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Exploring the Landscape of Virtual and Augmented Reality Laboratories in Top Universities Worldwide

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Abstract

This study investigates the current state of Virtual Reality (VR) and Augmented Reality (AR) laboratories among the top 100 QS-ranked universities worldwide in the field of architecture and built environment. The results indicate that roughly half of the laboratories apply VR and AR techniques together, while the remaining focus is on VR or AR independently. The most widely used device is the Head Mounted Display (HMD), immersive projection environments, and driving simulators. Those simulation tools are often coupled with environmental and physiological sensors and motion capture systems. The results of this study provide valuable information on the current distribution and application of VR/AR facilities among the top universities and highlight the need for regular monitoring of these facilities to track their development and growth.

Keywords
Augmented Reality; Virtual Reality; Urban Simulation; QS-ranked universities

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Introduction

The advancement of technology has brought about a significant shift in the traditional visualization tools used in architecture, landscape design, and urban planning. With a different level of spreading and adoption, digitalization has progressively introduced new ways of dealing with the urban environment; for instance, pen-and-paper sketches can be native virtual using digital sketch boards, Geographic Information Systems (GIS) can store data connected to maps, and physical models can be augmented with digital simulations [Al-Kodmany 1999, pp. 37-45]. Over the last decade, there has been exponential academic interest in Virtual Reality (VR) and Augmented Reality (AR) in architecture and built environment. Indeed, a query on the Web of Science platform (fig. 1) reveals that the growth rate for VR and AR topics has increased respectively by 369% and 490% from 2012 to 2022. Taking into account the affiliation of the first authors, the United States, China, England, Italy and Germany are the countries with the highest concentration of scientific production in these fields (fig. 2). Virtual Reality has been proven to be a valuable tool in architecture and construction education, as it provides students with a safe environment to simulate construction issues and improve their problem-solving skills [Pour Rahimian et al. 2014, pp. 1-12]. Indeed, using VR combined with a Head Mounted Display (HMD) led to a more enjoyable learning experience and a greater understanding of building construction [Bashabsheh et al. 2019, pp. 713-723]. In fact, Virtual Environments (VEs) support collaboration, while a subjective view of a full-scale scene enables students and teachers to evaluate design proposals and alternatives from the experiential perspective [Cruz-Neira et al. 1992, pp. 64-72; Milovanovic et al. 2017, pp. 1-20]. Tangible User Interfaces (TUI) combine digital and physical objects, allowing for real-time manipulation of the environment and the corresponding dynamic feedback, e.g. showing the change of shadow casting according to the different orientations of the buildings in space, fostering a practical understanding of the physical layout and the complex relationship between its features [Cibien 2017, pp. 191-205; Cibien et al. 2011, pp. 253-258; Shaer 2009, pp. 1-137; Ullmer, Ishii 2000, pp. 915-931]. Augmented Reality [Milgram, Colquhoun 1999, pp. 5-30; Wang, Dunston 2011, pp. 493-508] has numerous applications in the field of architecture since it provides a valuable means for students to understand better the cumulative outcomes of urban transformations and the relevance of such devices and visualization techniques for co-design activities [Piga et al. 2022, pp. 137-144]. AR also facilitates co-design approaches and project reviews from the user's point of view, involving multiple people [Piga et al. 2022, pp. 137-144; Russo 2021, pp. 2-38]. Previous studies have noted the growing interest in AR in Architecture, Construction, and Engineering (ACE) education, with the USA as one of the most prominent countries in this field [Diao, Shih 2019, pp. 1-19]. Instead, motion capture systems are mainly utilized in urban safety studies to evaluate pedestrian reactions to vehicles and assess accessibility issues in architectural and urban layouts [Feldstein et al. 2016, pp. 239-244; Maruyama et al. 2016, pp. 250-265].

