Bacheloroppgave

IBE600 IT og digitalisering

The use of Virtual Reality Technology in Streamlining the Construction Industry

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Preface

As we are nearing the end of our time at Molde University College, the place we’ve stayed at through the majority of Covid-19, we would like to thank Molde University College for their help along the way to make it a pleasurable learning experience. Through zoom lectures and physical lectures made to comply with the guidelines set by the government, we have for sure had an interesting experience.

We thank our teachers and fellow students that have been with us through our time at Molde University College. We would also especially like to thank our homeroom teacher Ketil Danielsen for his assistance and prompt replies whenever we have had questions.

Through working on this bachelor paper, we’ve been given direction, insight and help by Sindre Gundersen from XPro, as well as the people at Nivero. We would like to thank them for helping us along the way to finish our bachelor's paper.

Through working on this paper, our initial goal was to find whether virtual reality could be used in assisting blueprints in the construction industry but it quickly developed into how virtual reality could be used in streamlining the construction industry, once we saw the potential virtual reality has. We hope our paper shines a light on the possibilities of virtual reality in general, and especially in the construction industry.

Best regards,

Sander Hyldbakk & Vegar Alsgaard Skaue

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1.0 Summary

In this paper, we explore the potential uses of Virtual Reality (VR) in the industrial sector, specifically in regards to the construction industry. With the development efforts made to further improve VR equipment, we decided that this was an opportune moment to explore and suggest some uses for VR technology. Through the ideas suggested in this paper, we hope to improve the efficiency of the processes in the construction industry, thus increasing the feasibility of projects by reducing the costs related to the development process.

We performed an experiment in Unity to get hands-on experience to make a judgement about the potential uses of VR. Furthermore, after finishing our experiment, we discussed the potential uses of VR together with a local company, XPro; a company that focuses on project administrative processes related to the construction industry.

Through our experiment and subsequent meeting with XPro, we have suggested some ideas for implementing VR into the construction industry, along with some of the potential problems and their respective resolutions. Finally, we have suggested some directions for future research and some metrics that would be relevant when measuring the effect of the suggestions made in this paper.

2.0 Beginning

Internet technology has brought with it great changes to how we handle information and how we communicate. It has been a great disruptor in many industries, and with it, the development of new technologies has been accelerated. Because of these technologies' significant impact on established industries, (i.e., Manufacturing, Logistics, Agriculture, etc.) we have precedent for assuming that other emerging technologies will be able to have an equally significant disruptive impact.

To give an example, the development of robotics has further revolutionised factories all over the world. (Pham et al. 2018, 126) This stands as an example that we should work with new technology to find how we can implement it into the industry, in hopes that the technology can improve the quality, speed or capacity of the products created.

Virtual reality (VR) is a relatively new technology, however, it has already seen some commercial use for the execution of emergency simulations for rare situations such as tunnel fires. (Kinateder et al. 2014, 116-125) This goes to show the potential VR can have for testing, as well as for developing procedures that would otherwise be difficult to implement. In addition, VR has been used as a medium for collaborative work. (Fraser et al. 2000, 29-37) The special properties of VR technology make the process of remote work more viable, and could become one of the cornerstones of white-collar work.

Because of the forthcoming improvements to VR technology, we believe that there is a need to evaluate how VR technology can be used to improve the efficiency of the different sectors of the industry. Our personal belief is that with a little bit of work, VR technology could be integrated into the industry as a cornerstone component of testing and development. Our focus in this paper will be to explore the uses of VR technology in the construction industry.

3.0 The unprecedented growth of VR

In this section, we introduce some of the developments in recent years to show the attention VR has received from the international community, as well as to illustrate the potential VR technology has for future development.

The year 2014 saw a massive rise in interest in VR technology, with Facebook's (later rebranded to Meta) acquisition of Oculus, and Sony’s announcement to add a VR add-on for the PlayStation 4. (VRS 2019) 2014 was also the year that the Google cardboard was released, a product that introduced the concept of VR to millions of people, offering a cheap but somewhat limited VR experience that opened many people's eyes to the possibilities of VR. (Sutrich 2019) Google cardboard had kicked off an era of mobile VR, with apps that varied from virtual roller coaster rides to placing you in real or fictional environments where you were free to look around as you wanted.

After the mainstream attention given to VR in 2014, it would only be a few years later between 2016 and 2017 when VR broke out of its shell. With the release of several ready-to-go VR devices (VRS 2019), Oculus released The Rift, Valve released the HTC Vive, and Sony released their VR add-on for the PlayStation 4, the PSVR. On the opposite side of mobile VR, were these new VR headsets and handheld controllers, that allowed users to do much more than simply spectate their environment. With the use of integrated controllers, you were able to walk around and interact with objects as well as with other users. You could play games and immerse yourself in a digital world.

Moving forward after 2017, the VR industry continued to develop in both popularity and technology. In 2018 the release of the Oculus quest opened the door for standalone VR headsets that didn’t depend on a mobile device or computer, which caused mobile VR to decline rapidly in popularity. Before mobile VR eventually died down in 2019, when normal VR headsets and standalone VR headsets had gotten both more advanced and had become relatively much cheaper than the previous generation of VR headsets.

Since 2019, VR development hasn’t slowed down, the hardware for VR has gotten much more affordable, and the software to go along with the hardware is advancing by the day. VR has the advantage of being a new technology that can be moulded into an endless amount of use cases, a few of which we're already familiar with such as driving simulations, medical simulation training, and viewing houses and house designs that are being used in the entertainment industry, the field of medicine, and for real estate and architecture. (Thompson 2022) These are but a few examples of where VR is being used today. With the advancing technology, it will become much easier for VR to branch into more and more industries, where it can lay its roots as a new and possibly disruptive technology.

In late 2020, Facebook, released the oculus quest 2, a follow-up to their successful standalone VR device, the oculus quest. With more than 10 million units sold by February 2022 (Painter 2022) Facebook has gained a large part of the commercial VR market, inching towards 50% of all VR headsets used on Steam VR being an oculus quest 2. (Feltham, Heaney, and Baker 2022) Steam VR is the primary online game distributor for VR pc games. Seconded only by Steam's own VR headset, The Valve Index, with around ~15% of all users. The difference in market share can be explained by looking at the price differences for the two headsets. The oculus quest 2 costs 3990 NOK, while the Valve Index costs more than twice that, costing 9751 NOK. Now, while the different VR headsets available can vary in price and quality, they all fulfil the purpose of being the hardware to run VR experiences and simulations. Meaning, that any VR headset can be used to test and develop VR experiences, simulations, and software. Seeing the potential in this technology, Facebook rebranded itself to Meta, (Bariso 2021) changing the direction of the company to focus on the massively transformative VR industry, with the metaverse. This means that in the future, Meta will contribute to the growth of VR, along with competitors, creating a hopefully healthy market for VR.

4.0 How VR is used today

VR today is primarily used for entertainment, as well as for simulations, and to practice skills in different fields. Most VR experiences will be used by the consumer sector which is the largest sector (“IDC, Finances Online” 2020), where VR is being used to play many forms of games and to explore real-life places or virtual simulations. It can also be found as a tool for communication, allowing people to hold a meeting, or hang out together, despite not being in the same location. The other side of how VR is being used today is the industrial sector, where the practical applications can be of more value to businesses and industries. Where instead of being used recreationally, it is used as a tool to increase individual skills in for example the health sector, by allowing doctors to practise complex procedures or let crisis rescue teams simulate challenging situations. (Øyvann 2019) (“SimInsights Simulations” 2021) It is even being used in education, by allowing for more creative and engaging teaching. (Babich 2019)

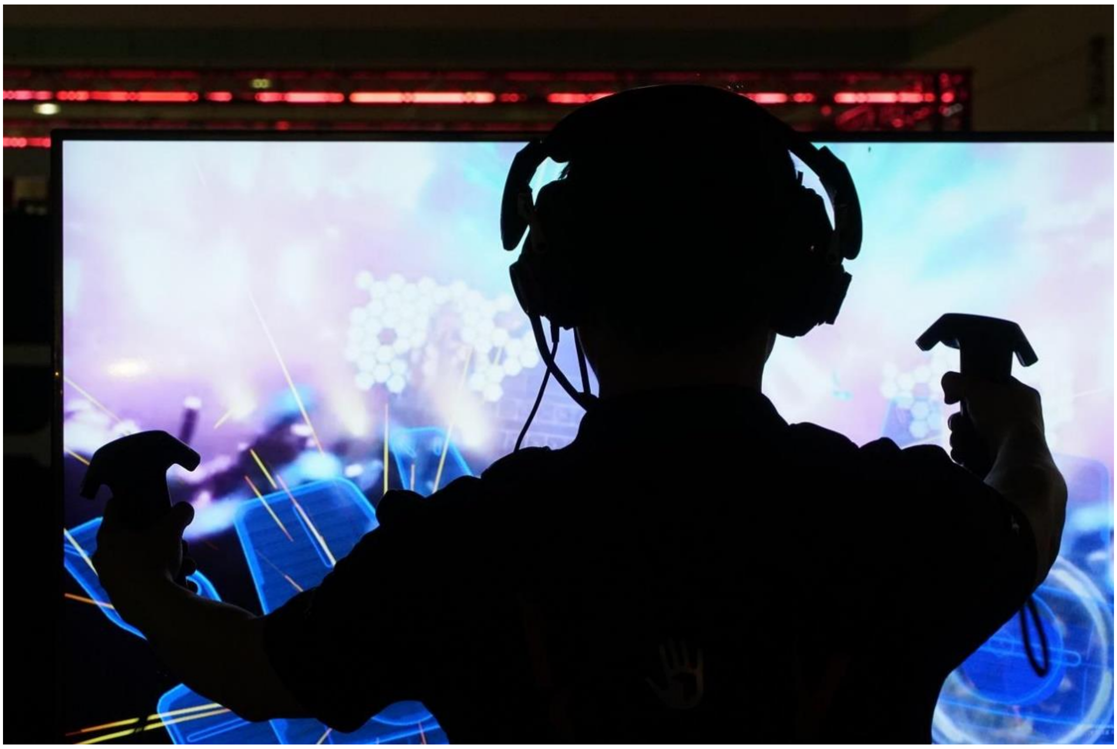

Figure 1 VR used as entertainment

Integrating VR into the different industries has introduced many benefits as well, allowing for the development of competence without wasting resources, increased communication and the ability to visually share information. With VR being a transformative technology that will likely see integration into even more industries.

