Chair of Mining Engineering and Mineral Economics

Master's Thesis

Digitalisation of open educational resources for lifelong learning in mining engineering education

Enhancing education with the help of augmented and virtual reality

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Preface, Dedication, Acknowledgements

The journey at Montauniversität Leoben was longer than anticipated but I am very thankful for the knowledge and experience I gained. The best thing of course was to meet and work with new colleagues and friends. A lot of energy needed for this time was generated by the interaction with family and friends. Therefore, I first want to sincerely thank my family for supporting me on this journey. And then I want to thank my friends who made me laugh, also in more challenging times.

Owain is a Welsh name, when translated it’s meaning is well-born. And well-born can only relate to the environment I was lucky to be born into. A strong and supportive family with a focus on education, music and international friendships. I am very thankful for this.

I also want to thank Peter Moser, Mariaelena Murphy and Denis Kalkofen for their supervision of my thesis. Without your feedback this would not have been possible. Furthermore, I want to thank Manuel Ortega, Michael Tost and Nikolaus August Sifferlinger as well as all staff members of Montanuniversität Leoben who were involved in this process.

Our generation faces many challenges but I have a positive outlook as I believe in the good in people.

Abstract

Mining engineering education is prone to change as technological advances and new topics such as environmental considerations need to be addressed. Today's young generation can be described as digital natives but some industry professionals could improve their digital knowledge. Open educational resources for lifelong learning are seen as an opportunity to close this gap. The implementation of augmented and virtual reality in mining engineering education can also benefit new students as insight into complex mining systems is made possible. Digital field trips and 3D models of complex mining systems can enhance students learning. Analysis of open or low-cost online educational resources and the improvement of augmented and virtual reality technology lead to development of a publicly accessible immersive learning platform for mining engineering education as part of the MiReBooks project.

Zusammenfassung

Die Ausbildung im Bereich des Bergbaus muss Veränderungen aufgrund von technologischen Fortschritten und Nachhaltigkeitsthemen berücksichtigen. Die heutige junge Generation kann als "Digital Natives" bezeichnet werden, aber einige Fachleute der Branche können ihre digitalen Kenntnisse verbessern. Offene Bildungsressourcen für lebenslanges Lernen können eine Lösung darstellen um diese Lücke zu schließen. Die Implementierung von Augmented und Virtual Reality in der Ausbildung für Bergbauingenieure kann auch neuen Studierenden zugutekommen, da Einblicke in komplexe Bergbausysteme ermöglicht werden. Digitale Exkursionen und 3D-Modelle komplexer Bergbausysteme können Studierenden dabei helfen das Lernergebnis zu verbessern. Die Analyse von offenen oder kostengünstigen Online-Bildungsressourcen und die Entwicklung von Augmented und Virtual Reality führen zur Entwicklung einer öffentlich zugänglichen immersiven Lernplattform für die Ausbildung im Bergbauingenieurwesen im Rahmen des Projekts MiReBooks.

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1 Introduction

In 2023 the most up-to-date mining engineering handbook available was published in 2011 (SME, 2011, see section 4.3). Therefore, a consortium of Mining Engineering Professors from Europe under the lead of Montanuniversität Leoben have the goal of publishing new Mining Engineering Handbooks. Due to complex geology in mining (geometry, size and mineralization of deposits, in situ stresses, rock and rock mass properties) a wide variety of mine designs and layouts and therefore mining methods and mining equipment exist. To visualize these complex topics in mining an immersive learning platform is proposed. It will consist of videos, 360° videos, augmented and virtual reality (AR and VR) resources linked directly to corresponding topics in the newly published Mining Engineering Handbooks under the project acronym MiReBooks (Mixed Reality Handbooks for Mining Education).

Mining engineering education faces many challenges today but integrating sustainability and digitalisation are the most pressing issues. Digital technologies are evolving fast and are impacting mining companies, making them a fundamental part of mining (Klein, Walsh, 2017). According to Klein, Walsh (2017) the five key features on digitalisation in mining are automation and remote operation, real-time data capture, digital twins, drones and wearables. Mining engineering curricula often fall behind with the teaching of new technological advances and lack the power to improve in order to do so. Therefore, specialised lifelong learning courses could be seen as a solution to overcome this situation (Zrno, Bohanek, Šoštarić, 2021).

With the help of digital tools such as augmented and virtual reality students will have the opportunity to have a better understanding of the complexity of mining and will help them make use of these tools in their future careers. Also, researchers and professors will need to improve their understanding of the digital tools such as AR and VR and their implication on curricula (Jones, 2018). The TrainESEE project held a 5-day teaching methodology module in 2021 where one of the three main topics was the training of pedagogical implementation of augmented and virtual reality technologies into mining engineering curricula (Yaneva et al. 2021).

Modern sensors in mining produce vast amounts of data – and with current computing power – can be displayed in real time. Visualising data sets in 3D and in time will require engineers who are familiar with these technologies (Jones, 2018). Mining today is impacted by technological advances, therefore interaction between data, computer systems and humans is of paramount importance. Two main technological areas are integration and automation – the use of the Internet of Things (IoT) to create data and subsequently driving automation from the data generated (Jurgens, 2017).

Two important implementations of augmented and virtual reality are to first visualise data and then to use the ability of humans to find problems visually. The best pattern recognition and anomaly detection is currently still the human brain (Vasak, Suorineni, 2011). The creation of data with the help of sensors can be beneficial but as stated by a coal mining executive (Peterson, LaTourrette, Bartis, 2001) "Data is not as interesting as insight".

Mining engineers today need to be equipped with competences also in the field of 3D data visualisation and interpretation. The tools to create and visualise theses data need to be accessible to students and professors and data visualisation should be part of current mining engineering curricula (Kazanin, Drebenstedt, 2017).

The three steps - moving from paper to calculators, from calculators to computers and from computer visualisation to an immersive virtual reality data visualisation – can all be seen as equally big steps (Vasak, Suorineni, 2011).

The objective of this master's thesis is to find out which mining related complex topics can benefit from immersive media and to select state of the art technology to present these topics as part of the new mining handbooks.

1.1 Methodology

Mining engineering education is changing fast with evolving digital technologies. Today's generation are digital natives but mining engineering professionals who are not digital natives still lack some skills in the area of digitalisation. Current digital pedagogy often lacks immersive media like augmented and virtual reality and can be seen as an asynchronous digital twin of classical face-to-face education. The purpose of this thesis is to research digital open educational resources for lifelong learning in the area of mining engineering education, their implementation and how they make use of augmented and virtual reality. In order to analyse this, the following overarching research question was applied:

> How to enhance digital open educational resources for lifelong learning in mining engineering education?

Enhancement in the form of augmented and virtual reality can increase the learning outcome by enabling students to conceptualise complex mining systems. The analysis of existing online resources and the development of augmented and virtual reality lay the basis for the implementation of augmented reality in an immersive learning platform for mining engineers.

In Chapter 2 educational resources for lifelong learning in the area of mining engineering was analysed. For this, the term lifelong learning and its necessity will be determined and a list of available educational resources was compiled.

In Chapter 3 the development of augmented and virtual reality and especially its application in education was evaluated. This requires definitions of augmented and virtual reality as well as the investigation of the benefits of these technologies.

In Chapter 4 the concept of an immersive learning platform for mining engineering education with the help of augmented reality was established. This learning platform will be accompanying newly published mining engineering handbooks by the MiReBooks consortium.

The systematic qualitative research in this thesis aims to find a solution to implement augmented reality for mining engineering education.

2 Digital pedagogy

2.1 Introduction

The European Commission published the Digital Education Action Plan in 2018 where it proposes the following:

> *"Digital technology enriches learning in a variety of ways and offers learning opportunities, which must be accessible to all. It opens up access to a wealth of information and resources" (EC, 2018).*

Continuous education in digital technology is highly recommended for individuals to be well equipped for a highly dynamic job market. However, the implementation of digital tools in education still lags behind (EC, 2018).

The United Nations' 2030 Agenda for Sustainable Development has 17 sustainable development goals (SDGs) of which goal 4 is to "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" (UN, 2015). The United Nations did not only put emphasis on quality education but, as the title of goal 4 also includes lifelong learning, it can be seen as an important and pressing topic.

Lifelong learning is the process of continuous acquisition of experience, knowledge and skills and includes formal learning settings but also personal development through experience. The benefits are plentiful but most prominently personal development and the acquisition of transferrable skills will increase income stability as the ability to adapt will increase.

Lifelong learning provides professionals with knowledge of current developments in their respective sectors, transversal skills like critical thinking and problem-solving as well as social skills. Higher education institutions are best suited to provide lifelong learning as they are often closely linked to industry and are aware of current developments especially in engineering education. Companies have a vested interest in higher education institutions continuing to be the source of knowledge for lifelong learning (Linzalone, Schiuma, Ammirato, 2020).

Sustainability issues, safety requirements and fast evolving digitalisation topics are currently the most pressing issues and should be accessible to professionals in all fields especially in the engineering community.

Changes in industrial processes will induce the need for highly skilled professionals in new fields. For instance, coal and lignite mining in the European Union will see dramatic drops in the near and mid-term future. This is due to the fact that CO_2 emissions will need to be reduced dramatically to reach the European Union's climate change mitigation goals. Therefore, burning of coal and lignite for energy production and other processes like the Linz-Donawitz process in steelmaking will be replaced by new technologies like wind and solar power and direct-reduction processes.

Lower ore grades and the increasing complexity of underground deposits will be challenging for current and future engineers and therefore, lifelong learning could be an opportunity to overcome engineering difficulties (Bueno et al. 2020). Not only do professionals benefit from the content taught but can engage with stakeholders who have similar problems and collaborate with them in a professional setting. It can also lead to identification of problems which are then brought back to the universities for research – thus increasing their research portfolio to include the challenges that industry faces today.

Qualifying engineers for these new technological developments will require lifelong learning and/or requalification for some. Countries able to provide these services will be more resilient to a changing job market (World Bank, 2019). However, useful systems implementing lifelong learning from higher education institutions are still lagging behind (UNESCO, 2022).

Digital learning platforms such as the proposed MiRebooks platform are a low-threshold service which can be used by professionals to stay up-to-date with current developments.

Lifelong learning will also be viewed with much interest by mining companies, as they will want their employees equipped with knowledge in the field of digitalisation, data processing and data representations (Jones, 2018). Future generations of engineers will face an ever-increasing development of digitalisation. To keep up-to-date with these developments, courses which focus on these topics will be asked for by professionals as well as the companies themselves (Jones, 2018).

Changing job markets also ask for lifelong learning opportunities. One solution to overcome staff shortage could be in the form of qualifying otherwise under- and/or unqualified personnel with the help of online courses as they can be cost-effective and very specific (Jones, 2018). Establishing online resources for lifelong learning for young professionals and also undergraduates in the mining engineering sector can be seen as beneficial for many. In this chapter different technical systems, credit and/or certification and current online educational resources for mining engineering education will be highlighted.

