XR in Teaching Roadmap

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<u>**Contributors and Collaborators**</u>
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Abstract

This report explores the comprehensive journey undertaken by the .dcall project *XR in Teaching* to formulate a cohesive strategy for integrating Extended Reality (XR) into teaching methodologies. The primary objective of this endeavour was to establish a unified strategy that caters to the diverse academic landscape at TU Wien. The study involved an extensive research phase, engaging in a meticulous exploration of XR technologies and their potential applications in various educational settings.

To foster inclusivity and garner insights from the diverse academic community, workshops were conducted with representatives from all eight faculties. These sessions served as collaborative platforms, facilitating discussions on the potential benefits and challenges of incorporating *XR in Teaching* practices. Through this interdisciplinary approach, a nuanced understanding of the unique requirements and expectations across faculties was attained.
A pivotal finding emerged from this collective effort: the main challenge lies in content creation for XR applications.

In response to these findings, the project team introduced a new multidisciplinary lecture in the winter semester of 2023/2024. This innovative course aimed to engage students and teaching staff collaboratively, focusing on the creation of an XR roadmap. The ultimate goal is to empower participants to potentially implement XR elements into specific lectures, providing a hands-on, practical approach to the integration of *XR in Teaching*.

This report not only contributes valuable insights into the challenges and opportunities of *XR in Teaching* but also outlines a concrete action plan for TU Wien, setting the stage for a unified and forward-thinking approach to the integration of XR technologies within the academic realm.

Contents

List of Abbreviations

AEC	Architecture, Engineering and Construction
AR	Augmented Reality
ARCH	Faculty of Architecture and Planning
BIM	Building Information Modeling
CEE	Faculty of Civil and Environmental Engineering
CHEM	Faculty of Technical Chemistry
ETIT	Faculty of Electrical Engineering and Information Technology
INF	Faculty of Informatics
MG	Faculty of Mathematics and Geoinformation
MR	Mixed Reality
MWBW	Faculty of Mechanical and Industrial Engineering
PHY	Faculty of Physics
VR	Virtual Reality
XR	Extended Reality

1 XR in Teaching project overview

This section discusses the origin of the *XR in Teaching* project, as well as the already existing XR initiatives at TU Wien.

1.1 Introduction

The use of Extended Reality (XR) in teaching is an emerging trend that has the potential to revolutionize the way students learn. However, despite its potential benefits, the incorporation of Augmented Reality (AR) or Virtual Reality (VR) technology into the curriculum is still limited in educational programmes. AR/VR technology can enhance traditional teaching methods by providing immersive and interactive experiences for students. This technology can create virtual environments that simulate real-life scenarios, allowing students to practice skills and gain experience without any risk. Moreover, it reduces costs by eliminating expensive field trips to e.g. interesting architectural sights, which instead could be visited in VR /AR..
A deficiency persists in the development of well-defined teaching methodologies utilizing AR/VR technology, prevalent not only at TU Wien but also across various educational institutions. The conspicuous gap in research-centric pedagogy within the domain of XR-enhanced teaching has been effectively addressed through the *XR in Teaching* project. This initiative has successfully filled the void by constructing a comprehensive XR roadmap tailored for TU Wien, concurrently establishing a solid foundation for the ongoing development of XR content within the university.

1.2 Project Overview

Initiated between April 2023 and December 2023, the *XR in Teaching* project was commenced as an interfaculty collaborative effort funded by the Rektorat of TU Wien and .digital office of TU Wien. The project has been conducted as a joint collaboration between 3 institutes: the Institute of Construction Process and Construction Economics, the Institute of Management Science and the Institute of Building and Industrial Construction. This innovative endeavour, undertaken as part of the. d.call initiative, aimed to enhance the educational landscape at TU Wien by integrating XR technologies into teaching practices. To achieve this goal, the project team, led by Harald Urban, Julia Reisinger and Linus Kohl, initially defined four work packages:

- WP01 – Evalution and collection of XR teaching content
- WP02 – Create XR content
- WP03 – Definition of requirements (Definition XR-Roadmap)
- WP04 – Technical service and further development from AR-supported Teaching to XRsupported Teaching

The project commenced with a thorough investigation into the prevailing practices at TU Wien and an exhaustive exploration of *XR in Teaching* methodologies adopted by other universities. This initial phase involved comprehensive research to assess the current state of the art in both contexts, laying the groundwork for subsequent project developments. Subsequently, a series of workshops were conducted, engaging teaching representatives from all eight faculties within the university. These workshops served as a forum to collect invaluable insights and feedback, establishing a robust foundation for the subsequent phases of the project. To expand the content available for AR-supported Teaching, new teaching scenes were created on an ongoing basis. This approach allowed for the testing of new features directly. Leveraging the expertise of XR specialists within TU Wien, a concerted effort was undertaken to integrate XR elements into the university's curriculum seamlessly. This initiative resulted in the introduction of a multidisciplinary lecture, where students from all faculties collaboratively worked with teaching staff to craft customized XR roadmaps tailored to specific courses. To see how well this new way of teaching worked, we carefully gathered information and feedback from students, teachers, and others involved. We asked teachers at TU Wien to fill out questionnaires. The information we collected gave us important insights into how effective XR technology was in making teaching and learning better. Using what we learned, we created a detailed plan for using *XR in Teaching* across the entire university. This plan outlined a smart strategy for bringing XR technologies into different departments, focusing on improving the learning experience for students. The workshops and lecture defined the requirements for an XR platform. The development of the TU Wien's internal AR platform, AR-supported Teaching, was based on these demands. Particular attention was paid to extending the functions originally focused on the architecture, engineering, and construction sector (AEC sector) to a broader range of applications.

1.3 Extended Reality at TU Wien

At the moment there is no common XR strategy in teaching at TU Wien. However, there are already three significant initiatives that offer space and hardware for XR possibilities in teaching as well as research.

MR Lab

A Mixed Reality (MR) Lab, conceptualized and coordinated by Prof. Hannes Kaufmann, head of the Research Unit Virtual and Augmented Reality (E193-03), is set to be established at TU Wien. The Federal Ministry of Education, Science and Research (Bundesministerium für Bildung, Wissenschaft und Forschung, BMBWF) has approved this proposal. The MR Lab will serve as a centre for collaboration and interdisciplinary research in Austria, offering technological support for basic and applied research across various fields including Industry 4.0, Physics, Civil Engineering, Archaeology, Biology, Architecture, and more.

The MR Lab, to be opened at Favoritenstrasse 9, is set to be a hub for mixed reality innovation. Spanning a 30x5x4 meter space, it will feature precise motion tracking with a Qualisys system throughout the room. An advanced 192-channel audio system will complement the immersive experience. The lab will be equipped with over 50 head-mounted displays (HMDs) for both VR and AR, catering to teaching and research needs. Additionally, it will include an LED Cave and a virtual production stage, alongside cutting-edge holographic displays, providing a comprehensive suite of tools for exploring the frontiers of mixed reality. In the figure 1 below, you can see the draft of the MR Lab

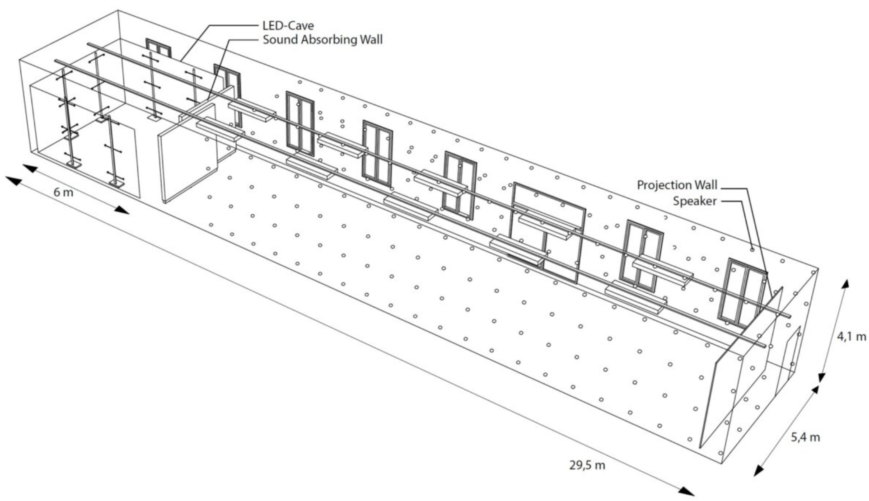


Figure 1: Draft sketch of the MR Lab

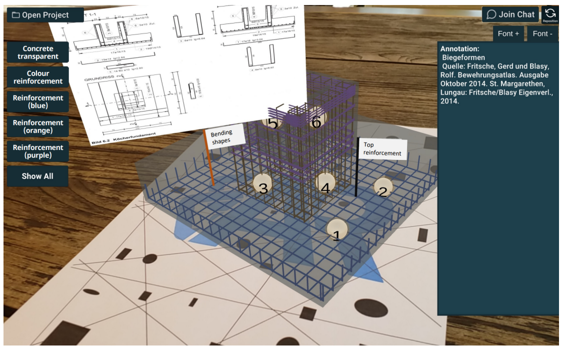
Davis

Davis, the Data Visualization Space of the TU Wien Bibliothek, is designed as an experimental learning space for teachers and students. It provides infrastructure for experimenting with and implementing 2D and 3D visualization projects. A 3D-capable, floor-to-ceiling LED wall (format 270 x 480 cm) and optical head and hand tracking, with the help of shutter glasses, enable visualization in 3D stereo and thus an intuitive and immersive experience of complex interrelationships of digital data for groups of about 10 people. The 3D LED wall installation allows the use of a wide range of interactive 3D applications and is supported by the computing and graphics card power required for this purpose. The opposite video wall is an interactive touch wall consisting of LCD displays with an IR touch frame (size 409 x 121 cm). It is driven by a controller that enables various operating scenarios and allows up to six simultaneous users to operate content simultaneously using standard gestures. A single 65” touch screen with 4K resolution on the back of the touchscreen allows the display of the same content for accessible operation by wheelchair users.

AR-supported Teaching

The AR platform AR-supported Teaching enables the creation of teaching scenes without programming knowledge. The aim is to provide teachers with applications that enable the independent creation of AR teaching scenes, independent of software products and without programming knowledge. AR-supported Teaching is applicable both as a teaching support tool and for teaching the productive use of AR tools. For this purpose, the team created three applications (AR editor=Create; AR viewer=View; website=Manage) functionally separate but interconnected. With the help of the AR editor, teachers can create AR teaching scenes using an existing threedimensional model, which can be imported into the AR editor. At the time of writing, the neutral, openBIM format Industry Foundation Classes (IFC) and the equally open Graphics Library Transmission Format (glTF) are supported. The IFC format is widely used in the AEC sector and includes both geometric and alphanumeric data, such as material and fire resistance class, which can be utilized in teaching. Additionally, IFC is a non-proprietary format, allowing AR-supported Teaching to work independently of specific BIM authoring software. The standardization of IFC in ISO 16739-1:2018 ensures the longevity of teaching scenes. In the AR editor teaching scene can then be adapted or extended with ditactic elements like annotations, animations, layers and buttons while the base file format remains intact. The AR editor saves the contents of a teaching scene in a database, which improves data access and data up-to-dateness. The end-user views the created teaching scenes with the AR viewer. Buttons enable self-directed, exploratory learning. The speed is freely selectable, which prevents cognitive overload. The "Live Session" function makes a live connection between AR editor and AR viewer possible, allowing communication between learners and teachers across spatial barriers. The user of the AR editor can set markers in the live session and expand it with media files (images, videos). An message chat also supports communication. A web application is used to administer users. This administration mainly involves defining user roles and assigning groups. Roles regulate which AR-supported Teaching applications a user can use. Teaching scenes are not user-specific but always refer to groups. These are tree-like and can also be created in the web application. To promote the user base, it is possible to publish scenes. These appear on the website, can be presented there and can be downloaded by anyone in the AR viewer. For additional information, see the publication on the development of AR-supported Teaching [2]. In fig. 2 two different teaching scenes are given as examples. The AR-supported Teaching website offers additional public teaching scenes that can be viewed without registration.

(a) Formwork teaching scene in the AR editor



(b) Reinforcement of a sleeve foundation: AR viewer with annotations and buttons to activate animations

Figure 2: Screenshots of teaching scenes from the AR-supported Teaching platform in the AR editor and AR viewer

2 Methodology

In this project, the research methodology unfolded in distinct steps. Firstly, a comprehensive analysis of XR in teaching at other universities and in the industry was conducted (Phase 1). Following this, four workshops engaged teaching staff from all TU Wien faculties, focusing on discerning demands, needs, content requirements, and current (digital) teaching methods, and qualitative data was collected (Phase 2). A questionnaire distributed to TU Wien professors and lecturers provided specific quantitative data and feedback (Phase 3), revealing a prominent challenge for teaching personnel: the lack of XR knowledge and 3D visualization content. To address this, a multidisciplinary lecture was introduced in WS 23/24, allowing students in interdisciplinary teams to develop XR content and strategy roadmaps for specific courses, working closely with supervisors (Phase 4). The results from these steps were then systematically gathered, analyzed, and synthesized, leading to the formulation of recommendations and a roadmap for integrating XR methods into TU Wien's teaching. Throughout the project, the MR Lab by Hannes Kaufmann and Davis, existing XR institutions at TU Wien, provided valuable support. Figure 3 below shows the overview of the methodology applied during the project.

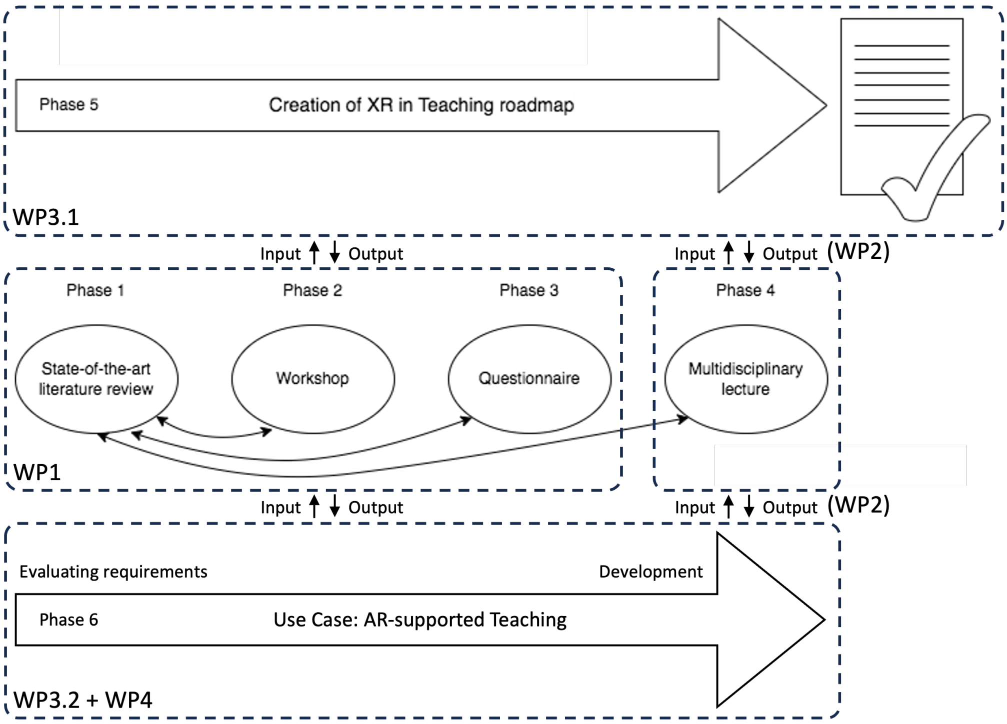


Figure 3: Methodology overview

2.1 Phase 1 - State-of-the-art literature review

A state-of-the-art analysis was conducted to investigate the scientific research foundation, as well as the already existing utilization of *XR in Teaching* at various universities. Following this, an in-depth analysis was carried out to identify potential benefits and applications that could prove advantageous for TU Wien.