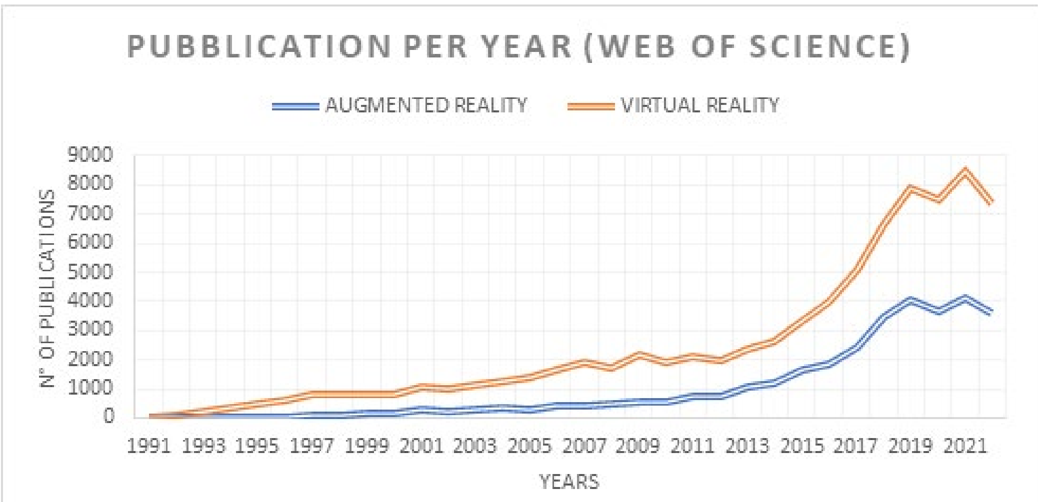

Fig. 1. Number of publications per year on the topics of Virtual Reality and Augmented Reality in the field of Architecture and Built Environment. The chart shows a relevant increasing of publications in the last decade. Web of Science, 25 January 2023.

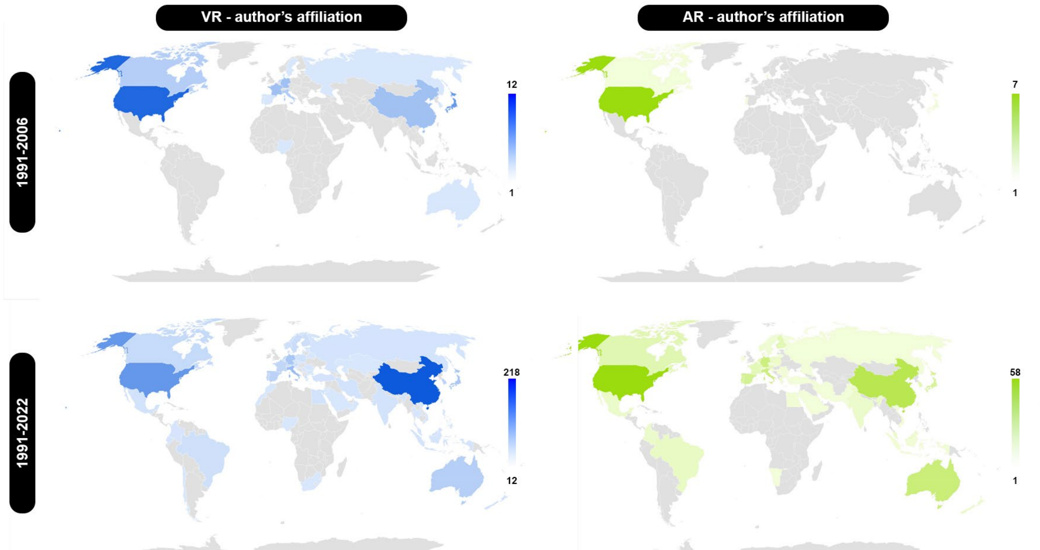

Fig. 2. Geographic distribution of publications on the base of first author affiliations. Topic VR, period 1991-2006 (top left); topic VR, period 1991-2006 (bottom left); topic AR, period 1991-2006 (top right); topic AR, period 1991-2006 (bottom right). Web of Science, 25 January 2023.

While VR/AR technologies have the potential to revolutionize academic education, they are not without their weaknesses. One of the main challenges of VR/AR is the cost of high-end technologies, which can be prohibitive for many institutions [Cook et al. 2019, pp. 25-48]. Additionally, there are concerns about the potential negative effects of prolonged exposure to VR/AR, such as eye strain, headaches, and motion sickness [Chang et al. 2020, pp. 1658-1682]. Furthermore, while VR/AR can enhance the learning experience, they cannot replace real-world experience and hands-on training. Finally, there is a risk that the excitement and novelty of VR/AR may distract from the actual learning objectives, leading to a superficial understanding of the subject matter [Stojšić et al. 2019, pp. 353-369]. Therefore, it is essential to carefully consider the implementation of VR/AR technologies in academic education and ensure that they are used in conjunction with traditional teaching methods to provide a well-rounded and effective learning experience.