2.2 Credit systems for lifelong learning

In order to make lifelong learning outcomes more comparable credit systems are available around the world. These credit systems are diverse and range from ECTS credits which are also used in higher education in Europe as well as specific lifelong learning credits like continuing education units (CEU) or micro-credentials (for lifelong learning and employability). The European Union`s micro-credential system still uses ECTS credits for measurement of workload but are a certification standard where all relevant information regarding the lifelong learning activity are listed (e.g. training schools, involved teachers, etc.).

“The European approach to micro-credentials offers a common definition that is valid across sectors of education and the world of work and mirrors the societal mission of education and training institutions, including higher and vocational education and training (VET) institutions, and nonformal providers as well as employers and labour market actors” (European Union, 2021).

“ECTS credits express the volume of learning based on the defined learning outcomes and their associated workload. 60 ECTS credits are allocated to the learning outcomes and associated workload of a full-time academic year. In most cases, the workload ranges from 1,500 to 1,800 hours for an academic year, which means that one credit corresponds to 25 to 30 hours of work” (EC, 2015/2017).

The International Association for Continuing Education and Training and the U.S. Department of Education defined lifelong learning credits as follows:

“One continuing education unit (CEU) equals 10 contact hours of learner interaction with the learning activity content, which includes classroom, self-paced instruction, pre/post assignments, and/or homework in support of a learning outcome” (IACET, 2018).

As can be seen above the European Union only introduced the micro-credential system for lifelong learning including short courses or training in 2021. Adaption of this system will surly take time, but as ECTS credits still lay the foundations, higher education institutions will have lower difficulties implementing micro-credentials for professional training when offering short courses or similar lifelong learning activities.

2.3 Terminology

CMS

A content management system (CMS) is a software mostly accessed via a web-interface. It is used to organise and store data like text, photos, videos and 3D models. It makes use of a graphical user interface so that the user can modify, create and upload content which is then displayed on a website. CMSs are mostly referred to when they are used in the context of websites (i.e. web content management – WCM) but they can also be used in the case of enterprise content management systems (ECM). In this thesis the term CMS will always refer to web content management and ECM (or learning management system - LMS) will be otherwise specified. All systems, CMS, ECM and LMS are browser-based software and store data on servers. The benefit is cross-platform compatibility and cloud storage. This means that all data is processed and stored on a dedicated system which is then accessible via a hyperlink on the world wide web no matter which operating system is used (Microsoft Windows, Appel MacOS, Google Android, Apple iOS or iPadOS, etc.).

LMS

A learning management system (LMS) is similar to a CMS but has specific additional features, such as courses and exams. Another important feature which CMS does not always require is the user management. This allows teachers to invite students to courses and exams, see their progress and participation as well as results from exams taken.

ECM

An enterprise content management system (ECM) is a form of CMS whereas the focus lies on collaborative management, storage and editing of files, contacts, communications and so on within a business. The main added benefit is that the processes of a business can be analysed, therefore decision-making and development of business cases can be made visible to everybody involved.

Wikipedia

The foundation of the publicly known Wikipedia is a wiki software system which is used to store and access information. The information is created in a collaborative manner. The difference to an ECM is mostly in security and access control. These features are possible to integrate but would require additional programming.

MOOC

A massive open online course (MOOC) is usually rolled out via an LMS. It is usually openly accessible but sometimes payment is required. The term "open" therefore means that the course is accessible via the worldwide web for everyone interested. A specific learning content is created in the form of a course with defined goals whereas the content can include text, videos, assignments and questionnaires or exams. The benefit for content creators is the ease of creating and updating the information and for students to freely choose courses from nearly all scientific areas as well as self-paced studying. Usually if the student wants to receive an official certificate he or she will have to pay.

OER

An open educational resource (OER) can either be in the form of Wikipedia pages, MOOCs, videos or other content. YouTube and Wikipedia are probably the biggest OERs as users can access unlimited free information. The downside is that some information lacks proof or references and therefore has to be examined with caution. Nevertheless, high quality free collaboratively created OERs is one of the most beneficial aspects of the Internet for humankind.

2.4 Historical development

One of the pioneers offering OERs is the MIT OpenCourseWare platform which was established in 2001 by the Massachusetts Institute of Technology, USA, and currently hosts over 2500 courses (https://ocw.mit.edu/, 17.05.2023). It might not have been the first platform but it is definitely the one which has had the highest impact from early on. Given that the Internet was only widely available in the 1990s, establishing an OER in 2001 with content from a higher education institution can be seen as revolutionary.

But OERs have the limitation that students lack feedback from teachers. Some MOOCs therefore implement video calls as part of their courses to increase user engagement.

Wikipedia was established in 2001 and is the first and still most popular open access encyclopaedia. It currently contains 61.044.923 articles when including all language editions. In 2005 YouTube was created where users could upload their own content. The downside is that the videos provided often lack scientific background.

Home schooling around the year 2020 further increased the need for learning platforms and video calls all around the world. Many systems were already developed but implementation in curricula of higher education lagged behind. Today lectures can be held online, in person or in a hybrid fashion. LMS are widely used and courses can be held with the help of them.

2.5 Selected mining engineering education related online resources

Edumine

The Northern Miner Group (https://www.glacierrig.com/) currently runs a multitude of mining related platforms, for example, https://www.mining.com/ which is a news company related to mining, data and analytical services and https://www.edumine.com/ (25.04.2023) which is a for-profit course platform.

Edumine provides around 160 courses directly or indirectly related to mining, mineral processing and similar topics, whereas the courses cost a minimum of $249 and go up to $449. (15.04.23) The platform hands out certificates after completion of the courses and also awards Continuing Education Units (CEU) and Professional Development Hours (PDH).

BAEKTEL project

The BAEKTEL project (Blending academic and entrepreneurial knowledge in technology enhanced learning) started in spring 2014 with consortium partners mostly from east and south-east Europe and was co-funded by the Tempus programme of the European Union. Its main goal was to establish an open educational resource in the form of online courses. Courses in the area of information technology, course material creation (structure of courses, video editing, etc.), geoinformatics, mining and environmental protection were uploaded to the platform from 2014 to 2017. The main website http://baektel.eu/ is currently no longer active, but a backup can be found at the Faculty of Mining and Geology at the University of Belgrade at http://baektel.rgf.bg.ac.rs/index.php (20.04.2023). The last snapshot taken by the Internet archive service Wayback Machine (https://archive.org/web/) when the website was still functional was in December 2021 (https://web.archive.org/web/20211218162343/http://baektel.eu/, 20.04.2023).
Via the subdomain http://edx.baektel.eu/ 34 courses were published. The edX subdomain also reveals the technology “Open edX” which was used to publish and administer the courses.

CARONTE

The CARONTE project (Continuing education and scientific information literacy on raw materials for professionals) was a project supported by the EIT RawMaterials Academy. The courses were developed as face-to-face courses and nine learning modules were created:

- Web search strategies for companies
- Deep insight into your topic
- Keep and re-find information
- Information retrieval for European project design
- Management and sharing of information in teams
- Stay updated on your topic
- Summarize the state of the art
- Find open scientific information and data
- Find researchers, working groups and organizations

The target audience of the CARONTE project were research and development managers from mining related companies.
http://www.caronteproject.eu/training (17.04.2023)

CLLEFE II

The EIT RawMaterials project CLLEFE II (Concept for Life Long Education for Foundry Employees) published information on http://www.e-cast.eu/ regarding high pressure die casting processes. E-CAST was reachable until December 2020 according to Wayback Machine. (https://web.archive.org/web/20201230020803/http://www.e-cast.eu/) The courses were hosted on https://www.easy-lms.com/ a browser-based learning management system (LMS). However, it is unclear if the course content is still accessible as the service is behind a login page. (https://participant.easy-lms.com/ecast-academy/login)

DIM-ESEE

The Dubrovnik International ESEE Mining school (DIM-ESEE) is an EU-funded education project for lifelong learning. The first classes were held in Autumn 2016 and the school is still running and is offering courses in autumn 2023. The courses are mostly face-to-face but during COVID-19 some courses were also held in a hybrid fashion. The topics change every year:

- 2016: Innovative approaches to blasting
- 2017: Zero waste management
- 2018: Deep intelligent mining
- 2019: Small mining sites – innovation in mining
- 2020: Small mining sites – innovation in exploitation and processing
- 2021: Innovation in exploration
- 2022: Innovation in process-oriented orebody characterisation
- 2023: Innovation in extraction
- 2024: Innovation in ore processing

The target audience of the DIM-ESEE are students from master and PhD programmes as well as industry professionals.
https://dim-esee.eu/ (17.04.2023)

RawMatCop Academy

The RawMatCop programme is co-funded by the EIT RawMaterials and the European Commission's Directorate General for Defence Industry and Space (DG DEFI) and started in 2017. Several projects within the programme were funded. The programme aims to create a link between earth observation and raw materials topics such as exploration and land use. In 2023 the RawMatCop Academy offers online and face-to-face courses.

- Introductory Course (16h, online, 850 € - discounts apply)
- Advanced course on earth observation for the raw materials sector (5 days, presence, 900 € - discounts apply)

https://rawmatcop.eitrawmaterials.eu/ (17.04.2023)

https://site.unibo.it/rawmatcop-alliance/en (17.04.2023)

ECLC ProSchool

The CLC-EAST Professional School offered MOOCs in the area of mining engineering as well as face-to-face sessions for industry professionals. It was tailored for east and south-east Europe and was set up by a consortium with six partners including Montanuniversität Leoben. The online resources in the form of MOOCs are no longer available.

(https://web.archive.org/web/20211208165651/https://tu-freiberg.de/en/eitrawmaterials/eclc-proschool, 19.05.2023)

TrainESEE

Twelve project partners are pursuing the TrainESEE project (Training the trainers in east and southeast Europe) which is developing four modular training workshops for mining engineering education. These courses can then be used by the project partners within their respective institutions – for example at the National Technical University of Athens. (https://trainesee2.eu/, 21.05.2023)

SusCritMat

The SusCritMat (Sustainable Management of Critical Raw Materials) project website and the some of the created content are still accessible via the project website https://www.suscritmat.eu/. The project aims to increase the understanding of critical raw materials (CRM) and what role they play in the transition to a circular economy. Learning content for some topics are still available: (https://www.suscritmat.eu/learning-content/, 19.05.2023)

- Basics of CRM
- Circularity consideration
- Governance

- Impact on Society and the Environment
- Tools

The target audience are Master and PhD students in mining or similar engineering pathways looking to broaden their knowledge in the area of CRMs, their supply risk and the necessity for a circular economy.

