research.

Major equipment:

- Force feedback haptic device
- Kinova and Optitrack robotics equipment
- Motion-capture equipment
- Miniature threaded inline load cell
- Robotic arm and hand

iii. Integrated Virtual Design and Construction Lab

The Integrated Virtual Design and Construction Lab is embarking on research projects in 3D visualization, Building Information Modeling (BIM), 4D simulation, 5D model-based cost estimating, model validation, reality capture, quality control, and training.

Major equipment:

- Alienware Laptop (high configuration)
- HTC Vive VR system
- Laser scanner
- Magic Leap VR headset
- Microsoft HoloLens mixed-reality headset
- Oculus Rift VR headset
- Samsung 360 camera

c. Personnel:

Dr. Mehrdad Aliasgari, Chair, Computer Engineering & Computer Science Department

Dr. Aliasgari joined CSULB in 2013 after completing his Ph.D. in Computer Science and Engineering from the University of Notre Dame. He received his B.S. in Electrical Engineering from Sharif University of Technology and his M.S. in Computer Science and Engineering from University of Notre Dame. Aliasgari's research area is mainly computer security and applied cryptography. He focuses on privacy-preserving computation and outsourcing, verifiable and secure outsourcing and storage of data, private biometric and genomic computation and cloud security. His dissertation was entitled "Secure Computation and Outsourcing of Biometric Data." He developed the first efficient solution on secure multiparty floating-point computation which has numerous applications in the field of secure computation and outsourcing. He teaches computer security and cryptography courses at CSULB.

Dr. Vahid Balali, Civil Engineering & Construction Engineering Management Department

Dr. Vahid Balali received his B.S. and M.S. in Civil Engineering from the University of Tehran, his second M.S. in Construction Engineering and Management from Virginia Tech, and his Ph.D. in Civil Engineering from the University of Illinois at Urbana-Champaign. Upon completion of graduate school, he worked for two years as a BIM Manager in the industry. He is a recipient of a Consulting-Specifying Engineer's (CSE) 40 Under 40. Dr. Balali's research focuses on the visual data sensing and analytics for the AEC industry, virtual design and construction for infrastructure asset management and interoperable system integration, and smart cities in transportation for sustainable infrastructure decision-making. He has been the principal investigator on research projects supported by Caltrans, Mineta Transportation Institute, Associated of General Contractors of America (AGC), and several industry entities. He is currently an associate member of ASCE and CMAA, committee member of the ASCE Data Sensing and Analysis (DSA) and ASCE Visual Information Modeling and Simulation (VIMS) committees, and friend member of relevant TRB committees. He also serves on the editorial board of the American Journal of Civil and Architectural Engineering and is a reviewer with several top-notch journals. He is actively collaborating with industrial partners and involved in professional and outreach activities.

Dr. Emel Demircan, Biomedical Engineering and Mechanical & Aerospace Engineering Departments

Dr. Emel Demircan joined CSULB in 2015 and holds a joint appointment in the Mechanical & Aerospace Engineering and Biomedical Engineering departments. Dr. Demircan obtained her Ph.D in Mechanical Engineering from Stanford University in 2012. She was a postdoctoral scholar at Stanford from 2012-14 and a visiting assistant professor at University of Tokyo from 2014 to 2015. She is also a part-time scientist at Lucile Salter Packard Children's Hospital Gait Analysis Lab at Stanford University. Dr. Demircan's research focuses on the application of dynamics and control theory for the simulation and analysis of biomechanical and robotic systems. Her research interests include experimental and computational approaches for the study of human movement, rehabilitation robotics, sports biomechanics, human motion synthesis, natural motion generation in humanoid robotics and human motor control. In 2014, Dr. Demircan established an IEEE RAS Technical Committee on "Human Movement Understanding." She is actively collaborating with clinical, athletic and industrial partners and is involved in professional and outreach activities within the IEEE Robotics Society.

Dr. I-Hung Khoo, Biomedical Engineering and Electrical Engineering Departments

Dr. Khoo joined CSULB in 2006. He holds a joint appointment in the Electrical Engineering and Biomedical Engineering departments. Dr. Khoo's research interests include high-speed and mixed-signal circuit design, and analog and digital signal processing. He is currently the advisor for the Electronics and Computer Engineering Technology programs. Dr. Khoo is a

member of IEEE and received his Ph.D. in electrical and computer engineering from University of California, Irvine in 2002.