Methods and analysis

The present study assesses the geo-distribution of university simulation facilities dealing with Virtual Reality (VR) and Augmented Reality (AR) (later simulation laboratories or simply laboratories) available for students of architecture worldwide. The analysis is limited to the top 100 universities of 2022 according to the Quacquarelli Symonds (QS) World University Rankings in 'Architecture & Built Environment' field. The QS university ranking system is based on six indicators: academic reputation, employer reputation, faculty/student ratio, citations per faculty, international student ratio & international faculty ratio [Jöns, Hoyler 2013, pp. 45-59]. The university evaluation outcome is shown on the QS official website [1], which rates more than 1300 universities worldwide.
The study focuses on laboratories including didactic purposes in architecture, landscape architecture, civil engineering, urban planning, and urban design. Data analysis and comparison allow spatialized benchmarking to identify emerging trends. Data were retrieved from university and laboratories websites and recorded in a database designed *ad hoc* [2] to efficiently manage, store, and analyze the information. As an exception, we have included the *CORAULIS* project (described below) in the dataset for its innovative aspects in integrating different technologies in immersive environments for educational purposes. Quantification and geolocation of items in the database allow the semiautomatic production of graphs and maps representing the outcomes.
The online research was conducted using Google™ with the following keyword combinations: (university name AND ((Virtual OR Augmented) AND Reality)) AND (laboratory

OR lab OR facilit*) AND (architecture OR design OR 'landscape architecture' OR 'urban design' OR 'urban planning' OR 'urban simulation'). The research took into consideration official declarations, documentation, and photos published on the laboratories' websites. For each laboratory identified, the following information was collected: extended name, official acronym, URL, toolset (including brand and model when available), and pictures of the laboratory space and devices. The laboratory's expertise was then categorized based on the official laboratory description and/or the declared research, courses, and events presented online.
The declared devices in documents or displayed on the laboratories' websites were collected and categorized into the following categories: I) Visualization/Interaction Devices, which includes Virtual Environment, Head Mounted Display, Multi-User Touchscreen, Mobile/Tablet; II) Collaborative Tangible User Interface (TUI), which includes Treadmill, Haptic Interface; III) XR Input Devices, which includes Luminous Planning Table, Holographic System; IV) Subjective/Environmental Data Capturing Devices, which includes Motion Capture System, Physiological Sensors, Environmental Sensors, Panoramic Camera; V) Hardware/Software Support, which includes Computers System, Simulation Software. The type, brand, and model were also noted for each device. When the devices' specific characteristics were not explicitly declared, the typology was recorded without any specific product reference.
The collected data allowed us to define the percentage of laboratories per country and represent them using a choropleth map [Schiewe 2019, pp. 217-228] based on Natural Earth shapefiles and geopandas functions. The study also computes the instances of AR and VR expertise declared by university laboratories and the percentage of these technique applications.

Results

67 out of 100 universities analyzed have laboratories using AR and VR. Some of them host monodisciplinary laboratories dedicated to architecture, while others have multidisciplinary ones. The geographic distribution of these laboratories is represented in fig. 3, and the percentages by country (fig. 4) are: USA 20.9%, Great Britain 11.9%, Hong Kong 10.4%, Italy 8.9%, Sweden 7.4%, Germany 7.4%, Switzerland 4.5%, Australia 3.0%, Chile 3.0%, France 3.0%, China 3.0%, Finland 3.0%, Norway 3.0%, New Zealand 3.0%, Netherlands 1.5%, Spain 1.5%, Canada 1.5%, People's Republic of Korea 1.5%, Monaco 1.5%. The Venn diagram (fig. 5) shows that 51.2% of labs apply both VR and AR techniques, 39.5% focus on