VRMine

The VRMine project (Integrating Virtual Reality into European Mining Education) created a digital twin of a tungsten mine site in Mittersill, Austria. With the help of virtual reality students can fulfil different tasks related to mining. The project consortium consisted of the Company Wolfram Bergbau und Hütten AG, RWTH Aachen and Taltech. The digital twin was used within the European Mining Course and the results were shared with Montanuniversität Leoben. Integration into the MiReBooks project could be pursued in the future. (https://mre.rwth-aachen.de/forschung/referenzen/vr-mine/, 19.05.2023)

2.6 EIT RawMaterials MOOCs

EIT RawMaterials

The EIT RawMaterials and the EIT RawMaterials Academy have co-funded several education projects with educational output in the area of raw materials. Table 1 provides a list of courses which were either funded by EIT RawMaterials or are listed on their website. The "EIT RawMaterials Academy Online Learning" page lists MOOCs by categories. All courses were accessible when the website was checked (https://eitrawmaterials.eu/academy/online-learning/eit-rawmaterals-academy-courses/, 18.04.2023).

Table 1: MOOCs listed on the EIT RawMaterials homepage which were co-funded by EIT RawMaterials (18.04.2023)

Category / Course Title	Platform links	Duration	Costs
Circular Economy			
Circular Economy - Sustainable Materials Management	https://www.coursera.org/learn/circular-economy/	19 hrs	free
Engineering Design for a Circular Economy	https://www.edx.org/course/engineering-design-for-a-circular-economy	~ 20 hrs	Free for duration of course, certificate for 136 €
Introduction to Metal Additive Manufacturing AM Technology	https://www.futurelearn.com/courses/general-introduction-to-metal-additive-manufacturing	3 hrs	Free for duration of course, certificate for 89 €
Additive Manufacturing for Business: Practices and Ecosystem	https://www.futurelearn.com/courses/business-opportunities-in-additive-manufacturing	6 hrs	Free for duration of course, certificate for 89 €
Intermediate Additive Manufacturing: 3D Printing	https://www.futurelearn.com/experttracks/additive-manufacturing	27 hrs	36 € /month
Critical Raw Materials			
Waste Management and Critical Raw Materials	https://www.edx.org/course/waste-management-and-critical-raw-materials	30 hrs	Free for duration of course, certificate for 136 €
SusCritMat - Sustainable Critical Raw Materials	https://suscritmat.eu/video-learning-content/	N/A	free
SusCritMat - Managing Resources for a Sustainable Future	https://www.edx.org/course/critical-raw-materials-managing-resources-for-a-sustainable-future	36 hrs	Free for duration of course, certificate for 136 €
Entrepreneurship & Innovation			
Teach like an Entrepreneur	https://www.futurelearn.com/courses/teach-like-an-entrepreneur-bringing-entrepreneurship-into-the-classroom	16	Free for duration of course, certificate for 84 €

RM TechFlow - Professional training course for Researchers	https://rmtechflow.eitrawmaterials.eu/online-courses	3 hrs	Free
RM TechFlow - Professional training course for Tech Transfer Personnel	https://rmtechflow.eitrawmaterials.eu/online-courses	3 hrs	Free
Mining			
Small Mining Sites: Innovation in Mining	https://dim-esee.eu/dim-esee-2019/	N/A	N/A

Furthermore, MOOCs from partners from the EIT RawMaterials community are given in Table 2.

Table 2: MOOCs listed on the EIT RawMaterials homepage which were published by EIT RawMaterials partners (18.04.2023)

Category / Course Title	Provider	Platform links	Duration	Costs
Circular Economy				
A Circular Economy of Metals: Towards a Sustainable Societal Metabolism	Leiden University	https://www.coursera.org/learn/circular-economy-metals	N/A	free
Design				
Lightweight Design	RWTH Aachen University	https://www.edx.org/course/lightweight-design	54 hrs	Free for duration of course, certificate for 127 €
Digitalisation				
Seven Key Skills in the Digital Era	Polytechnic University of Madrid	N/A, Spanish language - https://miriadax.net/web/siete-habilidades-clave-en-la-era-digital-3-edicion/inicio	N/A	N/A
Engineering				
Basic Terms of Mechanics for Technical Applications	Montanuniversität Leoben	German language - https://imoox.at/course/mech22	12 hrs	free

Entrepreneurship & Innovation				
Business Model Thinking	Coventry University	N/A - https://www.futurelearn.com/courses/business-model-thinking	N/A	N/A
Uncovering Your Entrepreneurial Potential	Coventry University	N/A - https://www.futurelearn.com/courses/uncovering-your-entrepreneurial-potential	N/A	N/A
Entrepreneurship for Engineers	TU Delft	https://www.edx.org/course/entrepreneurship-for-engineers	20 hrs	Free for duration of course, certificate for 90 €
Responsible Innovation: Building Tomorrow's Responsible Firms	TU Delft	N/A - https://online-learning.tudelft.nl/courses/innovation-strategies-for-socially-responsible-firms/	N/A	N/A
Starting Up	Aalto University	https://courses.minnalearn.com/en/courses/startingup/	N/A	Free
Introduction to the Innovation Economy	University of Bordeaux	French language - https://www.my-mooc.com/en/mooc/introduction-a-leconomie-de-linnovation/	21 hrs	Free
Venture Capital	RWTH Aachen University	https://www.edx.org/course/venture-capital	38,5 hrs	Free for duration of course, certificate for 90 €
Thinking & Acting like an Entrepreneur	RWTH Aachen University	https://www.edx.org/course/thinking-acting-like-an-entrepreneur-2	42 hrs	Free for duration of course, certificate for 181 €
Innovation and Creativity Management	RWTH Aachen University	https://www.edx.org/course/innovation-and-creativity-management	42 hrs	Free for duration of course, certificate for 181 €

Customer-Centric Innovation	RWTH Aachen University	https://www.edx.org/course/customer-centric-innovation	42 hrs	Free for duration of course, certificate for 181 €
Understanding Venture Capitalists: How to Get Money for Your Start Up	RWTH Aachen University	https://www.edx.org/course/understanding-venture-capitalists-how-to-get-money	21 hrs	Free for duration of course, certificate for 90 €
Entrepreneurs without borders	Politecnico di Milano	https://www.pok.polimi.it/courses/course-v1:Polimi+EWB101+2022_M10/about	22,5 hrs	free
Designing and Implementing Effective Entrepreneurship Policies	Politecnico di Milano	https://www.pok.polimi.it/courses/course-v1:Polimi+EEP101+2022_M7/about	6 hrs	free
Materials Science				
Introduction to the Science of Biomaterials	Polytechnic University of Madrid	N/A, Spanish language - https://miriadax.net/web/introduccion-a-la-ciencia-de-biomateriales-6-edicion/inicio	N/A	N/A
Recycling				
ConstruiREcycler	University of Liège	N/A	N/A	N/A
Sustainable Development				
Achieving Sustainable Development	Trinity College Dublin	https://www.futurelearn.com/courses/achieving-sustainable-development	16 hrs	Free for duration of course, certificate for 119 €
Greening the Economy: Sustainable Cities	Lund University	https://www.coursera.org/learn/gte-sustainable-cities	9 hrs	free
Greening the Economy: Lessons and Experiences from Scandinavia	Lund University	https://www.coursera.org/learn/greening-the-economy	15 hrs	free

The UN Sustainable Development Goals: an Interdisciplinary Academic Introduction	KU Leuven	https://www.edx.org/course/the-un-sustainable-development-goals-an-interdisci	28 hrs	Free for duration of course, certificate for 45 €
Higher Education for Sustainable Development Goals	Politecnico di Milano	https://www.pok.polimi.it/courses/course-v1:Polimi+HE4SDGs+2022_M12/about	9 hrs	free

2.6.1 List of MOOC platforms hosting mining related content

The following platforms are currently hosting courses in the field of mining or related to mining, such as mineral processing or critical raw materials:

Global platforms

- FutureLearn – online courses from top universities (https://www.futurelearn.com/)
- Coursera (https://www.coursera.org/)
- edX (https://www.edx.org/)
- My Mooc (https://www.my-mooc.com/en/)

Region-specific platforms

- iMooX (https://imoox.at/page/about)
- FUN MOOC (https://www.fun-mooc.fr/en/)

MOOCs from specific universities

- TU Delft Online Learning – edX (https://online-learning.tudelft.nl/)
- Politecnico di Milano Open Knowledge MOOC OPEN edX (https://www.pok.polimi.it/)

2.7 Online learning: asynchronous compared to synchronous learning paths

When comparing online and in-person learning settings the differences fade with the existence of video conferencing. Historically synchronous learning paths were only possible when students and teachers were in the same room, whereas today's high-speed Internet connections provide the opportunity to meet by using computers or smartphones. Still, most teachers prefer lecturing in person as they receive more feedback from the students. On the other hand, MOOCs or similar online teaching processes can be seen as an opportunity for independent asynchronous learning paths, meaning the student can acquire knowledge (mostly within a given timeframe) at a pace that suits him or her best. But these asynchronous opportunities also have two main limitations: accessibly to content and completion rate.

Project sustainability and accessibility to online courses

As the lists above show, many different projects directly related to mining engineering education were carried out. Nevertheless, most projects did not continue after funding ended. Some projects, which have a high continuous workload to keep successful and therefore need some sort of financial backflow, have not prevailed. OER, for example in the BAEKTEL project, should be accessible for a long lifetime as running costs are low. Sadly, the created content is no longer available but only accessible via the Internet Archive. All courses still available via the EIT RawMaterials website are hosted on dedicated learning platforms such as coursera, futurelearn or edX.

User engagement in MOOCs

MOOCs lack user engagement and are often not completed by the participants. Completion rates are as low as 13% (Onah, Sinclair, Boyatt 2014). Different strategies exist to motivate users to complete courses, of which gamification and enrolment fees are two. Probably the most well-known example for gamification of MOOCs is the language training app Duolingo (https://www.duolingo.com/, 21.05.2023). It offers free language courses and, with the help of rewards, users are motivated to engage on a daily basis. Another way to motivate users to complete a course could be in the form of payment for the course.

2.8 Section conclusion

Digital educational resources in the area of mining engineering education are dominated by Edumine which is run by a profit-making organisation and access to the courses requires a paid subscription. The European Union with its EIT RawMaterials funding scheme supported numerous education projects, either related to open education resources or augmented and virtual reality in mining engineering education. Two main problems arise when looking at these projects: first financial sustainability is not given, therefore the results from these projects are often not used, and secondly for MOOCs, even if they are still available, the courses lack user engagement and it is not clear whether support from teachers is available. An open educational resource platform in the area of mining engineering could be established and sustained with minimal running costs. The benefit of open access is low maintenance and high user engagement. The best example is the MIT OpenCourseWare which was already established in 2001 and hosts more than 2500 freely accessible courses. Open educational resources can be seen as free lifelong learning opportunities especially for non-digital natives and/or learners from a low socioeconomic background.