2.2 Phase 2 - Workshop

Workshops with teaching personnel of all faculties of TU Wien were conducted. Thereby, the eight faculties of TU Wien were divided into four distinct groups based on their potential suitability for

similar applications of XR. These groups consisted of the Faculty of Architecture (ARCH) and the Faculty of Civil and Environmental Engineering (CEE) (Group 1) - 11 participants; the Faculty of Mathematics & Geoinformation (MG) and the Faculty of Informatics (INF) (Group 2) - 8 participants; the Faculty of Mechanical & Industrial Engineering (MWBW) and the Faculty of Electrical Engineering & Information Technology (ETIT) (Group 3) - 5 participants; and the Faculty of Technical Chemistry (CHEM) and the Faculty of Physics (PHY) (Group 4) - 8 participants. The workshop invitations have been sent to the teaching staff of TU Wien 3 weeks before the first workshop date. The team also recognized an opportunity to extend our educational outreach by adding an additional workshop date. This initiative aimed to provide the "Fachschaften" with tailored workshops and a platform to share the students' needs to implement XR technology in teaching. Upon disseminating the invitations for the proposed extra workshop date, the team anticipated a positive response from the Fachschaften. However, the feedback received was considerably lower than expected. The lack of response led to the decision to cancel the workshop for the Fachschaften. In total 4 workshops have been held at the Institute of Building and Industrial Construction of TU Wien.
The summary of the workshop dates and number of participants can be found in the table 1.

Group	**Date**	**Number of participants**
Faculty of Architecture, Faculty of Civil and Environmental Engineering	03.07.2023 9.00-11.00	11
Faculty of Mathematics & Geoinformation, Faculty of Informatics	03.07.2023 14.00-16.00	8
Faculty of Mechanical & Industrial Engineering, Faculty of Electrical Engineering & Information Technology	07.07.2023 9.00-11.00	5
Faculty of Technical Chemistry, Faculty of Physics	07.07.2023 14.00-16.00	8

Table 1: Overview of the workshop organisation

Within the workshop, project objectives and the project structure were introduced, followed by an introductory round where participants shared their current teaching practice and if available, respective experiences with XR. Subsequently, the fundamental concepts of XR, AR, and VR were presented, along with their potential benefits in the context of teaching. A comprehensive overview of XR projects implemented by other universities, as well as exemplary practices from renowned educational institutions, which had been gathered during the preceding research phase, was also provided. The workshop then shifted to an interactive phase, posing four key questions to participants, with their responses documented on flipcharts. Figure 4 provides an overview of the questions addressed during this engaging segment.

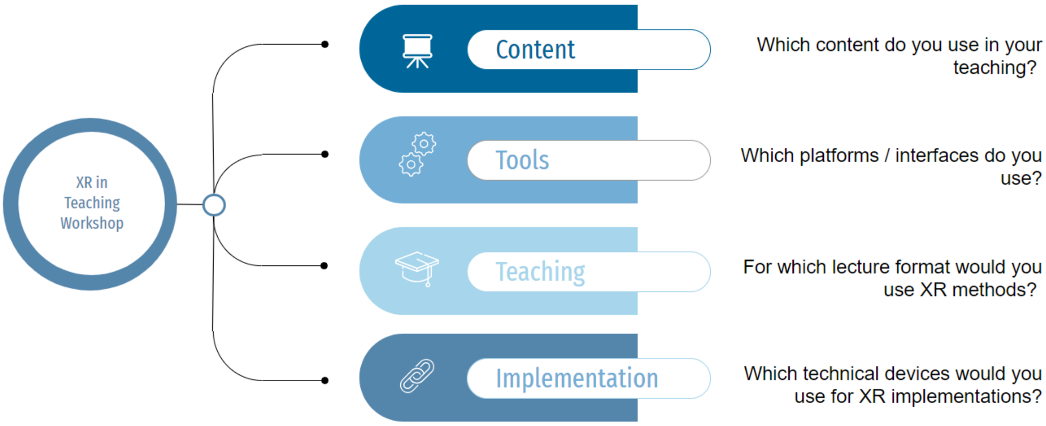


Figure 4: Workshop structure

Figure 5: Examples of workshop results

Following, a discussion was facilitated to delve into the insights and ideas conveyed during the workshop. Also, current challenges and concerns were gathered. Additionally, an overview of a previous project, "BIM Flexi-VR," undertaken by Julia Reisinger, was presented, along with a dedicated presentation on AR-supported Teaching delivered by Harald Urban. The workshop wrapped up with an informal exchange of ideas discussing the potential benefits of *XR in Teaching* for both students and teaching staff. In the pictures 6 below, some snapshots of the workshop can be found. Participants also outlined their requirements for an XR platform and provided feedback on AR-supported Teaching.

Figure 6: Workshop snapshots

2.3 Phase 3 - Questionnaire

During the questionnaire phase of the project, an online questionnaire created in Microsoft Forms comprising 18 questions was prepared. The questionnaire was designed to maintain anonymity among respondents and sent out to the whole teaching personnel of TU Wien's faculties. The initial section of the questionnaire sought information about the university affiliation of the individuals responding. The second part of the questionnaire inquired about the prevailing teaching methodologies and technologies employed by the teaching staff at TU Wien, with an emphasis on assessing interest in the integration of XR into their teaching practices. The third section was dedicated to exploring the transferability of content from conventional teaching approaches to XR-based teaching, as well as identifying the primary beneficiaries and perceived challenges associated with XR adoption from the perspective of teaching staff. The concluding portion of the questionnaire sought insights regarding the necessity and potential advantages of implementing *XR in Teaching*.

The questionnaire questions can be found in Appendix A.1.

2.4 Phase 4 - Multidisciplinary lecture

To explore potential topics relevant to introducing XR and providing an introduction to this process, a targeted multidisciplinary lecture was organised in the winter semester 23/24 - the course LVA 234.139 MULTIDISCIPLINARY PLANNING led by Julia Reisinger. The XR content and roadmap developed by students throughout the course for specific topics were offered to the interested teaching personnel.

Promotion of the new lecture module was undertaken with a dual-faceted approach. Posters were displayed in the main communal areas of the university, designed to inform and engage the students. Furthermore, an email was disseminated to all students enrolled at TU Wien, extending an invitation to participate in the lecture. The initiative was met with a high level of interest, all available 26 spots for the course have been filled in advance of the start date on the 2nd of October. In the figure 7, the course calendar and organisation overview can be seen.

The multidisciplinary lecture poster can be found in Appendix A.2.

Date	Time	Description
02.10.2023	13:00 - 16:00	Kick-Off
09.10.2023	13:00 - 16:00	Matchmaking + Davis tour
16.10, 06.11.2023	13:00 - 16:00	Feedback round
13.11.2023	13:00 - 16:00	Midterm presentation
20.11, 27.11.2023	13:00 - 16:00	Feedback round
04.12.2023	13:00 - 16:00	Final presentation
11.12.2023	23:59	Report submission

Seminarraum AF 02 22 - Hauptgebäude Stiege 6, 2.Stock - Institut für Hoch- und Industriebau E210

Figure 7: Course organisation

The course was initiated on a kick-off session where the students received introductory information on the course as well as the basics of XR methods were presented. The students also received an introduction to AR-supported Teaching and the use of the platform to learn about existing, practical solutions at TU Wien. In the following week, the matchmaking session took place. A selection of 12 distinct topics was presented to the students for their consideration. Then, they had the opportunity to meet with the specific supervisors (course leads) assigned to their provided topics. During these sessions, they could engage in discussions with the course leads, exchange ideas about expectations, and receive a brief introduction to the chosen topic. Additionally, a tour of the Davis, TU Wien Bibliothek has been conducted.

Within the lecture framework, students were organized into pairs, and they were given the opportunity to collaborate with the supervisor to formulate a roadmap for the integration of XR into courses led by the chosen supervisor. As part of their coursework, students were asked to prepare both a midterm and a final presentation, in addition to producing a comprehensive report upon the conclusion of the course. Students were given an opportunity to receive feedback on their projects during the feedback sessions with the lecture teaching staff and were encouraged to participate and review their work as well as their colleagues. The final presentations were held directly at the Davis, TU Wien Bibliothek. In the table 2, the list of topics available to students with their corresponding supervisors can be found.

Topic	Supervisor
234.161 VU Industrial Building (CEE)	Julia Reisinger, Philipp Rufinatscha
194.025 VU Introduction to Machine Learning (INF)	Pascal Welke
Digital Content Creation for Mixed Reality Laboratory	Peter Kán
120.109 VU Topographic and Hydrographic Models (MG)	Gottfried Mandlburger
234.174 SE Integrated BIM Design Lab (CEE)	Philipp Stauss
134.152 VO Introduction to Nanotechnology (PHY)	Ilse-Christine Gebeshuber
A Glimpse Into the World of Chemistry at TU Wien	Dennis Svatunek
330.308 Production Information Management Systems (MWBW)	Steffen Nixdorf
Inclusive Design of Work Systems – accessibility, equality in the workplace (MWBW)	Atieh Karbasi
Experience pattern formation in H2 oxidation – understanding catalytic reaction mechanisms	Johannes Zeininger
330.317 Digital Simulation of Ergonomics and Robotics (DSER) (MWBW)	Clara Fischer, Felix Aigner
232.029 SE Railway simulation (CEE)	Markus Lagler

Table 2: List of topics available for the students and their supervisors

2.5 Phase 5 - Creation of the XR in Teaching roadmap

Finally, the project team has gathered the findings of all aforementioned steps and created a roadmap for TU Wien highlighting potentials and challenges for TU Wien to integrate XR methods into the academic curriculum in the future. The roadmap is presented in this report.

2.6 Phase 6 - Use cases with AR-supported Teaching

The integration of the theoretical basis, in the form of workshops and the lecture “Multidisciplinary lecture”, should be accompanied by practical case studies. The requirements of these two phases will be included in the further development of the successful AR-supported Teaching platform created at the TU Wien. Figure 8 illustrates the chosen approach for the further development of AR-supported Teaching. The requirements for an XR platform were derived from the workshop (phase 2). New functions and features were defined on the basis of these requirements and user feedback, which were then evaluated by the authors on a scale of 1 to 5 in two ways: Realisability was rated on a scale of 1 to 5, with 1 indicating a simple and quick implementation and 5 representing a very complex implementation. Relevancy was also assessed on a scale of 1 to 5, with 1 indicating very high relevance and 5 very low relevance. The ratings were used to implement the functions on the platform. The newly implemented functions were continuously tested and improved as necessary. The results are presented in section 3.5.

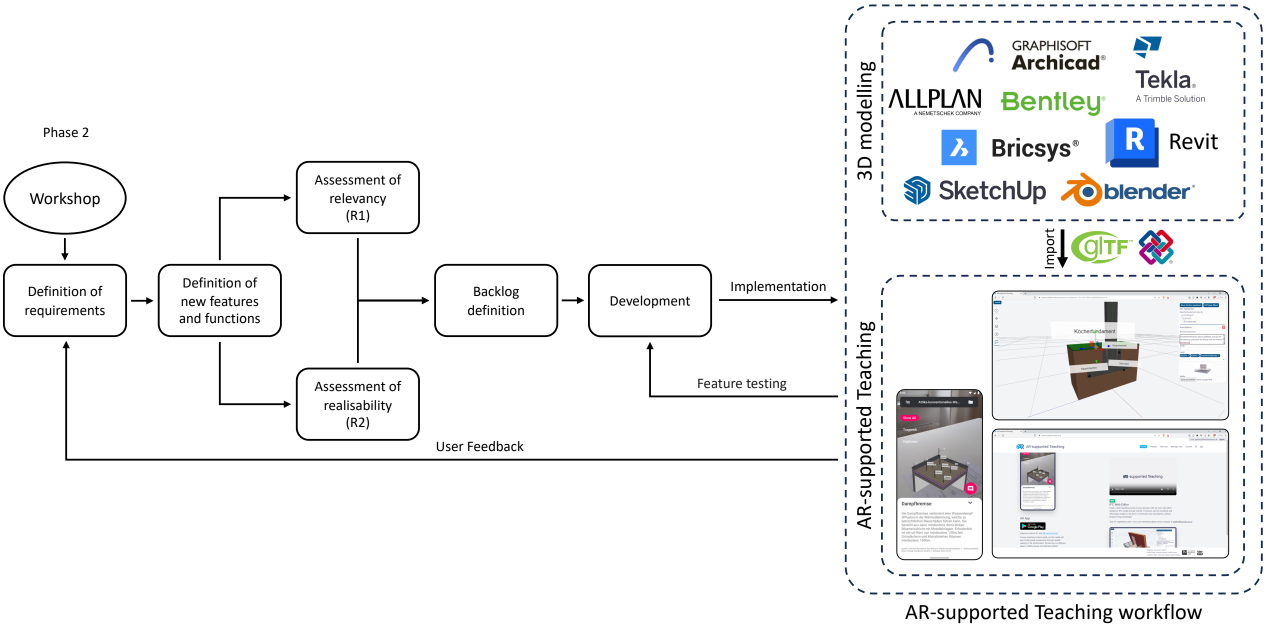


Figure 8: Methodology for the further development of AR-supported Teaching

3 Results

The following chapter describes the findings of the individual phases that finally led to the creation of the *XR in Teaching* roadmap.

3.1 State-of-the-art literature review

UNESCO defines one of its 'Education for Sustainable Development' goals to 'ensure inclusive and equitable quality education and promote lifelong learning opportunities for all'. [3] XR technologies simplify access to information and education, not restricted to a specific field or domain. Nevertheless, especially students enrolled in STEM courses, which include the majority of TU Wien's courses, struggle to understand complex scientific problems. [4]
Enhancing traditional science lessons with virtual (mathematical) objects or visiting an architectural site in a three-dimensional AR environment help to understand complex abstract concepts. [5] Generally speaking, implementing XR technologies into teaching lessons have proven to result in educational benefits, such as an increase in the students' motivation and engagement in the topic, which ultimately results in better overall performances. [6] [7] Moreover, learning through immersive experience can increase the quality of learning and promote knowledge retention by as much as 90 percent. [8] The most significant advantage of XR is "unique ability to create immersive hybrid learning environments that combine digital and physical objects, thereby facilitating the development of processing skills such as critical thinking, problem solving, and communicating through interdependent collaborative exercises." [9]
Renowned elite university like Stanford University [10], Massachusetts Institute of Technology [11] or University of Oxford [12] are already investing a lot into XR technologies and upgrading their teaching with XR methods.

3.2 Workshop results

The series of workshops conducted for the *XR in Teaching* project yielded insightful outcomes that are crucial to our understanding of XR's educational impact. Here, we present a synthesis of the key findings that emerged from these sessions.

3.2.1 Workshop Results per Workshop Groups

Workshop 1 - Faculty of Architecture, Faculty of Civil and Environmental Engineering

The first workshop organized for ARCH and CEE demonstrated the potential of XR in architectural and civil engineering education. Highlights included the exploration of VR for material modelling, allowing students to simulate and observe changes in real time. The concept of revisiting field trip locations using XR and gamification for student motivation was positively received. However, challenges in visualizing code in XR were noted. The potential for spatial planning through VR, AR applications in viewing building infrastructures, and high-resolution models for art history seminars were also discussed. The workshop concluded with insights into using XR for performance feedback within mathematical simulations or design feedback. In the figures 9 and 10 you can see the overview of the answers from the first workshop and a summary of the findings.

