Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
VR industrial applications—A singapore perspective

Athirah SYAMIMI, Yiwei GONG*, Ryan LIEW

VRcollab Pte. Ltd., 75 Ayer Rajah Crescent, 139953 Singapore

* Corresponding author, yiwei@vrcollab.com

Received: 5 March 2020   Revised: 21 June 2020   Accepted: 22 June 2020

Citation: Athirah SYAMIMI, Yiwei GONG, Ryan LIEW. VR industrial applications—A singapore perspective. Virtual Reality & Intelligent Hardware, 2020, 2(5): 409—420

DOI: 10.1016/j.vrih.2020.06.001

Abstract  Virtual Reality (VR) has been around for a long time but has come into the spotlight only recently. From an industrial perspective, this article serves as a proverbial scalpel to dissect the different use cases and commercial applications of VR in Singapore. Before researching the Singapore market, we examine how VR has evolved. At the moment, the global annual budget for VR (and augmented reality) is at an upward trend with a leading growth in market value for the training sector. VR in Singapore has also seen a rapid development in recent years. We discuss some of the Singapore government's initiatives to promote the commercial adoption of VR for the digital economy of the nation. To address the mass adoption of VR, we present VRcollab's business solutions for the construction and building industry. 2020 is one of the most important years for VR in history.

Keywords  Virtual reality; VR applications; Building information modeling

1 Introduction

Virtual Reality (VR) is widely credited to Ivan Sutherland for his work[1] in the 1960s. Over the last 50 years, the popularity of VR has gone up and down. In particular, VR has garnered the attention of many tech giants in terms of investments into VR and its counterpart, Augmented Reality (AR) in recent years. For instance, in 2014, Facebook acquired Oculus, a VR technology company[2], for 2 billion US dollars and started driving VR into its new era. Today, all major players, such as Apple, Google, Sony, and Samsung, have significantly invested in the field with efforts to make VR accessible and affordable.

In this article, we first revisit VR from a global view before we turn to the VR landscape in Singapore. Specifically, we elaborate Singapore government's new initiatives aiming to increase the adoption of VR in both commercial and consumer markets as part of Singapore's digital economy. In fact, VR is now one of the four key technology advancements of the state country. From the application point of view, VR is commonly used in the entertainment industry. An increasing number of game developers have turned their business focus to create a variety of VR games. This is accompanied by industrial applications of VR in healthcare, construction, retail, and education. Several case studies are discussed to showcase the VR industrial landscape in the context of Singapore.

VRcollab is a startup in Singapore with a core business focusing on VR technology applications for
Architecture, Engineering, and Construction (AEC). This article will share VRcollab's solution, which is already deployed in the AEC industry in Singapore. More specifically, the next generation of the Virtual Design & Construction (VDC) software with VRcollab solution through stakeholder collaboration for Building Information Modeling (BIM) interrogation will be discussed with an emphasis on its conciseness and on the effectiveness of the software tool. Currently, Singapore and the rest of the world are facing crisis due to the Covid-19 pandemic. For instance, the work-from-home scenario in Singapore is calling for new ways of working or collaborating. VR is offering an alternative solution to the conventional working mode. In this article, we present the latest work from VRcollab to assist our clients in these unusual circumstances.

A brief history of VR is presented in Section 2. Section 3 discusses the current VR development landscape. Section 4 introduces VRcollab, a VR Startup in Singapore. Section 5 presents the conclusions of this paper.

2 Brief history of VR

The history of VR often dates back to the 1960s, with the concept going further beyond 1938. That said, VR back then was very different from what we now have. The first ever widely known VR head-mounted display (HMD) is The Sword of Damocles, invented by computer scientist Ivan Sutherland and his students, Bob Sproull, Quinit Foster, and Danny Cohen. The VR system required users to be strapped in as the entire setup was too heavy for users. This infeasibility made the use of The Sword of Damocles limited to laboratory only.

VR HMD has evolved since then. In 2019, Facebook released its standalone and wireless VR headset, Oculus Quest. Users no longer require a PC or mobile phone to operate and use camera-based positional tracking (Oculus Insight). This new headset, with a built-in computer unit, brings a new era of mobility and freedom to VR. The Oculus Quest headset was sold out across multiple retail stores in a week and brought $5 million worth of VR content sales in the first two weeks.