“Education is part of the foundation of all progress and growth, both as an individual and as a society.” (anonymous)

3 Augmented and virtual reality in education

3.1 Introduction

Augmented and virtual reality are types of immersive media. The media is displayed with the help of screens – either in the form of computer displays, television, mobile phones or dedicated hardware like head mounted displays (HMD, see 3.2). The media was either created on the basis of videos and photos or artificially created with the help of computers. The rapid development of computer systems, especially HMDs and mobile phones lead to a new level of immersion. HMDs and mobile phones have built-in accelerometers and gyroscopes thus making it possible for users to change perspective within a three-dimensional environment by just moving their head (sometimes hand movements can also be recognised and serve as interactive input). HMDs have made users feel over three times more immersed into the computer displayed environment (Hui Zhang, 2017). Mining and mineral processing plants are complex systems and students should be able to envision the complexity already during training. But field trips are often not possible due to costs or safety considerations therefore augmented and virtual reality can offer a first insight into the mining sector.

Lampropoulos, Keramopoulos (2022) conducted a keyword search via the twitter application programming interface (API, see 3.2) with augmented and virtual reality and education related keywords. They found 10.157.427 tweets related only to augmented and virtual reality and 299.917 which were additionally related to education. The tweets regarding augmented and virtual reality peaked in 2016 and the augmented and virtual reality tweets which additionally included education keyword peaked two years later in 2018.

The peak interest in 2016 coincides with the release of a popular augmented reality game and the availability of an HMD which had high resolution screens and advanced positional and movement tracking.

In this chapter the benefits and limitations of augmented and virtual reality compared to classical computer screens and/or physical attendance are analysed.

3.2 Terminology

Augmented Reality

Augmented reality is the technology in which virtual or digitalised real objects are rendered and displayed on either translucent displays or displays which show the surrounding environment with the help of cameras. Therefore, the user can interact with objects in the real-world environment making use of the processing power and sensors of modern handheld devices like mobile phones and tablets or HMDs.

Virtual Reality

Virtual reality is similar to augmented reality but the user is fully immersed into the computer displayed environment. Also, handheld controllers can add to the virtual environment experience by giving feedback to the user, for instance in the form of vibrations. Typically, HMDs are required for this technology, but also 360-degree room-filling computer screens can be seen as a virtual reality experience.

HMD

Head mounted displays are either only computer displays making use of the processing power of a normal computer or a full standalone device with integrated software similar to a mobile phone. There are a variety of HMDs available, motion and location sensors can either be built into the HMDs or are positioned within close proximity within the room. Cameras can also be built-in to make augmented reality possible – but this technology is just emerging. They can either fully immerse the user when they block vision to the surrounding environment or they are built just to augment the vision with small screens to display information – leaving most of the field of vision free to the real world.

Mixed Reality

In 1995 Milgram et al. proposed the term mixed reality (MR) (see Figure 1) in order to describe “the spectrum between the real environment and a virtual environment”. The proposed mixed reality, however, does not include full virtual reality experiences like computer games (with or without HMD) or real environments that are experienced by a student on a field trip. As this thesis mainly discusses either virtual reality or augmented reality the terminology mixed reality does not prove helpful as it excludes virtual reality. Therefore, in this thesis virtual and augmented reality will always be written out.

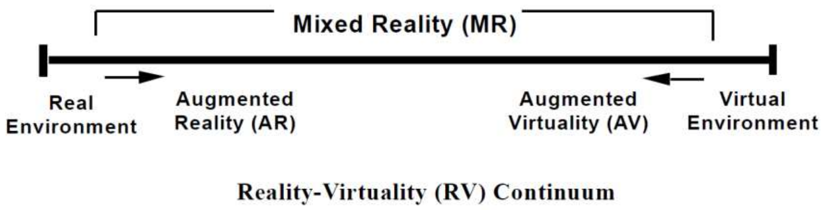

Figure 1: Reality-Virtuality (RV) Continuum (From Milgram et al. 1995)

API

Application programming interfaces is the standardisation of communication between software. For instance, when generating a 3D model, the browser on a mobile phone exchanges information with the website where the 3D model is hosted. This information can be a type of operating system or mobile phone model information. The exchange of information leads to either positive results in generating the model or can lead to neglecting the request because, for instance, the mobile phone does not fulfil minimum requirements to process the 3D model.

Web-based augmented reality

Web-based augmented reality can be seen as a breakthrough as it has a low entry point for users. Most importantly users do not have to install a dedicated application on their smartphones and developers can publish augmented reality tools without the need of programming an app and make it available to different systems like iOS and Android (mobile phone operation systems). This helps to overcome the fact that some users refrain from installing an application or to retain it on their systems (Garzón, 2021).

WebGL

On the basis of the programming language JavaScript the API WebGL uses the processing capabilities of devices to render 3D models. In most browsers it is built-in and is managed by the Khronos Group. It is the most common standard for rendering (generating graphics from data) images and 3D models.

WebXR

WebXR is a standard which makes use of WebGL and WebGL 2 and is pursued by the Word Wide Web Consortium (W3C). It is an application programming interface (API) for accessing augmented and virtual reality content with mobile devices. This standard is the communication basis between input parameters and output visualisations. For instance, if the user tilts its head with an HMD or tilts a mobile phone, the built-in sensors of the device detect these movements. In order to adjust the output on the screens these signals must be processed. The communication between the virtual environment and the input and output parameter is standardised via the WebXR API. This is a relatively new standard, and as Rodríguez, Peraro, Abriata (2022) have stated, it assures cross-device compatibility.

ARKit

Although WebXR and the underlying WebGL standard are developed with the help of all major players like Google, Samsung and Meta the operating system iOS from Apple does not natively support it. Apple uses its proprietary augmented and virtual reality toolkit under the name ARKit. (https://www.protocol.com/entertainment/apple-webxr-ar-ios-iphone, 18.05.2023)

3.3 Historical development of augmented and virtual reality

The first HMD introduced was called the “Sword of Damocles” described in the paper “A head-mounted three dimensional display” and was developed by *Sutherland and Sproul* (see Sutherland, 1968). It projected wireframe images onto see-through cathode ray tubes and is therefore a form of augmented reality display as the user could also see the surroundings (see Figure 2).

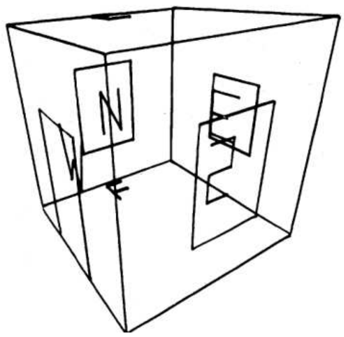

Figure 2: Image which was presented to the viewer (from Sutherland, 1968)

Even though the projection itself is 2 dimensional it changes as users move their head in different directions. This effect is able to convince users to see a 3-dimensional object described as “kinetic depth effect” already in 1968 by Sutherland.

Since that time a vast number of HMDs have been developed but one problem was that the technology had not yet reached a point where the immersion could be seen as complete (Tibbett, Suorineni, Hebblewhite, 2015). The first commercial HMD which had a substantial impact was the Oculus Rift which was available to the public in spring 2016 (see Figure 4). The new HMD generation was able to track movement of individuals making the displayed content more immersive.

While virtual reality always relies on dedicated hardware to display projections either of virtual or recorded environments, augmented reality can be delivered with the help of many different devices. An HMD with either cameras or see through lenses like the “Sword of Damocles” can project images whereas the user can either still see the environment or a projection of it with the help of cameras. One example for dedicated modern augmented reality HMD would be the Google Glass whose first iteration was made available in spring 2013 (see Figure 3). Nevertheless, a commercial breakthrough did not happen and Google Glass was discontinued in March 2023 (https://www.google.com/glass/start/, 24.04.2023).

Figure 3: Google Glass (from Wikipedia, Mikepanhu CC BY-SA 3.0)

Figure 4: Oculus Rift Consumer Version 1 (from Wikipedia, Evan-Amos, public domain)

A far cheaper and user-friendly approach to augmented reality is the delivery with the help of smartphones. Here the breakthrough and continuous success can be seen in mobile games, especially the release of Pokémon Go (https://pokemongolive.com/, 21.05.2023) in July 2016. Mobile augmented reality makes use of the processing power and the cameras of a smartphone.

The historical development of AR can be seen in three steps from hardware-based, like the Sword of Damocles from Sutherland, to application-based like Pokemon Go and to the emerging web-based augmented reality standard WebXR – which will probably be a game changer in augmented reality development (see Figure 5) (Garzón, 2021).

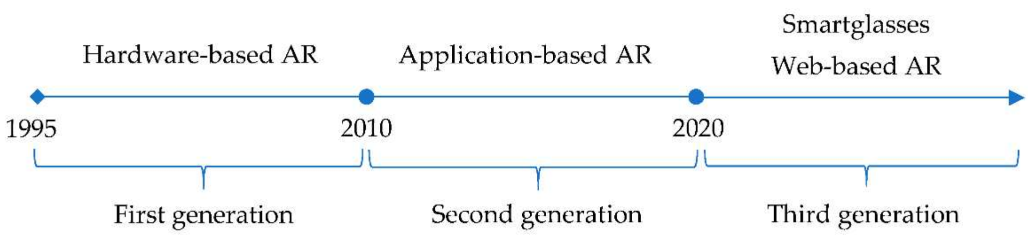

Figure 5: Three generations of augmented reality in education (from Garzón, 2021)

3.4 Benefits of augmented and virtual reality systems in education

Modern mobile phones and standalone HMDs have high processing power, high quality displays, built-in Gyroscopes, accelerometers and sometimes hand movement tracking. These are prerequisites for highly responsive and a realistic display of augmented and virtual reality. This technology allows users to be immerse into new worlds. Two main benefits arise from this technology – better insight into data and complex systems compared to classical computer screens and partial cessation of physical attendance. Another benefit in education is that augmented reality can lower the threshold to otherwise inaccessible experiences, especially for the visually and hearing impaired as well as people with physical and/or intellectual disabilities. This is due to multiple factors, either text-to-speech or speech-to-text conversions, improved social interactions or the fact that less physical interaction with the computer system is needed (Garzón, 2021).

3.4.1 Augmented and virtual reality compared to classical computer screens

"Virtual reality visualization has opened new opportunities for complex 3 dimensional (x, y, z), 4 dimensional (x, y, z, t) or even nD data interpretation" (Kaiser et al., 2005). Therefore, spatiotemporal data visualisation can benefit mining due to everchanging conditions underground (Vasak, Suorineni, 2011). Virtual reality can serve as a quality control system for data acquired from sensors in a mine (Vasak, Suorineni, 2011). Furthermore, virtual reality can be used in all stages of mining from mine planning to mine closure, bring together experts from all areas and display relevant data (Vasak, Suorineni, 2011). Virtual reality can help to interpret data from underground mining such as block caving. Seismic data from underground operations can be visualized in time and in space, which leads to improved data interpretation and prediction (Kaiser et al., 2005). Computer-based data visualization is limited as users cannot have a full 3D experience – limited by computer screens. With augmented and virtual reality technology users are able to change the perspective and scroll through the data. This has significant benefits as 3D perception and interpretation to humans is often difficult when only presented on a computer screen (Tibbett, Suorineni, Hebblewhite, 2015).