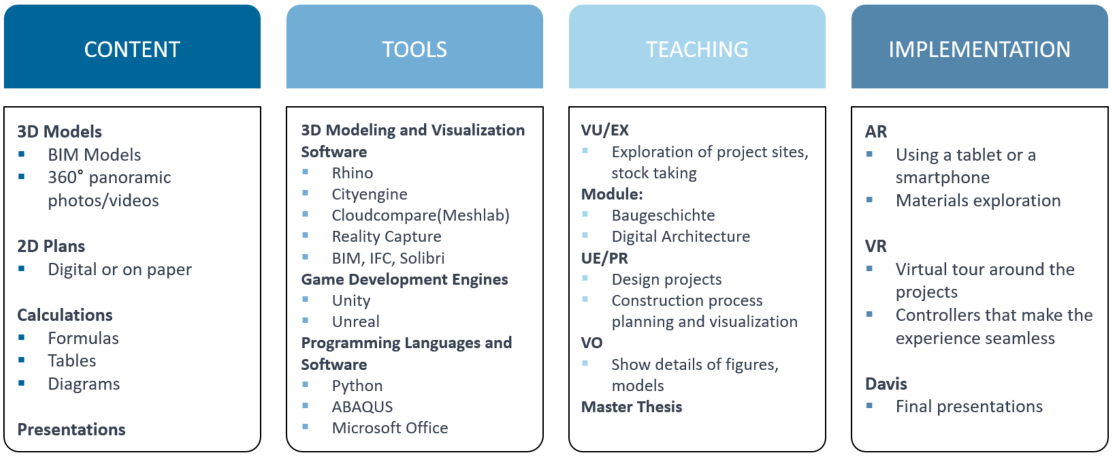


Figure 9: Overview of the answers from the first workshop

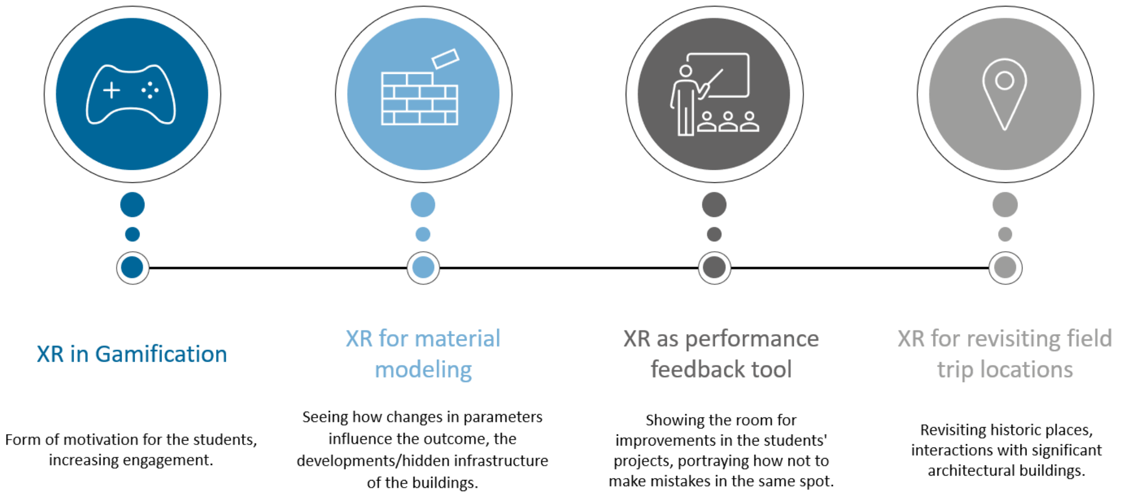


Figure 10: Summary of the first workshop findings

Workshop 2 - Faculty of Mathematics & Geoinformation, Faculty of Informatics

The second session with the MG and the INF addressed the technical limitations of XR, particularly in representing complex 3D models. The workshop identified opportunities for interdisciplinary collaboration between computer science students and peers from other domains for specific XR application development. Robotics, hydraulic turbines, and geodesy were discussed as areas where

VR could enhance understanding. The session highlighted the need for user-friendly interfaces and the potential of VR in informatics, including distributed systems and group learning environments. In the figures 11 and 12 you can see the overview of the answers from the second workshop and a summary of the findings.

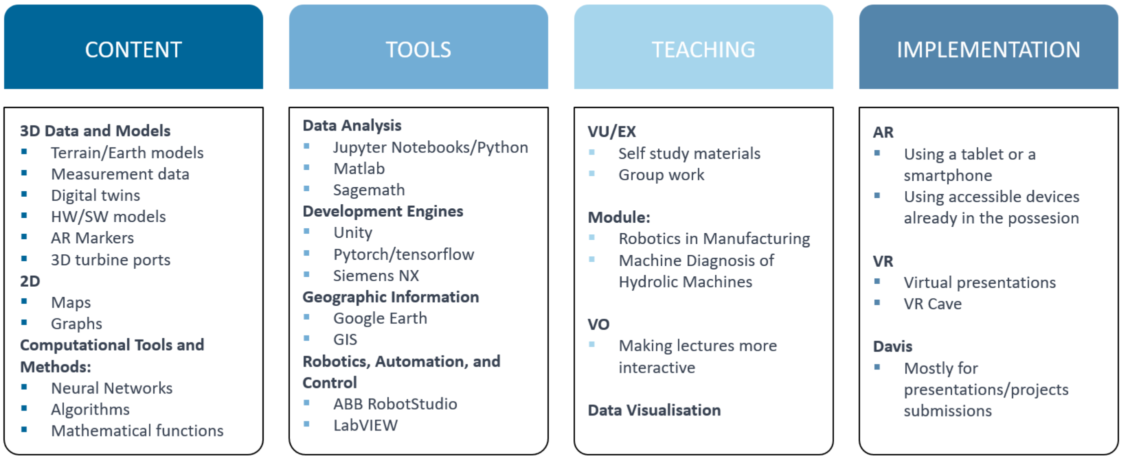


Figure 11: Overview of the answers from the second workshop

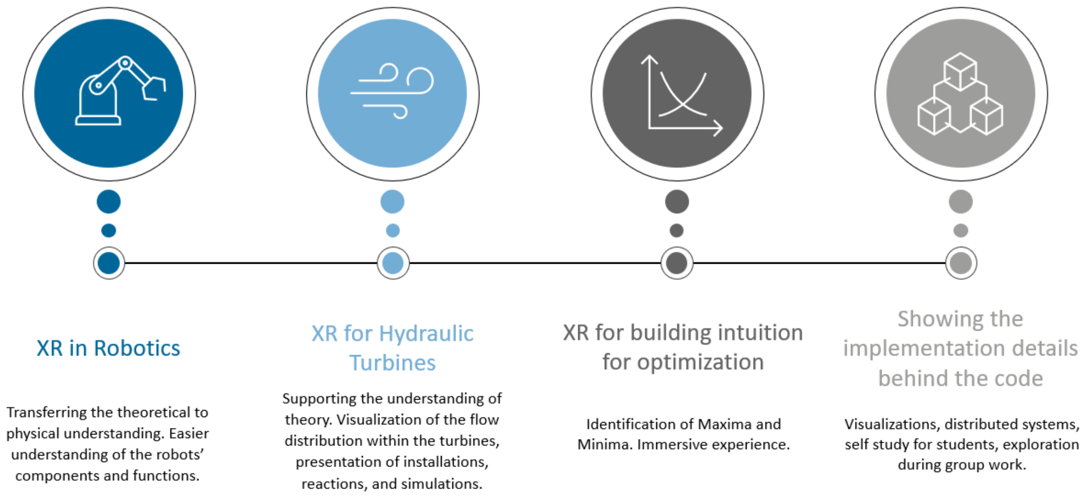


Figure 12: Summary of the second workshop findings

Workshop 3 - Faculty of Mechanical & Industrial Engineering, Faculty of Electrical Engineering & Information Technology

During the third workshop conducted with MWBW and ETIT, the focus was on integrating future learning techniques and the fun factor in teaching to attract students. Discussion points included the need for web-based solutions due to software diversity. The potential role of student assistants in developing XR content and the use of platforms like Euphoria was discussed. The session highlighted the challenges in motivating students and the importance of easy-to-use platforms for live simulations. In the figures 13 and 14 you can see the overview of the answers from the third workshop and a summary of the findings.

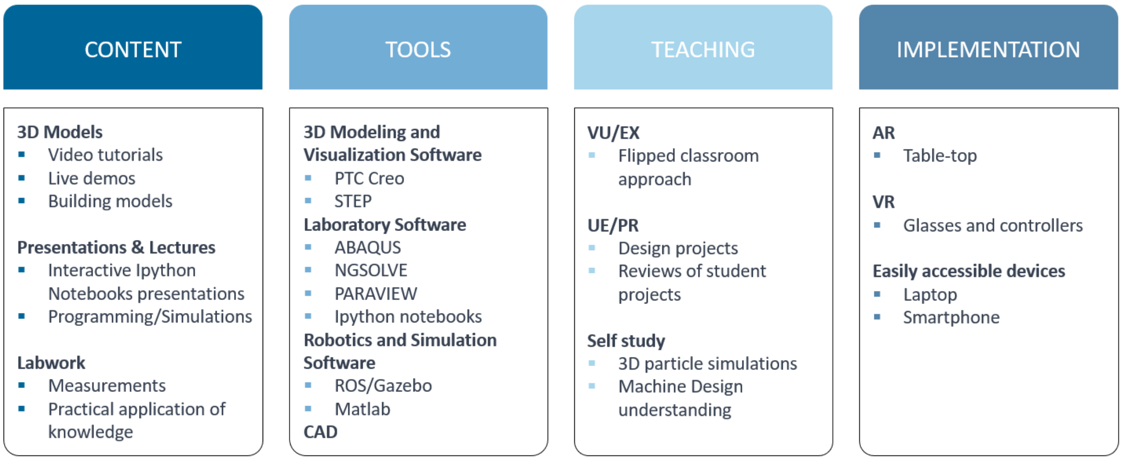


Figure 13: Overview of the answers from the third workshop

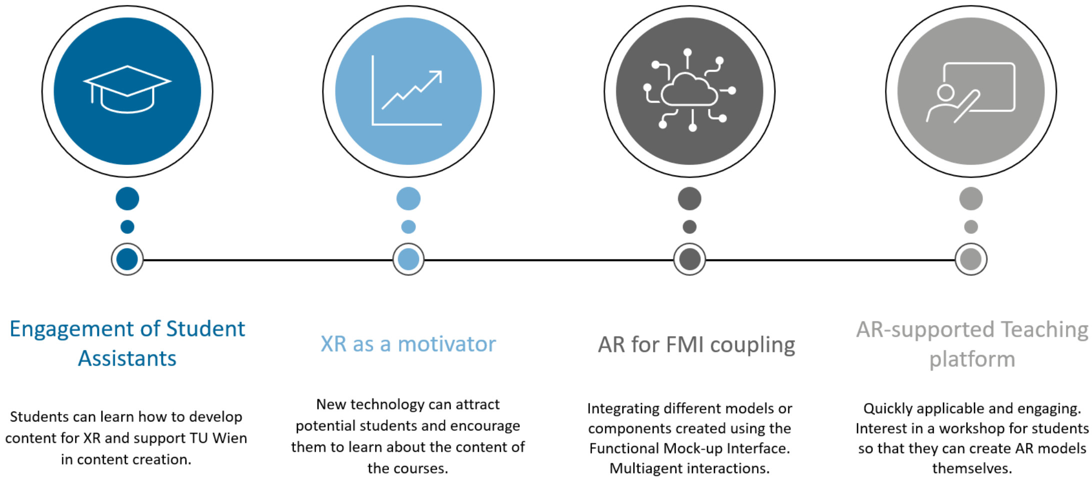


Figure 14: Summary of the third workshop findings

Workshop 4 - Faculty of Technical Chemistry, Faculty of Physics

The final workshop conducted with CHEM and PHY explored the feasibility of integrating XR into physics and chemistry education. While acknowledging the time constraints of implementing XR in lectures, significant potential was noted in exercises, lab introductions, and safety training. Nanotechnology, fluid dynamics, and 3D chemical structures were identified where XR can provide substantial educational benefits. The workshop proposed the use of XR in Berufs und Studieninformationsmesse (BEST) to attract new students and suggested the development of virtual labs as part of the .dcall project. In the figures 15 and 16 you can see the overview of the answers from the final workshop and a summary of the findings. Civil engineers and architects have participated in this workshop series due to time collapses, leading to the mention of specialized building design tools such as Archicad, Dlubal, and Scia in Figure 15. These tools are specifically designed for use in the fields of architecture and civil engineering.

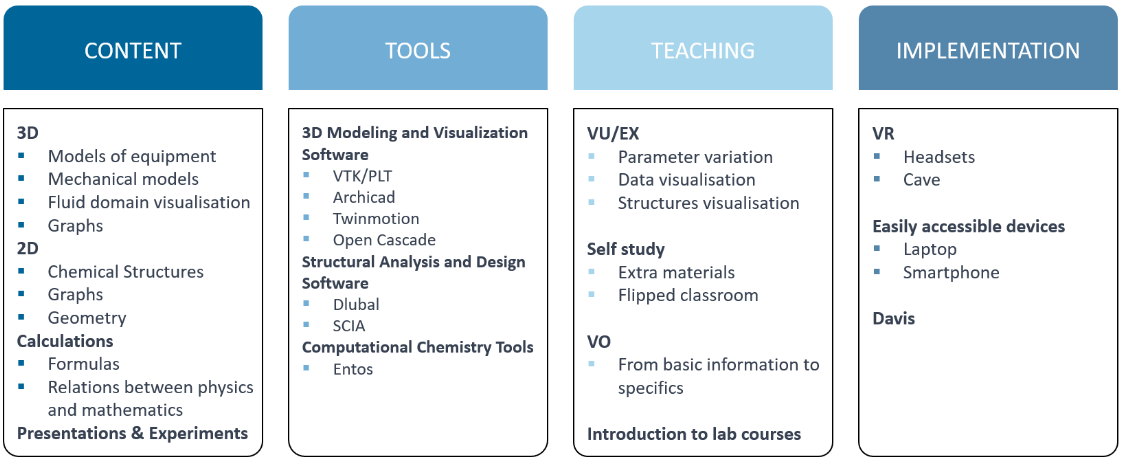


Figure 15: Overview of the answers from the fourth workshop

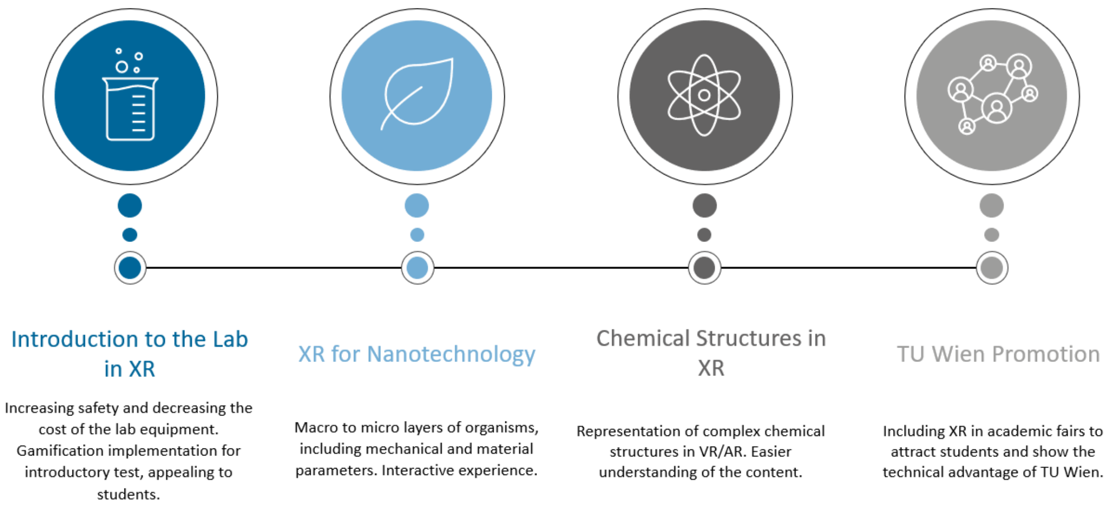


Figure 16: Summary of the fourth workshop findings

3.2.2 Overall workshop findings for TU Wien

The 4 workshops with all 8 faculties identified key opportunities for utilizing XR in educational settings. These include using VR for immersive material modelling, revisiting field trips in XR for enhanced learning experiences, and gamification to increase student engagement. XR's role in providing performance feedback, notably in areas like "Schadensplanung," and its capacity to facilitate interdisciplinary collaboration were also emphasized. Additionally, XR's potential to add value to teaching, reducing costs and safety risks in lab environments, and attracting new students at events was highlighted. However, challenges were identified, such as the limitations in handling complex 3D models in XR and the time-consuming nature of individual XR content and model development. The workshops underscored the need for user-friendly and web-based XR solutions to ensure broader adoption and effective integration into educational practices. More in-depth analysis of the findings from the workshop can be seen below in the SWOT diagram 17.