4.1 Development in the construction industry

A lot of similar technology used in developing VR experiences has long since been used by the construction industry. In construction, the use of models to display ideas for projects has been common practice, often used to explore the three-dimensional aspects of a design, and showcase it to clients, investors, stakeholders, and the public. ("Designing Buildings" 2021) In recent times the models developed for these purposes have been digital, model-based designs, created with software for computer-aided design (CAD) and building information modelling (BIM). The way the construction industry has been developing digital models is similar to how the VR industry creates virtual designs and environments to showcase the possibilities of VR.

With the similarities between the construction industry creating digital models of their projects and the VR industry using models and environments to provide digital experiences, it isn't difficult to imagine how the construction industry could take advantage of the emerging VR technology. The possibility to utilise VR in showcasing and displaying their models to clients, investors, or the public could help raise excitement or even funding for the project. For a construction company to provide a fully developed and well-functioning VR experience surrounding their projects could prove disruptive for the industry. However, the development of functional experiences does still prove a challenge, considering the lacking digital talent as we were told by our connection at XPro, and the minimal spending the construction industry uses on innovation. ("deloitteeditor" 2018)

Something that will be pushing change in the coming future is the youths growing up accustomed to the technology developed in industry 4.0. With more and more people growing up experiencing these advanced technologies on a daily basis, the higher the future digital competence will be. With more time and by slowly taking in new talent, the construction industry will raise its information technology competence. With a better understanding of new technologies like VR, and the software surrounding it, implementations of new products and solutions could take place with more efficiency. Considering what has been mentioned previously about the growth of VR, it's reasonable to say that a significant amount of youths are familiar with at least the concept and uses of VR.

Similarly, VR could be used as a tool to assist in the concept development for the construction industry in collaboration with the customers they work for, by giving a method for collaboration and a platform to figure out the main points of interest for the project, e.g., figuring out an efficient and smart design. Additionally, this could be assisted by gamification, which we mention later in section 8.2.

4.2 VR hardware

Good VR hardware is in high demand, as VR technology has only recently advanced as a mature technology, and only a few large companies have entered the market to work on developing products and accessories. Despite this, it is still a fairly competitive market. The most notable example of the demand for good VR hardware can be seen by the release of the Valve Index in June 2019, where the product had been almost entirely sold out by early 2020, likely from the inclusion of the highly anticipated game Half-Life Alyx. (Makedonski 2020) Along with the appearance of the COVID-19 pandemic, the demand for VR shot up, where consumers of the Valve index would have to wait on average between two to three weeks, up to three months.

The different types of available VR hardware that can be found are tethered equipment and standalone equipment, both of these types have their pros and cons. The difference between the two types is their connection, the tethered type requires that the device is connected to a computer or similar device like the PS4. While the standalone equipment has all it needs to run independently. (Lucas 2022)

Tethered VR equipment naturally has more computing power, which gives an opportunity for a higher screen resolution since it's connected to a PC, from which it receives power and display. Having said that, adapters that will allow tethered VR hardware to connect wirelessly to computers are being developed. It also allows for screen sharing of what is being viewed. While seen as more powerful, the tethered type usually comes at a higher price point than the standalone, as well as limitations to mobility, and requires a high-end computer that can run VR.

Opposite to tethered VR hardware, we find the standalone type, which can run entirely on its own, without requiring any additional hardware. Standalone VR is often more flexible, allowing for better mobility and comfort, without needing to be close to any computers. It has a more intuitive set-up while also being more compact and easier to transport. The highlights of standalone come at the cost of data limitations, standalone is less powerful and can’t provide the same quality. However, standalone VR hardware does in most cases have a method of connecting with computers, allowing it to be used with improved data power.

In the following sections, we will compare the current commercially available VR equipment, their current prices as of May 2022, along with potential accessories to give a baseline understanding of which VR equipment a company should use based on their needs. Furthermore, we mention additional equipment that may be relevant to improving the VR experience.

Popular VR headsets are used by both the commercial sector where consumers seek out the best equipment, whether that is the most cost-effective or most technologically advanced. In addition to enterprises that seek to develop or integrate the technology into their work process. To this extent, there are quite a few different VR headsets available, ranging from affordable bare-bones headsets to more pricey headsets containing more features and accessories. For companies interested in seeing the possibilities of VR, there’s nothing but just a decent VR headset and controllers needed, for that the popular Oculus quest 2 is a good option. The oculus quest 2 has a base price of 3990 NOK, with the opportunity to buy additional accessories like a battery pack to increase its lifetime and a connection cord to connect it to a computer which will allow for increased data power, and lastly, the oculus quest 2 has a simple set-up and continues to improve its software.

In the higher price range, popular among companies and tech enthusiasts alike, we see headsets like the Valve index, Pico Neo 3 pro, and the HP reverb G2, that sit in a price range of between 6000 NOK and 10,000 NOK. These headsets offer higher quality in terms of screen resolution, headset tracking, and aspect ratio.

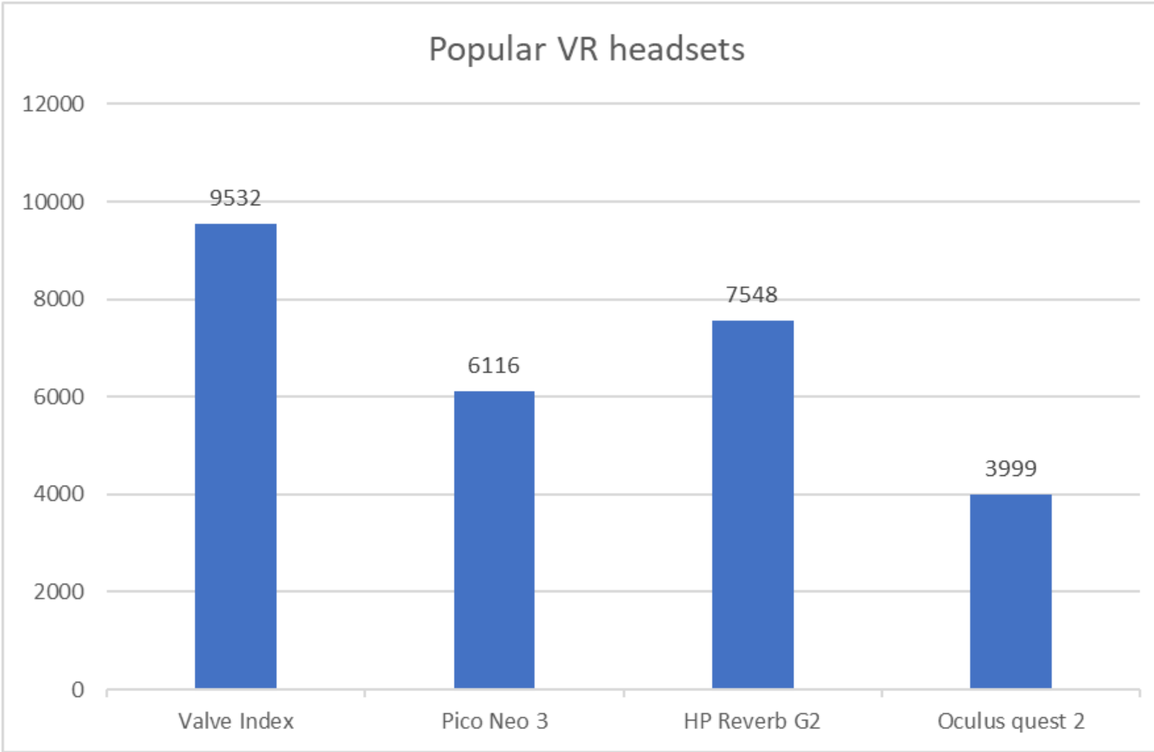

Figure 2 Price comparison of four popular VR headsets, in NOK

For those that would spare no expense, there are also headsets like the Varjo VR3. With the heavy price tag of 33,078 NOK and the additional software support subscription of 7746 NOK per year, the Varjo has some of the most advanced technology of any VR headset with eye-tracking, hand tracking, and the industry's highest resolution over its field of view. (Hamilton, Baker, and Feltham 2020)

In addition to the VR headset and the controllers that come along, there are many other accessories developed to improve the experiences of VR. One of which is the improved motion tracking that comes from using a set of base stations. Base stations work by sending out infrared light that scans their environment and communicates positioning data for VR headsets and controllers, ("Base Station Basics" 2021) as well as other compatible devices. Having two base stations working along with VR equipment will guarantee a high level of tracking accuracy with little to no deviation. The base stations send GPS signals wirelessly to the computer, working with tethered headsets to provide optimal tracking. Besides tracking only the VR headset and the controllers, there are also tracking devices available, working with the base stations that give the opportunity for full-body tracking. Another impressive accessory that is being developed to work with VR, is treadmills, which could solve the space limitations of users. VR treadmills will allow users to walk around virtual places with their movements, helping to solve problems of space limitations for VR so that users won't accidentally bump into objects around the room or office.

As a maturing technology VR hardware is continuing to advance, appearing more and more as a useful tool for businesses and industries to help improve and advance technologies in varied fields. In a 2020 survey, it was found that 56% of organisations that participated, had implemented some form of extended reality (XR), that being either VR or augmented reality (AR), over the last 12 months. Another 35% of organisations had plans to do so. ("Gridraster" 2020) This shows that organisations and industries take interest in the possibilities of VR.

5.0 Development of BIM and digital models

The construction industry has been an avid user of models for viewing and showcasing construction projects. Through real-life miniature models or the now more used method of digitally developed models, the industry can showcase its projects and work out flaws in the design. For this purpose, communication between the different parties in construction is key to assembling a model that fulfils the requirements set by the customer. For the models that are set to be built and constructed in the world, the term BIM is used. The benefit of a BIM model is how it digitally recreates the finished construction project before the construction process begins. Assembling the structure, the rooms and hallways, staircases, ventilation, lights, and more aspects that, when put together, make up the complete construction project.