3 Current VR development landscape

The global growth of VR has been aggressive in recent years partially due to its fast acceptance by the consumer market. Its primary demand comes from the industries of gaming, entertainment, and experiential events. VR has changed the way we consume content, giving users a more interactive and immersive experience. The VR industry is projected to reach US $209.2 billion globally by 2022.

"AR/VR commercial uptake will continue to expand as cost of entry declines and benefits from full deployment become more tangible. Focus is shifting from talking about technology benefits to showing real and measurable business outcomes, including productivity and efficiency gains, knowledge transfer, employee's safety, and more engaging customer experiences", said Giulia Carosella from European Industry Solutions, Customer Insights & Analysis.

Almost 50% of all AR/VR spending in 2020 is for commercial use cases with US$2.6 billion in training and US$914 million in industrial maintenance. Consumer spending takes up a third of the total AR/VR spending with US$3.3 billion in VR games and US$1.4 billion in VR feature viewing. According to IDC Media Centre on Worldwide Spending on AR and VR, the top 3 fastest forecast spending growths from 2019–2023 are post-secondary lab and field at a 190.1% Compound Annual Growth Rate (CAGR), K-12 lab and field at 168.7% CAGR, and onsite assembly and safety with a CAGR of 129.5%. Training use cases will be the largest forecast spending in 2023.

Seeing the potential of VR growth, Apple, Google, Microsoft, Facebook, Samsung, IBM and other
major players invested heavily in VR as of 2020. VR definitely has promising backers and believers moving forward. The use of VR for commerce\(^7\), primarily by enhancing shoppers' experience, is also a trend. Often, virtual tools \(^7\) are used to augment real world environments helping shoppers locate items in a physical store\(^7\). VR is also used by allowing shoppers to customize a product of their interest. Even more interestingly, shoppers are now able to remotely and virtually walk through a digital twin of the store and purchase products as they would do in real life.

An upcoming trend in recent years would be the use of artificial intelligence (AI) technology to further enhance existing immersive technologies. Google in 2018 released a blogpost\(^8\) explaining how they retrofitted the lens of a microscope with a deep learning computational device which feeds its overlay outputs to the AR display sitting over the lens. This device may be potentially used to better identify cancer tumors with the aid of deep learning, virtual and augmented reality technologies.

### 3.1 Government initiatives in Singapore

The Infocomm Media Development Authority of Singapore has VR immersive media as one key technology of its four focus areas in establishing Singapore's digital economy\(^9\). VR is expected to hugely impact the evolution of Singapore's digital economy in engineering, media, healthcare, education and retail. Among several national initiatives, here we introduce two of them which were mentioned by Dr. Yaacob Ibrahim, Minister of Communications and Information\(^10\). The first is a pilot project launched in December 2016 involving five Primary Schools in Singapore using VR in their Social Studies. The schools involved are Beacon Primary School, CHIJ Our Lady of Good Counsel, Fuhua Primary School, Montfort Junior School, and West Spring Primary School.

The other was launched in 2017 for VR/AR enhanced clinical training at Tan Tock Seng Hospital. "At present, VR will be used to complement traditional methods of clinical training because it cannot yet fully replicate qualities like tactile responses, patient and dynamic environmental changes," said Dr. Ibrahim during his speech at the Infocomm Media Business Exchange (imbX) opening ceremony\(^10\).

### 3.2 Commercial VR applications in Singapore

Since the birth of the Internet, Infocomm and Media Technology has been growing exponentially, with VR innovation playing a significant role. In the past, VR was primarily in the consumer gaming space. While this trend will continue, we are seeing a rapid increase in VR commercial applications. This is largely due to the change of consumer habits as well as the drastic reduction of VR hardware cost. A further contribution comes from the relatively lower entry barriers to do VR compared to decades ago, allowing for VR to be a feasible solution and enhancement for multiple segments of use cases.

To improve productivity, increase efficiency, and reduce operation costs, a good number of enterprises in Singapore are embracing the latest VR technology for various applications from training to working. On the other end, general consumers, especially the younger population, become increasingly ready to use VR for the purpose of enhancing their different consuming experiences, such as shopping and entertainment. Government agencies are also incorporating VR in some of their critical operations. For instance, police and civil defense departments have adopted VR in their training. VR is mandated for certain government building projects. We will further elaborate on these applications in the following areas of communication, collaboration and coordination, training, as well as visualization.