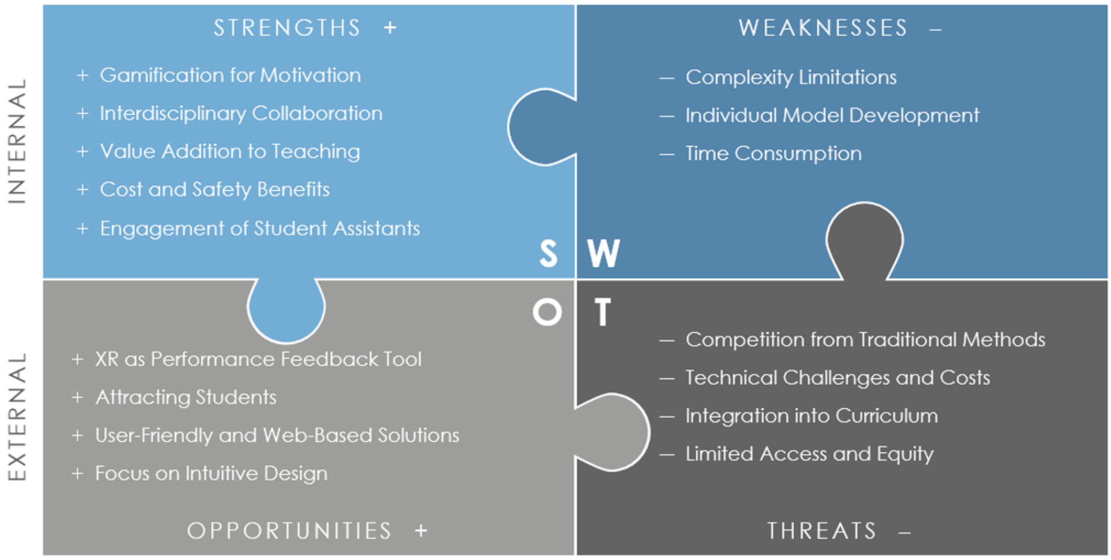


Figure 17: SWOT analysis of XR at TU Wien

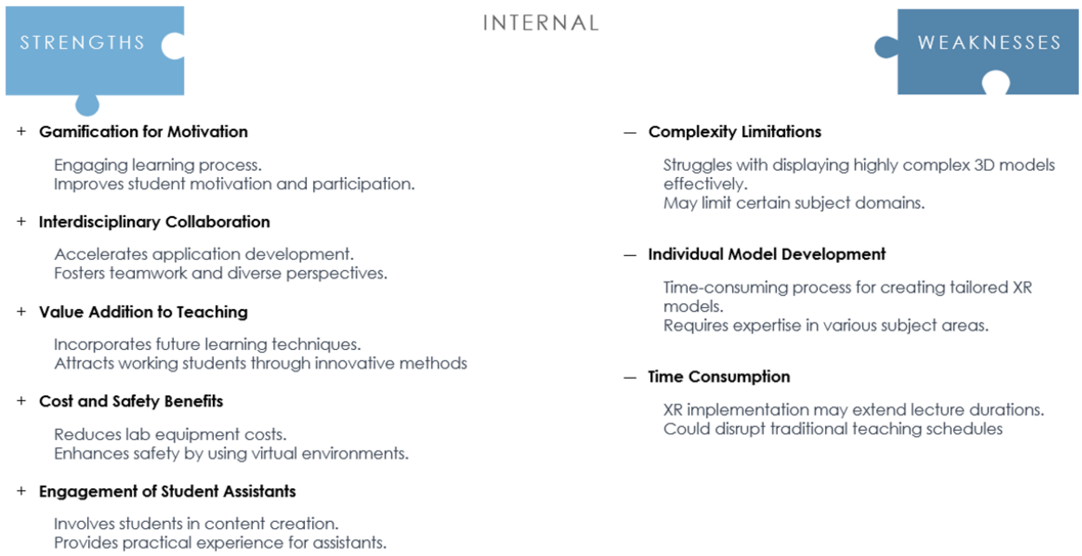


Figure 18: Strengths and weaknesses of XR at TU Wien

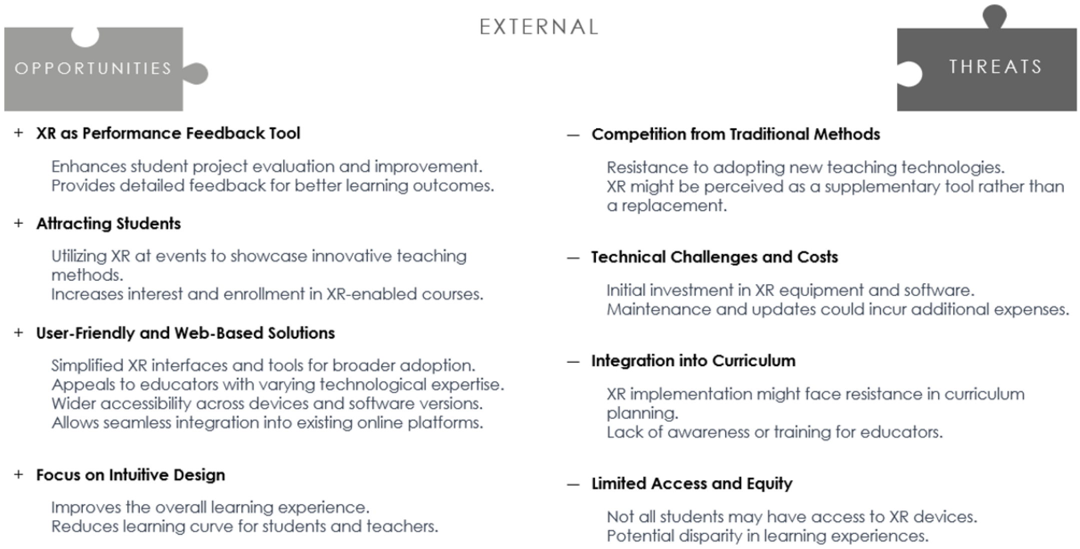


Figure 19: Opportunities and threats of XR at TU Wien

It can be seen that all faculties and lecturers have different demands, data files they work with and different needs. Hardly any platforms and 3D models for the visualization of their traditional teaching content are available yet. Key takeaways from the workshop include XR's potential in immersive learning, interdisciplinary collaboration, and its capability to attract new students, all while addressing the practical challenges of the technology. However, the need for user-friendly, web-based XR solutions was emphasized to overcome the challenges of complex model handling and content development. These insights pave the way for a strategic and informed integration of XR technologies into the university's curriculum, aligning with the future vision of education at TU Wien.

3.3 Questionnaire results

The online questionnaire revealed valuable insights on the sentiment among the TU Wien teaching staff. 40 responses were collected in total and statistically evaluated with all eight faculties represented in the survey, as figure 20 shows. The section below inspects the responses to all questions in more detail.

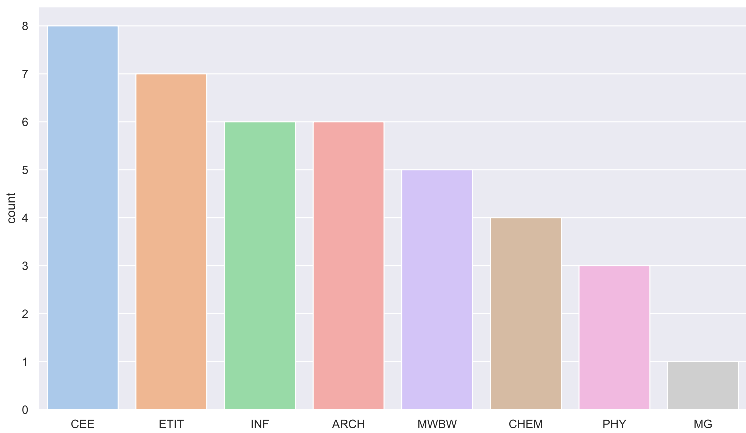


Figure 20: Distribution of questionnaire participants over faculties

The 39 participants are distributed over 30 different institutes and research units. Moreover, most participants either supervise seminars or exercises with up to 50 students or standard lectures with even more than 100 students. Thus, the requirements probably differ depending on the lecture format and corresponding complexity to make XR available for all students. For example, it is easier to organize and supervise a VR exercise for a seminar group of 15 people compared to a STEOP lecture with 300 students.

Figure 21 below illustrates the current teaching technologies used in lectures (many students), as well as in seminars or exercises (smaller groups). The bigger the word, the higher is the response frequency. For all lecture formats, live lectures are still the most popular teaching method. However, especially for teaching formats with smaller groups, online video platforms like Zoom, MS Teams or Skype are popular as well. Furthermore, online tutorials and e-learnings are also mentioned frequently, which might be enhanced with XR technology.

Figure 21: Currently used technologies (left: VO, right: VU/SE/UE)

The questionnaire also contained a question regarding the biggest challenges regarding XR methods in teaching. From figure 22, we can see that **content** was the most frequent response, which fortifies the workshop findings and the decision to host the *XR in Teaching* multidisciplinary lecture to create content. Unsurprisingly, other technological challenges are mentioned as well, such as interface, hardware, design or usability. Time and effort, as well as accessibility, are of course also valid challenges.
The next question was about specific challenges in their respective field and the responses displayed in figure 22 revealed the same trends. The effort for content creation, the complexity of the technologies, the availability of hardware, and the potential loss of seriousness during the lecture are just some examples.
On the contrary, the biggest potential for *XR in teaching* is the transferral of complex context through visualizations and 3D simulations.

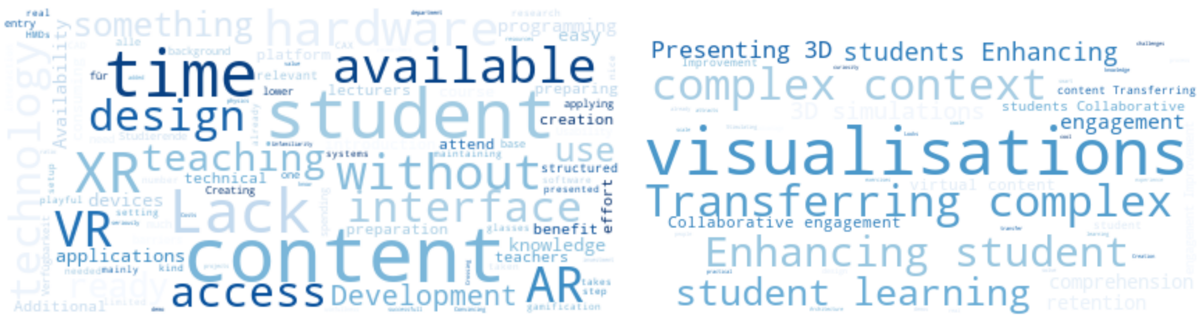


Figure 22: Biggest challenges for XR (left: in general, right: in their respective domain)

Depending on the faculty and teaching domain, the potential content for XR methods varies. However, it is important to notice that regardless of the teaching content, the interest and need for XR is consistent, as seen in figure 23.

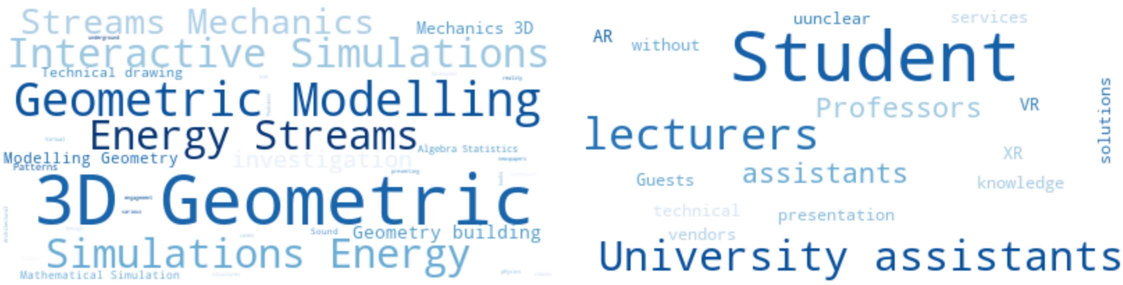


Figure 23: Potential XR content and benefactors

Last but not least, the participants were asked to rate their interest in XR teaching methods, as well as its importance, on a range from 0 (very low) to 5 (very high). As expected, the average interest was rated a bit higher (3.75) than the average importance (3.30), as figures 24 and 25 show. The opinions differ depending on the faculty, but in order to gain significant findings, more representatives from each faculties would have to be interviewed.

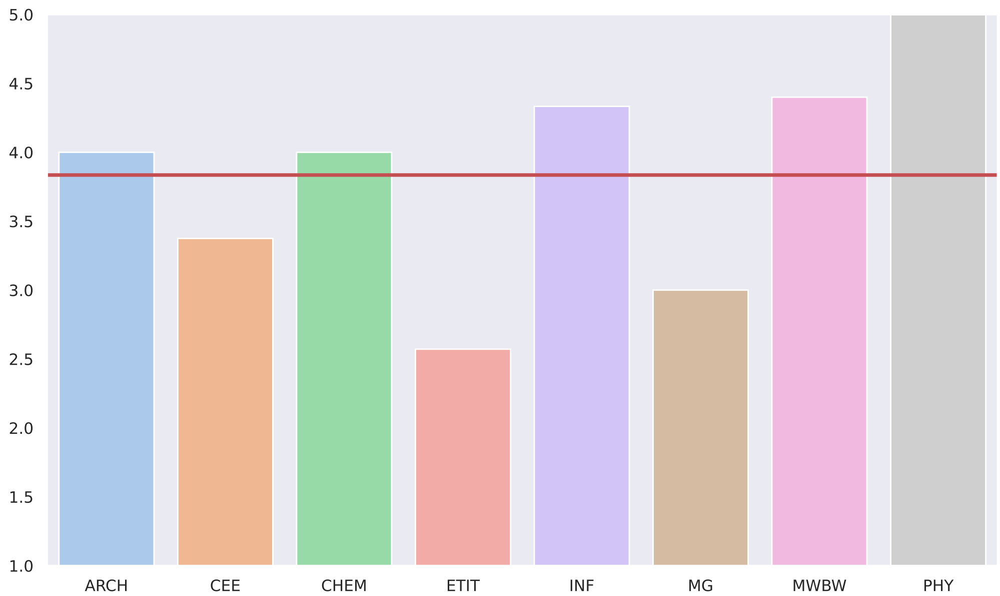


Figure 24: Interest in XR teaching methods

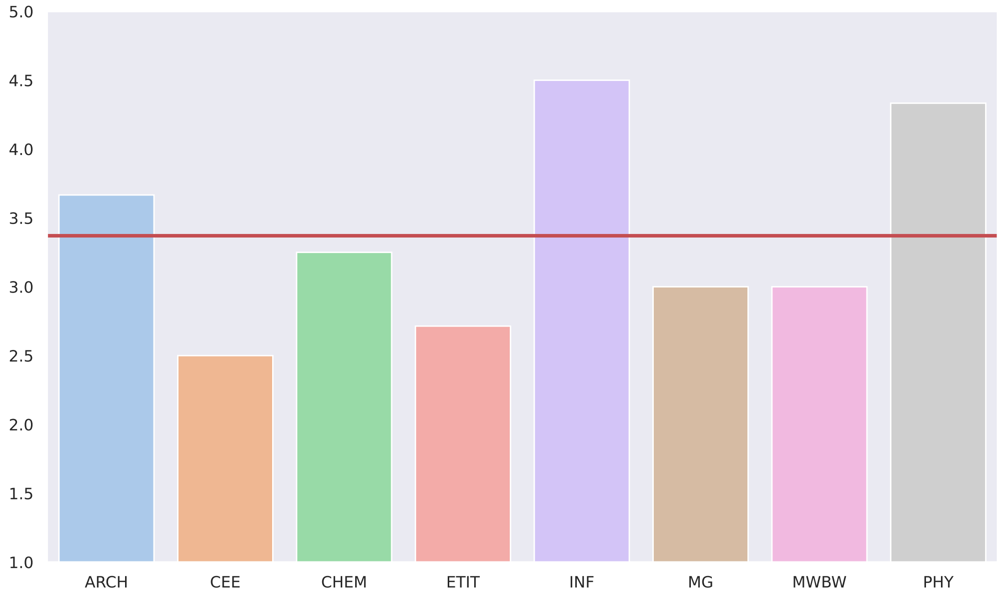


Figure 25: Importance of XR teaching methods

As highlighted in figure 26, the trend for potential of *XR in teaching* is consistent again, with an average of 3.57.