Computer displays are non-immersive compared to augmented and virtual reality systems and are less suited to show users multidimensional data. The usual interaction of a user is a 2-dimensional projection of 3-dimensional data. The benefit of the augmented and virtual reality systems is for an enhanced display of data in both space and time, making data visualisations quick and user-friendly. This requires high computational power and user interaction – both possible today with virtual reality systems like Oculus Quest 2 for virtual reality or modern mobile phones with higher computing power than average (Bryson, 1996). In the future, engineers will have the possibility to retrieve, visualise and interpret data from underground mining systems in real time. Whereas augmented and virtual reality will play an important role for the engineers to have an even more detailed picture of the current situation underground (Tibbett, Suorineni, Hebblewhite, 2015). The 4-dimensional data representation with the help of augmented and virtual reality technology can also be used to show predictions and future scenarios (Jones, 2018).

But some limitations exist. For one, accessibility to augmented and virtual reality experience can be difficult for some as modern mobile phones with high processing power or specialised HMDs are necessary. A further limitation is that if more than one person uses HMDs to experience virtual reality, there is a lack in the sense of what the other persons are seeing (Tibbett, Suorineni, Hebblewhite, 2015).

3.4.2 Augmented and virtual reality compared to physical attendance

Situated learning gives students experience in a virtual setting or safe real setting. The setting will let students interact with the environment thus creating a deeper understanding of the topic. Nevertheless, situated learning with regard to mining and making use of augmented and virtual reality technology is still underrepresented. This is partly due to the fact that creating these environments is hard to achieve – as interaction with objects in a digital setting requires precise physics and special representation in order for users to acknowledge the learning experience. Still, augmented and virtual reality can provide situated learning experiences when they are implemented properly and therefore create a ‘close to the real environment situation’ for the users (Dede, Jacobson, Richards, 2017).

Allowing students to experience a mine site can be difficult, costly and dangerous. But to fully understand how a complex mining system with extraction, hauling and processing works, and to see how the environment is impacted, a mining engineering student should have a minimum amount of either practical training or mine site visits. Sometimes this is not possible or hardly achievable and augmented and virtual reality tools can build a bridge for students to experience a mine visit.

Similarly, Arvanitis et al. (2017) argue that a virtual setting for experiments which would otherwise not be possible to execute within the school building can benefit students. Lack of adequate training is often the root cause of fatal and non-fatal accidents according to the U.S. Mine Safety and Health Administration (MSHA). Lack of practical training could therefore be overcome with the help of digital tools such as augmented and virtual reality (Orr, Mallet, Margolis, 2019).

Augmented and virtual reality can give students the opportunity to experience spaces with no risk, that are either difficult to reach or are otherwise not accessible due to the dangers originating from underground mines such as rock fall, rock bursts, etc. (Daling et al., 2022).

In addition to being able to provide valuable insight into otherwise inaccessible areas the technology can also serve in a remote teaching setting. With the help of tools such as augmented and virtual reality, teachers or trainers can interact with students also if they are not physically present. Making dialogue possible with the help of video conferencing also reduces the impact on the environment where, especially in mining with remote operations, this is of great interest (Bergamo, et al., 2022).

3.5 Section Conclusion

The definition of both augmented and virtual reality is easy but attempts to find a single word to represent both experiences have not yet yielded positive results and therefore both words are used separately.

Augmented and virtual reality systems date back as far as 1968. But only in 2016 was a breakthrough for these technologies achieved. Therefore, 48 years of technological development was needed to achieve acceptable immersive media.
This is mainly due to the tremendous development of the processing power of computer chips and miniaturisation of components such as accelerometers and gyroscopes. The benefits of augmented and virtual reality are manifold. Be it multidimensional data visualisation, virtual access to remote and/or dangerous areas or increased insight to complex systems.

4 Immersive Learning Platform

4.1 Introduction

The analysis of the existing implementation of augmented and virtual reality in education provides the foundation for the creation of an immersive learning platform. Building the platform involves multiple considerations such as design, navigation, feature application and technical requirements. The selection of an appropriate software is the foundation of being able to implement all prerequisites. The path from 3D model to augmented reality involves multiple steps and the technical realisation requires knowledge of computer systems and intercomputer communication protocols. Delivering 3D models with the help of web-based augmented reality will make programming of a dedicated application unnecessary. This solves numerous problems such as session synchronisation between the application and the website, programming effort and application deployment to different operating systems such as Android or iOS.

4.2 Terminology

Hyperlinks

Hyperlinks are text elements which refer to a digital resource. They can be used to refer between points of a document or Internet resources like websites on the world wide web. The user usually interacts with them by clicking and therefore accessing the resources. A hyperlink in form of a URL (uniform resource locator) links to resources on websites or other digital media.

Redirects

Internet redirects were established for multiple purposes. Either to inform the user if a webpage was deleted or moved, or to redirect the user to a new page.

Permalinks

Permalinks are links to online resources that are intended to never change. One example for a link that does not change are DOIs – digital object identifiers. Permalinks in the form of URLs link to websites with the intention of keeping them unchanged.

Front-end and back-end

These terms refer to work related to websites. While front-end is the work (programming) related to the visual aspect of a website, back-end is the term used for work related to the servers and infrastructure behind a website.

UI and UX

UI refers to the term user interface and UX to user experience. User interface on a website are usually menus and interactive media like videos and photos. User experience refers to the look and feel of a website – which includes but is not limited to colour scheme, responsiveness and typography.

Web component <model-viewer>

The web component <model-viewer> from Google helps to process 3D models. In order to make use of <model-viewer> the component has to be imported and then it can be used like any other HTML element (see Figure 6). The benefit of using <model-viewer> is that it is able to convert 3D model filetypes for Android and iOS operating systems.

```
<!-- Import the component -->
<script type="module" src="https://ajax.googleapis.com/ajax/libs/model-viewer/3.1.1/model-
viewer.min.js"></script>

<!-- Use it like any other HTML element -->
<model-viewer alt="Neil Armstrong's Spacesuit from the Smithsonian Digitization Programs Office
and National Air and Space Museum" src="shared-assets/models/NeilArmstrong.glb" ar
environment-image="shared-assets/environments/moon_1k.hdr" poster="shared-
assets/models/NeilArmstrong.webp" shadow-intensity="1" camera-controls touch-action="pan-
y"></model-viewer>
```

Figure 6: From https://modelviewer.dev/, ©Copyright 2018-2021 Google Inc. Licensed under the Apache License 2.0 (25.04.2023)

3D model data formats for Web-based AR

Most commonly the filetype ".glb" (Binary Graphics Language Transmission Format) is used as it includes all textures and mesh data whereas, ".gltf" (Graphics Language Transmission Format) has support files making it more complex to handle. Nevertheless, both file types have been supported natively in Chrome browsers for Android operating systems as of late 2019 (https://developer.chrome.com/blog/new-in-chrome-79/#webxr, 20.04.2023). On the other hand, Apples iOS has used the file format USDZ (Universal Scene Description, compressed Version) since September 2017 (https://en.wikipedia.org/wiki/IOS_11, 20.04.2023). But Support for browser-based augmented reality with the help of AR Quick Look on the basis of ARkit only emerged in October 2020 (https://cwervo.com/writing/quicklook-web/, 20.04.2023).

QR Codes

QR codes are black and white matrix images containing information in the form of text. If a modern mobile phone or tablet scans the code with the built-in camera it can extract information. It is most widely used to store hyperlinks to websites but can also be used to store other forms of text like business cards or simply text. The matrix can be modified in size to store more information or to include error detection.

4.3 Current Situation

Mining Education Handbooks

The most recently published mining education handbook is probably the 2011 "SME Mining Engineering Handbook 3rd edition" by the Society for Mining, Metallurgy, and Exploration (SME, 2011). The handbook comprises two volumes that cover nearly all areas related to the mining sector and is the follow up publication to the 1992 handbook. Other handbooks covering a similar broad perspective on mining that were published within the last 20 years were not found.

Similar Immersive Learning Experiences

The "Österreichische Bundesverlag Schulbuch" offers some schoolbooks for K-12 education which are enhanced with digital content such as videos and questionnaires. Digital content can be accessed with a code printed on to the physical books thus making the online resources not publicly accessible. Download and use of an application is also possible and is most beneficial for language courses as all listening tracks are always available. (https://www.oebv.at/digi4school, German, 18.05.2023)

The company DEVAR tech also offers digitally enhanced books for children. For the use of augmented reality, a dedicated application must be downloaded. The benefit is that all 3D models can be pre-downloaded making high speed Internet unnecessary while exploring the digital content. (https://catalog.devar.tech/, 21.05.2023)

Other immersive learning examples include, but are not limited to, virtual reality only experiences (lacking accompanying textbooks) such as ClassVR (https://www.classvr.com/, 18.05.2023) or augmented reality only experiences such as Anatomage (https://anatomage.com/, 18.05.2023). ClassVR offers a multitude of learning experiences mainly for K-12 education whereas Anatomage offers virtual dissection for medical students which greatly reduces costs and makes procedures repeatable.

4.3.1 Augmented and virtual reality projects in Mining Engineering Education

The MireBooks project consortium consists of 12 European partners from universities to industry in the area of mining. Its goal is to publish digitally enhanced textbooks for mining engineering education. "Many current challenges in mining education will be confronted in an innovative way, by combining classical paper-based teaching materials with MR materials and their transformation into pedagogically and didactically coherent MR handbooks for integrative classroom use" (https://mirebooks.com/about-project/, 20.05.2023). The project lasted from January 2019 until December 2021 and produced numerous applications either for augmented or virtual reality. Currently the publication of the first handbook is foreseen for 2023 accompanied by a digital learning platform.

Next to the MiReBooks project only a few projects were found which make use of virtual reality for mining engineering education.

Hui Zhang (2017) was probably the pioneer for HMD virtual reality training for mining engineering education. He made use of a mobile phone which was inserted into a head mount. The student was then tasked with a simple drilling operation in virtual reality.

Bellanca et al. (2019) developed a framework for virtual reality development mainly for safety considerations, and performed case studies in self-escape and proximity detection. They point out that the framework can be adapted to numerous mining scenarios and virtual reality models can be created rapidly.

Isleyen, Duzgun, (2019) created a virtual reality environment where students can determine and counteract against roof fall hazards. They can make use of various and adaptable rock support systems to counteract against roof fall hazards. They mentioned that students who go through this training will better manage dangerous situations.

Suppes, et al. (2019) describe a virtual reality mine developed for HMD where users can access a digital replica of the Wolfram mine site in Mittersill, Austria. The authors envision that the concept of virtual reality mine visits and/or training can be implemented worldwide in mining engineering curricula making available numerous digital replicas of mines.

