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Roberts, S., Page, R., and Richardson, M. (2020) Designing in virtual environments: The integration of virtual reality tools into industrial design research and education, in Boess, S., Cheung, M. and Cain, R. (eds.), *Synergy - DRS International Conference 2020*, 11-14 August, Held online. https://doi.org/10.21606/drs.2020.284

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Designing in virtual environments: The integration of virtual reality tools into industrial design research and education

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doi: https://doi.org/10.21606/drs.2020.284

Abstract: Virtual reality (VR) has become an increasingly common tool in consumer and professional settings. While there are many documented applications of industrial designers using VR in large corporations, there is limited literature detailing applications in studio-based education. This paper shares learnings from three case-studies across undergraduate, postgraduate, and design research projects. These projects share some of the possibilities and limitations of VR tools for future industrial design practitioners. The application of these tools spans across the product development process, from virtual 3D sketching and CAD modelling, visualization, usability testing to co-design workshops with members of the public. VR has moved beyond just a tool for visualization and decision making, and can now play an active role in all stages of the design process. These projects detail the possibilities for VR in industrial design and illuminate some of the challenges in teaching these emerging technologies and tools to design students.

Keywords: virtual-reality; design education; emerging technology

1. Introduction

Virtual Reality (VR) is used to create immersive, three-dimensional (3D) virtual environments, through visual and audio simulations. While VR technology has existed for decades, it has only recently become a reliable, flexible, and affordable tool (Berg & Vance, 2017). With this increased accessibility, VR is moving from a niche design tool used by large industry players – in the well-financed product development contexts of automotive and aerospace – to an affordable design tool that will be integrated into many product design contexts (Berg & Vance, 2017).

These VR product development environments are increasingly desired due to their ability to be used as an immersive test-bed for prototypes of product designs and proposals (Grajewski

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et al., 2015), particularly in large scale projects. With VR, designers are less restricted to 2D concept visualizations as VR provides a means for designers to 'interact with synthetic object' within a 'rich immersive 3D experiences.' This immersion helps designers to be more creative through a more direct engagement with their designs (Jimeno-Morenilla et al., 2016, Abulrub et al., 2011). VR provides a relatively low-cost platform to quickly iterate, test and prototype concepts within a 1:1 scale 3D environment. With these immersive environments also providing additional communication tools to explain designs to clients and external stakeholders. As VR becomes more common within the industry, sharing concepts and experiences is becoming normalised, allowing for greater immersion and concept understanding to be achieved.

Computer-aided design, digital sketching, and rapid prototyping technologies all had a significant impact on the product development process. Like these technologies, VR offers the potential to not just enhance the quality of the outputs of the industrial design process (Lawson et al., 2016), but to have a significant impact on the design process itself. Industrial design education needs to respond to the challenges of preparing young-designers for the rapid changes that new technologies bring to the design process. Equipping students not just with the skills needed to use these technologies, but with an experimental mindset and openness to trying, learning, and incorporating new technologies in their design practice. VR is an emerging technology highly related to 3D form development and provides a timely and relevant experimental ground for furthering technological exploration with young designers.

This paper presents a series of three case studies that detail the application of VR tools in the industrial design programs at Monash University in Melbourne, Australia. These case studies are grounded within a review of published literature related to applications of VR in industrial product development. Each of these projects demonstrates the possibilities and limitations of virtual reality tools for future industrial design practitioners. The application of these VR tools spans across the product development process, from virtual three-dimensional sketching and CAD modelling to visualization, usability testing and co-design activities in VR. We observe that VR has moved beyond just a tool for visualization and decision making, and is now capable of playing an active role in all stages of the design process. These case-studies illuminate some of the breadths of possibilities in the application of VR tools for industrial design and highlight the challenges in teaching these essential new tools to design students. Figure 1 is an example of a design developed in VR.