Dr. Panadda (Nim) Marayong, Mechanical & Aerospace Engineering Department

Dr. Panadda (Nim) Marayong is a Professor in the Department of Mechanical & Aerospace Engineering and the Director of the Robotics and Interactive Systems Engineering (RISE) Laboratory. She received her M.S. and Ph.D. in Mechanical Engineering from Johns Hopkins University in 2008. Dr. Marayong's research interests are in the areas of robotics, human-machine collaborative systems, and haptics. Dr. Marayong is dedicated to teaching and has led numerous educational outreach programs to promote student participation in science and engineering. She currently serves as the Director of the Research Enrichment Core and a PI of the CSULB BUILD program funded by the National Institutes of Health. She is a member of ASEE, IEEE, and Tau Beta Pi. Currently, she also serves as the faculty advisor of the Society of Women Engineers at CSULB.

Dr. Hamid Rahai, COE Associate Dean of Research & Graduate Studies

Dr. Rahai is founding director of the Center for Energy and Environmental Research & Services (CEERS), COE Associate Dean for Research & Graduate Studies, and a professor in CSULB's Mechanical & Aerospace Engineering and Biomedical Engineering departments. He has supervised over 70 M.S. theses and projects and Ph.D. dissertations, and authored more than 90 papers and presentations. He has overseen more than $6 million in grants and contracts from the NSF, Federal Highway Administration, California Energy Commission, California Air Resources Board, Port of Los Angeles, Caltrans, Boeing, Southern California Edison, Long Beach Airport, Long Beach Transit, and private industries. The holder of two awarded patents in wind energy and four pending patents for drag reduction of vehicles and aircraft, vehicle emission controls, and patient-specific diagnostic systems of lung function, Dr. Rahai is a Senior Member of the National Academy of Inventors and the recipient of a 2004 Northrop Grumman Excellence in Teaching Award and 2014 Outstanding Engineering Educator Award from the Orange County Engineering Council.

Dr. Praveen Shankar, Mechanical & Aerospace Engineering Department

Dr. Praveen Shankar obtained M.S. and Ph.D. degrees in Aeronautical and Astronautical Engineering from The Ohio State University in March 2004 and August 2007 respectively. His research expertise is in the development of advanced control systems for complex aerospace and robot applications. He serves as the Director of the Collaborative Autonomous Systems Laboratory.

Dr. Wenlu Zhang, Computer Engineering & Computer Science Department

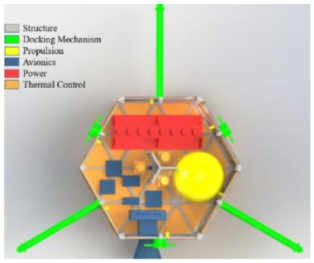
Dr. Wenlu Zhang joined CSULB as an Assistant Professor in Fall 2017. She worked as a postdoctoral associate in the Washington State University School of Electrical Engineering and Computer Science for one year after earning her Ph.D. in Computer Science from Old Dominion University in 2016. Dr. Zhang received an Outstanding Research Assistant Award while a graduate student at Old Dominion. She and her team participated in the MICCAI Challenge on Circuit Reconstruction from Electron Microscopy Images (CREMI). Her team ranked first on synaptic cleft detection and second on neuron segmentation tasks. Zhang also serves as a program committee member for the ACM SIGKDD Conference on Knowledge Discovery and Data Mining (KDD) and the ACM International Conference on Information and Knowledge Management (CIKM).

4. POSSIBLE APPLICATIONS TO CURRICULUM:

i. **Lab Instruction**—AR/VR can be leveraged in lab instruction throughout the College of Engineering, to teach concepts and demonstrate experiments.

ii. **Aerospace Engineering** — Students can use AR/VR to create immersive simulations based on their Senior Design Projects. Students in the BSAE program complete a paper design on topics such as aircraft, spacecraft, launch vehicles and space missions. However, they are unable to manufacture/prototype these novel designs nor visualize the missions due to their scale. As such, the virtual reality environment would be an ideal platform for these designs to be simulated and tested.