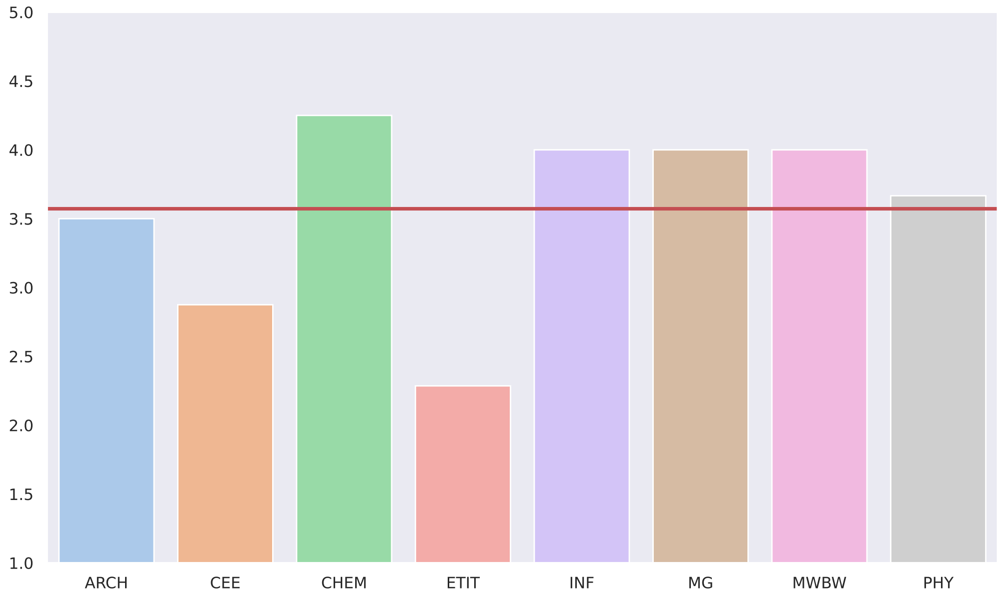


Figure 26: Potential of using VR/AR/XR-technology in the next 5 years

The personal benefit for teaching staff is not yet super clear and thus only achieves a 3.05 average score. The distribution of responses over faculties is shown below in figure 27.

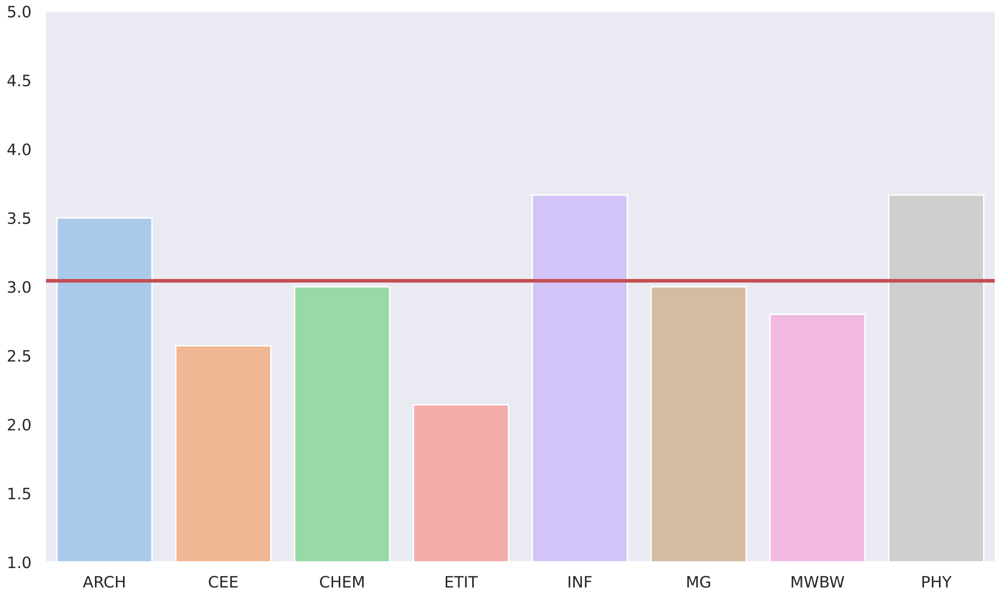


Figure 27: Personal benefit of XR technologies

Additionally, the need for XR technologies at the 30 individual participating institutes was only rated with a 2.73, as shown in figure 28 Therefore it can be concluded that the interest and importance is still higher than the actual current need.

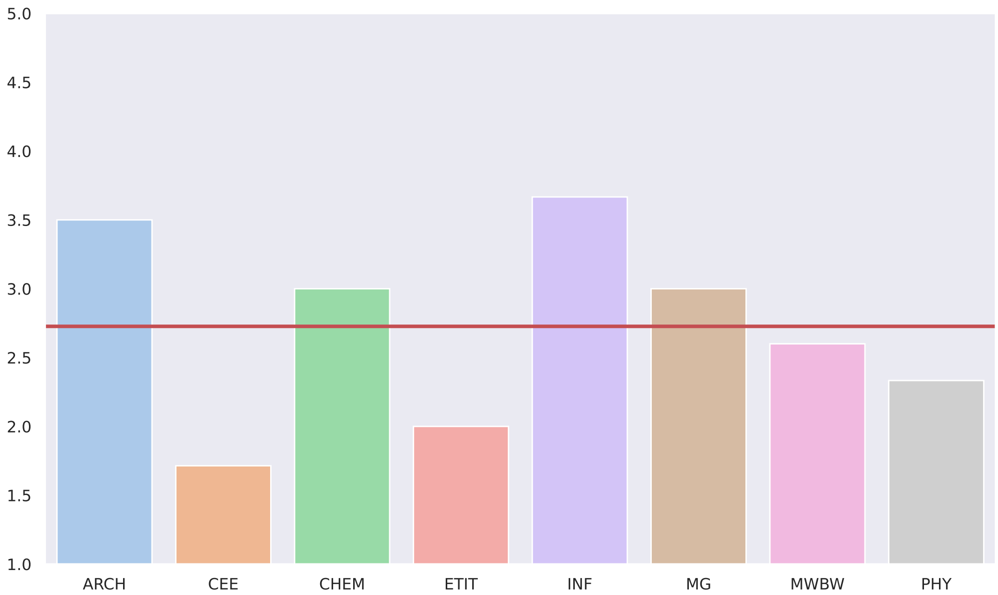


Figure 28: Need for XR at respective institute

The graphs above already show a clear trend when focusing on the different faculties. When analysing the Pearson correlation coefficient in figure 29, all five questions above show a strong positive linear correlation. That means, that the higher participant's rated one questions, the higher they rated another question too and vice versa.
The strongest correlation is between the questions "How much would you as a lecturer benefit from XR methods" and "How big do you see the potential of using XR technology in the next 5 years?" with a score of 0.8.

Q1	How interested are you to adapt your teaching methods to technological innovations like VR/AR/XR teaching?
Q2	How important would you rate supporting your current teaching methods with VR/AR/XR technology?
Q3	How big do you see the real potential of using VR/AR/XR-technology in the next 5 years?
Q4	How much would You as a lecturer benefit from VR/AR/XR teaching methods?
Q5	How large is the need to introduce VR/AR/XR technology for teaching in your institute?

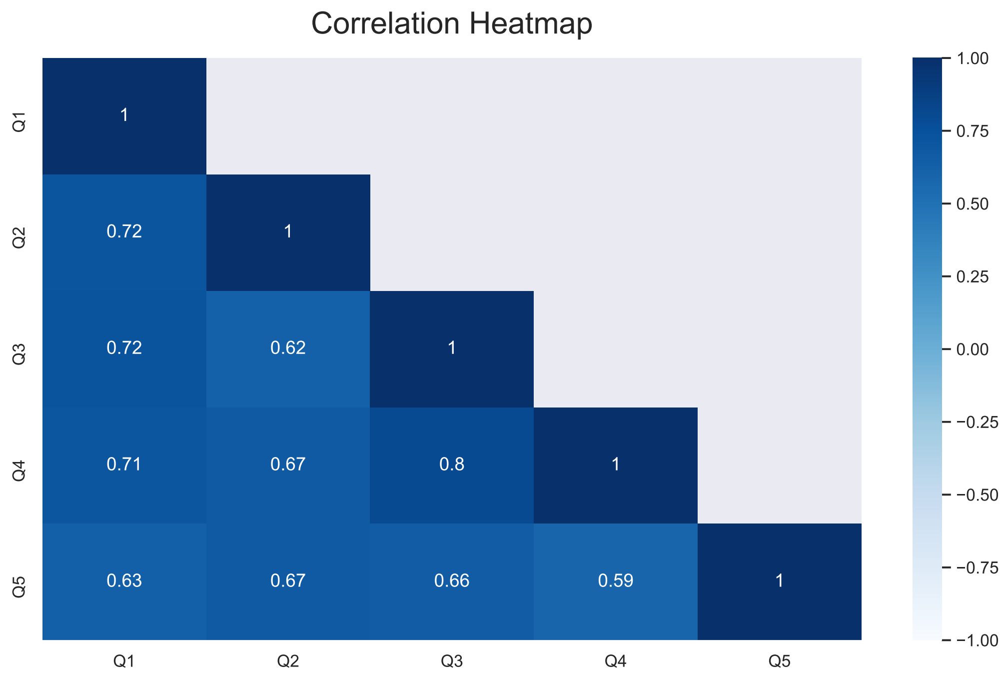


Figure 29: Correlation Matrix of questionnaire results

Generally, the faculty of architecture and planning shows the least interest in XR and raise the most concerns, whereas the faculty physics seems to have the most interest and potential for XR. However, in order to make statements based on significant quantitative data, we would need to repeat the survey with more representatives from each faculty.

3.4 Lecture results

The *XR in Teaching* project has made substantial progress in its lecture phase. Out of the 12 available topics (specific courses from the curriculum) provided by teaching personnel, students were able to successfully create content and roadmaps for 9 of them due to the number of interested students. A total of 15 students have registered to realise 9 topics. This achievement underscores the project's effectiveness in covering a broad spectrum of the curriculum. In the table 3, a list of topics with the assigned students can be found.

Topic	**Group**
234.161 VU Industrial Building (CEE)	Architecture Student, Architecture Student
Digital Content Creation for Mixed Reality Laboratory	Engineering Sciences Business Informatics Student
120.109 VU Topographic and Hydrographic Models (MG)	Software & Information Engineering Student
234.174 SE Integrated BIM Design Lab (CEE)	Civil Engineering Student, Architecture Student
134.152 VO Introduction to Nanotechnology (PHY)	Architecture Student, Nanotechnology Student
330.308 Production Information Management Systems (MWBW)	Mechanical Engineering - Management Student, Media Informatics and Visual Computing Student
Experience pattern formation in H2 oxidation – understanding catalytic reaction mechanisms	Technical Physics Student
330.317 Digital Simulation of Ergonomics and Robotics (DSER) (MWBW)	Business Informatics Student, Mechanical Engineering Student
232.029 SE Railway simulation (CEE)	Environmental Engineering Student, Civil Engineering Science Student

Table 3: List of topics and the students assigned

The course culminated in 9 final presentations, which were organized in Davis. These presentations were not only academic exercises but also showcases of practical application and innovation. Remarkably, 3 out of these 9 presentations included a live demonstration of the 3D implementation related to the topic. These live demos were a testament to the practical skills acquired by the students and provided a tangible demonstration of how XR can be effectively utilized in an educational setting. Figures 30 and 31 show the snapshots from the final presentations and the small format versions of posters presented.

Figure 30: Final presentations at Davis snapshots: Group photo of the course participants and the teaching staff (left), "Nanotechnology in XR Teaching" presentation(right)

Figure 31: Examples of posters delivered during the *XR in Teaching* multidisciplinary lecture

All final presentation posters in a bigger format can be found in Appendix A3 A.3.

234.161 VU Industrial Building

The students have decided to include the XR in the lecture in the form of the final presentations in

Davis in the 3D environment. The main benefits of this approach include providing an immersive experience, enhancing decision-making processes, and the use of VR for modelling, supported by open-source software. However, limitations exist, such as the restriction of modelling activities to PCs only and issues with poor shading quality. The group presented a live demo at the end of their presentation where the use of XR in the Industrial Building could be observed. In the figure 32 you can see the snapshot from the final Industrial Building topic presentation.

Figure 32: "XR in Industrial Building Design" live demo presentation at Davis

Digital Content Creation for Mixed Reality Laboratory

The student has also suggested that before the opening of the MR Lab, Davis is the best tool available at TU Wien for creating and navigating 3D Scenes. Both teams have expressed the need for a general booking system for Davis that would ensure good communication and allow students and teaching staff to work comfortably. The student proposed that a monthly lecture would take place at Davis, conducted by experts in XR technology to provide hands-on experience with XR technology, enhance understanding of complex subjects, and foster innovative teaching methods.

120.109 VU Topographic and Hydrographic Models

Topographic and Hydrographic Models topic realised by a Software & Information Engineering Student has shown that implementing XR can be very beneficial for the lecture. Environmental engineers utilizing XR tools gain a more intimate and detailed perspective of their projects. By employing XR, they can vividly visualize the environmental impact of their work in a way that surpasses the limitations of traditional 2D monitors, offering a deeper understanding of the changes and consequences in a three-dimensional context. For this topic, the use of Davis was suggested as well. The results of this collaboration could be used as a project work or as a tool to increase understanding of the topographic and hydrographic models.

134.152 VO Introduction to Nanotechnology

The students who were working on the "Nanotechnology in XR teaching" topic, managed to develop the first AR and VR Demo Prototypes of an application with a Content Library of 4 Graphene Products in different scales. They have decided on AR technology in the future implementation because of its availability and compatibility with AI. The developed AR application offers a better understanding of the concepts presented in the course Introduction to Nanotechnology. In this case: carbon nanotubes, two dimensional materials and space elevator. The application will consist of individual scenes which can be selected and after that specific three-dimensional models will be visualized in augmented reality with their corresponding descriptions. The group presented the first version of the application during the final presentation 33, 34.

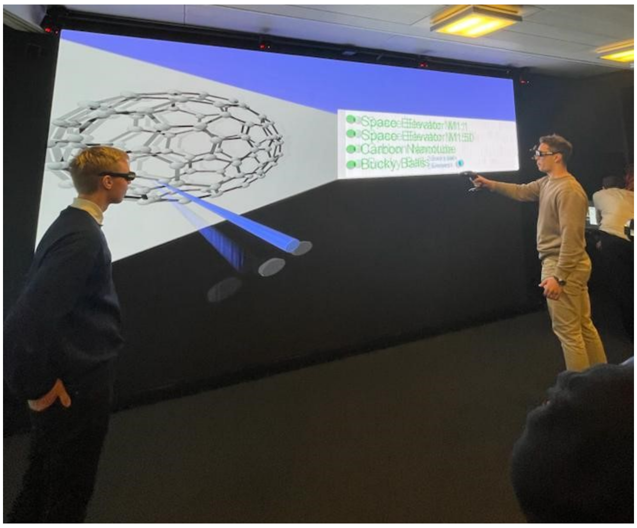


Figure 33: "Nanotechnology in XR teaching" live demo presentation at Davis

Figure 34: Graphic showing the future implementation of XR in nanotechnology teaching

234.174 SE Integrated BIM Design Lab

The team that realised the Integrated BIM Design Lab topic has suggested the use of holographic tables when introducing XR into the lecture. With the use of these tools, students have the opportunity for hands-on experience with architectural concepts. The teaching process becomes more dynamic, and educators have the chance to easily present complex architectural concepts through interactive tools. The multitouch holographic table could be used as a tool for an explanation of some architectural concepts difficult to understand with two-dimensional tools.

330.317 Digital Simulation of Ergonomics and Robotics (DSER)

The results of this project have shown that VR technology would be the most beneficial for the lecture. In the case of robotics, it is crucial to be able to visualise the machines in 3D for a better understanding and space awareness. The updated classroom setting would include all students wearing VR glasses and be accompanied by a teaching assistant conducting the simulations.

232.029 SE Railway simulation

For this topic, the students decided on the use of VR technology, because of its creative freedom and scalability. The technology would be used for explaining complex concepts and visualisation of data. The knowledge about block sections would be better communicated as a result.