Figure 1 Gravity sketch (Gravity sketch 2019): drink bottle ideation

2. VR in industrial design and new product development: a review of published literature.

There is limited literature describing the use of virtual reality tools in industrial design education. Yet, in industry and academic publications there is a growing discussion of the use of VR tools in new product development. Due to the previously high cost of VR devices and the computers necessary for high-quality immersive virtual environments, these tools are primarily discussed within high investment product development contexts such as in automotive vehicle design (Lawson et al., 2016). Yet, as these tools become more affordable and accessible they are trickling down to lower-investment product design contexts and educational environments.

In commercial product development, VR tools are documented not just for visualization but to also aid in the layout of manufacturing workflows, optimising assembly, and enhance worker's ergonomic comfort through simulating automotive assembly line production tasks (Caputo et al., 2017). These tools are also used to assist in the visualization of customization options, allowing complex products, with bespoke public transport fit-outs, to be easily customized and visualized in consultation with the client (Gorski et al., 2016). In many cases, these immersive visualizations can replace costly physical mockups and offer greater experiential detail than flat two-dimensional visualizations. These highly realistic immersive environments are allowing users to experience products earlier – and at more frequent stages – throughout the design process. Conducting user observations and interviews in virtual environments has been used to allow people with cognitive and other impairments to describe their knowledge and experiences and evaluate designs (Wallergard et al., 2008) in ways that allow for more controlled testing and evaluation environments than physical mockups. Additionally, this tool enables visualizations to occur in context, virtual environments that reflect where the final design will be used (Grajewski et al., 2015; Rentzos et al., 2014), allowing access to difficult contexts or currently non-existent environments (Wallergård et al., 2008). Within these environments, designs can also be animated and visualized in motion with added sound and other effects, adding realism that can be difficult to achieve with physical properties alone.

Not all design is even intended for the real (physical) world anymore. The prevalence of online, virtual communities, games and 'realities' is necessitating design methods that are oriented exclusively for the virtual (Kohler et al., 2011). VR's use in other aspects of product development, such as manufacturing and training, is championing its use across all aspects of new product development, including design. Utilizing these technologies increases the compatibility of the design processes with these other functions (Lawson et al., 2016) through common experiential access to CAD files. This allows for better collaboration and review, with files able to be easily sent across the world.

In an educational environment, the application of blended learning within design education (incorporating digital learning materials within traditional classes (Chen, Huang, & Chou 2017)) has grown in recent years. Such approaches are said to improve learning effectiveness, content accessibility, deliverability and flexibility, and costs (ibid) as they provide alternative tools to deliver information, through active learning platforms. When user-centred these tools have been identified with encouraging student curiosity and motivations helping to improve their ability to learn (ibid; Herloa 2015). VR offers blended learning opportunities, providing students with tools to learn and engage within realistic real-world simulations, as well as environments to develop and assess their designs within (Kirkley & Kirkley 2015). Digital designs allow files to easily be worked on at home by students on personal computers and then shared in class in virtual reality environments. VR supports a more natural and better intuitive understanding of scale and spatial relationships in an experiential and direct manner (Chang 2017) compared to the abstraction of evaluating CAD on a 2D screen. The directness of these interactions can reduce errors, by allowing real-time editing within a direct 3D experience (Jimeno-Morenilla et al 2016). Overcoming the errors caused by the abstraction of perspective and scale in 2D media (Dorta & Lalande 2014). Barriers to adopting VR as a blended learning tool are the users' ability to learn and engage with the new technologies (Kirkley & Kirkley 2015), as well as accessibility issues. However, if effectively taught, one of the primary drivers of VR prototyping is the reduced design development time and reduced costs when compared to physical prototyping (Caputu et al., 2017; Wallergård, et al., 2008), particularly during the early design stages (Rentzos et al., 2014) when multiple options may need to be explored, drastic changes happen often, and detail may not be sufficient to create physical properties.

These environments allow for greater immersion and real-time interaction with the type of early product design work that is often conducted in sketches and CAD systems. While 3D CAD systems allow us to experience a design's shape, materials, movements etc. they do not allow for real-time interaction and immersion at scale in the way that VR environments do (Rentzos et al., 2014). This allows for more than just visualization but extends to allowing formative testing, experimentation, simulation and evaluation within the early stages of design. Conducting usability testing in VR allows data about users (such as reaction times, or eye-tracking) to be comprehensively captured and analyzed, such as through motion capture (Caputu et al., 2017) enhancing the role of virtual prototypes in design validation. Data can also be captured through video and other data points such as reaction times can easily be quantified in software. This data can also be used to demonstrate compliance with ergonomic and other standards (Caputu et al., 2017).