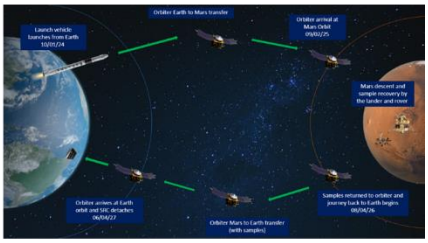
Helicopter Design



Spacecraft Design

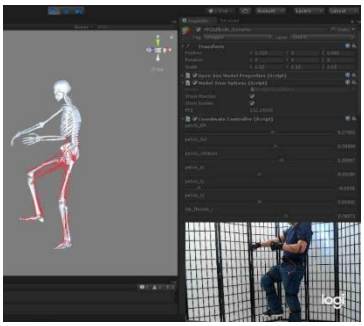
Aircraft Design

Launch Vehicle Design

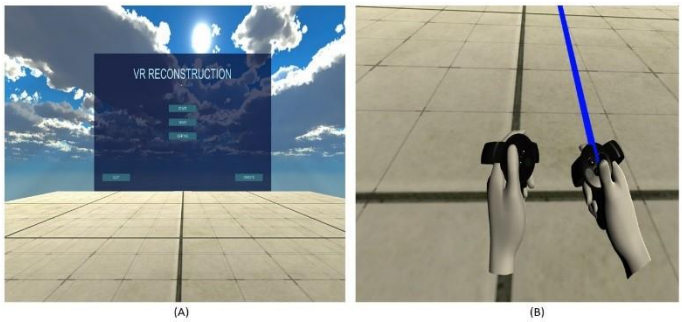


Space Mission Design

iii. **Biomedical Engineering (Anatomy)** — VR can be implemented to teach students about the human body with virtual musculoskeletal models. While students are wearing a VR head-mounted display, the students can explore and navigate virtual skeletal systems. Realistic musculoskeletal models can be scanned and integrated into virtual environments that allow students to see from any angle or perspective. In addition, the models can be altered to hide or show specific parts such as muscles, bones, and organs.



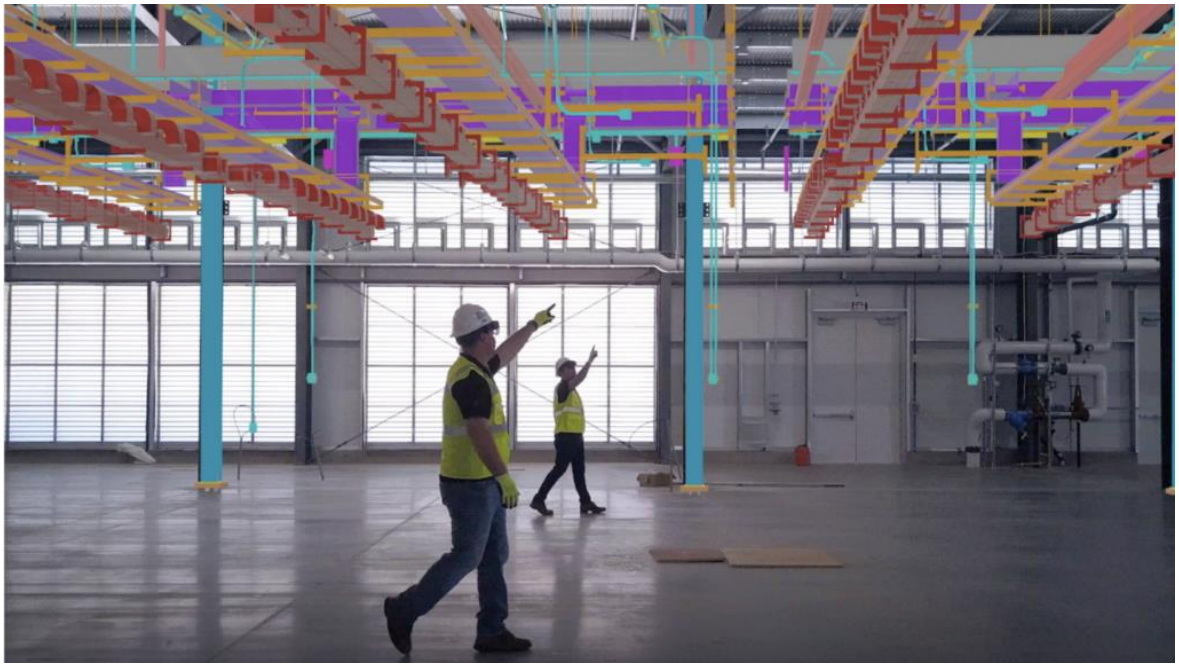
iv. **Biomedical Engineering (Human-Robot Interactions)—**Virtual, mixed, and augmented realities can be implemented during human-robot interactions. A robot can be connected to a computer to allow the user to control the robot via controllers. These controllers can be the VR system's controller or a haptic controller such as Force Dimension's omega.7 system. Surgeons can be trained to operate a robot to assist or perform virtual surgeries. The physical robot can simultaneously perform the physical version of the controls performed within virtual surgery. This allows surgeons to learn how a physical robot can be teleoperated while the surgeon uses virtual, mixed, or augmented reality. VR can be used for training while mixed and augmented reality can be used to allow the surgeon to see the surrounding environment such as the physical robot.