#### 3.2.1 Communication, collaboration and coordination

With the Internet, it is possible to work with people across different geographical locations in real time.
Yet, VR brings a new way of communication and collaboration. It creates an immersive and interactive experience for VR video conferencing by bringing people virtually closer to one another. Immersed in a VR environment, people can become much more focused in meetings without physical distractions. Research shows a 25% higher attention can be expected in VR immersive conferencing in comparison to conventional video conferencing\cite{11}. There are other substantial savings in terms of costs for traveling and spaces for physical meeting.

In the following, we will use the AEC industry as an example to illustrate the benefits of adopting VR. For example, architects, engineers and contractors are able to virtually walk in their building before construction begins. Coordination in a VR environment makes it easier for teams to work together, understand better the building design, and resolve issues\cite{12}. An architect overseas in New Zealand can collaborate and coordinate their work on the same building model with a contractor in Singapore as if they were in the same room.

In light of the Covid-19 pandemic and social distancing measures, many social and community functions and events have been cancelled entirely. Some of these events are of great importance to their participants. Events such as convocation ceremonies can be done in VR space. Graduates and event attendees are able to use their mobile phones and VR sets to join a virtual graduation ceremony from all over the world\cite{13}.

### 3.2.2 Training

VR is often used for training as it allows trainees to experience real situations in an immersive and safe environment. Traditional hands-on training typically requires physical equipment, space, and operational downtime. In some cases, trainees might be exposed to workplace hazards they are not prepared for. With VR, the training can take place anywhere and anytime, reducing costs for resources and waiting time. Trainers can also customize the VR environment to train employees for different scenarios, equipping trainees with a vast knowledge to tackle varying problems.

Bombardier is an engineering firm in Singapore that is using a visualization program for training. This VR video helps their training team to showcase upcoming transportation system changes, developing a better understanding of what is to be expected\cite{14}.

The Home Team, consisting of the Singapore Police Force, Immigrations & Checkpoints Authority, International Security Department and Central Narcotics Bureau, have been using VR technology paired with a multi-directional treadmill allowing trainees to move around a certain scenario in order to further hone their skills before going on to the actual field where the margin for error is small if not non-existent\cite{15}.

For example, first responders to a crime scene can be trained to handle a multitude of simulated scenarios and hone their decision-making skills repeatedly. This implementation also allows The Home Team to be more effective in use of physical storage and spaces, allowing for a larger number of people to be trained more frequently compared to traditional scenario mockups, which require physical props, mockups and costly spaces.

### 3.2.3 Visualization

Again in AEC businesses, VR helps users to visualize the design of a site before its construction, saving costs and producing better outcomes. From 2017 to 2019, there has been a rise in tender requirements for VR to be adopted in the direction of Virtual Design and Construction (VDC). A company will be at a big disadvantage without the VDC capability, if not completely excluded from competing for such projects. BIM is a mandatory process in Singapore and VR is in trend to follow suit.
Furthermore, industry sources have claimed that VR has even been mandated for highly confidential construction projects in Singapore dealing with Military Bases and Prison Complexes, where it is used in building design sign-offs before construction begins. This works by using mandatory BIM submissions that are converted into VR usage via software that is built on top of game engines like Unity or Unreal. One of the advantages of using VR with BIM is that designers and security consultants can validate their building design before construction can begin. This process allows for huge cost savings and mitigation of security concerns before the building is built.

3.3 VR Companies in Singapore

In the following section, a number of companies from Singapore will be presented to showcase the latest status of industrial VR development.

3.3.1 Hiverlab—Media & consultancy

Hiverlab\(^\text{[16]}\) is an award-winning company with a focus on immersive technology. Hiverlab provides service on VR, AR, Mixed Reality (MR), Data Visualization System Integration and more. Digital Twin and Storyhive are two of their main products.

Digital Twin is a digital replica of physical objects. Hiverlab VR system is able to visualize and interact with real-time data at different scales of perspectives. Such a digital twin service can effectively help in system monitoring, data analytics, scenarios simulation, and so on. In addition to preventing downtime, optimizing operations and improving performance, it can enable collaborations and assist decision making across geographies. Ultimately, all these lead a step forward into creating a smart city, a smart nation, and a smart world\(^\text{[17]}\).