Beyond the challenges and learning that is always present with new technologies, VR fits easily within product development as it is able to leverage these existing CAD development processes. In this way, VR evaluation can be seen as an extension of conventional CAD tools (Rentzos et al., 2014), with designers able to seamlessly move between these tools while using a common file language. This workflow offers a more direct experience of the object being designed and evaluated than forms of more abstract representation such as engineering drawings, sketches, or 3D models viewed on 2D displays. Allowing designers to have direct experiences with form manipulation analogous to working with a material such as clay, but with the benefits of digital technologies (such as undo, infinite materials, changing scales etc.) (Dorta & Lalande, 1998). This can be compared with analogous trends in digital 2D sketching, which is now a firmly established part of a modern industrial design process and offers similar advantages of the direct experience of sketching, paired with the advantages of infinite brushes, undos, colours and a direct integration between other image editing and image generating software (such as sketching directly over a CAD underlay).

This provides an additional means of exploring, testing, validating, and visualizing designs early in the design process increases the quality of the final design output (Lawson et al., 2016) through increasing opportunities for design validation. At the same time, the integration of these tools with the CAD workflow can speed up the design process and reduce time to market (Lawson et al., 2015). This allows designers to make better product design decisions through overcoming the limits of 2D visualization methods (Jimeno-Morenilla et al., 2016). This is similar to the way 3D printing and digital fabrication allows a more direct connection between design and prototyping. The following diagram (Figure 2) is a representation of how VR tools can be placed to help connect design methods and advance the design process. CAD is the centre of the diagram, with its development being a central anchor for multiple different virtual and physical fabrication techniques.