The method of developing 3D models has become an essential tool for architects that want to remain competitive in their field. (“Benefits of 3D Modelling” 2013) Through the use of computer-aided design (CAD) the designs for potential contractors can be satisfied and delivered in a faster and more presentable way. Since the designs are 3D the contractors can inspect and critique the design and ask for concrete changes. The method of using 3D models provides some solid benefits, like lowering the cost of the finished project, offering visual tours, and efficient promotion and marketing. As well as improving the overall quality of the project. (“Benefits of 3D Modelling” 2013)

After the completion of a CAD, the drawings for the project will be completed, and along with the CAD, the BIM will be integrated. With digital modelling, nothing has to be drawn twice. (“CADLearning” 2021) The BIM will give meaning to the model, assigning measurements and logic to the parts of the model.

The software needed to design and create models has already been developed and popularised within the industry, programs for creating BIM models and architecture designs like Revit, ArchiCAD, and Tekla, are essential tools for designing and creating the detailed models used in construction.

The benefits of using BIM and programs that can simulate construction designs are important tools to test the structural integrity of designs, seeing where the designs need additional support such as where to place columns to optimise that support.

It is worth noting an additional step within the construction industry's digital process, that is, the use of digital twins. BIM models implement data and logic to the models, which can be helpful in construction. Digital twins assist by allowing for simulations of the construction, which will help replace assumptions with definitive values. (“Difference Between Digital Twin and BIM” 2021) A digital twin will also be useful after the project has been completed, helpful to those that will be operating in the construction or make future improvements to the project.

6.0 VR as a maturing technology

As we've gone through the history of VR as well as having looked at some of the more modern hardware in the technology it's becoming clear that VR is a maturing technology. With one of the tech titans Meta, focusing its resources on development and several other companies contributing software, hardware and additional resources to the transformative technology that is VR. (Favreau 2022) (Bariso 2021)

What VR offers is something new, compared to technologies like computers and phones. With the power to immerse users fully into their games, their work, and even previously unachievable experiences, this shows the possibilities of the visual technology that is VR. Following the Gartner Hype Cycle, VR started as a mass of inflated expectations back in 2016, (Janszen 2019) and has slowly developed into an ever-growing and hugely transformative technology. With recent developments, we are starting to see the path of future development for VR technology. Now allowing users and companies the ability to see up close the minute details and inspect their products and projects, to help narrow out flaws and faults in their design. This, compared to a computer or phone, offers a three-dimensional view, where the screen would be limited to 2D inspection paired with a technical description.

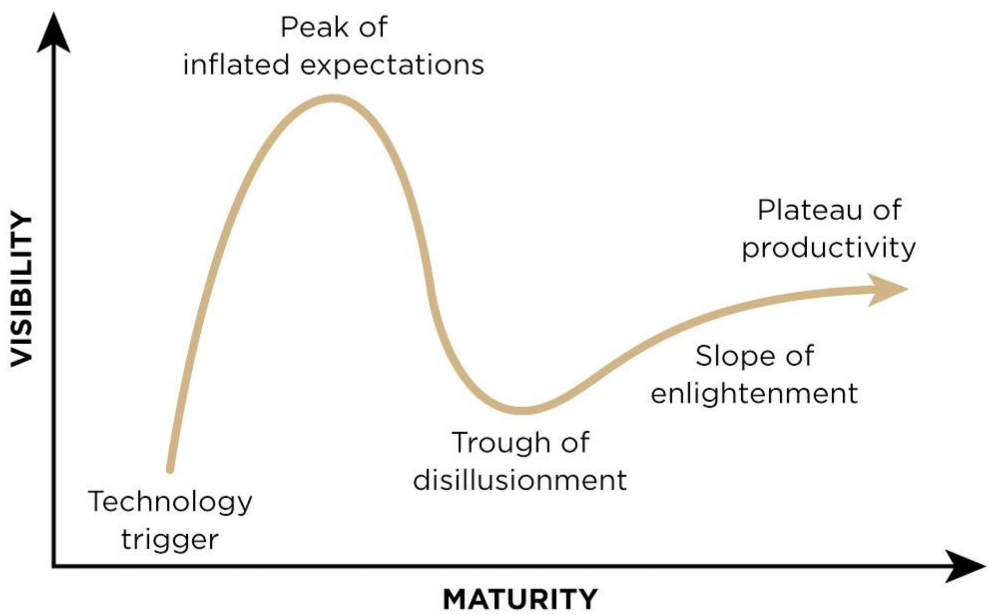

Figure 3 Gartner Hype Cycle

Using VR means getting hands-on with the technology, which can prove to be more engaging for the users. Having technology that can immerse the users seems to have a positive impact on attention. We've seen this in classrooms that attempt VR teaching, that compared to the "basic" teaching methods, VR appears more engaging and exciting for students. (Scott 2018) Taking this result we can apply it to an office or team setting, where we can imagine the benefits of improved attention, excitement, and engagement. Meta has already developed a tool to achieve a digital office, where co-workers can discuss together in VR from remote locations. ("Horizons Workrooms" 2021)

Horizon Workrooms was released by Meta in august of 2021 and is the previously mentioned tool to work with remote co-workers in a VR office setting. Despite being a functioning tool that fulfils its purpose fairly well, it is still a far way away from being an essential tool (Hendrickson 2021). The learning curve isn't too big, but it requires hardware and time to learn, which is keeping a decent portion of the market away. It also needs time to figure out small quirks that can be seen as annoyances for users. This will be something that VR has to battle with to cement itself as a useful tool that will assist teams and industries. If VR manages to get past this hurdle, we may see it appear more and more as a tool for communication in the different industries' VR experiences

Like with television, radio, books and other similar media, VR is also a medium for conveying information, be it for entertainment, or any other purpose. One such purpose that VR excels in is telepresence and teleoperation, where one can be present at a location existing in the real world, digitally. (LaValle 2020, 6) Depending on the application, VR can fulfil many purposes, and one can tailor a VR experience to a specific purpose. One can work remotely at a physical location, or one can create a virtual environment to use for performing work. Through the internet, it is also possible to perform cooperative work in a virtual environment, which is especially helpful if the virtual model is a plan for something that will exist in the real world. This is the main premise of the ideas we suggest in this paper.

Many aspects need to be considered when making a VR experience, and most of it is based on how we can create the experience in such a way that the difference between the real world and the virtual world is as small as possible. If there are some large incongruencies between the two, then the mismatch would lead to a break in immersion, or at worst, VR sickness. (LaValle 2020, 44)

VR experiences can be made to replicate any scenario that could exist in the real world. This means that VR experiences have applications that hold real implications for the real world. VR is known to be used to simulate scenarios such as fire evacuation training drills, emergency case-scenario training and other scenarios that are hard to realistically replicate in the real world. These scenarios can be made in a VR experience, and the experiences gained while using these VR experiences can give knowledge that will be helpful should one of these scenarios happen in the real world. As such, we know that a VR experience can give us knowledge that will apply to the real world.

As VR technology is a relatively new technology, there are few with extensive knowledge, which means that should one desire to make a VR experience, one will have to either learn how to do it oneself, which would require a lot of resources and time devoted to learning the software and additionally the time it would take to create the experience, which on average for a VR training experience takes around 8-10 weeks. (Smole 2021) Or, one spends extra to hire someone with the competence required, which would be more efficient. (Sokhanych 2017)

When developing VR environments, one can either start from scratch, or can use the much more convenient game engines that are available as freeware, such as Unity and Unreal Engine. These two game engines already have laid down the foundation for basic VR development through their VR development toolkits. In our endeavour to learn more about the development process, we used Unity to create an environment where we could walk around. In hindsight, with the software used in the construction industry i.e., BIM software such as Revit, ArchiCAD, Tekla, etc., Unreal Engine's Datasmith software allows us to export the models created in BIM software, and import them to the virtual environment. In the following section, we explain our experiment and the lessons we learned.

7.0 Experiment, VR demo

7.1 Hypothesis

Our hypothesis for the experiment went as follows: VR technology can be implemented into the construction process, thereby streamlining some of the processes.

We had two reasons for setting this as our hypothesis and performing the experiment in the first place. The first reason is that we could see untapped potential that could be used to improve the processes of the construction industry. The second reason was that we wished to get some practical experience working with VR technology.

7.2 Experiment

The experiment was a relatively simple one. By using Unity’s VR toolkit and the Oculus Quest 2, we created a scene in which we could move freely. Into this scene, we imported a simple 3D model of a house. This allowed us to move around and check the nooks and crannies of the building.