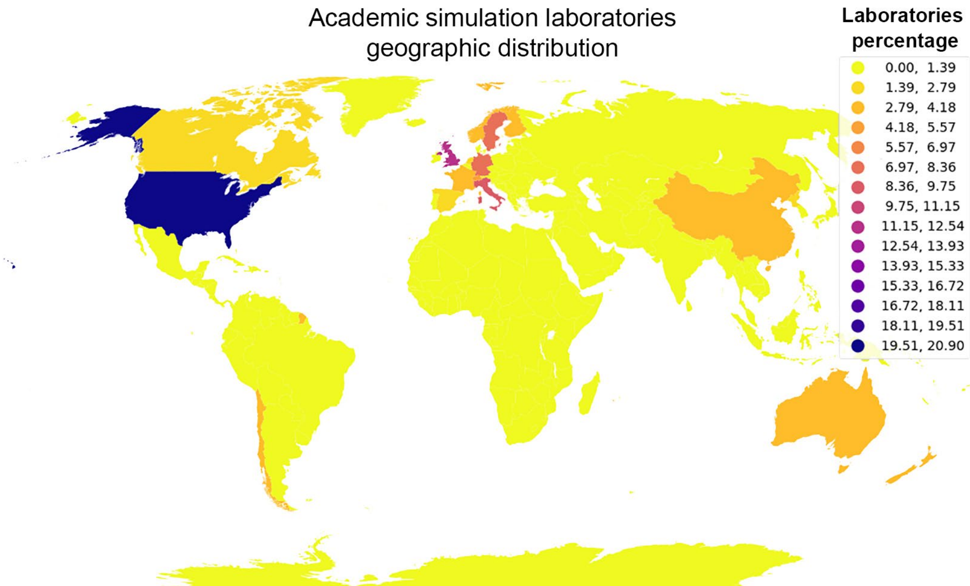

Fig. 3. Choropleth of the laboratory percentage per nation out of the QS top 100 universities in 'Architecture and Built Environment'. In blue the highest percentage of laboratories, in yellow the lowest. The map shows a higher percentage of facilities in Western countries compared to the Western ones.

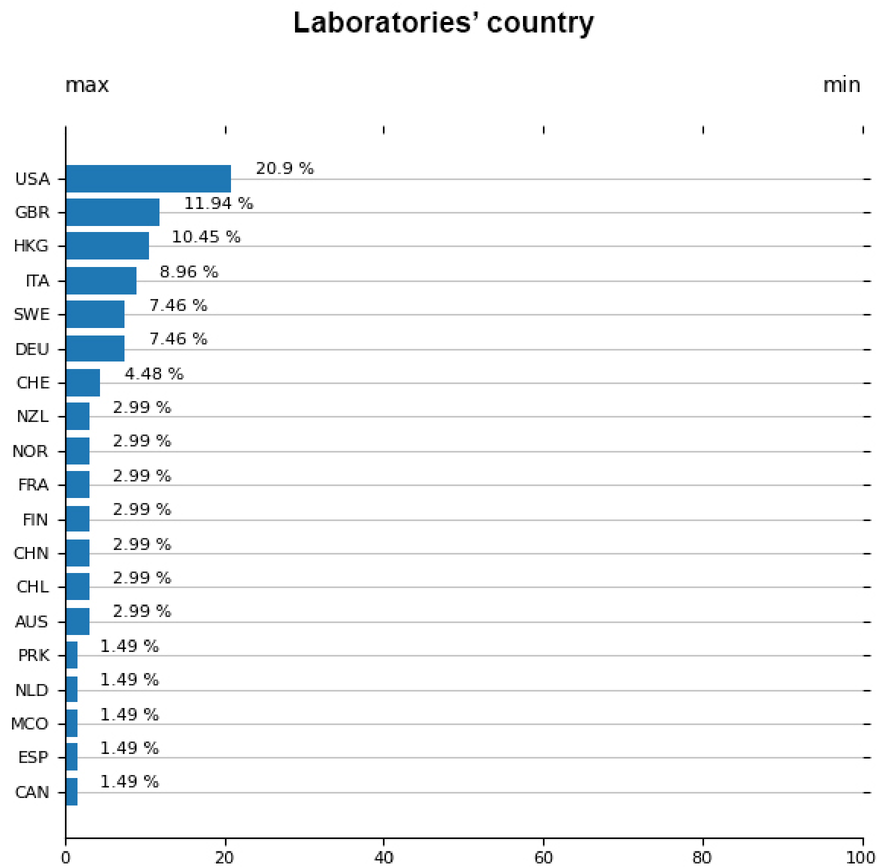

Fig. 4. Percentage of simulation laboratories identified per nation. Country codes according to ISO 3166, alpha-3 codes. The chart shows that USA has the highest concentration of VR/AR facilities, followed by Great Britain; an exception in the top five countries of this chart is Hong Kong.