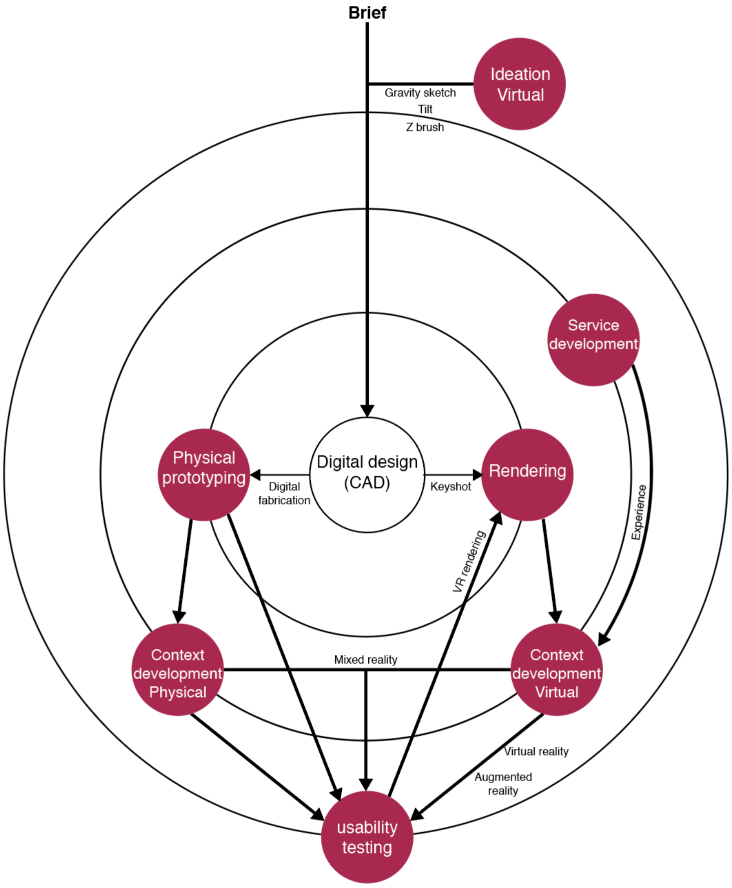

Figure 2 VR design process diagram

The development and application of new technologies is a key factor for success in an increasingly competitive market that requires faster time-to-market and ever-higher quality of products (Choi and Cheung, 2008; Lawson et al., 2016). Design is an iterative process whereby alternatives are constantly created and evaluated against other options/concepts. This iteration is one of the most expensive and time-consuming aspects of design development with up to 70% of the total cost of a product can occur in this design phase (Lawson et al., 2016). Virtual mockups can replace physical ones, saving time and money (Shao et al., 2012). Additionally, they simplify the review process as virtual models don't need to be modified and rebuilt (Kim et al., 2011 via Lawson et al., 2015) to match changes in digital CAD files, but can be reviewed in VR directly within the CAD environment. Using VR rather than building physical prototypes also allows for quicker iterations between design changes and showing the design to the client – or other stakeholders – between design changes as workflows can go directly from CAD to VR without the complexity and cost of building or editing physical mockups (Gorski et al., 2016). Multiple concepts, changes and modifications can be toggled on and off and reviewed side by side, by both designers and clients. Training can also be enhanced through immersive environments that allow for direct interaction with a product before it is constructed (Grajewski et al., 2015). This allows for better communication with clients ahead of design signoff as they have a better experience of the design, and an increased cooperative understanding (Gorski et al., 2016).

2.1 Current software and hardware technologies for VR in industrial design

Virtual reality technology consists of a spectrum of different configurations and setups, each providing various levels of engagement, cost and ease of use. For simplicity, virtual environments can be divided into two main categories to indicate the level of immersion the technology provides the user. Firstly, full immersion refers to users being fully surrounded by the virtual environment, helping to provide full audio and 1:1 scale visual experiences (Wallergård et al., 2008). Full immersion hardware configurations include Computer Automatic Virtual Environments (CAVE) and virtual reality headset systems. Secondly, semi and non-immersion consist of virtual environments such as desktop computer games or vehicle simulator rigs that allow people to experience the virtual environment whilst still being fully aware of the real world (Wallergård et al., 2008). Other virtual visualisation tools that can be considered within design education include augmented reality and mixed reality configurations, however, they are considered out of scope for this paper.

The virtual reality communication tools used within the following case studies centred around virtual reality headsets which incorporate screens and sounds to place the user within a 360-degree virtual environment. These headsets can be driven by computers with high processing power and a surrounding rig of sensors and controls to provide motion detection (eg. *Oculus Rift, HTC VIVE*). Additional headsets can be powered by mobile or tablet devices, where the device is inserted into the headset providing a screen for use (eg. *Google Cardboard*). The *Oculus Quest*; a computer, cable and sensor free version of the VR headsets, provides portability, accessibility, ease of use and cost-effectiveness to the VR field. The portability of the combined headset and controller arrangement allows increased access to VR software and applications within the classroom and between different site locations, encouraging borrowing, and VR engagement throughout the design process. Additionally, mirroring the viewpoint of the headset grants shared VR experiences and virtual presentations to be made, encouraging collaboration and discussion to take place between others and the headset user.

Programs such a *Gravity Sketch* (2019) allow designers to easily pick up, move and scale their designs during their creation. This provides additional layers to the traditional design process, allowing 3D development to be more of an engagement and a necessity during the designing process. The incorporation of *Unity* (2019) - traditionally gaming software skills - to the designer’s toolkit allows designers to go beyond the development of a single product, allowing a means of developing product and service iteration, as well as realistic environments, interactions and digital signage within an overall environment. These environments can provide a more accurate simulation for usability testing and behaviour understanding from a first-person perspective. Allowing designers to use VR to tell, and evaluate, ‘stories’ about a design (Berg & Vance, 2016), enabling people to ‘walk’ people through the experience. These tools are particularly important with products that incorporate digital and service components within their designs.

3. Case-studies of VR in industrial design education

As virtual reality continues to gain prominence within the industry, design education has begun to shift, allowing students to gain knowledge surrounding virtual technologies and the opportunities they provide within the traditional design process. Three case studies will be discussed, detailing how VR can be applied within educational settings to help lead the design process.