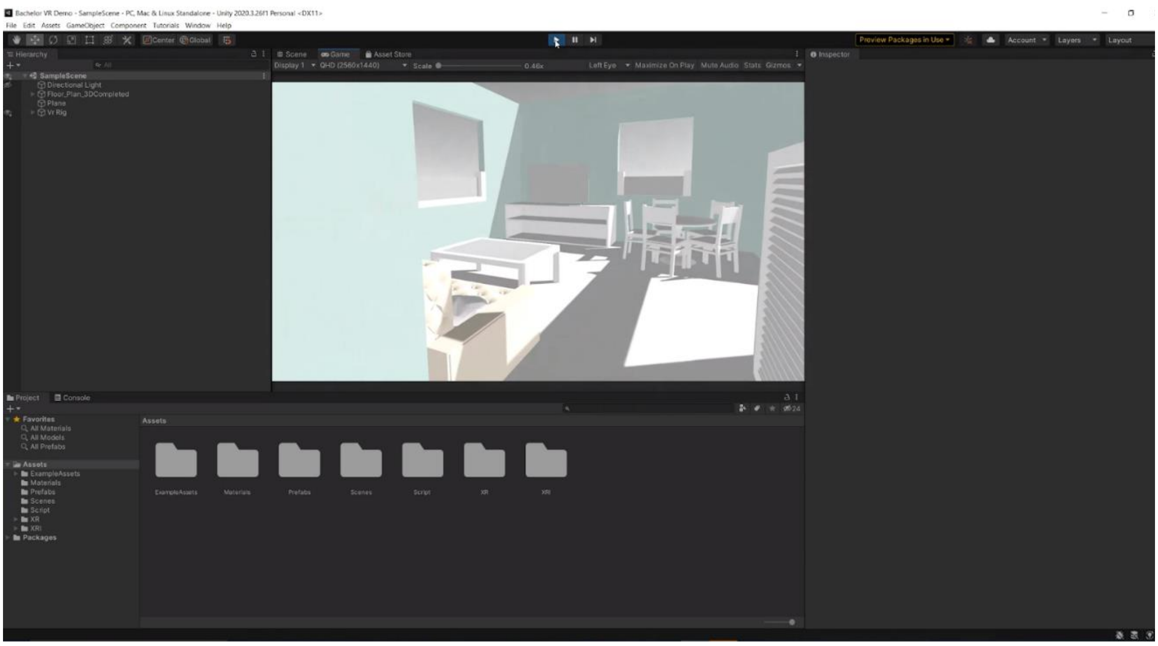

Figure 4 Example from our experiment, with the view as seen in the middle

As seen in the image, we got a first-person view that allowed us to check the model directly, as we would if the building had already been fully constructed. This allowed us to get a more intimate look at the building, showing us details that would otherwise be seen as less significant in the actual 3D model.

7.3 Experiences gained

Through working with VR technology practically, we developed a better understanding of some of the issues that need to be taken into consideration. Notably, VR sickness is a large issue that needs to be tackled, as one of the authors nearly puked himself while testing.

While checking the model we implemented into the scene, we found that we could better inspect the model through VR than when we inspect the model through the screen. This was due to the more direct first-person view that we got of the building. This is believed to be of great importance to a business working with 3D models or similar technology such as BIM.

7.3.1 Merits

By working with VR technology, we found that the merits of VR technology could apply to the construction industry. If these merits could be used as a foundation for further development, we believe that the use of VR to streamline the processes of the construction industry.

The largest merit of VR technology is that it is a visual, first-person experience. This means that what one experiences in the virtual world is rudimentarily aligned with what one experiences in the real world. As such, what one experiences in the virtual world can be expected to apply to the real world as well. As a tool for inspecting buildings virtually, we can expect the VR world to reflect the end result of the building, and as such, the technology is well-suited to performing inspections.

7.3.2 Demerits

Through developing the demo, we also learned that there are some clear demerits to VR technology that need to be handled.

First, we need to consider VR sickness. According to LaValle, VR sickness can be considered to be visually induced motion sickness, which is believed to be because of the mismatch between what the body is experiencing and what one's eyes are seeing. Symptoms include nausea, dizziness, drowsiness, fatigue, headache and other physiological responses such as sweating and flushing. (LaValle 2020, 349-351)

Second, for someone that has never been involved with VR before, the controls are difficult to get used to, and as such, it is reasonable to assume that any company that desires to use VR technology in their processes should consider the time needed for their employees to get accustomed with VR in general.

Third, the development costs and time needed to develop the software that will be used need to be considered. To be functional, the software needs to include several features. Despite the availability of basic features in development kits, if a company desires to expand on the functionality, they will have to develop the software themselves or commission an external company to create the features for them. As such, a company needs to consider how advanced its software needs to be depending on its desired purpose.

7.4 Deliberations

As personally experienced, we have found that the first-person view of the 3D model allows us to take a closer look at the model, and the coherency of the rooms in the house. Due to its inspective nature, we believe this advantage has a high potential to streamline processes that involve testing and inspection. The reason why we believe so is that these processes involve visual human interaction. As a visual technology, it may be possible to use this technology to streamline these processes.

Later in this paper, we will explore more use cases, in addition to giving examples of how we believe that VR technology would be best implemented in a construction planning company.

8.0 Meeting

Having gained experience through finishing our VR demo, we set up a meeting with XPro - a company focusing on project administrative processes related to the construction industry - to discuss the possibilities of VR in the current industry. In our discussion, we learned many points of importance that we wish to bring up and expand further upon.

During the meeting, we were given a demo of one of their projects implemented into a VR environment, wherein we were able to explore a building by walking around and seeing the inner systems of the building like the ventilation and staircases. Being able to do such things as measuring distances, drawing suggestions, and even splitting away part of the building to better see around the model with the software VREX. Along with the added ability to invite more people into the demo, both the authors were able to interact across VR and PC.

The process of digitally setting up a BIM model and making it possible to work on in teams was done using the programs Bimsync and VREX, which are programs that allow teams to collaborate and work on BIM models. Tools like these bring a lot to industries working on complex infrastructure and could help bring a new wave of digitalization to the construction industry as well.

VREX and Bimsync both offer free trials to get started with their software, making the primary challenge for those looking to start working with these programs the new technology they'd have to learn.

8.1 Fragmented industry

According to our meeting, we were told that the construction industry was a fragmented industry, with many companies that need to work together to complete a project. With all these companies, it is difficult to start a process due to the high costs that come with the projects. In addition to this, there needs to be an incentive and clear communication for a project to be initiated. As such, we can expect that if VR technology can help mitigate some of the costs, the industry would see improvement in the feasibility of their projects.

The companies that we suggest could improve their processes through the use of VR, are companies that are in a principal-agent relationship with the customer. The customer has an idea for a building, which they relay to the construction company. In this principal-agent relationship, both parties need to share the same initiative. (Investopedia Team 2022) If they don't share the same initiative, there could be a conflict of interest that, at worst, could lead to the project being cancelled, leading to an increase in costs for both parties. Given the use of VR, the company could better communicate with the customer by giving visual examples of what they are capable of creating, as well as coming to an agreement based on easy-to-understand visual examples. With VR acting as a mediator between the customer and the company, we could avoid conflicts of interest that result from a principal-agent problem.

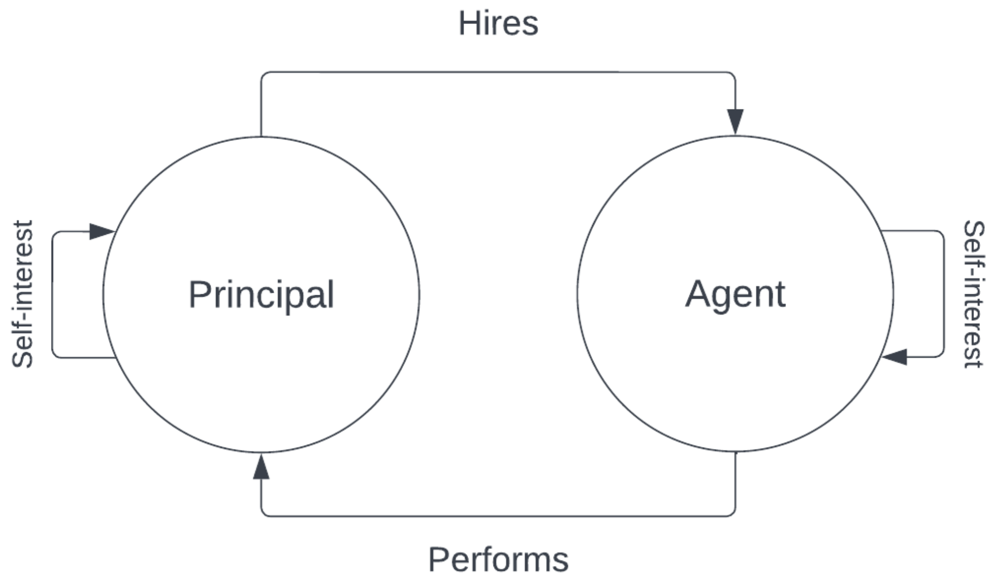

Figure 5 Principal-agent relationship

8.2 Gamification as a tool

A point that was brought up during the meeting was the fact that we can use gamification as a tool for making improvements to the work. By bringing scenarios that would otherwise be hard to imagine and visualise, such as flooding, fire and other catastrophes, we will be able to test the constructions and how they would fare against these catastrophes. By defining rules, similar to how one would to a game, and implementing this into the buildings, we could see where the building fails, thereby showing us what the companies need to improve on.

Given that we wish to test the building in the case of a fire, gamification would let us test the evacuation routes, and through this, we could pinpoint locations where the exits would be crammed. In addition, we could test how fires in different locations could affect the escape routes, as well as the countermeasures put in place, such as extinguishers and fire hoses. By defining rules for how the fire would spread based on material and location with factors such as airflow, we could create a VR simulation that would give a clear indication of which locations need improvement and extra caution.

To further expand on the use cases of gamification, we can imagine a flood. In some locations, this is of great importance and needs to be considered. An example of this is the Smithsonian Natural History Museum in America, which houses valuable artefacts susceptible to damage due to water, being at risk of flood damage, with some at a ground level that will soon be underwater. (Flavelle 2021) Through the use of gamification on e.g., BIM, CAD and digital models, we could - through a set of rules for how water would propagate through the building - determine how to best counter the effects of the water. If in the planning stages of the buildings, we could create accurate VR simulations that give specialised training to the ones that will use the building. In that case, we could provide additional value to the customers as well as aid the longevity of the building.

Additionally, gamification of a construction project could provide an understanding of flaws in the design. Through gamification, the entire structure could be set up digitally and put on trials to figure out flaws before even starting construction. Further on, it could give insight and data on how the structure would be used, giving important information on what parts of the building need extra support or more maintenance as well as environmental aspects. Allowing the opportunity to shave off any impracticalities, and giving knowledge of environmental flaws, to help get the most out of the project.

8.3 Implementation challenges

Despite its immense potential to provide value to companies, there are some challenges to the implementation of VR technology in the construction industry. And in our meeting with XPro, we brought up three main issues that need to be tackled if we desire to implement the technology seamlessly into the industry.