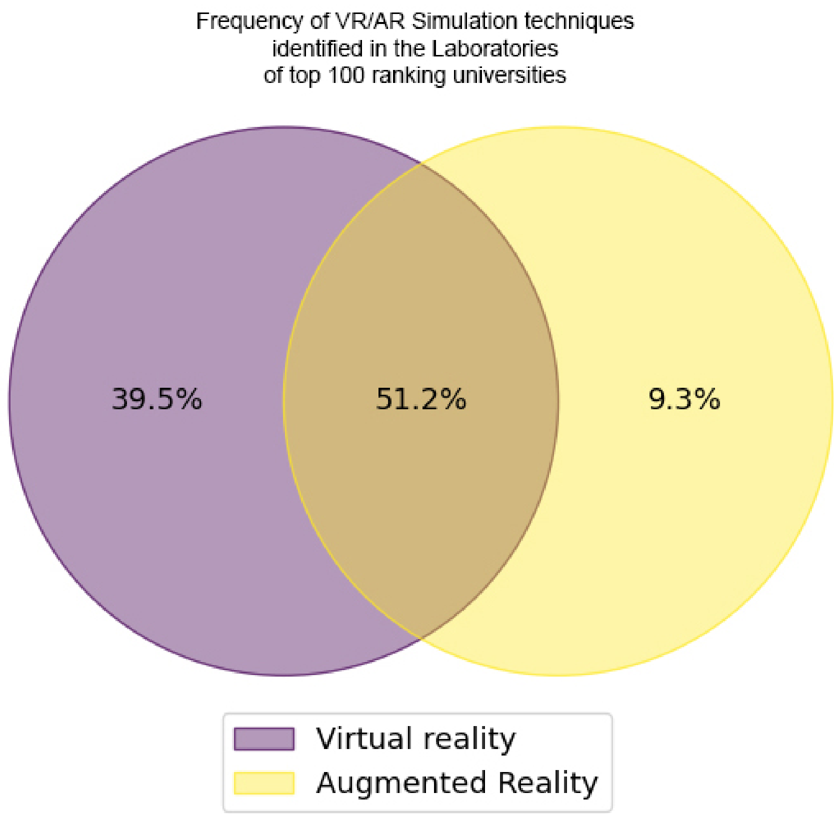

Fig. 5. Venn diagram showing how the simulation techniques adopted by the laboratories overlap. 51.2% of the laboratories' own devices for both VR and AR applications; 39.5% of them own devices for VR only; the remaining 9.3% are focused on AR applications.

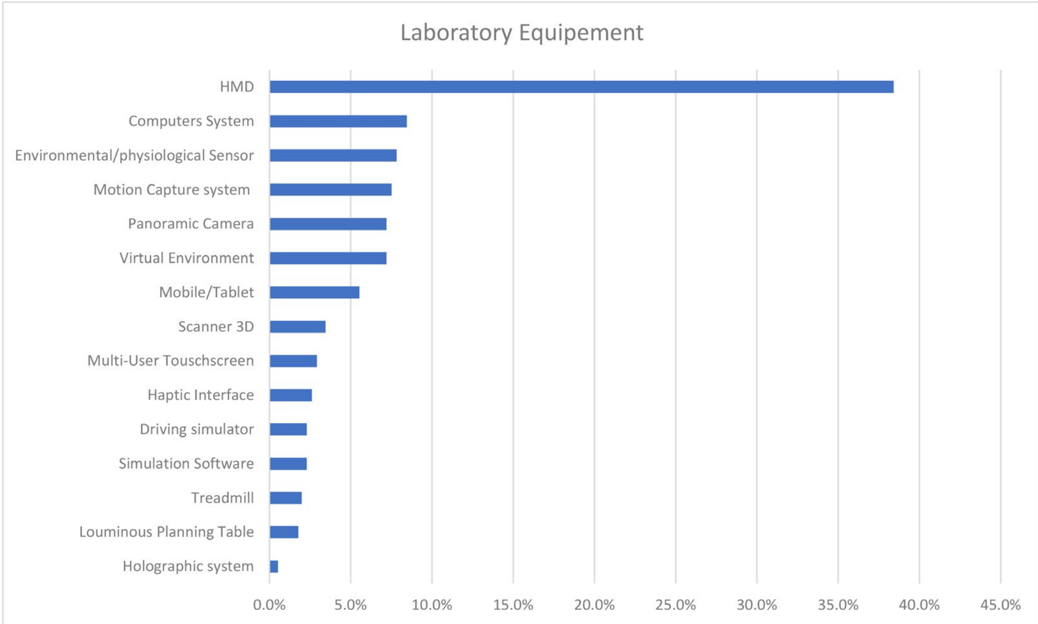

Fig. 6. Devices categories sorted by frequencies of the item instances collected across the international laboratories. The Head Mounted Display (HMD) are the most diffuse type 38.5%.