3.1 VR as a tool for early ideation and exploration

A semester-long industrial design studio based unit was developed that emphasised product development through virtual reality. This unit focused on how virtual tools can be applied throughout the design process to lead ideation and transition concepts towards physical outcomes. To prepare students for changing technological environments, the unit was structured to teach both software skills and independent project development. Independent learning and broad project scope was incorporated to encourage digital technology adaptability, allowing students the freedom to choose and apply appropriate tools based on individual project requirements.

The project focused on the development of smart home devices, with an emphasis of incorporating apps, digital displays and services in relation to the product. Exploring these different components as well as the incorporation of *Gravity Sketch* and *Unity* programs, allows students to learn and test different capabilities of VR within the single project. *Gravity Sketch* and activities such as virtual crazy 8's (Google, 2019) are used at the beginning of the design process to initiate design generation and allow students to become familiar with the hardware and software. As students progress through the unit, students are able to use different VR tools to help design and express different elements of their designs. For example, *Gravity sketch* could be continually used to bridge sketching, CAD, and 3D printing, where scale and correct 3D form could be developed. Alternatively, *Unity* could be incorporated to allow coding and animation to detail product interaction further, providing an additional platform for design iteration, see Figure 3. This structure challenges students to work out how virtual tools fit within their design process and how they can be used to create or inform their work. Similar to Jimeno-Morenilla et al., (2016) findings, these creative and thought-provoking processes which VR possess are believed to encourage active student participation during the design process as well as increased motivation.

Figure 3 VR design process using Unity software

VR application within the design process is believed to strengthen the diverse abilities of students, including enhancing their creativity (Abulrub, Attridge & Williams 2011 as cited in Jimeno-Morenilla et al., 2016) and engages them with autonomous learning environments. These kinds of autonomous learning environments are essential for preparing modern designers to adapt to the constantly changing technology tools and practices of modern design.

3.2 Evaluating usability and user experience in virtual environments

The second case study consisted of an industrial design practice-based PhD project, that used virtual reality as a means of conducting formative usability testing to better understand bus user experiences and validate design outcomes (Roberts 2020). As human research was undertaken Monash University ethical approval was gained - 9513.

As established, VR provides a low cost and time-efficient platform for establishing immersive 3D, context-specific, environments that early stage usability testing can be performed within (Caputu et al., 2017; Rentzos et al. 2014; Wallergård, Eriksson & Johansson 2008). These environments allow ergonomics, usability, aesthetics, scale and many other attributes to be assessed and improved quickly.

During early design stages of product development, formative testing is preferred as it allows concept validation, and feedback to be developed and applied as the project continues to develop (Falcão & Soares 2013; Hannington & Martin 2012; Jerald 2015). By placing the participant within a realistic environment and correct emotional context, more accurate product experiences can be met, resulting in more closely represented responses and real-world comparisons (Cooper & Evans 2006; Jerald 2015; Lindley, Sharma & Potts 2014).

The project's virtual environment was developed using *Unity*, enabling products, services and apps to be developed and tested cohesively. This arrangement allowed alternative scenarios as well as multiple iterations of products and services to be developed, providing a repeatable method to test general use, service failures and other points of difference within. The testing scenarios were set within a 1:1 scale, 360° accessible, low-polygon, highly saturated and cartoon aesthetically styled world (Figure 4). This style was designed to help prevent latency caused by hardware limitations, as well as to elicit a less refined and playful environment encouraging critique and creativity. Multiple alternative activities were undertaken to test environments with altered services, and product installations to determine a variety of interaction scenarios. During the activities, the headset imagery was cast onto a computer screen, visible to the facilitator (Figure 5). This coupled with the think-out-loud approach helped the researcher to gain a first-person view of the scenario and usability being undertaken, helping to build an empathic understanding of the design's value and failures.

Figure 4 Virtual environment

Figure 5 Outside the virtual environment

The VR usability testing was considered a successful way to conduct quick, formative testing, to gain qualitative information that can further inform the concept development process and to be controllable over differing testing environments. This low-cost, but highly complex, research simulation was especially well suited to a PhD research project, as it allowed a single researcher to conduct testing with a moderate budget.