First, we need to consider that since VR technology is a new technology, employees won't be familiar with how the technology is used. As such, there is a need to give systematic training for this new soft skill. This would be an additional cost for the companies, requiring additional attention from the employees. As such, we need to find a way to effectively develop new employees' soft skills to include the use of VR technology.

The most obvious solution to this issue is to implement systematic courses that give employees the experience they need to use the equipment. This would need to include not only explanations on how VR technology is used, but also on how to use the auxiliary software that allows the companies to run simulations. This training would need to be aimed at both those in the industry and their customers. The training for the employees needs to focus on the necessities they have for arranging the simulations for their testing needs. The training for the customers, however, needs to focus on training the customer to use the simulations effectively.

Second, we need to consider the adverse effects VR technology can have on one's body, i.e., vertigo. Through the mismatch of what one is seeing and what one's body is experiencing, many people perceive VR to be incredibly dizzying, and is considered one of the major issues with VR technology. (LaValle 2020, 348) We believe that there will one day be an effective solution to this problem, however, as it stands now, this is a topic for further research.

The current standard for mitigating some of the adverse effects of VR is to either make the person adapt to the VR environment through exposure or to use experimental studies to determine the causes of VR sickness and use this data to develop more comfortable experiences. (LaValle 2020, 357) There are other methods, but for the application in the construction industry, we believe that these two are the most relevant methods. The first method would require additional training, and may not be suited in the case of customer interaction. The second solution would mean incurring extra development costs, which is suboptimal when testing the feasibility of the implementation of VR in the industry.

Notably, we'd like to consider the systems implemented in VRChat to reduce visually induced motion sickness. Rotational acceleration is one of the greatest contributors to VR sickness (Lo and So 2001, 12) and to mitigate this, VRChat uses a system combining the physical rotation of the head, with locked-angle rotation through one's controllers. This will let the user "snap" onto an angle incremented or decremented by a predefined value. By locking the rotation outside of the physical movement of the head to a fixed angle, VRChat is able to significantly reduce nausea experienced in the virtual environment. If customers experience significant VR sickness, an alternative could be to implement similar functionality into the software used as a toggleable option.

Third and last, we need to consider any possible conflicts and incompatibilities with already established infrastructure. As a developed industry, the construction industry already has software to cover its needs, with most of the software relevant to VR technology being BIM software which is extensively used in the construction industry.

The simplest resolution to this issue would be for the leading actors that develop the software used by construction companies to change and implement features that allow for simplified exportation of the digital models to a virtual environment. This needs to be in such a way that one could easily implement necessary features such as object collisions, which we consider as necessary for the VR simulation to be a realistic experience that gives reliable data to work with, which is imperative to the validity of the mistakes where changes need to be made.

8.4 Comparing our demo with XPro's demo

Visiting XPro we got a lot of insight into the industry, and ideas as to what we could write about, additionally, we got to see an interesting demo, showcasing their testing with VR. A few differences between their demo and ours stood out.

Mainly the programs that had been used to create the two demos were different. We had used Unity and had to manually programmed in the controls for the player model we had. Whereas the demo we saw at XPro had used Unreal Engine, which seemed much more streamlined, with ready-to-go controls, and a set of different modes to test.

The second difference that stood out was the differences in models. Where we had found and used a VR floor built-in 3D from blueprints, XPro had a model from one of their previous projects, which stood out by having several floors and added details like ventilation, in short being a more detailed model.

From making our own VR demo, and seeing the one made by XPro, we got insights into both the development of virtual experiences, as well as an understanding of the possibilities of VR.

On top of seeing the VR demo from XPro, made in Unreal Engine, we got to see another one of their projects. We were able to see in both VR and on the computer of one of their models, which through the program VREX, allowed us to do more than just spectate. Which we have already mentioned in section 8.0.

9.0 The processes of the construction industry

The Norwegian government along with several construction companies have created a framework called “Next step”, which is a best-practice process containing eight steps from start to finish. This framework is widely used in the Norwegian construction industry. In this section, we will be using this framework as a basis for our discussion. (Bygg21 2015) Do note that we have taken the liberty of translating the terms in figure 6, and the figure is in no capacity an official translation.

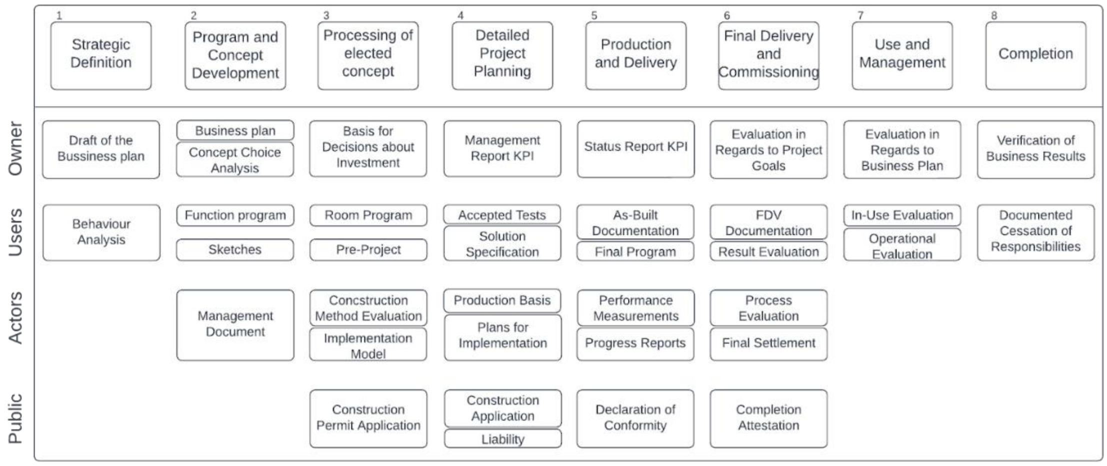

Figure 6 Bygg21 process, translated

9.1 Integration of VR in customer interaction

Of these eight steps, according to our meeting with XPro, we learned that steps one, two, three, seven and eight are of most interest to the customers. In the following paragraphs, we will be defining what these steps include, and whether VR can have an impact on these steps with the purpose of bettering customer interaction.

The first step of the process is Strategic Definition. The process is initiated with an idea or a problem to solve, and by the end of step one, the requirements should be explicitly stated, and an evaluation of financial feasibility should be completed. Unfortunately, as this step does not include digital models, this step is not relevant to us. At most, VR at this stage can only be used to advertise the capabilities of the company.

The second step of the process is Program and Development. With the requirements defined in the first step of the process, sketches are made and evaluated based on how well they fulfil the customers’ requirements. This step is considered complete after a final financial feasibility evaluation. Like with step one of the process, VR is not applicable due to the lack of digital modelling. It is, however, reasonable to assume that VR can be used as a reference for possible solutions that have been implemented in the company’s previously made buildings.

It is in step three that we believe VR holds the most value. The third step is where the company will develop its plans and make a model of the most important choices that need to be made in the project. This step is called Processing of Elected Concept. For most companies, this model is a BIM project, and will, therefore, be able to be exported into a VR environment for inspection. This will give the customer a clear display of the possible solutions, and the first-person view will give the customer a close indication of how the building would look in real life.

Step seven, Use and Management, is where the customer puts the building to use. As such, in this step, we need to consider the final needs of the customer as the building has been handed over. For this step, as the building is completed, the BIM model is a digital twin that can be used for simulation training. (e.g., fire-, earthquake- and flood evacuation)

The final step of the process, Completion, is one where the customer decides to end their ownership over their building by either deconstructing/demolishing or selling it to another owner. In this step, the VR environment can be used to remotely advertise and display the building to potential buyers. Through this, potential buyers can decide whether or not to inspect the building in the real world.

To conclude this section, we have argued that through VR, companies can provide improved customer service. We attribute this to the visual aspects of VR technology which, through its compatibility with the current business standard of creating virtual models, lets the customer inspect the models as they would be in the real world. As a digital twin of the real building, the model can be further used for simulation training and other purposes that also bring value to the customer.

9.2 Integration of VR in the development process

The remaining three steps, four through six, are where the technical aspects of developing a construction come in. To an untrained customer, these technical topics are of little relevance, and as such are not relevant to customer interaction. It is, however, worth noting that even for these steps, VR can still be used to illustrate the changes and conduct project showcases if it is considered to be relevant. In addition, VR technology can be used for testing purposes as we stated earlier in section 7.4.

Step four, Detailed Project Planning, is where the company completes the BIM model to specifications, taking extra notice of the requirements set by the customer, as well as the processes chosen to construct the building. In this step, we imagine that companies can use VR technology for inspecting the building and checking if the building meets the requirements. In addition, through the iterative process of testing and fixing mentioned later in section 12.2, this process may have the potential to be sped up without reducing the overall quality, which means that there is potential to save money.

Step five, Production and Delivery, is where digital turns into physical, marking the beginning of the construction. In this step, along with documentation that needs to be made, the building is also created to specifications. We imagine that VR, or more specifically AR, could have some use in facilitating this process. By overlaying the digital twin on the physical location with correct scales and tracking, one can better plan the construction process, making sure that there are no mistakes when compared to the digital plans. Any inconsistencies will, through this method, be clear to see. Not only could this have the potential to speed up the process, but it also works to reduce the mistakes made, and thus, reduce the unexpected costs.

Step six, Final Delivery and Commissioning, is the final step before handing control of the building over to the customer. In this step, tests are performed to check if the building is up to specifications and whether the systems are working as they should. Once these tests are complete, the building is handed over to the customer to let them perform trials to familiarise themselves with the use of the building. In this step, given that VR has been used in step five to make sure that the construction of the building followed the plans, VR will not have much use outside of what has already been mentioned.

To conclude this section, similar to section 9.1, we have argued that VR can be used as mentioned later in section 12.2 to streamline the development process through repeated testing and fixing. By using VR, we can not only test during the planning stages but also verify that no mistakes are being made when constructing the building. The company could potentially speed up these steps, and by speeding up these steps, they could also improve their competitiveness while reducing costs.