Gibson et al. (2022) designed a copper mineral processing plant, where students have to identify and solve a problem related to the pulp density. They highlighted the fact that students had limited field trip experience and that the technology is beneficial to show students the complexity of a mineral processing plant.

4.4 Platform building

The MiReBooks will be accompanied by digital content such as videos, links to websites as well as, but not limited to, augmented and virtual reality assets. In order to keep all digital content accessible and available as long as possible they will be integrated in the form of embedding or redirects directly on the project website https://www.mirebooks.com/. The website will therefore host digital assets in the area of mining and mineral processing that are directly related to the printed textbooks.

4.4.1 Immersive media for mining engineering education

Mining is a complex system of machines, humans and rock mass as well as considerations of environmental, legal and financial aspects. In order to prepare future engineers to understand the complexity of mining, digitally enhanced textbooks can help students identify problems in mining. Videos for instance can help students understand how machinery moves in space and time or how a blasting operation works and if it was successful. 3D models on the other hand can be seen as a form of immersive media where students have the possibility to explore either machinery and/or a digital replica of a mine.

4.4.2 Content delivery for digital objects

The MiReBooks reference many different Internet sources. The most sources are Youtube videos and websites. Internet hyperlinks in form of URLs and/or content stored on websites are prone to changes and deletion. To overcome this limitation all Internet sources will run via the MiReBooks website. Every online resource will be assigned a four-digit code. This four-digit code will then be used in URLs. For instance, the first online resource in the first book could receive the four-digit number 1001. This four-digit number is then added to the URL https://www.mirebooks.com/ in this form https://www.mirebooks.com/1001. The user therefore has the possibility to access every digital content by simply adding the four-digit code to the end of the MiReBooks website URL.

In order to save the user manually entering every website address, the hyperlinks https://www.mirebooks.com/XXXX (X=0-9) accompanying each online resource are also made available in the form of QR codes which can be processed with the help of smartphones or tablets. Therefor users have the possibility to access the online resource either with the help of QR codes or by entering the URL into a browser (see Figure 7).

Figure 7: QR code, leading to https://www.mirebooks.com/1002

4.4.3 Feature considerations

In this stage multiple considerations can be made. For instance, if a user login is established either from the beginning or at a later stage a comment function can be integrated. This, however, will need supervision in order to counteract misinformation and hate speech. Benefits on the other hand could be community building and exchange of knowledge and information with a low entry point. If researchers and qualified professionals interact with different topics, new knowledge and cooperation could be created.

Another possible feature of the website could be the placement of advertisements from industry partners. This feature should be implemented from the beginning, even if there is lack of interest to place advertisements, because programming efforts later could impact the sites UX. As a placeholder an advertisement for the MiReBooks could be placed.

A keyword search engine is also recommended right from the beginning. The benefit of this feature is that every subsite or blogpost can be found much more easily if keywords for each topic are created.

4.4.4 Layout and navigation

The basic concept of the platform including a general layout was developed for the MiReBooks project. This includes the general structure, navigation and technical requirements. For the general structure a wireframe was created which is a visual representation of the main website page (home) and a content site.

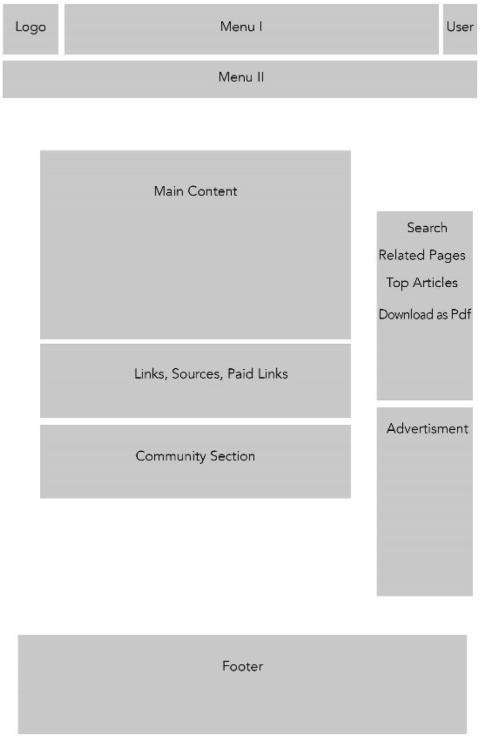

Figure 8: Wireframe for the main page of the MiReBooks website (own figure)

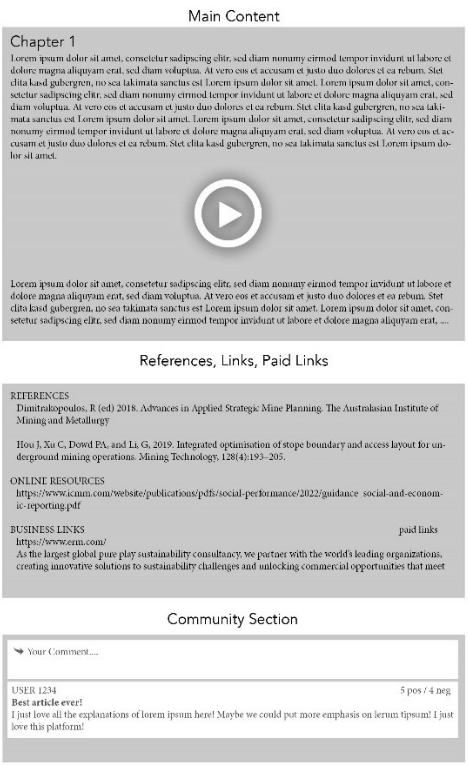

Figure 9: Wireframe for a content site of the MiReBooks website (own figure)

The basic layout is orientated towards most websites with the menu on the top, the main content in the middle and some further elements like related content and advertisements on the right-hand side (see Figure 8). If looking at the layout for digital content such as a video, descriptive text elements both on top and bottom can be implemented (see Figure 9). Below the digital content references, links to other online resources and paid links could be realised. At the bottom a community section could be set up in order to increase user engagement.

For the navigation a two-way navigation is proposed. Either the user can explore the digital assets by a topic-based navigation menu or by a list-based navigation. In the case of a topic-based navigation menu items could be, but are not limited to, sustainability, mine planning, reclamation and other mining related topics (see Figure 10). Within these topics, subtopics, and then finally the digital content, can be accessed. The list-based navigation on the other hand is driven by content type. A user for instance is actively looking for 3D models related to mining or mineral processing to obtain a deeper understanding of how specific machinery works. When using the list-based navigation the user is presented with the possibility of receiving a list with all 3D models and can further limit search results to, for instance, extraction machinery (see Figure 11).

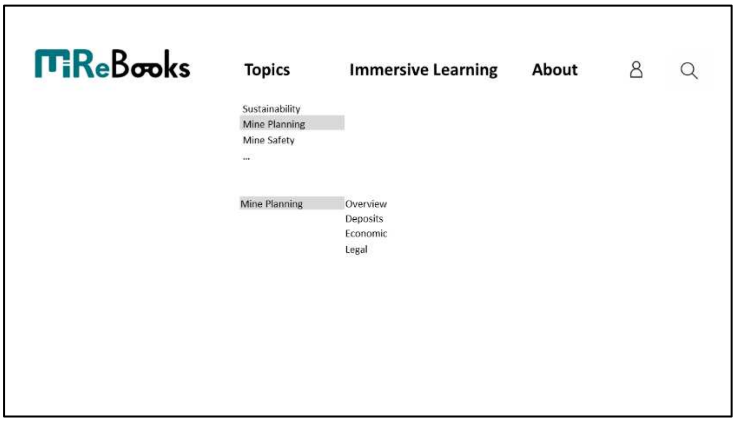

Figure 10: Example for a topic-based navigation (own figure)

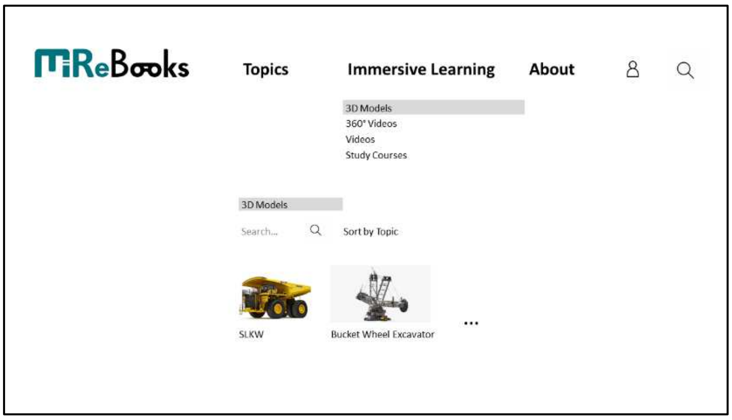

Figure 11: Example for a list-based navigation (own figure)

The benefit of this two-way navigation is that on the one hand a user can explore different mining related topics and can get a good overview. But some users specifically want to explore digital content like videos directly related to a specific topic in mining and can easily find results.

4.4.5 Features and their technical requirements

Design and functionality features most often require certain technical requirements in order to function. Theses technical requirements are often directly covered by the use of a CMS. For instance, every CMS as the name suggests has a built-in content management in which a user can - usually with the help of a graphical user interface (GUI) – manage pages, blog posts and rich media (see Figure 12).

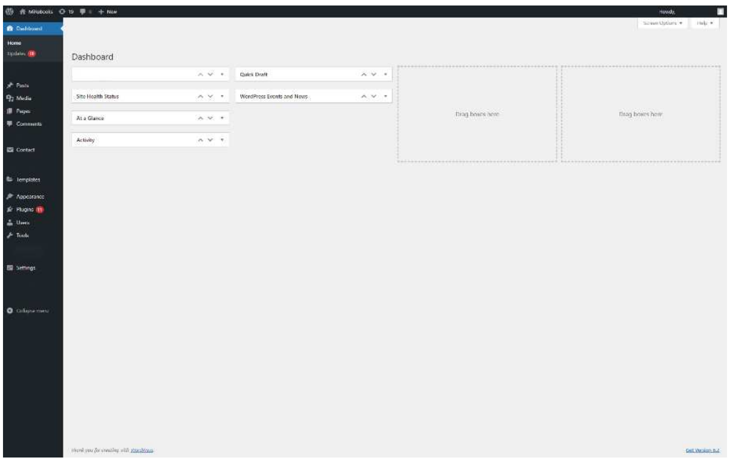

Figure 12: WordPress GUI used by MiReBooks project website (From https://wordpress.org/, GNU General Public License, version 2)

CMSs have usually the built-in capability to host, manage and display images and videos on websites. The MiReBooks website on the other hand will need to be able to host 360° videos and 3D models for an immersive learning experience – which requires special APIs and/or web components like Google's <model-viewer>.