Experience pattern formation in H2 oxidation – understanding catalytic reaction mechanisms

This topic was realised in collaboration with the Davis team from TU Wien Bibliothek, where the final presentation of the project took place. The student picked VR technology to implement an environment where they held the presentation and showed the live demo 35. They expressed that there is a lot of potential for XR in chemistry. Especially in surface chemistry a lot of the available material exists only as 2D simulations and animations. That means the added extra dimension greatly improves the visibility of simulations and effects.

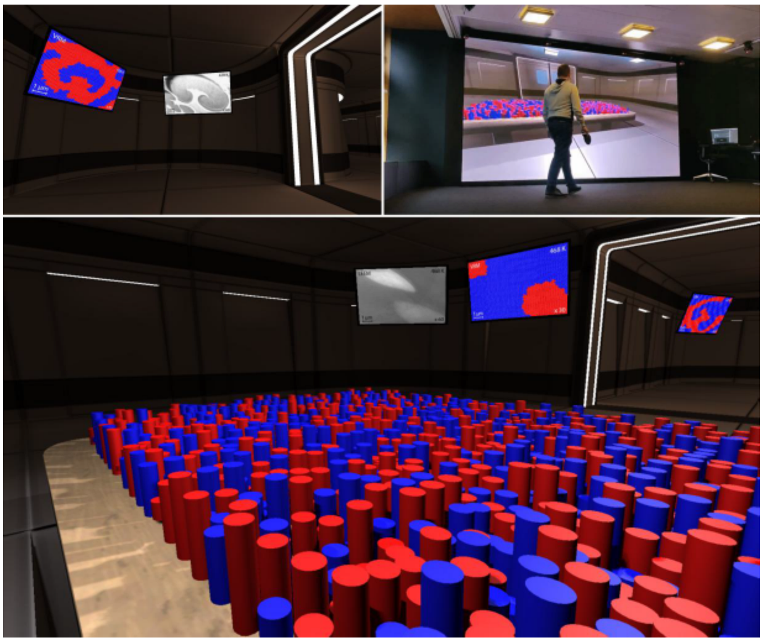


Figure 35: "XR in surface-chemistry" live demo presentation at Davis

330.308 Production Information Management Systems

The group conducted an in-depth analysis of the available technologies to decide which would be the best pick for the lecture. They decided in the end to implement the solution in VR as it allows the most creative freedom and the least difficulty of implementation. They also provided a mock-up video 36 of the possible solution which was presented at the final presentation. The group also expressed the possibility of expanding the system to AR technology in the future.

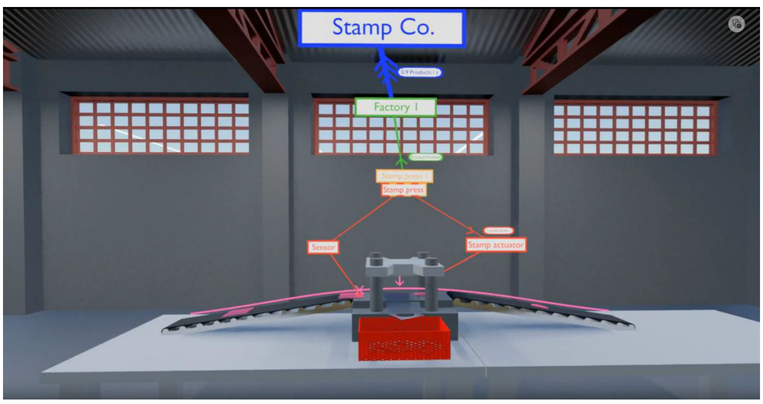


Figure 36: Mockup video screenshot

3.4.1 Lecture findings

Most of the students identified VR technology as more relevant for their courses with an interest in working with Davis (Industrial Building, Digital Content Creation for Mixed Reality Laboratory, Topographic and Hydrographic Models, Production Information Management Systems, Pattern formation in H2 oxidation, Digital Simulation of Ergonomics and Robotics, Railway simulation) only 1 group chose AR (Introduction to Nanotechnology) and 1 explored the project with a multitouch holographic table (Integrated BIM Design Lab).

An interesting pattern emerged regarding the composition of student teams and the quality of their projects. The most outstanding projects were those where students worked in pairs, combining distinct but complementary skills. Typically, these pairs consisted of one student with a domain-specific background, and another with expertise in programming or graphical implementations, often Architecture, Civil Engineering, or Data Visualization. The synergy between theoretical knowledge of the topic and technical skill in data visualisation in these teams was a key factor in the high quality of their outputs.

The success of these collaborations was not just limited to the course. Encouragingly, several participants expressed an interest in extending their project work beyond the course. This interest manifested in various forms, with some students considering the possibility of developing their projects into Bachelor theses. Others showed enthusiasm for continuing their work as project work at the university or even as hobby projects. This underlines how with some encouragement and guidance students can support the introduction of XR methods at TU Wien.

Overall, the lecture phase of the *XR in Teaching* project was highly successful. The students' enthusiasm and the high-quality work they produced are clear indicators of the project's positive impact. The integration of theoretical knowledge with practical demonstrations, especially in the advanced setting of Davis, highlights the project's forward-thinking approach and its potential to revolutionize teaching methodologies. The positive response from students also opens avenues for continued collaboration with the teaching staff. Such ongoing engagements not only benefit the students in their academic and professional development but also contribute to the enrichment of the *XR in Teaching* project itself. The prospect of these projects evolving into more substantial academic or personal pursuits is a clear indication of the project's impact and its potential for fostering a lasting interest in XR applications.

3.5 Further development of AR-supported Teaching

The creation of an XR application for each individual lecture is a very complex task. This applies not only to developing, but also to operating and maintaining. Therefore, it is advisable to utilise the TU Wien initiatives presented in section 1.3. AR-supported Teaching acted as a source of inspiration for the students' final presentations as part of the "Multidisciplinary lecture" course. AR-supported Teaching has the advantage of low-threshold access to AR, as it only requires a smartphone (=hardly any hardware costs). Additionally, it does not require a special room, making it suitable for lectures with a large number of students. Appendix A.4 contains examples of teaching scenes created during the project. The "Modellkläranlage" teaching scene is particularly noteworthy. It is based on a real model sewage treatment plant (see [13]) and was expanded during a bachelor's thesis in collaboration with E226-01.

Table 4 presents the development of AR-supported Teaching that fulfils the requirements submitted during the workshop and lecture, along with their evaluation and comments on the individual functions. The term "in process" indicates that the feature will continue to be developed after the project.

Requirements from the workshops	R1	R2	Status	Comment
Animation API	1		completed	Creation of the animation in Blender and transfer to AR-supported Teaching via JSON.
Annotations API	1		completed	
Annotations Font types	3		completed	
Applicable for a large group of students	2		completed	A new group management system allows multiple users to be imported simultaneously using a CSV file.
Documentation of the platform	2		completed	Comprehensive tutorials are available on the website after registration.
Easy transfer from the systems we use to the platform	2	3	ongoing	No proprietary format is supported at the moment. This is often not even possible and contradicts the open source concept. Two open, standardised file formats (IFC and GLTF) are already supported, which are available as export formats in most programs.
File Support: glTF	2		completed	With the support of glTF, the interoperability of AR-supported Teaching has been further enhanced. This is because many other file formats (e.g. CITY.GML, GEOJSON, STEP, RSTAB, RFEM) can be converted to a glTF format.
File Support: JSON	4		completed	
Mozilla Firefox support	1		completed	Expansion of supported browsers.
OS independent	1		completed	Every AR-supported Teaching application is web-based and therefore does not have a specific operating system requirement.
Safari support	1		completed	Expansion of supported browsers.
Support for smartphones	1		completed	AR-supported Teaching can be viewed on smartphones or tablets. An implementation on AR glasses is currently being evaluated.
Usability	1	2	ongoing	Ongoing valuation using Handheld augmented reality usability scale (HARUS) and System Usability Scale (SUS).
Using only open source components	1		completed	All components used consist of open source solutions (three.js, ifc.js). AR-supported Teaching could therefore be made completely open source.
Versioning of teaching scenes	2		completed	Versioning is possible directly in the platform. In addition, editors can choose which version is available to the public. This allows editors to work on new versions without restricting public access to the teaching scene.
Webbased Viewer	1		completed	
Animation	1	2	in process	A visual scripting environment is used to create complex animations. The development for this is almost complete. The creation of animations via API (JSON) already exists.
Animation with automatic exploded view	3	2	in process	Was already integrated in an older version of AR-supported Teaching. The creation could be done via the visual scripting environment.
Changing the scaling during use	3	3	not started	
Save predefined views	3	1	not started	
File format converter	5	3	not scope	There is already a large number of converters that are freely accessible.
Integration Python	4	3	not scope	
Integration TUWEL	3	1	not scope	

Table 4: Proposed features and requirements for an XR platform and comparison with AR-supported Teaching

3.6 Creation of the XR in Teaching roadmap

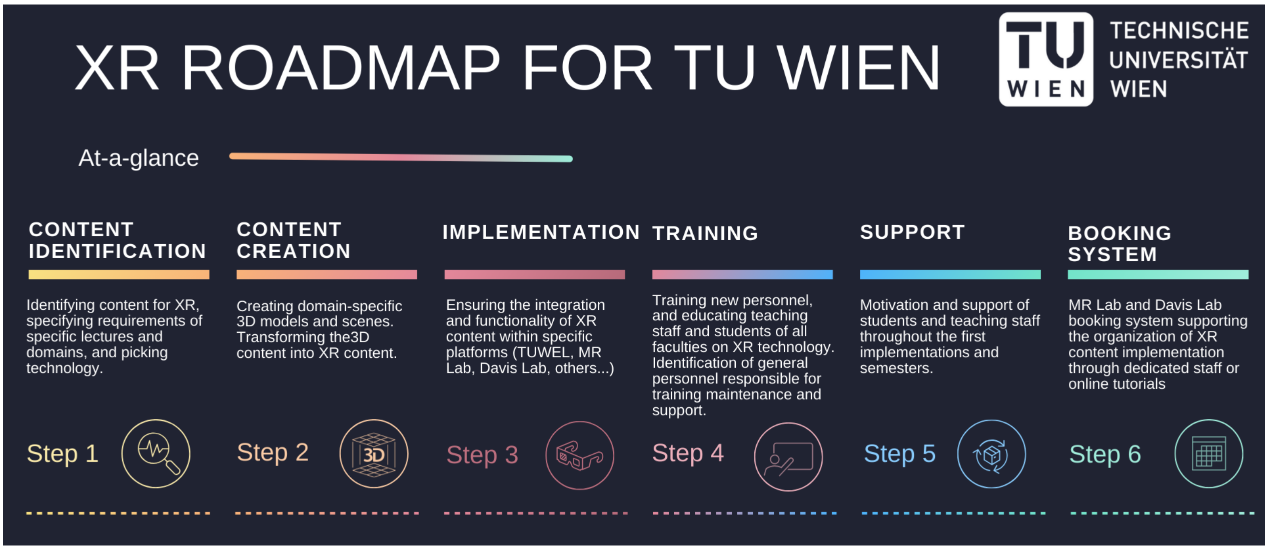


Figure 37: XR roadmap for TU Wien

The figure illustrates the comprehensive XR Roadmap for TU Wien, designed to streamline the integration of Extended Reality (XR) into the university's curriculum and research. This six-step strategic plan begins with Content Identification, where relevant XR content is pinpointed and tailored to fit specific lectures and domains as they all use different technologies and have different needs. It proceeds to Content Creation, involving the transformation of domain-specific 3D models and scenes into XR content. The technical support regarding the choice of the best-suiting XR technology as well as creating the content should be assured on the university side. The third step, Implementation, focuses on integrating and ensuring the functionality of XR content across various platforms like TUWEL, MR Lab, and Davis. All platforms have different requirements and limitations, so it is crucial to be mindful of them when implementing the content. The fourth step, Training, emphasizes the importance of educating new personnel, teaching staff, and students across all faculties and relevant central divisions, such as the TU Wien Bibliothek with XR technology and establishing a support structure for ongoing maintenance. Support, the fifth step, is about motivating and assisting students and teaching staff through the initial implementation phases. Lastly, the roadmap outlines the establishment of a Booking System for the MR Lab and Davis, ensuring organized access to XR content and facilitating its implementation through dedicated staff or online tutorials.

4 Conclusion and Future Outlook

In essence, while XR presents significant opportunities for enhancing learning, its successful implementation in education requires addressing its current technical limitations and focusing on developing intuitive, accessible platforms.

In our assessment of the current Extended Reality (XR) initiatives at TU Wien, we recognize the urgent need for a centralized channel or website for cross-facultative use. Such a platform would serve as a comprehensive repository for all ongoing XR projects and teaching endeavours, accessible to both students and lecturers. While we have identified several active AR and MR initiatives at TU Wien such as MR Lab, Davis, and AR-supported Teaching some challenges persist across these initiatives. Davis has already demonstrated its value for individual student work and courses, mostly for Architectural Design courses. The MR Lab is set to expand XR research at TU Wien. However, a significant challenge is that the XR content required for specific subjects is mostly unavailable and needs to be custom-created for each case. It is crucial to consolidate knowledge, content and projects into a unified, user-friendly platform, ensuring that valuable resources and applications as well as support are readily available to enrich the teaching and learning at TU Wien. The scope of this platform would be to be a comprehensive resource for XR in education at TU Wien, focusing on both content and technology. It aims to document effective XR teaching approaches across various courses and disciplines, offering a repository of XR applications and content tailored for educational purposes. Additionally, it would serve as a knowledge base where educators can share their experiences and solutions. While aiming for broad applicability, the platform would recognize the unique challenges posed by specific hardware infrastructures like Davis and the MRLab. It suggests a blend of centralized and decentralized approaches for information sharing to accommodate the diverse needs of educational institutions, promoting innovation and practical application of XR in teaching at TU Wien.

The reluctance among a majority of the teaching staff to alter their conventional lecture formats or incorporate XR technologies has been observed. Despite the university's large number of teaching staff, only a fraction showed active interest in participating in the workshops.

One of the key challenges identified is the need for tailored 3D content and platforms for individual subjects and lectures. The demand for software developers and 3D modellers in the general staff highlights the necessity for dedicated personnel to assist lecturers in content creation. Additionally, the ongoing administration and updating of these models and systems are expected to be time-consuming.

In terms of technology preference, VR has been frequently mentioned by both teaching staff and students as more effective for courses, while AR is seen as more suitable for field applications such as site trips, spatial planning, and presenting nano-scale models. Furthermore, students exhibited high engagement and interest, with some continuing to work on projects and content development even after the multidisciplinary lecture *XR in Teaching* completion.

The project findings also emphasize that while XR offers significant benefits in visualizing and interacting with models in robotics, ergonomics, and building design, it is not universally applicable to all lecture formats. Its effectiveness is most pronounced in sessions where students receive informed feedback on their projects, enhancing motivation and engagement. For final presentations, XR technologies provide a dynamic platform for students to showcase their work.

Given the episodic need for XR technologies like VR and AR glasses—required not throughout the semester but during specific sessions—the importance of facilities such as the MR Lab and Davis Lab is amplified. These labs must have effective support and booking systems to manage the high demand from various courses and groups effectively. Usage patterns can vary widely: some courses may utilize Davis exclusively for final presentations, while others might engage it for iterative design meetings or even for early and/or regular VR-based presentations. To streamline this process and ensure equitable access, the implementation of a planning tool is essential. Such a tool would enable precise assessment of course requirements, facilitating advanced planning and scheduling to mitigate congestion and optimize lab usage, particularly during the critical final weeks of each term.

The multidisciplinary lecture *XR in Teaching* and workshops at TU Wien have underscored the need for interdisciplinary collaboration to create high-quality XR content. This involves uniting domain experts, programming and data visualization students, and teaching staff. Such collaboration is crucial for developing XR experiences that are both technically adept and educationally relevant.

The establishment of the *Mixed Reality Lab at TU Wien* is a step towards integrating XR technologies into teaching and learning. This lab will provide a space where educators will be able to develop and refine XR-based teaching methodologies, effectively bridging the gap between theoretical knowledge and practical application. It will offer students an opportunity for immersive learning experiences, enhancing their engagement and understanding of complex topics. Additionally, the lab will act as a resource for educators to acquire skills in XR technologies, ensuring their seamless integration into everyday teaching. There is an initiative from the MR Lab Team to collaborate further and find common ground to proceed with introducing AR/VR-supported education more broadly at the TU Wien.