Storyhive is Hiverlab’s proprietary AR/VR system and platform for interactive presentation, broadcasting, and communication with immersive technology. It empowers content creators to upload and create their immersive experiences. Since its launch in 2016, Storyhive has been widely used for training, education, corporate communication, marketing campaigns, public events, virtual tourism regionally and globally\(^\text{[18]}\).

3.3.2 IGNITE VR—Entertainment, software development & event

Believing that the virtual space will be a game changer in many aspects of human activities, IgniteVR\(^\text{[19]}\) is committed to being part of this change. Their services are geared towards exposing the masses to the possibilities of VR, by providing immersive experiences along with informative discussions. IgniteVR offers services such as VR hardware rental, VR events, VR development and prototyping.

"VR is a new thing so we need to educate people on how to use the hardware, what are the benefits, why they are paying so much for it and what is their return on investment", said Roy Koo, founder of IgniteVR. He also highlighted some daily challenges we face with VR.

3.3.3 VizioFly—Content developer, event & consultancy

Based in Singapore, VizioFly\(^\text{[20]}\) is an interactive media content production company for film, education, travel, and other applications. It specializes in creating premium 360° video, VR, AR, and MR content for corporate and others. VizioFly has developed numerous VR mobile applications which can be found on Google Playstore and the App store. Some of these applications include Rollercoaster VR, VR Gardens by the Bay, and Singapore 360 VR. Their solutions have been used regionally and globally for training, education, marketing campaigns, virtual tourism, and public events.
3.3.4 MAGES STUDIO—Games & consultancy

Creating meaningful solutions in the domain of VR, AR & Applied Games, MAGES STUDIO\(^{(23)}\) is a Creative Tech solution provider in Singapore. MAGES STUDIO is skilled in building complex interactions for 3D VR solutions using popular game engines like Unreal and Unity3D. MAGES STUDIO provides virtual shopping experience by creating a 360° virtual retail environment using superimposed computer generated 3D products, Gaze tracking, and so on\(^{(22)}\).

MAGES STUDIO also worked with some prominent airlines to build hyper-realistic training modules for a wide variety of aircrafts. Such VR-enabled training sessions lead to massive cost savings, while collecting valuable training data that can improve further developments\(^{(21)}\).

3.3.5 EON reality—Content, platform & APP development

EON Reality\(^{(24)}\) is a multinational company and the world leader in VR/AR academic and industry training solutions with more than 20 locations worldwide. EON Reality has created the largest AR/VR training library with over 8000 applications and 40 million users around the world. EON Reality Singapore is the regional headquarters and R&D center in Asia with a focus on the local market for content creation, platform and application development. In 2019, EON Reality was awarded the top honors for best AR/VR solution in education at EduTECH Asia.

4 Singapore VR startup VRcollab

US$177.5 billion are wasted annually due to poor communication, reworks, and bad data management in the AEC industry\(^{(25)}\). As such, Virtual Design Reviews play a crucial role in the shift towards a fully Integrated Digital Delivery (IDD) process for the industry. To fully harness the potential of BIM, the traditional design reviews are being transited in a novel way conducted in virtual reality, enabling consultants to literally step into their 3D models, and experience their buildings at a 1:1 scale. The perception of the building from this vantage point is believed to provide better understanding of issues and challenges across the different phases of the design process.

Digital Construction and Digital Asset Delivery & Management are gaining importance as two major components within this overall framework for IDD. To facilitate this shift, a crucial task is to embrace cloud and digital technologies that can integrate stakeholders in the building life cycle management of any given project. This calls for collaborative digital platforms to be developed in order to aid building consultants through the entire workflow digitally. Certainly, VR can add value to this paradigm shift.

Founded in December 2016, VRcollab develops VR technology for remote VR coordination and collaboration to take place through a multi-user internet meeting. Figure 1 shows the Boustead Projects' team in their headquarters coordinating with their team at the on-site office with the VR tool developed by VRcollab. VR allows the two teams in headquarters and on-site to view and work on the same model in a 1:1 scale.