Fig. 7. Two examples of TUI CityScope by MIT MediaLab (MIT). <https://bit.ly/44ax6TI> (accessed 24 January 2023).

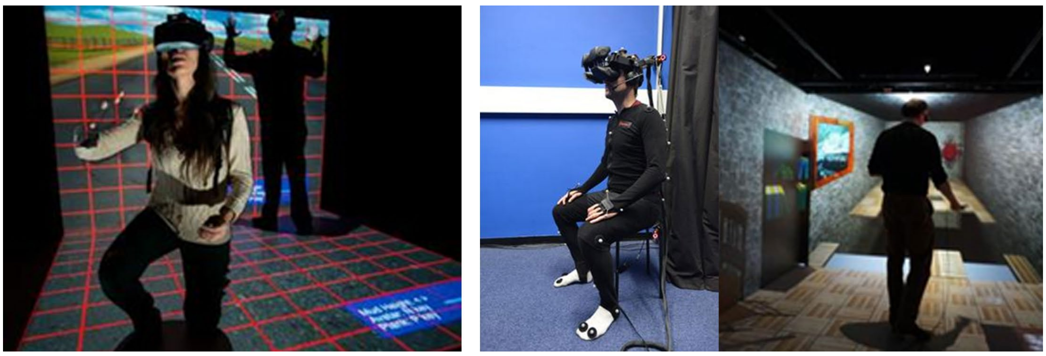
Fig. 8. HMD to exploring spaces. Virtual Reality Room (VR Room) (UPM) in Spain (left), <https://bit.ly/3L3GVtc>. Immersive Virtual Environments Laboratory (UCL) (right), <https://bit.ly/3L61LrY> (accessed 24 January 2023).

VR only, and 9.3% focus on AR only. None of the analyzed laboratories were devoted to educational activities only. All laboratories are connected to education; most are also research-oriented, and few are also dedicated to participatory activities with citizens or public organizations. Among all the devices owned by laboratories, the most used device is the Head Mounted Display (HMD); other equipment has a meager percentage of adoption compared to the HMD. Indeed, our analysis revealed the adoption of 123 different devices in the sample, with the top ten being: HMD 38.4%; Computers System 8.5%; Environmental/physiological Sensor 7.8%; Motion Capture system 7.5%; Panoramic Camera 7.2%; Virtual Environment 7.2%; Mobile/Tablet 5.5%; Scanner 3D 3.4%; Multi-User Touchscreen 2.9%; Haptic Interface 2.6%; Driving simulator 2.3%; Simulation Software 2.3%; Treadmill 2.0%; Luminous Planning Table 1.8%; Holographic system 0.5%.

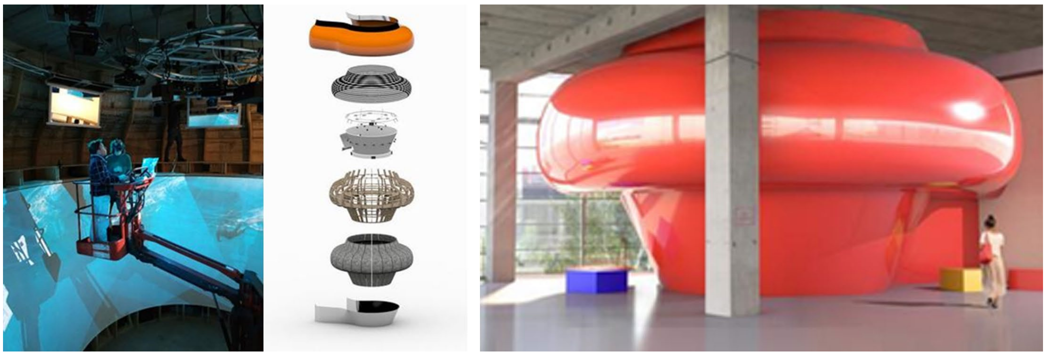

Fig. 9. *CORAULIS*, a Virtual Environment by CRENEAU. <https://bit.ly/3AqoJol> (accessed 24 January 2023).