Specific attention was given to user reaction during testing to determine the value of virtual environments during complex scenarios. Even with the low fidelity environment, participants (after the primer activity) interacted with the bus environment as expected, following footpaths, checking bus stop signage etc. Interestingly during one scene where the bus was delayed and unexpectedly missed the stop, the participants gave similar reactions and asked similar questions to what has been observed within similar real-world scenarios, helping to validate the potential worth of the tool. Although VR cannot replace real-world usability testing, it provides a great alternative for collecting qualitative user behaviour early on, helping to shape designs towards more user-centred solutions.

3.3 VR tools for co-designing with non-designers

CoMake Melbourne (MUHREC 19365) was an initiative funded by the Lord Mayor's Charitable Foundation run across 2019 with 15-24 year old students who have fallen outside mainstream education to help prepare them for the future of work. A team of academics from Monash University and RMIT collaborated with partners from Gateway School, Youth Central Broadmeadows, and Hume City Council to deliver a program aimed at fostering intrinsically motivated learner-led learning. Over the year we ran weekly sessions designed to develop participants' 'soft' and 'hard' skills for more adaptive, technologically adept and resilient skills acquisition. The project team worked intensively with the participants to gain a grasp of cutting edge technologies like 3D printing, virtual reality, digital media production and media broadcasting, but also to develop future-of-work personal traits such as curiosity, tenacity, peer-to-peer sharing, and emotional resilience. Our primary motivation was to discover how we might use hands-on making to generate engaged learning of future-of-work-skills for those who do not have access to them through traditional school learning.

As a hands-on future-of-work technical skill, the project team introduced digital modelling in virtual reality using *Oculus Quest* Headsets with the applications *Tiltbrush* and *Gravity Sketch*. As learning facilitators we had very little experience with the tools, having briefly encountered them only a week prior to giving them to participants to use. On the first week of the program, the participants were briefly introduced to the applications then left to their own devices to develop digital models at 1:1 scale in virtual space through unstructured play. Our aim was then to translate these to physical models through 3D printing, laser cutting and CNC routing to replicate what we anticipate future industry processes to be.

Our proposition was that, given the ability to see and 'feel' products at full size using intuitive modelling tools, the tools themselves begin to disappear into the background and imagination can come to the foreground through 'hands-on' digitally mediated making. Both *Tiltbrush* and *Gravity Sketch* allow participants to 'sketch' in 3D using surface-generating brushes controlled by controller handsets. We paired the learning of the modelling applications with other games available on the *Oculus Quest* platform which shared many of the control and interactivity mechanisms as the digital modelling applications. This allowed seamless, fluid intuitive and embodied interaction across the applications providing tacit dexterity shared between the digital modelling applications and games. Like the games, the applications were designed with simple and intuitive interfaces, menu systems and controls that directly relate to coordinated body movement. We found this reduced the abstract thinking required when using a mouse or other controllers in industry-standard CAD programs like Solidworks and Rhino.

Given the user is 'in' the modelling environment and the controllers are represented, the virtual reality process effectively removes the need to translate 2D sketch to 3D form through a CAD program and/or production drawings, modelling directly through sketching in a cartesian environment. This reduces barriers to making sophisticated objects that can be made through digital-physical production tools. Even though we provided very little tuition and relied on the participant's curiosity to drive their learning, those who were interested enough to engage with the technology were able to develop sketch models that were thoughtfully 'designed' within the space of an hour and continue building on this learning at their own pace according to each project's needs moment by moment.

4. Conclusion

This paper expresses the importance of introducing VR to industrial design education, to prepare students for the shifting trend towards virtual design tools. Emerging technologies are increasingly becoming part of industry design teams and are driving shifts in how young designers practice. The development of methodologies to successfully teach technology resilience and adaptability to industrial designers is necessary. Numerous literature was found to discuss the applications and benefits of VR to provide cost-effective design evaluation and development during the early design process. However, limited literature discussed studio-based education practice and methods of teaching VR skills and processes to industrial design students, so that they can be prepared for shifts in industry practice. This paper discussed three case studies that emphasised the benefits, challenges and methods of teaching VR within an industrial design context. This discussion focused on the application of VR to aid the design process at various stages from concept development to usability testing.