4.1 VR Critical to construction methodology

"Build Twice: First Virtual, and then Real\(^{(26)}\)" is a phrase by the Building Construction Authority (BCA) of Singapore to illustrate the essence of the VDC construction methodology. Building twice enables a project team to fully simulate design and construction in a virtual environment first, prior to actual execution on site. This means that at every stage from design to actual construction, virtual designs of the buildings will first have to be validated and approved before the construction phase can begin.
This is exactly where VR plays a critical role, allowing designers to be virtually immersed in the building before it is actually built. This way possible errors and mistakes can be ironed out as early as in the design or planning phases. VR can be further served as a new medium throughout various construction stages for collaboration between consultants during design reviews. VR will primarily be adopted in VDC to address constructability issues within a project by spotting potential conflicts virtually, prior to actual execution. The potential benefits would include reduced schedule variability, a smoother workflow and increased productivity overall.

4.2 VR as a collaborative platform

Digital Construction and Digital Asset Delivery & Management are gaining importance as two major components within this overall framework for IDD. To facilitate this shift, it will be crucial to embrace cloud and digital technologies that can integrate stakeholders in the building life cycle management of any given project. As such, collaborative digital platforms are being developed that can aid building consultants in this new digital workflow.

One such platform for collaboration between construction professionals would be VRcollab LITE, a software that converts BIM for use in VR design reviews, building requirement approval and construction coordination. It is compatible with industry standard BIM formats including: ArchiCAD, REVIT, Rhino, Sketchup, Navisworks, and Obj. With VRcollab, AEC professionals can host coordination meetings in an interactive, immersive 1:1 scaled VR environment. In Figure 2, two users stand in front of a green screen to illustrate what they can experience with VR headsets to coordinate a BIM design review in a VR environment.

4.3 VR usage during a pandemic

The Covid-19 pandemic has affected countries globally. Many cities have served lockdown notices as an effort to flatten the infection curve and slow down the death rate. The Singapore government has introduced the "Circuit Breaker" for a period from April 7th to June 1st 2020. As of the time this article is prepared, we cannot say for certain the end date of the Circuit Breaker. What we do know is that the pandemic has changed how companies operate. Non-essential businesses have to be done from home.
Otherwise, the business must stop its operations until the Circuit Breaker period is over\(^{(27)}\).

Under the work-from-home scheme, project teams can work remotely with the VRcollab LITE platform. Collaboration and coordination can be developed without the physical presence on-site, taking advantage of VR visualization. VRcollab's innovative solution enables project teams working from home to be immersed in the same virtual environment resembling a digital twin of the actual work environment; making it more convenient for professionals to work without disruption in this Circuit Breaker period.

During the Stay Home Notice period, VRcollab has seen an increase in requests from potential clients on how they could use VR in their operations with VRcollab's collaboration and coordination solution. Figure 3 demonstrates how a collaboration project can be done through a coordination meeting with two or more individuals presented in the VR environment.

A survey was conducted with three VRcollab clients. The feedback is illustrated in Tables 1, 2 and 3 with a simple comparison on productivity, manpower, and cost changes using VR tools. It can be seen in Table 1 that with the help of VRcollab, a Surbana Jurong project team achieves an improvement of
operational efficiency from 5 days of coordination to 1 day, and a reduction of their manpower from 4 to 2 staff members. However, the survey does not include operational expenses and sales revenues.

The results from BHCC Construction Pte. Ltd. is shown in Table 2 indicating an improvement in operational efficiency from 8 hours to 5 hours. In total, they moved from 5 days of coordination to 1 day, saving the team a total of 4 days.

The results from Hexacon Construction Pte. Ltd. (Table 3) shows an improvement in operational efficiency from 2 days to 1 day. In total, they moved from 2 days of coordination to 1 day, saving the team a whole day. A significant cost savings is seen in manpower savings from 10 staffs needed to 6 staffs used. Using VRcollab, Hexacon is able to cut down 4 staff required in a typical coordination and design review process. The lower manpower required helps Hexacon reduce operating expenses from S$ 400000 to S$ 300000; saving the organization S$ 100000 of expenses. At the same time, Hexacon sees an increase in sales revenue (S$ 50000) from S$ 20000 before using VRcollab to S$ 250000 after using VRcollab. It's a huge overall improvement for Hexacon, with reductions in operating expenses, labor, and time required; and an increase in productivity and revenue.

In summary, there is a clear indication that VR helps improve manpower utilization and operational efficiency. In the survey, however, not all clients can measure the benefits in terms of financial performance contributing directly from the use of VR technology.