Some examples of solutions adopted by universities worldwide are listed below. The MIT MediaLab project *CityScope* (fig. 7) uses a TUI to solve spatial design and urban planning challenges, encouraging collaborative urban planning through an interactive tangible interface. Furthermore, MIT Medialab Fluid Interfaces group developed the shared immersive Virtual Environment framework CoCoVerse [Greenwald, Maes 2017] enabling collaborative experiences in teaching and learning applications.
The 'Virtual Reality Room' at the Universidad Politécnica de Madrid (UPM) in Spain and the 'Immersive Virtual Environments Laboratory' at University College London (UCL) in Great Britain are examples of laboratories using HMD devices to explore virtual environments (fig. 8). The Centre d'Observation en Réalité Augmentée et Lieu d'Immersion Sonore (CORAULIS) system developed at the Ecole Nationale Supérieure d'Architecture de Nantes (ENSA) by Urban Architecture Nantes Research Centre (CRENAU) (fig. 9) is an example of a Virtual Environment, offering a panoramic 4K view and the ability to observe a project from multiple perspectives (ground floor, and mezzanine). Since August 2021 AU-CRENAU laboratory in Nantes University, with the support of the Ouest Industries Creatives program, has been working on the project *Immersive design education: the impact of immersive virtual environments on learning co-design* intending to develop an analytical framework to evaluate the influence of immersive virtual environments on collaborative work within architecture workshops involving university students.

Discussion and conclusions

This study aimed to evaluate the availability and distribution of university simulation facilities offering VR and AR to students studying architecture, landscape architecture, civil engineering, urban planning, and urban design. The top 100 universities in the Architecture and Built Environment field, according to the QS World University Rankings 2022, were analyzed, and the results showed that 67 out of 100 universities had laboratories using VR and AR. The study found that the laboratories were mostly concentrated in the United States, Great Britain, Hong Kong, Italy, Germany, and Sweden. Moreover, it was identified that half of the VR/AR laboratories analyzed used both VR and AR techniques, while more than a third focused on VR only and the rest on AR. The Head Mounted Display (HMD) was the most widely used tool, although the overall technological assets varied and could include environmental and physiological sensors, motion capture systems, Virtual Environments, and driving simulators. Future research could explore how academic laboratories apply these tools in their research activities.

Note

[1] QS World University Rankings 2022. (2023). <https://www.topuniversities.com/university-rankings/world-university-rankings/2022> (accessed 19 January 2023)

[2] A Django app connected to a PostgreSQL database.

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Credits

The authors' contribution, according to CRediT (Contributor Roles Taxonomy), is described as follows. Conceptualization, B.P.; methodology, B.P., G.S.; formal analysis, G.S.; investigation, B.P., G.S.; data curation, G.S.; writing – original draft preparation, G.S.; writing – review and editing, B.P.; visualization, B.P., and G.S.; supervision, B.P. All authors have read and agreed to the published version of the manuscript.

References

Al-Kodmany K. (1999). Using visualization techniques for enhancing public participation in planning and design: Process, implementation, and evaluation. In *Landscape and Urban Planning*, Vol. 45(1), pp. 37-45.

Bashabsheh A.K., Alzoubi H.H., Ali M.Z. (2019). The application of virtual reality technology in architectural pedagogy for building constructions. In *Alexandria Engineering Journal*, Vol. 58(2), pp. 713-723.

Chang E., Kim HT., Yoo B. (2020). Virtual Reality Sickness: A Review of Causes and Measurements. In *International Journal of Human-Computer Interaction*, Vol. 36(17), pp. 1658-1682.

Cibien L. (2017). Luminous Planning Table: TUI as Support for Education and Public Participation. In B.E.A. Piga, R. Salerno (Eds.). *Urban Design and Representation. A Multidisciplinary and Multisensory Approach*, pp. 191-205. Cham: Springer International Publishing.

Cibien L., Piga B.E.A., Secchi F. (2011). The "Tavolo Luminoso" How To Built A New Tool Suitable For Supporting Representation, Communication And Participation. In *EAEA 2011*, pp. 253-258.