Special technical implementations are also required for a keyword search engine and advertisements. For advertisements popular services like Google Ad Manger exist but have to be thoroughly considered. On the one hand handling and monetary reimbursement are easy but on the other hand privacy and ad blocking by users have to be examined closely. Another limitation of using ad services is that the monetary reimbursement is controlled by the ad service rather than by the company itself. If advertisement areas on the MiReBooks website are self-organised (Hosted Ads) the project consortium can control payment and with some technical knowledge trick out popular ad blocking services like AdBlock Plus.

4.4.6 CMS selection

The platform will be developed with the help of a CMS. Many different open source CMSs for websites exist, but if certain features are required a subscription is often necessary. The biggest and most well-known CMS for websites is WordPress. It has a market share of 63,3 which accounts for 43,1% of all websites (see Table 3) (https://w3techs.com/technologies/overview/content_management, 16.05.2023). Many considerations are made when selecting a CMS, the most prominent is probably the handling itself – how easily content can be created and managed. What You See Is What You Get (WYSIWYG) is the concept of directly editing a website content such as a page or a blogpost where the results can be seen immediately (i.e. fonts, colours, image size and position). WYSIWYG editing can either be achieved as built-in functionality by specialised CMSs or also within WordPress with plugins. Next to WYSIWYG plugins WordPress has the advantage of offering more than 55.000 extensions, for example a <model-viewer> implementation extension that can publish 3D models for augmented reality application.

Table 3: Selected CMSs with market share and basic analysis of advantages and disadvantages

CMS	Share	Advantages	Disadvantages
WordPress	63,3	>55.000 extensions, Intuitive user interface	Plugins can create security issues
Typo3	0,6	High safety standards	Modifications and installations, complex, bloaty CMS
Drupal	1,8	Used in enterprise businesses, highly customizable	Complex user interface, bloaty CMS
Joomla	2,7	>8000 extensions, good for many editors	Only rich text editor, no membership extensions
Neos	<0,1	Modern spin-off from Typo3, inline editor	More of an enterprise solution

4.5 Web-based augmented reality instead of dedicated application

Delivery of 3D models in the MiReBooks project was developed in the form of a dedicated application for the operating system Android. One limitation is that users would require an Android-based smartphone or tablet. Furthermore, users often refrain from downloading applications or retaining them on their systems. Recent development of web-based augmented technology made it possible to deliver 3D models without the help of a dedicated mobile application. In this section the software and steps needed to deploy web-based augmented reality for 3D models is discussed.

4.5.1 Benefits of web-based augmented reality

Less programming effort

One limitation of using a dedicated mobile application for 3D model delivery is the high effort for programming and updating the application. Furthermore it has to be accesible via the app stores both for Android and iOS which requires approval procedures from both app stores. Apart from programming and bureaucratic hurdles, users often refrain from downloading and/or retaining applications on their mobile devices.

No session synchronisation required

If the MiReBooks project website develops further and users are required to login and make payments to see certain content, user management will need to be implemented. This task is possible also with a wordpress CMS but as soon as a dedicated application is programmend to deliver certain content such as 3D models further effort is needed. This is manly due to the fact that a user generly wants to expierence digital content in a continuous timeline. This means if a user makes use of the MiReBooks website on a laptop or computer and then switches to a mobile application the user wants to have both systems synchronised in order to be able to continue exaclty where the user stopped the last time the MiReBooks service was used. This is generally called session synchronisation and puts an extra effort to application-based augemnted reality. Therefore, when using a web-based augmented reality session, synchronisation will not be necessary, as users simply use a browser-based augmented reality (see Figure 13).

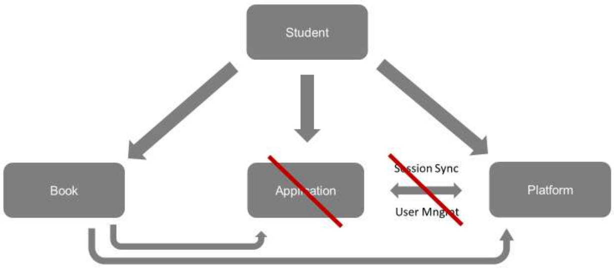

Figure 13: Session synchronisation between platform and application will become unnecessary (own figure)

4.5.2 3D model acquisition or creation

The MiReBooks project acquired numerous 3D models but also developed its own 3D models. The most well-known 3D model marketplaces are https://www.turbosquid.com/, https://sketchfab.com/ and https://www.cgtrader.com/. Most models available are Excavators and Haul Trucks. For creating 3D models special 3D software like Blender or 3DMax are used. In addition to the specialised software nearly any 3D model can also be used if exported to a convertible file format. For instance, a 3D model of a mine created in a Datamine or Surpac software (specialised software for mine planning) if exported as “.dxf” or “.stl” can be converted with the help of Blender to a “.glb” file. The “.glb” file can then be used for augmented or virtual reality.

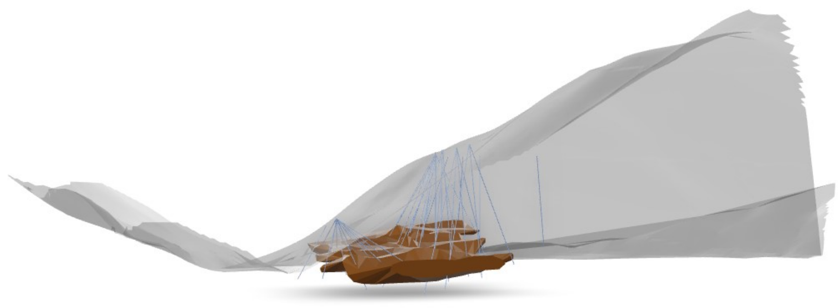

Figure 14: Example of a deposit model from https://www.mirebooks.com/1001 (own figure)

In Figure 14 a deposit model is made available for augmented reality. It was created with Datamine Studio software and converted with Blender. The grey surface represents the surface of the mountain, the brown area is the deposit and the thin blue lines are drill holes.

4.5.3 CMS WordPress compatibility for web-based augmented reality

The CMS WordPress has multiple benefits, one of the most important is the vast availability of plugins or extensions. One prominent plugin is the WYSIWYG editor Elementor which helps to create visually appealing sites (https://elementor.com/, 21.05.2023). For the deployment of web-based augmented reality in this thesis the web component <model-viewer> was chosen. In order to be able to use this component on a website managed with WordPress a plugin had to be installed, as web-based augmented reality is not a core functionality of the CMS. The installation of plugins is pretty straight forward: go to the plugin menu button in the back-end user menu of your WorPress CMS (see Figure 15) and click the button “Add New” next to the heading “Plugins”. This will open a search possibility where the term “model-viewer” was entered. The first plugin found which provided the needed technical implementation to make use of Google’s <model-viewer> was the “AR Model Viewer” created by BitBute (https://wordpress.org/plugins/ar-model-viewer-for-elementor/, https://bitbute.tech/, 20.05.23). The main benefit is that it can be used in combination with Elementor, therefore making the integration of a 3D model into a page very simple. After uploading the 3D model to the website CMS, the admin can create a page with the help of Elementor and then simply drag an “AR Model Viewer” widget (implementation functionality for different content types such as images, text or other) to an area of a page. Then the previously uploaded 3D model can be selected and published on the world wide web. The technical process of deploying the 3D model for augmented reality will be given in section 4.5.4 and the limitations of use of this technology in section 4.5.5.

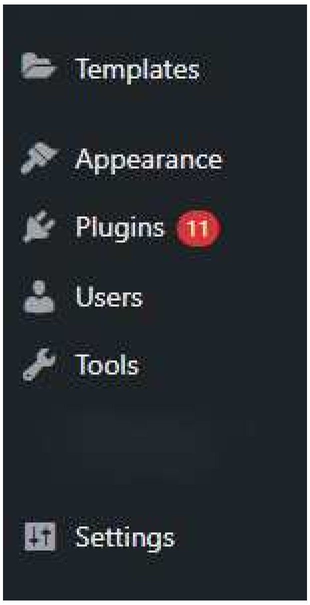

Figure 15: Section of the WordPress GUI menu used by MiReBooks project website (From https://wordpress.org/, GNU General Public License, version 2)

4.5.4 From 3D models to augmented reality

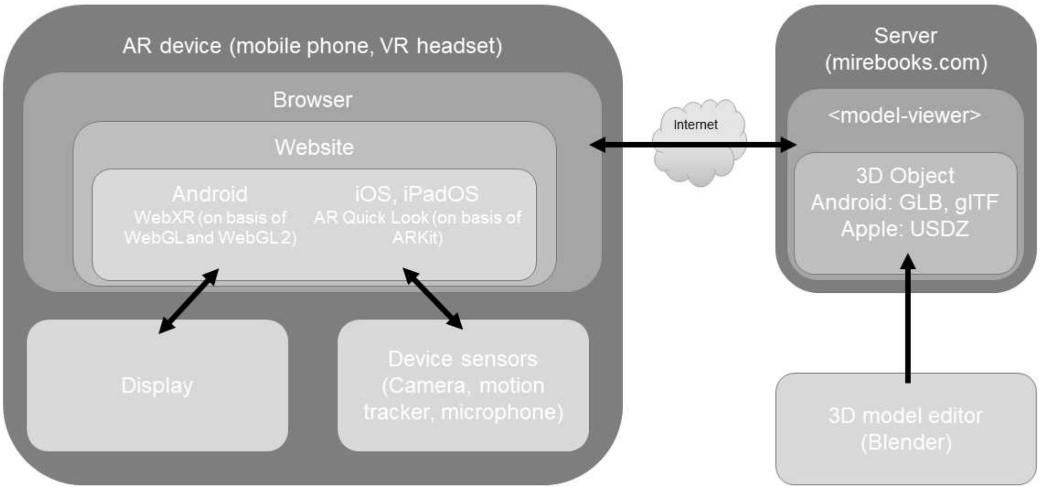

Figure 16: 3D model content delivery for augmented reality (own figure)

The delivery of 3D models for augmented reality can be seen in Figure 16. The first step to deliver 3D models for an immersive augmented reality experience is to create and scale a 3D model in a specialised 3D software like Blender.

The 3D object can be obtained from the Internet from different websites. Some models are free whereas some models require payment.

The following steps are required to deploy a 3D model for an augmented reality experience.

1. Download a 3D model from the Internet
   A 3D model of a haul truck from the MiReBooks project was used (see https://www.mirebooks.com/1002)
2. Scale 3D model in Blender
   This step is required to be able to place the 3D model in augmented reality onto a desktop surface. Scaling on mobile phones is possible, but if the initial size of the object is about 12m in length and the desired size to manipulate the model is about 0,4 m, scaling on the mobile device would have to be 3,33%. Therefore, before making 3D models available for augmented reality they should be scaled down to about 0.4m making scaling on the phone far more practical.