### 4.4 Tech innovations

The biggest problem of loading a BIM model into a VR system is the file size and the frame rate. Research shows that the human eye is not able to differentiate the virtual world and the real world only if the frame rate is higher than 90 fps\(^{(29)}\). But on the other hand, BIM files usually have a huge geometry size, which causes a big amount of draw calls and decreases the frame rate. VRcollab provides a technology which allows partially loading the file and rendering only the important geometry in front of the user. Moreover, we have integrated the latest Intel Ray Tracing framework Embree\(^{(29)}\) in the VRcollab solution aiming to develop a faster physics system instead of the Unity PhysX system (Table 4).

A school model is exported directly from its Revit sample model. In Table 4, we garner that for Unity's default physics engine, it has to synchronize with the rendering system; thus, it is impossible to evaluate the ray intersection on the separate threads. We use Embree as a native module in Unity to perform the ray intersection. Embree uses multi threads to build the acceleration structure and since there is no physics

### Table 1 Survey Results with Surbana Jurong Consultants Pte. Ltd. on the use of VRcollab

| Benefits                    | Before using solution | After using solution |
|-----------------------------|-----------------------|----------------------|
| Improvement in operational process (day) | 5                     | 1                    |
| Decrease in manpower (staff) | 4                     | 2                    |
| Reduction in operating expenses | N.A                 | N.A                  |
| Increase in sales revenue   | N.A                   | N.A                  |
| Time saving                 | N.A                   | N.A                  |

### Table 2 Survey with BHCC Construction Pte. Ltd. on the use of VRcollab

| Benefits                    | Before using | After using |
|-----------------------------|--------------|-------------|
| Improvement in operational process (hour) | 8           | 5           |
| Decrease in manpower        | –            | –           |
| Reduction in operating expenses | N.A       | N.A         |
| Increase in sales revenue   | N.A          | N.A         |
| Time saving                 | 5            | 1           |

### Table 3 Survey with Hexacon Construction Pte. Ltd. on the use of VRcollab

| Benefits                    | Before Using | After Using |
|-----------------------------|--------------|-------------|
| Improvement in operational process (day) | 2           | 1           |
| Manpower saving (staff)     | 10           | 6           |
| Reduction in operating expenses (S$) | 400000     | 300000     |
| Increase in sales revenue (S$) | 200000     | 250000     |
| Time saving                 | 2            | 1           |
simulation required, the ray intersection can be performed on the background thread. For a large scene, for example, 2GB meshes, VRcollab archives 2.5 times faster than Unity's default PhysX system.

4.5 BIM VR workflow

The "Merge" function with VRcollab allows multiple BIM that have been modeled on different software to be combined into one single model, facilitating an easy workflow (Figure 4) for consultants.

In addition, the multi-user VR functionality aids in the seamless communication between groups whether in one physical location or remotely via the internet. This is further enhanced by VDC-oriented software features and automated document generation, allowing professionals to be effective and efficient within the VR environment³⁰.

5 Conclusion

VR is already being massively adopted and utilized across multiple industries in Singapore, as the country moves towards a digital economy. The demand for VR technology will continue to rise in both the commercial and consumer markets. In the coming years, VR is expected to be widely used in every Singaporeans' daily life and companies' operations as it becomes more accessible and affordable. For this reason, we foresee a slight shift in the commercial market as some might start to switch from VR to AR or MR. 2020 is definitely a critical time for VR, as technology giants fight to bring new enhancements to existing VR applications and further increase the technological ceiling of what immersive technologies can do.

Table 4 A comparison between Embree BVH build time and PhysX BVH build time

| Scene                  | Size   | BVH Build Time (Embree) | BVH Build Time (PhysX) |
|------------------------|--------|-------------------------|------------------------|
| Sample School          | 25MB   | 96ms                    | 205ms                  |
| Campus                 | 786MB  | 9.25s                   | 28.4s                  |
| Singapore MRT Station  | 2.18GB | 41.2s                   | 90.1s                  |
Declaration of Competing Interest The authors declare no competing financial interest.