The advantage of using VR tools within design education was found to offer additional tools for students to undertake the design process, allowing blended learning opportunities and engagement to take place. Currently, within industrial design education, the application of blended learning and digital software is rapidly expanding, with CAD being a central point of design development, communication, and fabrication (see Figure 2). VR was found during the literature and case studies to offer alternative tools to develop, evaluate and present CAD product designs, within contextual, 1:1, immersive 3D spaces. Whilst encouraging service, interface and environmental relations to be continuously considered and assessed during the product design process. Additionally, VR tools promoted the following:

- Develop and test designs within a realistic 1:1 scale environment.
- Quick generation and modifiable designs, encouraging iterative usability testing and human insights to be gained at early design stages.
- Easy transferral of CAD files, allowing designs to be constructed and evaluated remotely.
- Oculus Quest VR headsets allow for cost-effective and portable headset solutions.
- VR software allows 3D sketch generation and interactive scenario development tools.
- VR challenges students to become adaptive to applying new technologies to the design process. A skill that will encourage greater technology flexibility with emerging technologies during their careers.

Lessons and limitations of VR in industrial design education learnt from the studies and literature are described.

- Objects can be difficult to perceive and interact with due to depth perceptions, especially near scale applications (Lawson et al., 2015) and the lack of haptic feedback including the absence of object weight, tactility and force (Lawson et al., 2015). The lack of fine-grained levels of hand control is limited in most VR systems, this affects physical touch, causing indirect manipulation of the digital product to take place and making design evaluations such as ergonomics and tactile functions difficult to assess (Kuutti at el. 2001; Ran & Wang 2011). Augmented reality and mixed reality (Ran & Wang 2011) can bridge these limitations.
- Limited sensory attributes caused by headset usage, can cause isolating, limiting virtual collaboration amongst students and communication during usability testing. To help encourage communication, think-out-loud approaches, casting VR screens to monitors, limited audio usage and screen projections were used. CAVE like systems are also suggested as an alternative solution to encourage virtual collaborative spaces.
- Motion sickness and latency problems caused by headset usage and hardware limitation can influence usability and can cause attritional biases (Jerald 2015). Low polygon designs and less asset inclusion can help reduce this with designers needing to be aware of their scenes capabilities.
- Students are required to learn additional skills to be able to implement their projects within virtual environments.
- VR hardware is rapidly evolving and can be expensive and tedious to continuously install and uninstall. The Oculus Quest headset featuring minimum cables and inbuilt computer provides a solution.
- The lack of familiarity students have with VR tools, and the lack of industry-standard processes and tutorials.

Despite the above limitations, VR was identified as an important tool to help lead and advance the design process, providing multiple avenues for creativity and iteration to be developed within a 3D context. These case studies identified future work to help teach virtual reality tools consisting of a better understanding and application of mixed reality and augmented reality tools within industrial design education. Adapting mixed reality processes so students can learn to integrate physical and digital products allows ergonomics and tactile usability of a product to be assessed. Figure 6 is an example of how physical objects such as a bus stop, can help mentally and physically prepare users for the environment within the virtual reality headset.

Figure 6 Virtual reality bus stop. Part of Roberts (2020) thesis exhibition.

Further understanding and translating of traditional design methods – from early ideation to usability testing – across to virtual tools is also considered an area of future exploration. Current connections between VR and traditional design methods are currently limited beyond visualization, VR can be implemented across the breadth of activities within the industrial design process and further development in the technology will only open up additional exciting possibilities for industrial design.

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Dr Sarah Roberts' current interests are in designing human centred design outcomes through physical, digital and service applications. She has a particular focus in mobility design, exploring how product service systems can be developed to create improved human mobility opportunities.

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Dr Mark Richardson Through Open Design, upcycling and modularity I believe we can generate low-cost enabling tools-for-living that can be made by anyone, anywhere in a sustainable way. Further, physical acts of making and co-designing can impact wellbeing, inclusiveness and attachment to objects, people, space, place and environment.