3. Export file from Blender

   Various filetypes for 3D models and 3D animations exist. Usually they are interconvertible so for instance using a ".blender" file (3D software Blender specific filetype) while creating a model does not restrict the output to be a ".gltf". Export filetype was chosen to be a ".glb" as it includes all textures and meshes and therefore can be handled more easily.
4. Upload the model to a server.
5. Make 3D model available.

   In order to make the 3D model available to users it is published with the help of the <model-viewer> web component. The <model-viewer> makes the 3D model available on both Android and iOS devices because it converts the ".glb" file to ".USDZ" if a iOS browser is used. (https://modelviewer.dev/docs/faq.html, 25.04.2023)
6. Experience augmented reality.

   Entering a hyperlink like https://mirebooks.com/1002 either directly into a browser or by scanning a QR code (see Chapter 4.4.2, Figure 7) will show the 3D object. By selecting the AR button (see Figure 17) the user is prompted to scan the environment. Scanning the environment is necessary in order to properly place the digital objects (3D models) into the real world. After the environment is scanned the 3D model will be placed and the user can experience augmented reality.

Figure 17: AR Symbol as shown by <model-viewer> both on iOS and Android, extracted from https://modelviewer.dev/, © Copyright 2018-2021 Google Inc. Licensed under the Apache License 2.0 (25.04.2023)

4.5.5 Use of web-based augmented reality

“<model-viewer> is supported on the last two major versions of all evergreen desktop and mobile browsers, plus the last two versions of Safari (on MacOS and iOS)” (https://modelviewer.dev/, 20.05.2023). This means that if a user wants to experience web-based augmented reality with the help of <model-viewer> he or she needs to use the built-in browser of either Android or iOS operating systems (Google Chrome or Safari). These two operating systems were used by more than 99% of users in April 2023 (https://gs.statcounter.com/os-market-share/mobile/worldwide, 19.05.2023) and their respective browsers combined account for more than 88% of the market share (https://gs.statcounter.com/browser-market-share/mobile/worldwide, 19.05.2023). All other operating systems and/or browsers are not always supported, but as the market is dominated by these two systems and their browsers it is unclear if support will be added by <model-viewer> at a later stage.

Therefore, in order to be able to use the web-based augmented reality functionality the user should make use of either the Chrome browser on Android or the Safari browser on iOS. The last two figures show a QR code and the accompanying 3D model augmented into a meeting room at Montanuniversität Leoben (see Figure 18 and Figure 19).

Figure 18: QR code leading to https://mirebooks.com/1001/

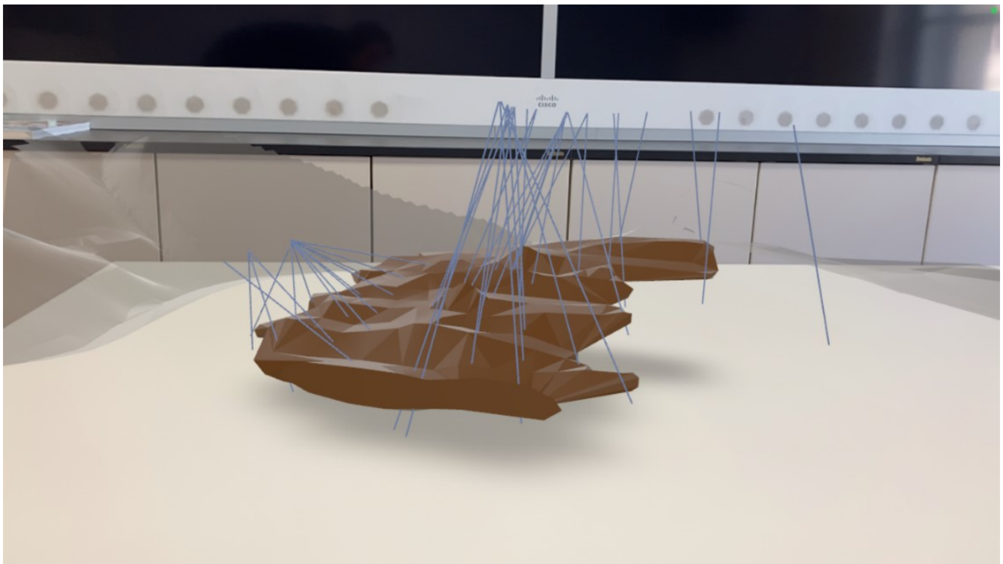

Figure 19: Example of web-based augmented reality (own figure)

4.6 Section Conclusion

Building an immersive learning platform for mining engineering education requires consideration of many factors. Only linking online resources with a hyperlink could make them unavailable if the content is deleted or moved. Embedding the content can minimise the risk of dead links as the content can be replaced with new or similar online resources. This will be achieved with the help of dedicated links to the MiReBooks project website which will then either redirect to the content or embed it directly.
The web-based augmented reality eliminates the costly development of a dedicated application for augmented reality experiences. Another benefit of web-based augmented reality is that no dedicated application has to be loaded and users can simply activate an immersive experience with the touch of a button (Garzón, 2021).
Many steps are necessary to publish 3D models but they are rather easy to achieve. Publication of 3D models of complex underground mining systems is possible if the software with which they were created offers the possibility to export formats which are compatible with 3D modelling software such as Blender.

5 Conclusions

Educational resources are not always freely accessible but with the help of the Internet knowledge can be shared with all of humanity. Making mining engineering topics available in the form of open educational resources can benefit the mining community by establishing a basis for discussion with topics such as the environmental impact, safety or digitalisation.

The breakthrough in the application of augmented and virtual reality has only been possible with the massive development and miniaturisation of computer processing chips and related technology like accelerometers and gyroscopes. Application of augmented and virtual reality in education can bring insight to complex topics such as mining but can also be used to visualise data in 4 dimensions. (x, y, z, and time) This can be a very powerful tool especially in mining as it can help to analyse rock stress in an underground mine.

Building an immersive learning platform for mining engineering education requires multiple considerations. Only publishing the digital content accompanying the printed textbooks would make the platform unusable for the general public. But if the knowledge created in the printed textbooks could be partially published on the MiReBooks website it could be developed into something deeper: an immersive open educational resource for mining engineering topics.

This thesis is systematic qualitative research for the use and implementation of immersive media like augmented and virtual reality in education – especially mining engineering education. The overarching research question was:

How to enhance digital open educational resources for lifelong learning in mining engineering education?

The research into this topic found a lack in the implementation of these new technologies in mining engineering education but a solution was pointed out in the form of an immersive learning platform for mining engineering education. Making the platform publicly accessible in form of an open educational resource could benefit non-digital natives and make it possible for them to increase their knowledge in new areas even though they are already working as industry professionals. This concept is commonly referred to as lifelong learning. The benefits of lifelong learning are plentiful and mostly aid those who want or need to re- or upskill in order to be attractive on the job market. But lifelong learning can also stimulate self-development and improvement thus helping to achieve self-actualisation - to know what and be happy with what one is doing. (Maslow, 1943). Continuous contact with experts in their respective fields as part of continuous education can stimulate not only the students but also the expert as both will gain insight into the development of their respective fields – thus making discussions more diverse. Another benefit of open educational resources is the increased awareness in public knowledge about thus making public debates about mining more profound. The use of augmented and virtual reality can even further increase insight into complex mining related topics.

6 Recommendations

Open educational resources are beneficial to society. Not only by making the digital content of the MiReBooks available but basic knowledge of mining can improve public awareness of mining. Mining is necessary to provide raw materials for the world we live in today but it can have a major impact on the environment. Public awareness could be improved if, in particular, sustainability topics and modern approaches to minimise the environmental impact are made available as a free online resource. Financial sustainability could be achieved in the form of sponsorship by industry and/or public funding. Paid sections or subscription fees for users could also benefit financial sustainability. Integration of MOOCs could increase user engagement, but special thought must be given to completion rate. Gamification and/or payment could improve these results. A community section could also increase user engagement by fostering mining relevant discussions. Creation of, or cooperation with, mining relevant journals, a calendar of mining relevant conferences and a news section could lead to the platform being the number one source for information in mining in Europe (similar to https://www.mining.com/).

As a first step all digital assets published should come with accompanying explanations. This would make the platform and its assets usable independently from the printed handbooks. And as a second step an overview of basic mining topics as well as sustainability topics should be published as an open educational resource. Not only could the public perception of mining be improved but children could be motivated to pursue a career or study a course in mining or mining related processes.

Currently the MiReBooks project uses HMDs to make 360° videos available for students with the help of a specialised software. Implementation of augmented reality in the form of 3D models can be achieved with relatively low effort as described in Chapter 4.5.4.

Making 3D models of complex underground mining systems available for augmented reality could benefit students with increased insight. Enhancing digital education platforms with this new technology provides an opportunity for all to benefit – digital and non-digital natives – thus helping to close the gap. Offering these new experiences to the public will make learning opportunities more intense thus helping to not only experience or see, but also understand.

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10 List of Abbreviations

Abbreviation	Definition
API	Application programming interface
AR	Augmented reality
BAEKTEL	Blending academic and entrepreneurial knowledge in technology enhanced learning
CARONTE	Continuing education and scientific information literacy on raw materials for professionals
CEU	Continuing Education Units
CLC-EAST	EIT RawMaterials Innovation Hub co-location center East
CLLEFE II	Concept for Life Long Education for Foundry Employees
CMS	Content management systems
CRM	Critical raw materials
DG DEFI	European Commission’s Directorate General for Defence Industry and Space
Dig.	Digitalisation
DIM-ESEE	Dubrovnik International ESEE Mining school
DOI	Digital object identifier
EC	European Commission
ECM	Enterprise Content Management
ECTS	European Credit Transfer System
Eng.	Engineering
ESEE	East and southeast Europe
glb	Binary Graphics Language Transmission Format
glTF	Graphics Language Transmission Format
GUI	Graphical user interface
HMD	Head mounted display
IoT	Internet of Things
K-12	Primary and secondary education in the United States, Canada, and Australia
LLL	Lifelong learning

LMS	Learning management system
MiReBooks	Mixed Reality Handbooks for Mining Engineers
MOOC	Massive Open Online Course
MR	Mixed reality
MSHA	U.S. Mine Safety and Health Administration
N/A	Not available, not applicable
OER	Open educational resource
PDH	Professional Development Hours
SDG	Sustainable development goals
SME	Society for Mining, Metallurgy, and Exploration
SusCritMat	Sustainable Management of Critical Raw Materials
TrainESEE	Training the trainers in east and southeast Europe
U.S.	United States of America
UI	User interface
UN	United Nations
URL	Uniform resource locator
USA	United States of America
USDZ	Universal Scene Description, compressed Version
UX	User experience
VET	Vocational education and training
VR	Virtual reality
VRMine	Integrating Virtual Reality into European Mining Education
W3C	Word Wide Web Consortium
WCM	Web content management
WYSIWYG	What You See Is What You Get