10.0 Modernising the construction industry

The construction industry has seen many changes since the introduction of digital technologies. With new technologies being developed, the processes of the construction industry have quite drastically changed. New materials that allow us to make stronger and taller buildings, new technologies that allow us to plan better and improve the communication with suppliers and customers. With improved transportation technology, materials could get transported over further distances more efficiently, revolutionising the supply chain. (IBM 2022) All these factors considered, the construction industry has seen vast improvements. These disruptive technologies have led to a significantly more streamlined industry.

With new technologies constantly being developed, we must consider the potential of all these technologies carefully. We believe that VR could have significant implications for the construction industry and that it may be a disruptive technology similar to the ones mentioned earlier in this section. As such, in the following sections, we will explore the performance indicators that we believe VR could affect. Furthermore, we will suggest how we believe VR could be used in the industry.

11.0 The efficiency of VR

The main driver for many modern companies to integrate technology into their work processes is the intent of improving efficiency and cutting costs. With many forthcoming technologies disrupting the different fields (i.e., infrastructure, manufacturing, transportation), the need to improve and stay competitive has been increasing rapidly since 2011 with the start of industry 4.0.

Companies have gone from using physical copies to using digital copies, this is due to the many benefits of working digitally, as well as saving money and time by avoiding the physical documentation process. For construction companies to integrate VR technology into their business model, VR needs to either improve efficiency or make a process in the company more cost-effective. In addition, it needs to be feasibly implementable, lest the cost of development outweighs the benefits gained.

To give background for our reasonings, we believe that since VR technology is a visual technology, it has the potential to expand upon the visual processes of a company. In the case of a company using digital technologies to plan physical objects such as buildings, the results of the company's work can be better demonstrated through VR, which would facilitate the process of showcasing the development. Through VR technology, we can improve customer satisfaction through clearer communication, and we believe that this is another aspect to consider together with the other performance indicators.

11.1 Value of VR in construction

As an emerging and gradually more mature technology, VR has seen rapid improvement in the last few years as mentioned in section 6.0. As the technology is maturing, we should find how to implement VR into the processes in different industries. As a relatively new technology, VR has had limitations in both software and hardware, and it is possible that there may have been reservations against using VR commercially. However, with the new progress, we can conduct more thorough tests, as well as give a more personal look at what is being developed by the companies.

As mentioned earlier, VR is a visual technology. This is especially relevant for companies dealing with physical objects. Through digital copies, these companies can give a more intimate look at how the work is progressing. We believe that VR technology could help companies perform more thorough product meetings, as well as more interactive demos.

Ideally, a construction company would be able to export their digital work to a virtual environment, where they could inspect the work with VR goggles. This would give an entirely new perspective on their work, which could help further polish and improve the work. In addition, if the technology is further polished, it could be possible to make changes and bookmark locations for further inspection.

11.2 How would VR provide improved efficacy

As mentioned earlier, we believe that for a technology to be adopted into the processes of industrially competitive companies, the technology needs to improve one or more of the four properties: quality, time efficiency, cost and customer communication. These four aspects are what we believe to be central to providing a service that customers will be satisfied with, as well as helping the company sustain itself better in the market.

Most importantly, we should inspect whether VR technology can help a company improve the quality of their services. By improving the quality of their work, they will provide more value to their customers, therefore allowing the company to increase their competitiveness in the market.

As an integral part of any service, the speed at which a company can provide their services is of utmost importance, lest their competitors take their customers. We, therefore, need to consider how VR could help a company improve their speed.

In addition, we have to consider whether VR technology could help companies cut some of their costs, as this would give incentive to further develop VR technology commercially. For this, we need to consider the development costs, as well as the future savings made through this technological development.

Lastly, customer communication is a major contributor to customer satisfaction. (Ellinger, Daugherty, and Plair 1999, 122-123) By improving their communication with their customers, a company will be able to deliver more tailored products, not to mention the benefits of having a reputation as a great communicator.

In the coming section, we will go in-depth on how VR technology could be used to improve these four properties.

11.3 Use

11.3.1 Quality

The quality of a plan is directly correlated with how well it has been tested. Under the scrutiny of a trained eye, more errors in the construction plans would come to light. By knowing the errors, the company would be able to spend their time fixing and improving on the erroneous areas.

By removing errors and therefore improving the quality of the planning, the constructors will be able to avoid making mistakes that will cost the company. In addition, through constant refinement, the overall production quality will be improved, and the quality of the final product will, therefore, also improve.

If we can find a way to utilise VR technology in such a way that a company can facilitate the inspection process, thus making it easier to create higher quality plans, which in turn results in a higher quality end-product.

11.3.2 Time efficiency

The planning stages of a building is a laborious process, and it is difficult to speed up without reducing the overall quality. (Crewson 2020) The benefits of speed can, therefore, be correlated to the later stages of the construction process, which, if VR technology can contribute to reducing the errors in the plans, will naturally speed up because of the reduction in otherwise time-consuming errors.

11.3.3 Cost performance

The cost is always a subject that needs to be considered. By implementing new tools and technologies, some parts of the already-established process will change, and naturally, the cost profile will see some change as well. We, therefore, consider the aspects that lead to increased and decreased costs. First, we need to know where costs are incurred for a company dealing with construction. Referring to our meeting with XPro, we learned that four significant aspects lead to increased costs, of which we have reasoned that three, namely, Hardware/Software, time loss and development costs are relevant to the use of VR technology.

First, the costs of the hardware and software necessary to start the development process need to be considered. If we wish to use VR equipment to perform tests as per 9.2, we need to consider the price of equipping all the relevant personnel with the necessary VR equipment. Figure 2 shows the prices listed on Prisjakt 27.05.2022, which can be used as a reference for the potential costs of purchasing the required equipment. As the game engines with VR development kits mentioned in this text are freeware, we can assume that the costs of the software are negligible.

Second, for a business, any process that leads to a time loss leads to an increase in costs. By using VR technology, we have suggested that it is possible to reduce the time taken to develop a final product, thus reducing the costs.

Third, the development costs lead to an increase in costs. If we wish to develop a VR experience that can help us with inspecting the BIM models, we need to consider the time and personnel it will take to develop a template for the VR experience, as well as the process of learning the knowledge required to use and develop these VR experiences. All these factors considered, to use VR technology professionally, one should be prepared for a considerably high start-up cost.

To conclude, the use of VR technology professionally would mean incurring a significant start-up cost, with both the cost of the hardware and the time investment needed to gain proficiency in using the technology. However, once one has the required equipment and experience necessary to develop these VR experiences, there is potential for lowering the time required to finish the development process of a building, thus reducing the costs of the development process.

11.3.4 Customer communication

The improvement of customer communication is what we are most enthusiastic about, as there are many opportunities that give value in this area. By using VR technology for illustrative purposes, a company will be able to give demos of the buildings that they have made plans for, letting the customer get a more intuitive and intimate look at the building. By showing the customer how the building would look in person, instead of showing the building as an image through a screen, the company would offer more value to the customer.

In addition, if the customer could interact directly with the construction, bookmarking locations and adding notes where they wished, the company would be able to better tailor the construction to the needs of the customer, which would also provide more value to the customer.

By providing more value to the customer through the use of VR technology, the company would also gain the reputation of having good customer interaction. The company provides good value to the customer, making the customer an integral part of their team, thus helping the customer get the results they desire. This reputation is an intangible value that brings positive attention to the company.

11.4 Already existing VR frameworks

As a technology that has been used experimentally in the game industry, some development kits such as Unreal Engine and Unity have already created frameworks for working with VR equipment. As such, with little cost and some small reworks, a VR experience can easily be made, given that the company that wishes to do so has access to the assets they wish to create a VR experience out of. This was made clear in our experiment mentioned in section 7.2.

In our meeting with XPro, it was suggested that Unreal Engine has a more easy-to-implement toolkit, and as such, it would be more suited for rookie development. Our own experience tells us that Unity also has a decent framework for implementing the VR scene, however, Unreal Engine has a pre-made setup which runs smoothly, and for companies that would be interested in experimenting with VR technology, Unreal Engine would be well suited. However, XRBootcamp states that Unity has wider online support, and that one is more likely to find explanations and solutions online compared to Unreal Engine. (“XR Bootcamp” 2022) As such, one needs to consider these factors when choosing which engine one should use.

12.0 Industry software

In this section, we explore the software that is currently being used in the construction industry, which we find to be relevant to VR technology and the ideas we have proposed thus far. Aside from generic software such as text editors, Kanban software, spreadsheet software, etc. We take a look at BIM software and its relevance to VR technology and the ideas proposed in this paper, as well as our suggestions for how we can implement VR technology seamlessly into the industry.

12.1 BIM software

As VR is most relevant to digital modelling software, we take special consideration to BIM software. In this section, we will consider some of the more commonly used BIM software, and their lack of support for VR integration.

As it stands now, none of the current standard BIM software such as Revit, ArchiCAD, Tekla, etc., have strong support for VR integration. At most, they have options to export the models to a specific format that can be imported into the virtual environment such as Unreal Engine's Datasmith, which allows for the exportation of BIM models. As it stands now, without explicit support from the companies that develop the BIM software, making VR experiences using the current commonly used BIM software requires us to put in additional effort to make the technical aspects of the VR environment function properly. (i.e., physics, object collision, functional movement of objects such as doors, etc.) In the following section, we will deliberate on some of the possible solutions we have thought of, as well as expanding upon some of the ideas we have stated earlier in this paper.

12.2 Our suggestions

Taking inspiration from the game industry, the process of debugging could give a guideline for how VR could be implemented into the creation process in the construction industry. We suggest that VR can be used as an interface to allow testers to go through and inspect the construction. This would be of great help when checking for both problems and areas for improvement.