References

1 Sutherland I E. The ultimate display. In: Proceedings of the Congress of the International Federation of Information Processing (IFIP). 1965, 506–508
2 Luckerson V. Facebook Buys Oculus Rift Virtual Reality Manufacturer. Available from: https://time.com/37842/facebook-oculus-rift/
3 Sutherland I E. A head-mounted three dimensional display. In: Proceedings of fall joint computer conference, part I on-AFIPS ’68 (Fall, partl). San Francisco, California, New York, ACM Press, 1968, USA, 757–764 DOI:10.1145/1476589.1476686
4 OculusQuest. Available from: https://www.oculus.com/quest/features/
5 IMDA, Annexes A-2 Immersive Media And Advanced Interfaces Report. Available from: https://www.imda.gov.sg/-media/Imda/Files/Industry-Development/Infrastructure/Technology/Technology-Roadmap/Annexes-A-2-Immersive-Media-and-Advanced-Interfaces-Full-Report.pdf
6 Oculus sold $5 million worth of Quest content in the first 2 weeks on sale. Available from: https://techrunch.com/2019/06/10/oculus-sold-5-million-worth-of-quest-content-in-first-2-weeks-on-sale/
7 Home team turns to virtual reality to train crime scene investigators. Available from: https://www.straitstimes.com/singapore/home-team-turns-to-virtual-reality-to-train-crime-scene-investigators
8 Virtual reality shopping and artificial intelligence—5 Near-Term applications. Available from: https://emerj.com/ai-sector-overviews/virtual-reality-shopping-and-artificial-intelligence/
9 Worldwide spending on augmented and virtual reality expected to reach $18.8 billion in 2020, according to IDC. Available from: https://www.idc.com/getdoc.jsd?containerId=prUS45679219
10 Singapore identifies four frontier technology focus areas for digital economy. Available from: https://www.opengovasia.com/singapore-identifies-four-frontier-technology-focus-areas-for-digital-economy/
11 Singapore government exploring the use of virtual reality for school education and enhanced clinical training. Available from: https://www.opengovasia.com/singapore-government-exploring-the-use-of-virtual-reality-for-school-education-and-enhanced-clinical-training/
12 The future of communicating with your audience is here and it's VR. Available from: https://www.forbes.com/sites/stephanieburns/2020/01/02/the-future-of-communicating-with-your-audience-is-here-and-its-vr/#4872f2cf1d38
13 Intel®Embree. Available from: https://www.embree.org/
14 Storyhive. Available from: https://storyhive.io/
15 Polytechnic students hold virtual graduation ceremonies. Available from: https://www.tnp.sg/news/singapore/polytechnic-students-hold-virtual-graduation-ceremonies
16 Case study: using virtual reality in coordination meetings. Available from: https://vrcollab.com/blog.case-study-how-china-construction-uses-virtual-reality-in-coordination-meetings/
17 Hiverlab. Available from: https://www.hiverlab.com/
18 Covid-19 circuit breaker: Closure of workplace premises. Available from: https://www.gov.sg/article/covid-19-circuit-breaker-closure-of-workplace-premises
19 Bombardier VR train visualization case study. Available from: https://www.hiverlab.com/casestudy/Bombardier-VR-Visualization
20 IgniteVR. Available from: http://ignite-vr.com/
21 Viziofly. Available from: https://www.viziofly.com/
22 MagesStudio. Available from: https://magesstudio.com.sg/
23 MagesStudio, VRRetail E-commerce. Available from: https://magesstudio.com.sg/solutions/retail/pg-ecommerce-vr/
24 MagesStudio, VirtualReality. Available from: https://magesstudio.com.sg/services/virtual-reality/
25 EONReality. Available from: https://eonreality.com/
An augmented reality microscope for cancer detection. Available from: https://ai.googleblog.com/2018/04/an-augmented-reality-microscope.html

Miri M, Khaksefidi M. Cost management in construction projects: rework and its effects. Mediterranean Journal of Social Sciences, 2015, 6(6)
DOI: 10.5901/mjss.2015.v6n6s6p209

DigitalTwin, Hiverlab's official website. Available from: https://www.hiverlab.com/digitaltwin

Sener B, Beşli O. The use of virtual reality in Yacht design and visualization. International Naval Architecture and Maritime Symposium. 2018

Singapore VDCGuide, Version 1-October 2017. Available from: https://www.corenet.gov.sg/media/2094675/singapore-vdc-guide_version1_oct2017.pdf