v. **Computer Engineering & Computer Science (Computer Vision) —** Computer vision plays an essential role in AR/VR systems to see, analyze, and understand the world. In recent years, machine learning has been one the most popular areas in artificial intelligence. Especially, deep learning has made spectacular progress in pattern recognition and computer vision tasks such as image segmentation, object detection, video generation, and data completion. In CECS, interesting applications in machine learning will be introduced to students, such as deep neural networks in 2D/3D feature detection, object tracking in AR, real-time 3D scene generation, and game development in AR/VR.

vi. **Civil Engineering and Construction Engineering Management (Virtual Design Construction (VDC) Course)** — Dr. Vahid Balali began teaching a new three-unit course, Virtual Design and Construction (CEM 483), in Fall 2021. The course focuses on development, use, and transfer of a centralized data-rich virtual project model that facilitates documentation, design exploration, model-based quantity take-off and estimating, interference checking, construction coordination and sequencing, digital

fabrication and building information visualization. In this course, students will learn VDC's use in the Architecture, Engineering, and Construction (AEC) industry, examine geometry, spatial relationships, building information, quantities and properties of building components, and understand the benefit and improvement areas BIM process offers. The course will discuss the use of virtual environments for design exploration, as well as computer-aided manufacturing and fabrication.



vii. **Interdisciplinary Subjects** – AR/VR could potentially be used to for applications and collaborations with non-engineering subjects.

viii. **Mechanical Engineering (Equipment and Process Training)** — AR/VR can be used to train technicians or help manufacturers learn about new processes. A simulated virtual environment can immerse the technician or manufacturer with a virtual environment like the physical environment they will be working in. A virtual simulation of the process can allow the technician to virtually perform all tasks before using actual hardware. This type of virtual training increases the technician's overall experience prior to handling actual hardware to skip the learning curve associated with new processes.

ix. **Mechanical Engineering (Manufacturing)** — AR/VR can be used to instruct students in advanced manufacturing processes.

x. **Mechanical Engineering (Teleoperating Robot) —** VR can be used to teleoperate a robot. This work has been implemented using a robotic arm and a VR system. The user can control a virtual robot that acts as the controller of a physical robot. By expanding this work to augment reality, the application can include disable groups. Disabled people can be assisted by robotic arms that can be controlled via AR. One example includes having access to a mounted camera on a robot arm to allow the user to accurately control the robot when attempting to pick up items.

5. ONGOING PROJECTS:

i. **Boeing Partnership —** Boeing, a longtime partner, uses AR/VR extensively for training and is sharing its expertise with the College of Engineering for curriculum and grant proposals.

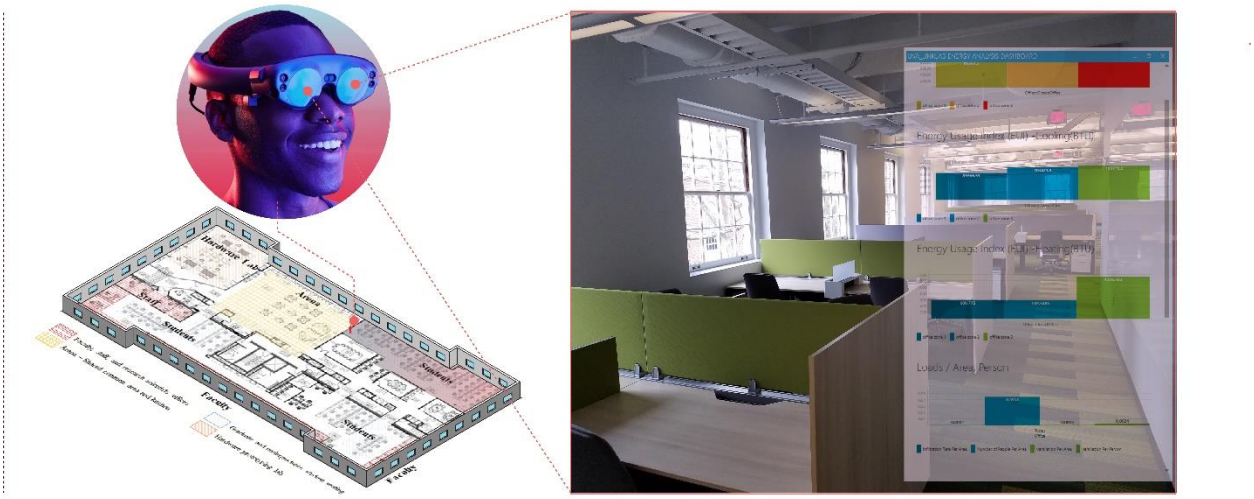
ii. **Education Virtual Reality (Collaboration with Dr. Gail Farmer) —** VR can be used to teach STEM topics to students with disabilities. One example includes an electrical engineering lab or course that requires students to assemble and test circuits. Electrical components can be small and difficult to manage if the student has a physical disability. VR can be appropriately used to allow the student to virtually assemble circuits. The controllers can be programmed and suited to the student. This would allow the student to learn how to properly assemble or place