Soon, *Davis* will likely become a central feature in many TU Wien courses, especially those in fields like chemistry, geosciences, and engineering, where data visualization is crucial. By providing a space where theoretical concepts can be dynamically visualized and interacted with, the lab is set to enhance the understanding and retention of complex information. Furthermore, Davis is expected to inspire new research projects and collaborations within the university. As an educational tool, it will not only benefit current students and faculty but also attract prospective students and researchers, solidifying TU Wien's reputation as a leader in integrating technology with education. The TU Wien Bibliothek employs dedicated personnel for managing, implementing and operating Davis. Recognizing visualisation techniques as an essential general skill for contemporary scientific work practices, the library extends its related course program by offering dedicated introductory courses for 2D and 3D visualisation. These courses are designed to provide a supportive environment for first experiments in VR and for fostering fruitful exchange between students of the different faculties of TU Wien, especially taking advantage of Davis' position in the central university infrastructure which allows equal access to all stakeholders of the institution. As far as teaching support is concerned, one of the main goals of the Davis team is to lower the entry barrier for potential users by providing pre-configured templates with out-of-the-box support for the VR features of DAVIS (Tracking, Stereo-vision) for as many different software tools as possible, enabling, for example, architecture students to explore their existing 3D models in Davis with reasonably low effort. As demonstrated by two successful student projects performed in Davis under the supervision of Prof. Kaufmann's team with the involvement of the Davis team, the development of prototypes for such templates is of interest to computer science students seeking project or thesis topics. Building on one of these outcomes in the context of *XR in Teaching*, the collaboration of the library staff with the student developing the *XR in surface-chemistry* project resulted in significant progress towards a template for the Unity3D environment.

AR-supported Teaching, developed at TU Wien, offers a simple way for students to use AR. It can be integrated into existing courses to enhance the learning experience. By using devices that most students already own, such as tablets and smartphones, it provides interactive learning environments. The project extended the range by supporting the glTF format, making it usable outside the AEC sector as well.

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A Appendix

A.1 Questionnaire

This questionnaire will take about 10 minutes and contains questions regarding the implementation of XR teaching methods at TU Wien. Your participation is highly appreciated and essential in order to obtain an accurate understanding of the current teaching situation and desired future development towards *XR in Teaching* at TU Wien.

In this questionnaire we will be using the terms VR (Virtual Reality), AR (Augmented Reality) and XR (Extended Reality).

By VR we mean computer-generated simulation or recreation of a three-dimensional environment that can be interacted with and explored by a person using a headset or hand-held controllers.

By AR we mean a technology that overlays digital information, such as images, text, and sounds, onto the real-world environment in real-time. AR is typically experienced through a device, such as a smartphone or a wearable headset, which uses a camera and other sensors to capture the surrounding environment and then superimpose digital content onto it.

For the following questions we use XR as overall term for VR/AR and their combination.

Section 1 - TU affiliation

1. Which faculty do you work at?

   ☐ Faculty of Mathematics and Geoinformation

   ☐ Faculty of Physics

   ☐ Faculty of Technical Chemistry

   ☐ Faculty of Informatics

   ☐ Faculty of Civil and Environmental Engineering

   ☐ Faculty of Architecture and Planning

   ☐ Faculty of Mechanical and Industrial Engineering

   ☐ Faculty of Electrical Engineering and Information Technology

2. Please state the full name of the institute you work at.

3. How many students do you have at your department seminars/project-based courses (SE/UE/VU), which could be relevant for VR/AR/XR?

   ☐ 5-20

   ☐ 21-50

   ☐ 51-100

   ☐ 100 +

4. How many students do you have at your department lectures (VO), which could be relevant for VR/AR/XR?

   ☐ 5-20

   ☐ 21-50

   ☐ 51-100

   ☐ 100 +

Section 2 - Present teaching situation

5. Which technologies are you currently applying in teaching?
   - ☐ Online Meeting Platforms (e.g., Zoom, MS Teams, Skype, ...)
   - ☐ E-learnings (e.g., TUWEL)
   - ☐ Video platforms (e.g., lecture recordings, online tutorials, ...)
   - ☐ In-class live lectures
   - ☐ Black board or flip chart
   - ☐ (Overhead) projector, ...
   - ☐ Virtual Reality
   - ☐ Augmented Reality
   - ☐ Podcasts / Ebooks
   - ☐ In-person discussions/correction meetings for the projects (In-person project feedback meetings)
   - ☐ Other ____________________
6. Which methods and technologies are you currently applying in your teaching for projects and seminars (SE/UE/VU)?
   - ☐ Online Meeting Platforms (e.g., Zoom, MS Teams, Skype, ...)
   - ☐ E-learnings (e.g., TUWEL)
   - ☐ Video platforms (e.g., lecture recordings, online tutorials, ...)
   - ☐ In-class live lectures
   - ☐ Black board or flip chart
   - ☐ (Overhead) projector, ...
   - ☐ Virtual Reality
   - ☐ Augmented Reality
   - ☐ Podcasts / Ebooks
   - ☐ In-person discussions/correction meetings for the projects (In-person project feedback meetings)
   - ☐ Other ____________________
7. How interested are you to adapt your teaching methods to technological innovations like VR/AR/XR teaching? (1-not interested, 5-very interested)
8. How important would you rate supporting your current teaching methods with VR/AR/XR technology? (1-not important, 5-very important)
9. In your opinion, what are currently the biggest challenges for teaching with VR/AR/XR methods at TU Wien?
10. Where do you see potential for VR/AR/XR in teaching?
    - ☐ Transferring complex context through visualisations to students
    - ☐ Enhancing student learning and engagement
    - ☐ Improvement of comprehension and retention of students
    - ☐ Presenting 3D simulations to students
    - ☐ Collaborative engagement on virtual content

☐ Other ____________________

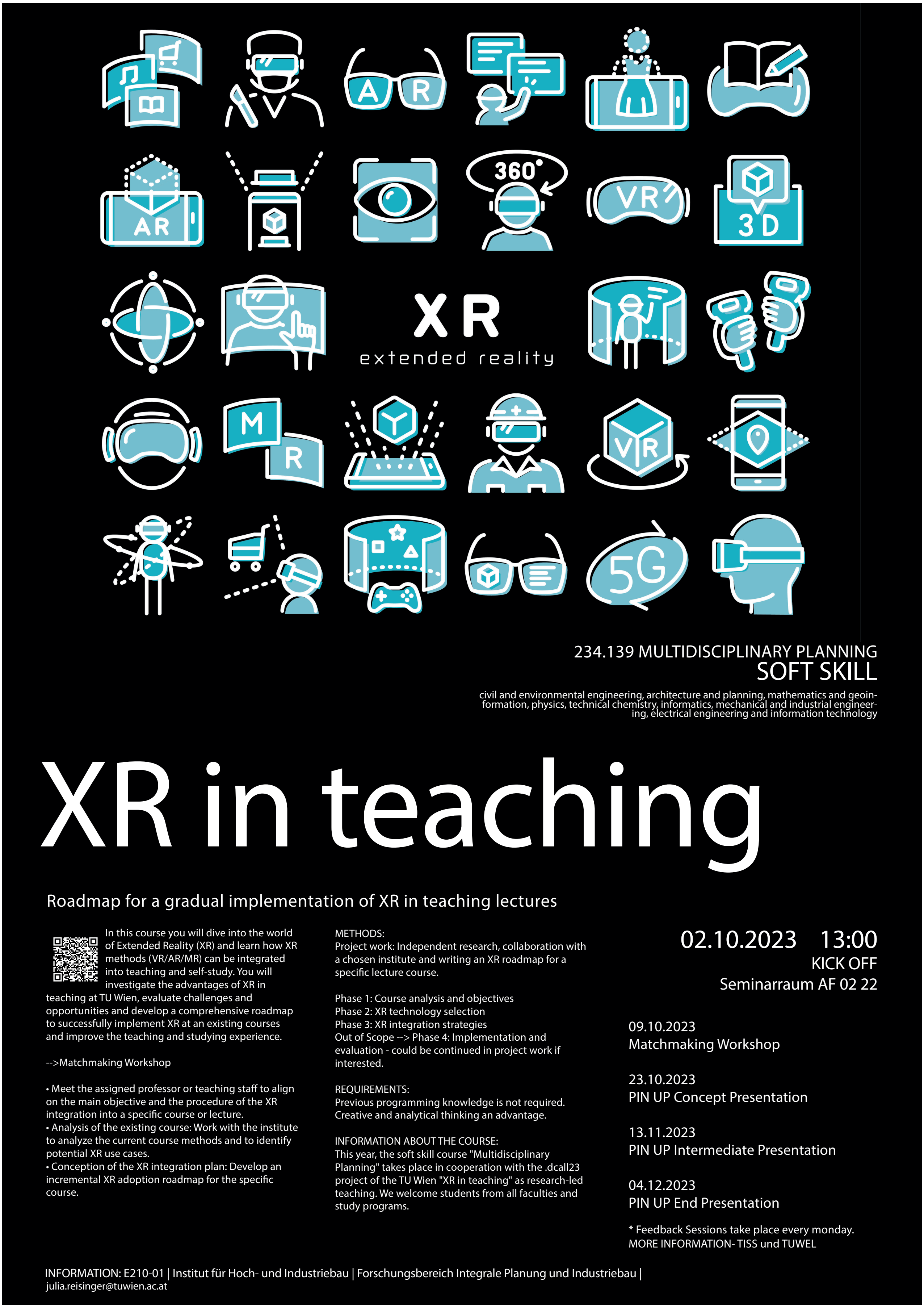
Section 3 - XR teaching content

11. What educational content do you see as potential for teaching in VR/AR/XR technology?
    - ☐ Interactive Simulations (Energy, Streams, Mechanics, ...)
    - ☐ 3D Geometric Modelling
    - ☐ Podcasts, books, newspapers
    - ☐ Geometry building and investigation
    - ☐ Patterns and Algebra/Statistics
    - ☐ Sound Simulation
    - ☐ Mathematical Simulation
    - ☐ Technical drawing
    - ☐ Other ____________________
12. Who would benefit mostly from VR/AR/XR methods?
    - ☐ Professors
    - ☐ Students
    - ☐ University assistants and lecturers
    - ☐ Student assistants
    - ☐ Other ____________________
13. What are the challenges for using XR/VR/AR in your respective field?

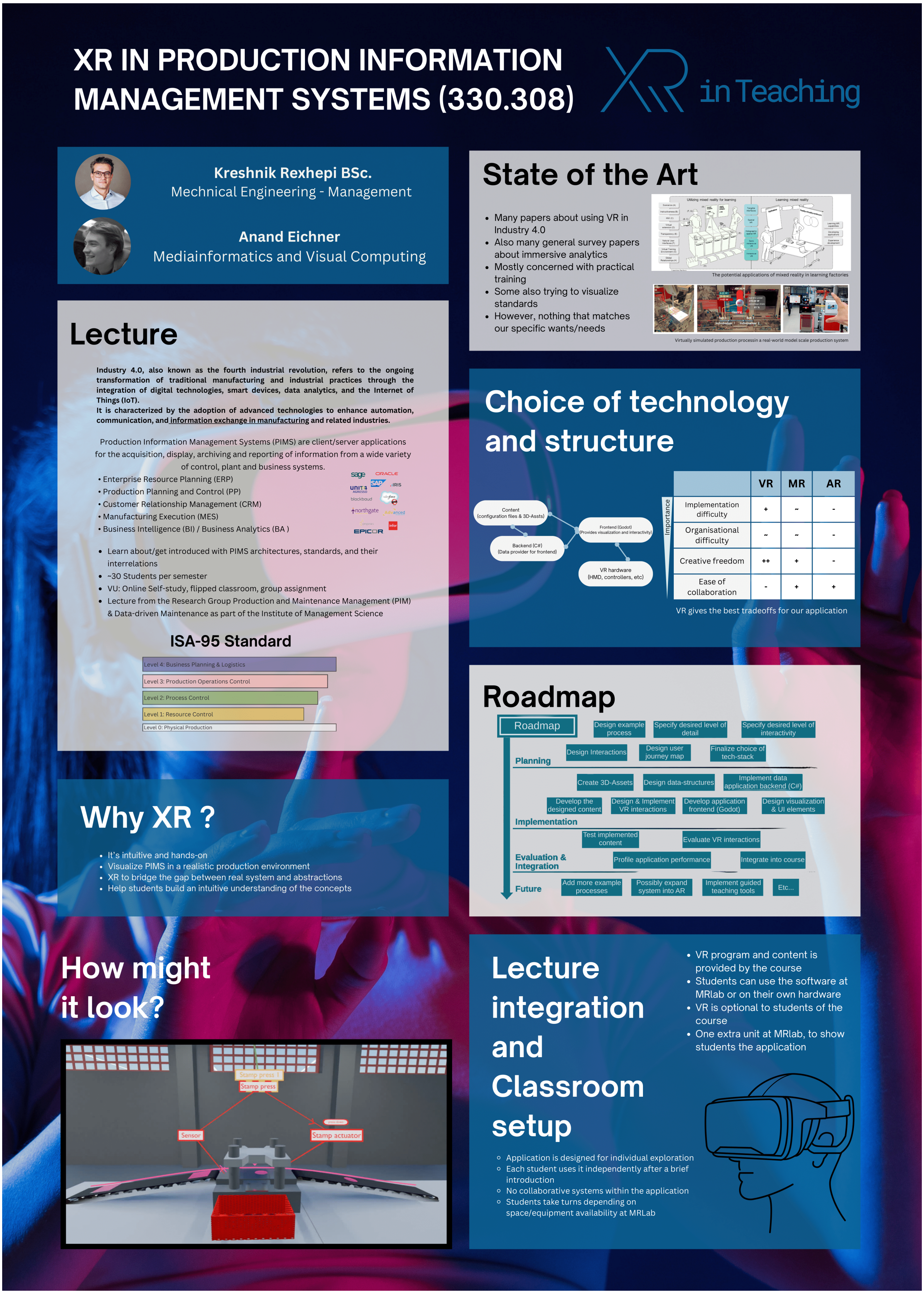
Section 4 - The need and benefit of XR teaching methods

14. How big do you see the real potential of using VR/AR/XR-technology in the next 5 years? (1-very little potential, 5-high potential)
15. How much would You as a lecturer benefit from VR/AR/XR teaching methods? (1-no benefit at all, 5-significant benefit)
16. Please explain why.
17. How large is the need to introduce VR/AR/XR technology for teaching in your institute? (1-very small, 5-very large)
18. Do you have any specific ideas how any VR/AR/XR teaching could be integrated to your teaching methods? Please share your thoughts.

A.2 Lecture poster



A.3 Students' posters



Aleksandar Babic 11841297
Michael Noll 12237966

XR in Teaching

Digital Simulation of Ergonomics and Robotics in VR

Lecture Information

Students: 20, sometimes more

ECTS Points: 3

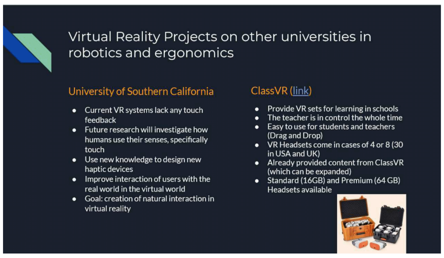
Lecturer: Clara Fischer

Lecture includes an introduction, self-study phase, 4 exercises and a final presentation.

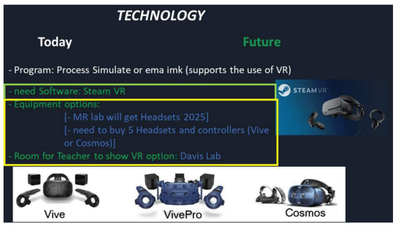
Classroom Setting

1. Introduction Meeting
2. Self-study phase - Students watch lecture videos, online check-test for 10% of the grade.
3. UE Ergonomic Assessment - Practical ergonomic exercises, usually teams of 3.
4. UE Robotic Simulation - RoboDK Software, practical robotics exercises.
5. VU Ergonomic Simulation of Workstations - Introduction to Simulation Tools, Process Simulate and ema imk, start of the Group work.
6. UE Ergonomic Simulation of Workstations, Group Work
7. Final Presentation - Group presentation of the simulated use-case, 15 minutes, use-cases for both simulation tools. Comparison of the programs.