Cook M., Lischer-Katz Z., Hall N., Hardesty J., Johnson J., McDonald R., Carlisle T. (2019). Challenges and Strategies for Educational Virtual Reality. In *Information Technology and Libraries*, Vol. 38, No. 4, pp. 25-48.

Cruz-Neira C., Sandin D.J., DeFanti T. A., Kenyon R.V., Hart J.C. (1992). The CAVE: Audio visual experience automatic virtual environment. In *Communications of the ACM*, Vol. 35, No. 6, pp. 64-72.

Diao P.H., Shih N.J. (2019). Trends and research issues of augmented reality studies in architectural and civil engineering education-A review of academic journal publications. In *Applied Sciences*, Vol. 9(9), pp. 1-19.

Feldstein I., Dietrich A., Milinkovic S., Bengler K. (2016). A Pedestrian Simulator for Urban Crossing Scenarios. In *IFAC-PapersOnLine*, Vol. 49(19), pp. 239-244.

Greenwald S.W., Maes P. (2017). Multi-User Framework for Collaboration and Co-Creation in Virtual Reality. In B. Smith, M. Borge, E. Mercier, K. Yon Lim (Eds.). *Making a Difference: Prioritizing Equity and Access in CSCL*. 12th International Conference on Computer Supported Collaborative Learning, Philadelphia, 18-22 June 2017, Vol. 2, pp. 879-880. Philadelphia: ISLS.

Jöns H., Hoyler M. (2013). Global geographies of higher education: The perspective of world university rankings. In *Geoforum*, Vol. 46, pp. 45-59.

Maruyama T., Kanai S., Date H., Tada M. (2016). Motion-capture-based walking simulation of digital human adapted to laser-scanned 3D as-is environments for accessibility evaluation. In *Journal of Computational Design and Engineering*, Vol. 3(3), pp. 250-265.

Milgram P., Colquhoun H. (1999). A Taxonomy of Real and Virtual World Display Integration. In Y. Ohta, H. Tamura (Eds.). *Mixed Reality: Merging Real and Virtual Words: International Symposium on Mixed Reality,* Yokohama, 9-11 March 1999, pp. 5-30. Springer Berlin Heidelberg.

Milovanovic J., Moreau G., Siret D., Miguet F. (2017). Virtual and Augmented Reality in Architectural Design and Education. In G. Çağdaş, M. Özkar, L F. Gül, E. Gürer (Eds.). *Future Trajectories of Computation in Design*. 17th International Conference, CAAD Futures 2017, Istanbul, 12-14 July 2017, pp. 1-20. Istanbul: Cenkler Matbaa.

Piga B.E.A., Stancato G., Boffi M., Rainisio N. (2022). Representation Types and Visualization Modalities in Co-Design Apps. In A. Giordano, M. Russo, R. Spallone (Eds.). *Representation Challenges. New Frontiers of AR and AI Research for Cultural Heritage and Innovative Design,* pp. 137-144. Milan: FrancoAngeli

Pour Rahimian F., Arciszewski T., Goulding J.S. (2014). Successful education for AEC professionals: Case study of applying immersive game-like virtual reality interfaces. In *Visualization in Engineering*, Vol. 2(1), pp. 1-12. Cham: Springer International Publishing.
Russo M. (2021). AR in the Architecture Domain: State of the Art. In *Applied Sciences*, Vol. 11(15), pp. 2-38.

Schiewe J. (2019). Empirical Studies on the Visual Perception of Spatial Patterns in Choropleth Maps. In *KN - Journal of Cartography and Geographic Information*, 69(3), pp. 217-228.

Shaer O. (2009). Tangible User Interfaces: Past, Present, and Future Directions. In *Foundations and Trends® in Human–Computer Interaction*, *3*(1-2), pp. 1-137.

Stojšić I., Ivkov-Džigurski A., Maričić O. (2019). Virtual Reality as a Learning Tool: How and Where to Start with Immersive Teaching. In L. Daniela (Ed.), *Didactics of Smart Pedagogy*, pp. 353-369. Cham: Springer International Publishing.

Ullmer B., Ishii H. (2000). Emerging frameworks for tangible user interfaces. In *IBM Systems Journal*, Vol. 39(3.4), pp. 915-931.
Wang X., Dunston P.S. (2011). A user-centered taxonomy for specifying mixed reality systems for AEC industry. In *Journal of Information Technology in Construction*, Vol. 16, pp. 493-508.

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