electrical components. Since lab assignments have expected behaviors, the virtual simulation can be programmed to portray the theory and behavior. This application can be applied to other classes or curriculums such physics, biology, and chemistry. Dr. Gail Farmer is a professor in the CSULB Department of Health Science and the Director of the CSULB Center for Disability Studies and Scholarship.

iii. **Integrated Virtual Design and Construction (iVDC Lab) —** Dr. Vahid Balali of the CSULB CECEM Department is exploring research ideas, publishing papers, and creating demos at iVDC Lab. Below are the papers and demos produced as a result of this effort:

- VR Facility Management with BIM LOD500 [Demo]

- Balali, V., Zalavadia, A., and Heydarian, A. (2020). "Real-Time Interaction and Cost Estimating within Immersive Virtual Environments." *ASCE Journal of Construction Engineering and Management,* 146(2), 04019098. [link] [Demo]
- Noghabaei, M., Heydarian, A., Balali, V., and Han, K. (2020). "Trend Analysis on Adoption of Virtual and Augmented Reality in the Architecture, Engineering, and Construction Industry." *Journal of Data,* 5(1), 26. [link]
- Carneiro, J.P., Varnosfaderani, M.P., Balali, V., and Heydarian, A. (2019). "Comprehensible and Interactive Visualization of Spatial Building Data in Augmented Reality." *ASCE International Conference on Computing in Civil Engineering (i3CE): Visualization, Information Modeling, and Simulation*, 79-86, Atlanta, GA, USA. [link] [Demo]



- Amouhadi, R., Balali, V., Zuidgeest, M., and Heydarian, A. (2019). "Measuring Walkability using a Mobile Phone Sensors and Applications." *Transportation Research Board 98th Annual Meeting (TRB)*, 19-0
- Bicycle Simulator [Demo]
- Pedestrian Cell Phone Crossing App Simulation [Demo]
- Bicycle Simulator-Bike Lane with Barrier [Demo]
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iv. **Urban Air Mobility —** Urban Air Mobility (UAM) refers to a system of passenger and cargo transportation within an urban area, as well as other Unmanned Aerial Systems (UAS) services that will be supported by a mix of onboard, ground-piloted and autonomous operations. The UAM operation framework offers an on-demand innovative transportation option that can reduce traffic congestion and pollution and increase mobility in metropolitan areas. Dr. Panadda Marayong and Dr. Praveen Shankar of the CSULB Mechanical & Aerospace Engineering Department collaborate with the Human Factors group (Psychology, CSULB) and scientists from San Jose State University Research Foundation & NASA Ames Research Center to develop a VR environment using the CAVE system as a testbed for human-automation teaming and airspace operations research for UAM.

6. ANTICIPATED IMPACTS:

Leveraging its AR/VR facilities and expanding AR/VR expertise has the potential to steer the CSULB College of Engineering toward the achievement of a great number of institutional and educational goals.

AR/VR technology will allow the College and its collaborators to develop imaginative, effective, and cutting-edge educational experiences tailored to diverse groups of students, including those with a broad range of learning or other disabilities.

It will provide compelling opportunities to increase engagement, appeal to a new generation of digital natives, and adapt to an era of hybrid classes. Using AR/VR, complex engineering concepts can be easily delivered in 3D, leading to increased comprehension and retention among students and greater efficiency among faculty.

The technology can be applied to fuel learning in myriad areas, from instructional labs throughout the College to senior design projects, reinforcing our core mission of providing hands-on learning experiences to supplement theoretical foundations. It can also provide students access to companies and outside organizations using virtual tours

AR/VR is a potentially powerful outreach tool, opening gateways for high school students and college freshmen to learn about different branches of engineering and tour College facilities virtually.

AR/VR will allow the College to share resources with its satellite Antelope Valley Engineering Program, as well as other CSULB colleges and other educational institutions. It will also provide opportunities for greater collaboration between COE and other colleges and organizations.