In our suggestion for how VR technology is best applied, we would like to bring up an example from the game industry as an allegory. Specifically, how the process of debugging is performed professionally. The process varies from country to country, however, most follow the same convention of first creating and compiling an alpha version by combining all the resources that need to be in the final product. After this preliminary step has been completed, game testers are brought in to inspect the product and write down any bugs, crashes, glitches and errors they can find. This information is then used to further improve and fix the code. The new and fixed code is compiled into a beta version, which is often made available to critics and mass media for evaluation and marketing. (Aoyama and Izushi 2004, 119-120)

Taking inspiration from the game industry, we suggest incorporating some of the methods used in the debugging process into the use of VR in the construction industry. Specifically, we suggest that similarly, once a building has finished its preliminary stages of planning, the alpha model is loaded into a VR environment. Thereafter, testers - whether they be from the company or an outside company - are brought in to inspect and write down any errors, conflicts or thoughts they have regarding the plans of the building. This information will be used to further improve the quality of the building to create a beta building, before submitting the plans for approval. In this way, the overall quality of the building will be improved and through the watchful inspection of the testers, the company will be able to reduce the number of errors in their plans. By reducing the number of errors, the construction company would be able to reduce the expenses that come as a consequence of fixing errors post-process.

With the current business standard, the implementation of VR would lead to an increase in overhead costs. As such, to increase the feasibility of our suggestions, one of two possible conditions needs to be fulfilled. Due to the conflict between current file formats and VR environments - namely, object collision or the lack thereof, in addition to other significant features - we need to find a method to seamlessly incorporate the file formats of the current industry-standard software into VR. Due to the lack of VR support, if a company desires to create a functioning VR environment, the employees will have to manually convert and add properties to the model, which for large buildings would become a strenuous process.

The first solution would be to have auxiliary software developed to allow us to add properties to the files exported from the company's main software. Through this software, an employee should be able to add features and behaviour to the object hierarchy. Through editing and adding properties to the hierarchy, doors would act like doors, and walls would act like walls as one would expect. This would allow for a nearly seamless integration of VR technology into the planning process.

The second solution is similar to the first solution, however, instead of having auxiliary software developed, this solution would be to have Autodesk add new features to Revit's already existing file formats, which will allow for easier implementation of a BIM model into a VR environment. This, given Autodesk's professionalism, should not be a problem given that the interest from their customers is great enough.

The features that need to be added to Revit should work similarly to how the suggested software in the first solution should work. Directly in the software, we should be able to add properties that define features such as doors, elevators and other technical aspects pertaining to movement in the model. The file format, when exported, should include the information on the properties of the objects in the model, which hold information about, but not limited to, the collision physics, movement along an axis and behaviour patterns (e.g., elevators) as well as other features.

With this new file, one could easily export the model into a VR environment, which could be used to check for issues or necessary changes as per the suggestions in 9.2, or it could be used for presenting the model to the customer in an easy-to-understand manner.

To conclude this section, we have suggested that by implementing VR into the testing stages as an iterative process, companies could streamline the development process without negatively affecting the quality of their end product. Furthermore, through the two methods proposed - i.e., developing auxiliary software to implement the desired object behaviour, and the current business leaders adding VR compatibility with their software - we have suggested that the feasibility of the implementation of VR technology is high enough to consider. Whether these suggestions remain effective is a subject for further systematic study.

13.0 Future improvements for implementations of VR in construction

What can be done to improve upon VR and its experiences in the future, what would make it easier for people and companies within construction to implement and help normalise the use of VR? Exploring some future improvements VR can make, we hope to reveal some of the answers.

Improved or automated conversion methods from digital models into virtual environments. By having a simple method of converting CAD, BIM or even digital twin models, into a compatible model that can be implemented into virtual environments, while maintaining the structural aspects of the model. This means that the walls, floors, and stairs of the structure would be registered as solid objects that you can't walk or see through unless you specifically want to. Similarly, objects that serve a purpose could be implemented and would be movable if the movement was part of its purpose like chairs, desks and controls. This would make it easier to view, inspect and play around with that model in a way that could contribute to the construction company.

Additionally, having a way of reversing this method, so that VR would be compatible with CAD, BIM, and even digital twins, would further assist in condensing the process. Making the time between the finished digital model and seeing the model in VR shorter. This could assist in making it convenient for those working in architecture design and construction to showcase and market their projects.

A method of converting digital models could be made easier with assistance from machine learning, having software that can recognize parts of the model and to a large degree automate the process of conversion. Recognizing different parts of the mesh structure and assigning values to it like, recognizing walls as solid objects and windows as see-through objects. Having this work in collaboration with for example the BIM which already contains a lot of the logic in the building would help shave off a large portion of the time it would take to manually complete the process.

Improvements to the steps between the purchase of VR and implementation in projects. Implementing VR in a project will require the users to have a baseline understanding of how VR works. So having a solution that quickly teaches users the basics of VR, as well as simplifying the available tools would be an important part of normalising the new technology, this is often already in place as a form of tutorial.

As has already been mentioned previously, a certain normalisation of VR is bound to come in the future as a new generation of people will grow up more accustomed to VR, which will make it easier for companies to implement, as the knowledge to implement it will come with new employees. Additionally, some countermeasures for the demerits in VR will likely become standardised, as mentioned in section 7.3.2.

With these points it's likely VR will find itself bringing value to the construction industry, as well as many other industries due to how much of a transformative technology it is, which we will see in the future.

14.0 Examples in construction where VR has assisted

Having a baseline understanding of how VR can assist in benefitting the construction industry, we'll now look at some real-life cases where VR has assisted and look at the positive takeaways.

Starting with the Finnish Nova hospital, which after having developed a construction design, shared it with hospital workers so they could review and give feedback regarding the design. Using the browser integrated program Tridify to experience the design, the hospital workers gave invaluable feedback that helped change the design. The result of this method is an expected 10% decrease in operating costs (Weatherley 2020) for the hospital. This example shows the benefit of letting those working in the field give their opinions and suggestions about the construction design. The viewing of which was made easier with VR.

Moving on to a much more ambitious project that's taking place in New Rochelle of New York, in the United States. There, in September of 2020, the city launched a virtual reality platform to visualise the improvements planned in New Rochelle's downtown. (Hickman 2020) Covering more than 3 million square miles (7,8 Million square kilometres) it is an ambitious project. By giving residents the ability to see the planned improvements with VR, they are including the residents in the designing process. The New Rochelle VR team worked on gathering the residents' feedback and collecting data, which would provide important information on what the residents feel about the existing development. Bringing residents into the design process is likely to raise excitement and support for the construction project.

In the last example, we'll mention the relationship between VR and the hotel industry. In a project by Program-Ace, they developed a solution for a hotel company, wherein they could create and design everything, choosing from a selection of 15 rooms and a wide selection of textures, they could edit e.g., furniture, bed size, bathroom interior, walls, curtain design and even time of day to see how it would look in the different lighting. ("Program-Ace" 2021) Removing the need for physical design, this solution helps in solving difficult and complex interior design tasks.

Seeing examples of how and where VR has contributed, we may imagine how it could have assisted modern buildings. Taking the Oslo Opera house as an example, would the input from stage workers or residents have changed the design in any meaningful way?

15.0 Future research

In this paper we have suggested some ideas that may apply to the construction industry. We have no proof of the ideas written in this paper, and as such, there is a need to perform more research regarding the efficacy of the suggested use cases of VR in the construction industry.

In section 11.3 we discussed some of the indicators worth considering when investigating the impact of VR on the construction industry. We suggest that in future research, these indicators are considered when measuring the effect VR technology has on the construction industry. Furthermore, we suggest that the measurements are used to evaluate both the positive and negative aspects of VR technology in the construction industry.

As a suggestion, as proposed in section 12.2, there are two areas in the construction process where we believe VR technology could be used. First, the use of VR technology for testing and inspection in the construction planning process, using a methodology for testing similar to what was mentioned in section 12.2, paragraph 3. Second, the use of VR or AR on-site for inspection during the construction, as mentioned in section 9.2. We believe that as technology, as well as VR technology, develops and matures further, both use cases are worth investigating.

With the results of the research, we can get an indicator of both the efficacy and cost-efficiency of VR technology when used in the construction industry. These results can give companies an indicator of whether VR technology is worth investing in or not.

16.0 Conclusion

In this paper we had the initial idea of finding uses for VR in the construction industry. By looking through earlier research and performing our own experiment, we hypothesised the potential use of VR to streamline the processes in the Norwegian construction standard process developed by Bygg21.

We have introduced some of the recent developments in the past decade, and through these developments, we have determined that VR is a maturing technology that could soon see use in the industrial sector. With the constant improvements seen in computer hardware, we can also expect there to be extra developments with VR hardware. Furthermore, through the interest shown over the past couple of years, there is potential for VR technology to see some drastic breakthroughs in the coming years. With this as our basis, we wished to explore the potential uses of VR technology and performed an experiment to get hands-on experience to form an opinion of how VR technology could be implemented in the industrial sector.

Our experiment was performed by using Unity's VR toolkit, along with Oculus Quest 2 VR goggles. The hypothesis of the experiment was that VR technology can be implemented into the construction process, thereby streamlining some of the processes. By getting a closer look through VR goggles, we could - through the first-person view offered by VR - get a better view of the model we were working with. This leads us to conclude that there is indeed potential for VR to be used when inspecting 3D models. Furthermore, due to the compatibility between the technologies used in the modern construction industry - i.e., BIM, CAD, Digital twin, etc. - we hypothesised that VR technology can be implemented into the construction industry.

In our hypotheses, we have suggested two possible use cases for VR technology. First, we have proposed that VR can be used in the development process of a building for testing purposes, which could potentially lead to increased quality and improved time efficiency. Second, we have proposed that VR or AR can be used during the construction of a building to overlay the digital model onto the real location, thus highlighting the issues that may arise during the construction process, making it easier to notice and resolve errors early.

After our experiments, we arranged a meeting with XPro, a local company working with project administrative processes related to the construction industry. Through our meeting with them, we learned that along with the benefits of VR, there are also problems that need to be considered. Namely, the problem of lacking familiarity with the technology in the industry, VR sickness and software conflicts. In our paper, we have suggested some solutions to these issues that we believe to be feasible. First, the lack of familiarity with VR technology is a problem that can be resolved through exposure, e.g., by systematically introducing VR technology, i.e., seminars. Second, VR sickness is still a problem, but through inspecting how VRChat has mitigated the adverse effects of rotation, we have suggested a possible implementation that may lead to reduced vertigo when using VR equipment. Third, we have suggested two possible solutions to the potential software conflicts between VR technology and BIM software. One solution is to create auxiliary software that bridges the gap between the BIM software and the VR environment. The other solution is to have the developers of BIM software add support for VR technology in their software.

Additionally, we have suggested some performance indicators that may be used in future research to decide the value of VR technology in the construction industry, along with possible use cases for VR technology. These suggestions form the basis of our suggestion for future research, and how - ideally - VR technology could be implemented into the construction industry.

All in all, we believe that with the developments happening in the hardware industry, as well as the international interest shown by major companies, VR has the potential to become a major disruptor in the construction process. This is especially in the digital stages of the process, but potentially also in the physical steps of the process. With extra research, we will be able to find better implementations of VR technology in the industrial sector and thereby radically improve some of the processes in the industrial sector.

References

Aoyama, Yuko, and Hiro Izushi. 2004. *Cultural Industries and the Production of Culture*. Edited by Allen J. Scott and Dominic Power. N.p.: Taylor & Francis.

"AR VR Simulations, Metaverse for Simulations | Siminsights." 2021. SimInsights. https://siminsights.com/ar-vr-simulations/

Babich, Nick. 2019. "How VR Education Will Change How We Learn & Teach | Adobe XD Ideas." Adobe XD | Fast & Powerful UI/UX Design & Collaboration Tool. https://xd.adobe.com/ideas/principles/emerging-technology/virtual-reality-will-change-learn-teach/

Bariso, Justin. 2021. "Facebook Changing Its Name to Meta Is a Brilliant Business Move. But It's Also Bad News for the Future." Inc. Magazine. https://www.inc.com/justin-bariso/facebook-meta-mark-zuckerberg-innovators-dilemma-why-did-facebook-change-its-name.html

"Base Station Basics." 2021. MCCC Knowledge Base. https://kb.mc3.edu/article/base-station-basics-11441.html

Bygg21. 2015. "Veileder for fasenormen "Neste Steg,"" Et felles rammeverk for norske byggeprosesser. 1.2. https://bygg21.no/wp-content/uploads/2021/03/veileder-for-stegstandard-ver-1.2-med-logoer-201116.pdf

"CADLearning." 2021. Wikipedia, the free encyclopedia. https://knowledge.autodesk.com/support/bim-360/learn-explore/caas/video/youtube/lesson/143344-courseId-100332.html

Crewson, Lee. 2020. "Managing Cost, Quality, and Speed in Construction: Speed." Peak Development Partners. https://teampeak.com/managing-cost-quality-and-speed-in-construction-speed/

"Difference Between Digital Twin and BIM (With Table)." 2021. Ask Any Difference. https://askanydifference.com/difference-between-digital-twin-and-bim/

Ellinger, Alexander E., Patricia J. Daugherty, and Quentin J. Plair. 1999. "Customer satisfaction and loyalty in supply chain: the role of communication." *Transportation Research Part E: Logistics and Transportation Review* 35, no. 2 (6): 144. 10.1016/S1366-5545(99)00006-X.

"Executive survey shows how and where organizations are leveraging ar/vr technology for greater production efficiencies & savings – Gridraster." 2020. Gridraster. https://gridraster.com/press-releases/executive-survey-shows-how-and-where-organizations-are-leveraging-ar-vr-technology-for-greater-production-efficiencies-savings/

Favreau, Jon. 2022. "20 Biggest Virtual Reality Companies | Top VR Companies 2022." Software Testing Help. https://www.softwaretestinghelp.com/top-virtual-reality-companies/

Feltham, Jamie, David Heaney, and Harry Baker. 2022. "Quest 2 Inches Towards 50% Of SteamVR Usage Once Again." UploadVR. https://uploadvr.com/quest-2-steam-vr-april-2022/

Flavelle, Christopher. 2021. "Climate Change Threatens Smithsonian Museums." *The New York Times*, November 25, 2021. https://www.nytimes.com/2021/11/25/climate/smithsonian-museum-flooding.html

Fraser, Mike, Tony Glover, Ivan Vaghi, Steve Benford, Chris Greenhalgh, Jon Hindmarsh, and Christian Heath. 2000. "Revealing the Realities of Collaborative Virtual Reality." *CVE '00: Proceedings of the third international conference on Collaborative virtual environments*, (9). 10.1145/351006.351010.

Hamilton, Ian, Harry Baker, and Jamie Feltham. 2020. "Varjo XR-3: LiDAR Powered With 12-MP Passthrough At 90 Hz." UploadVR. https://uploadvr.com/varjo-xr-3-vr-3-lidar/

Hendrickson, Josh. 2021. "Trying Facebook's VR Horizon Workrooms Felt Like the Future No One Will Embrace." Review Geek. https://www.reviewgeek.com/95372/trying-facebooks-vr-horizon-workspace-felt-like-the-future-no-one-will-embrace/

Hickman, Matt. 2020. "New Rochelle, New York, launches a virtual reality platform to visualize planned downtown improvements." The Architect's Newspaper. https://www.archpaper.com/2020/09/new-rochelle-virtual-reality-platform-to-visualize-planned-downtown-improvements/

"Horizon Workrooms for VR Remote Collaboration | Meta." 2021. Meta. https://about.fb.com/news/2021/08/introducing-horizon-workrooms-remote-collaboration-reimagined/

IBM. 2022. "What is Industry 4.0 and how does it work?" IBM. https://www.ibm.com/topics/industry-4-0.

Investopedia Team. 2022. "Principal-Agent Problem Definition." Investopedia. https://www.investopedia.com/terms/p/principal-agent-problem.asp

"IT Spending: From Value Preservation to Value Creation." 2018. The Wall Street Journal. https://deloitte.wsj.com/articles/it-spending-from-value-preservation-to-value-creation-1520830927

Janszen, Eric. 2019. "Virtual Reality 2019: VR Industry Enters High-Growth Adoption Phase." AR/VR Journey. https://arvrjourney.com/virtual-reality-2019-vr-industry-enters-high-growth-adoption-phase-82843d8cc41a

Kinateder, Max, Enrico Ronchi, Daniel Gromer, Mathias Müller, Michael Jost, Markus Nehfischer, Andreas Mühlberger, and Paul Pauli. 2014. "Social influence on route choice in a virtual reality tunnel fire." *Transportation Research Part F: Traffic Psychology and Behaviour* 26, no. A (9): 290. 10.1016/j.trf.2014.06.003.

LaValle, Steven M. 2020. *Virtual Reality*. N.p.: Cambridge University Press.

Lo, W.T., and Richard H. So. 2001. "Cybersickness in the presence of scene rotational movements along different axes." *Applied Ergonomics* 32, no. 1 (2): 14. 10.1016/S0003-6870(00)00059-4.

Lucas, Stephen. 2022. "Wireless VR vs. Tethered VR: Which Is Best For Your Virtual Reality Training Program?" Roundtable Learning. https://roundtablelearning.com/wireless-vr-tethered-vr-which-is-best-for-virtual-reality-training/

Makedonski, Brett. 2020. "Valve Index will be back in stock soon, but not with enough headsets to meet demand." Destructoid. https://www.destructoid.com/valve-index-will-be-back-in-stock-soon-but-not-with-enough-headsets-to-meet-demand/

"Many Benefits of 3D Modelling in Architectural Design." 2013. JH May. https://www.jhmay.com/many-benefits-of-3d-modelling-in-architectural-design/

"Models in the construction industry - Designing Buildings." 2021. Designing Buildings Wiki. https://www.designingbuildings.co.uk/wiki/Models_in_the_construction_industry

Øyvann, Stig. 2019. "Forsker på tunnelbrann i VR." Computerworld. https://www.cw.no/sintef-virtuell-virkelighet-vr/forsker-pa-tunnelbrann-i-vr/774613

Painter, Lewis. 2022. “Best Oculus Quest 2 Games 2022: Top VR Titles.” Tech Advisor. https://www.techadvisor.com/test-centre/game/best-oculus-quest-2-games-3811986/

Pham, Q.-C., Radhamadhavan Madhavan, Ludovic Righetti, William D. Smart, and R. Chatila. 2018. “The Impact of Robotics and Automation on Working Conditions and Employment.” *IEEE Robotics and Automation Magazine* 25, no. 2 (06): 130. 10.1109/MRA.2018.2822058.

Scott, Alice. 2018. “VR more engaging than video and textbooks when it comes to the classroom.” University of Warwick. https://warwick.ac.uk/newsandevents/pressreleases/vr_more_engaging/

Smole, Steve. 2021. “How Long Does It Take To Develop VR Training Content?” Roundtable Learning. https://roundtablelearning.com/how-long-to-develop-vr-training-content/

Oleksandr Sokhanych. 2017. “How to hire a VR developer: Skill Set and Sources - 2021.” ThinkMobiles. https://thinkmobiles.com/blog/how-much-cost-to-hire-vr-developer/

Sutrich, Nicholas. 2019. “Decade in review: Google Cardboard ushered in a new era for VR.” Android Central. https://www.androidcentral.com/best-decade-google-cardboard

Thompson, Sophie. 2022. “VR Applications: 23 Industries using Virtual Reality.” VirtualSpeech. https://virtualspeech.com/blog/vr-applications

“VR Hotel: Interactive Virtual Tour Case Study.” 2021. Program-Ace. https://program-ace.com/success-stories/vr-hotel/

VRS. 2019. “History Of Virtual Reality.” Virtual Reality Society. https://www.vrs.org.uk/virtual-reality/history.html

Weatherley, Dan. 2020. “Nova Hospital: VR and BIM powered construction.” Construction Digital. https://constructiondigital.com/technology-and-ai/nova-hospital-vr-and-bim-powered-construction

“Worldwide Spending on Augmented and Virtual Reality Forecast to Deliver Strong Growth Through 2024, According to a New IDC Spending Guide.” 2020. IDC. https://www.idc.com/getdoc.jsp?containerId=prUS47012020

"XR Bootcamp." 2022. XR Bootcamp. https://xrbootcamp.com/unity-vs-unreal-engine-for-xr-development/