What are other universities or industries doing? What is the state-of-the-art software?



Technical requirements/Platform concept



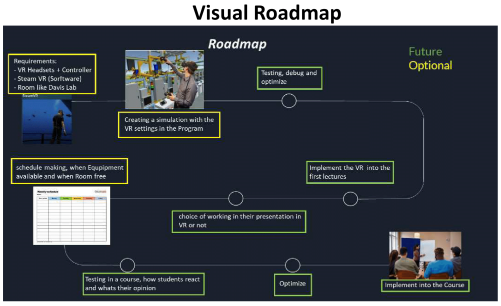
Main benefits and limitations

Borrowing and availability of the Headsets will be made very simple. Waiting time of one year, until the Headsets are really available.

"We don't have to reinvent the wheel." - Both Softwares have a VR option.

Learning phase - The system has to be set up first, so that the students can do the course without any additional difficulties.

Visual Roadmap



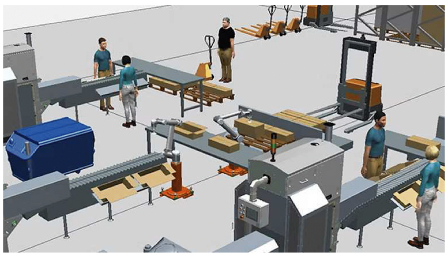
Next steps

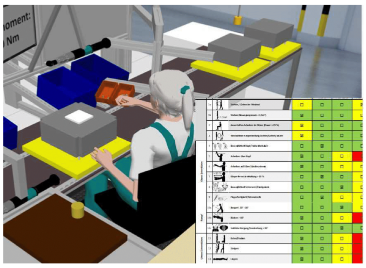
Getting the VR sets (Headsets)

Establishing a system for the borrowing of the headsets

Research on the VR options for Process Simulate and ema imk

Demo Screenshots





TECHNISCHE UNIVERSITÄT WIEN

234.139 Multidisciplinary Planning 2023W

Šarūnas Ščefanavičius - Institute of Applied Physics
Raman Levoshka – Institute of Architecture and Design

XR in Teaching

NANOTECHNOLOGY IN EXTERNAL REALITY TEACHING

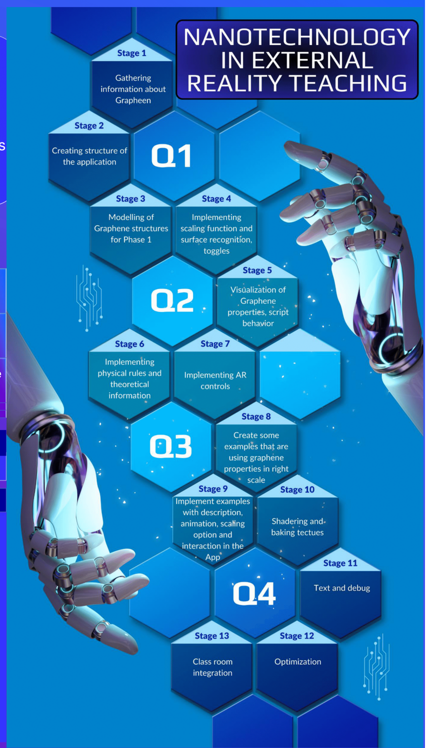
Lecture Information: 134.152 Introduction to Nanotechnology

Subject of the course:

- Nanorobotics
- Biomimetics
- Structural colors
- Carbon nanotubes, 2D materials
- Environment, health and safety issues
- Plant surfaces: structure and functions for biomimetic applications

What do students learn?

- Identify nanostructures
- Describe micro and nano fabrication
- List the applications
- Summarize the research fields of nano tribology and nano mechanics
- Justify the applications of monomolecular films



Problem Statement

The main problem of nanotechnology is obvious and comes out of the name of the discipline itself. It is about particularly small objects invisible to the human eye. This makes nanotechnology less accessible to understand and study, making communication between researchers and consumers, professors and students, manufacturers and investors very difficult.

Communication and demonstration in nanotechnology requires high quality and expensive equipment such as microscopes, laboratories and support staff, even if you have a microscope, only 1-2 people at most can observe the processes at the same time.

Our goal is to create an Augmented Reality (AR) application that let's physics students learn more about graphene and graphene structures.

Classroom Setting

Theoretical lecture, learning new concepts every week. Guided tours to laboratories. Group of 20 – 30 students.

What are other universities or industries doing? What is the state-of-the-art software?

Virual laboratory for fullerene products. National Tsing Hua University, Hsinchu, Taiwan.	Fisk university, Nashville, USA. Medical VR teaching.
Morehouse College, Atlanta, USA. History lectures in VR.	University of Maryland, USA. Profession teaching.

FISK UNIVERSITY ESTABLISHED 1866

MOREHOUSE COLLEGE ET FACTA EST LUX GEORGIA

UNIVERSITY OF MARYLAND 1856

Closest state of the art is the fullerene laboratory, but it uses VR, so it's accessibility is limited.

Technical requirements/Platform concept

Our application will use Augmented Reality (AR) because of wider availability than VR. Only a smartphone and an application is required. Unlike the case of VR where expensive and limited equipment is needed.
Other AR advantages:

- Availability and price.
- No cybersickness.
- Empowering reality instead of isolation.
- AI compatibility.

There is a possibility to use AR equipment to further enhance the experience.

Main benefits and limitations

XR Potential

- Immersive Storytelling
- Game-ification approach can increase motvation of students
- Portable XR laboratory increase accessability
- Detailed Visualisation of endproducts increase motivation and usability
- No social pressure and time limitations

Software used for development

For models: Photoshop, 3DS MAX
For application: Unity 3D, X CODE DEVELOPER

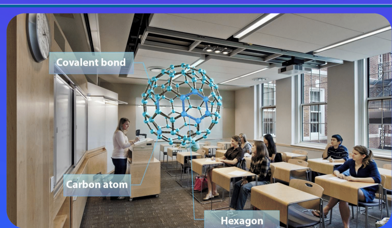
XCODE · Unity Hub · 3 MAX

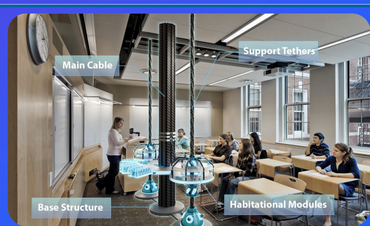
Next steps

- Application development
- Optimization
- New model development

Graphite	Graphene	Carbon nanotubes	Carbon buckyballs
Model	Model	Model	Model
	Fabrication methods	Fabrication methods	Fabrication methods

Demo Screenshots





TU WIEN TECHNISCHE UNIVERSITÄT WIEN

234.139 Multidisciplinary Planning 2023W
XR in Teaching

Magdalena Markiel
Jona Kulja

XR in Teaching

Integrated BIM Design Lab

This seminar marks a collaborative venture between the 210 Institute of Building and Industrial Construction (Faculty of Civil Engineering) and the 253 Institute of Architecture and Design (Faculty of Architecture). It represents a unique student competition wherein participants from the disciplines of architecture and civil engineering join forces. Together, they engage in a creative exchange of ideas to conceptualize and design projects centered around a specified theme. The participation is open to a select group of 20 to 30 students, fostering interdisciplinary collaboration and innovation.

As we draw inspiration from esteemed institutions like Humboldt University in Berlin and Milan University, our lecture is considering the adoption of cutting-edge hologram and multitouch technologies.
Following in the footsteps of these prestigious universities, we are exploring the transformative potential of these tools to enhance collaborative learning and design exploration within our architecture and civil engineering programs.

Hologram Table: Immerse in 3D holographic models for spatial comprehension.
Multitouch Table: Collaborate seamlessly with a responsive touch surface for multiple users.

Project-Based Learning:Structured around hands-on projects. Interdisciplinary collaboration within teams.

Feedback and Iteration: Real-time feedbac mechanism. Continuous improvement based on insights.

Professional Development: Ongoing faculty training. Instructors equipped for effective guidance.With these streamlined technical requirements and platform concepts, the lecture seamlessly integrates hologram or multitouch technologies, enhancing the collaborative learning experience.

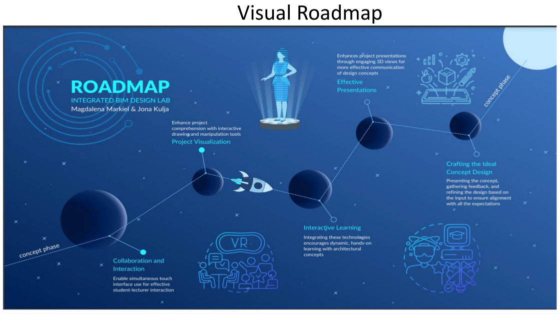
Hologram Table:

Immersive Visualization
Cost
Interactive Design
Limited Physical Interaction
Collaborative Learning

Multitouch Table:

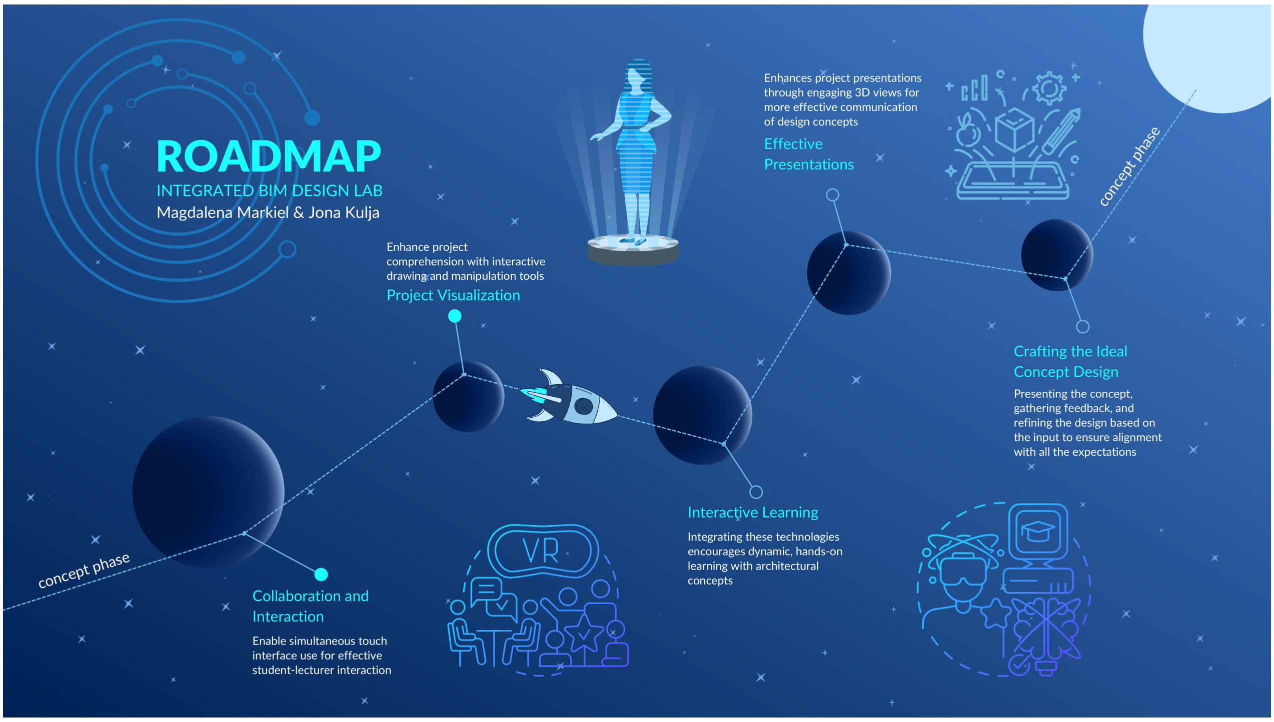
Interactive Collaboration
Limited 3D Visualization
Tactile Interaction
Screen Size Constraints
Cost-Effectiveness

Visual Roadmap



Engage with interactive workshops, explore collaborative projects, and witness the impact on diverse disciplines.

Demo Screenshots


ROADMAP
INTEGRATED BIM DESIGN LAB
Magdalena Markiel & Jona Kulja
Enhance project comprehension with interactive drawing and manipulation tools
Project Visualization
Enhances project presentations through engaging 3D views for more effective communication of design concepts
Effective Presentations
concept phase
Crafting the Ideal Concept Design
Presenting the concept, gathering feedback, and refining the design based on the input to ensure alignment with all the expectations
Interactive Learning
Integrating these technologies encourages dynamic, hands-on learning with architectural concepts
concept phase
Collaboration and Interaction
Enable simultaneous touch interface use for effective student-lecturer interaction
VR

Aleksandar Gavric

Crafting and Navigating 3D Scenes with DAVIS

Lecture Information

Topics Covered: Use of XR technology in various fields like architecture, engineering, and data visualization.
Speakers and Instructors: Experts in XR technology, experienced educators, and industry professionals.
Schedule and Duration: Monthly lectures, each lasting approximately 2 hours.
Learning Objectives: To provide hands-on experience with XR technology, enhance understanding of complex subjects, and foster innovative teaching methods.

Classroom Setting

Environment: The 4.8m x 2.7m 4K LED wall at DAVIS, configured for interactive VR presentations.
Interactivity: Utilization of head and hand tracking for immersive learning experiences.
Capacity: Sessions designed for small groups (up to 15 participants) to ensure personalized interaction.
Safety and Accessibility: Ensuring a safe, inclusive, and accessible learning environment for all users.

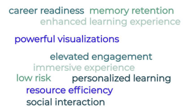
Comparative Analysis with Other Universities or Industries

University	Specific XR Hardware Used	Application in Teaching
MIT	Multi-panel LED display wall, capable of 3D stereoscopic views	Used in engineering and architecture for interactive design and collaborative projects.
Stanford University	Virtual Reality (VR) cave with motion tracking and head-mounted displays	In psychology and education for immersive learning experiences and conducting behavioral research.
Carnegie Mellon University	Room-scale VR systems with hand tracking and haptic feedback	In computer science and arts, for interactive design, gaming, and creative projects.
ETH Zurich	Immersive VR room with large-scale projection screens and real-time rendering	Utilized in spatial development and planning for realistic urban and architectural simulations.
University College London (UCL)	3D holographic displays and augmented reality (AR) interfaces	In archaeological and cultural heritage studies for interactive reconstruction of historical sites and artifacts.
Technical University of Munich	High-resolution interactive display walls with gesture control	In mechanical engineering and physics, for visualizing complex systems and enhancing interactive learning.
University of Cambridge	Large-scale VR environments with advanced molecular visualization tools	For molecular biology and

Technical requirements/Platform concept

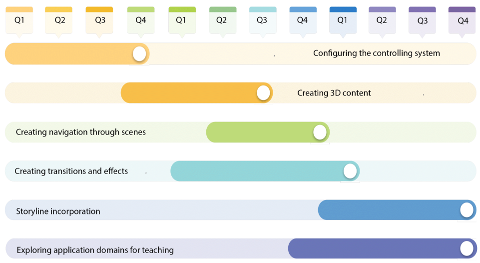
1. **Display Specifications**: Active 3D stereo for interactive VR presentations.
2. **Tracking and Interaction Systems**: Optical tracking system for head and hand tracking.
3. **3D Glasses**: Active 3D glasses designed to facilitate easy communication among viewers.
4. **Primary Purpose**: Suited for educational purposes, such as teaching and learning.
5. **Booking and Usage**:
    1. Availability for booking by the hour for teachers and students.
    2. Suitable for visualizing, experimenting, and discussing 3D data in courses or individual projects like master's theses.
6. **Software and Templates**:
    1. Preconfigured software products with project templates.
    2. Support for hardware features (3D stereo rendering, head and hand tracking).
7. **Educational Support and Requirements**:
    1. Library-hosted workshops and courses on basics, 3D data format transformation, and interaction elements.
    2. Mandatory introductory workshop for individual users and teachers to understand the functionality and usage of the equipment.

Main benefits and limitations



Educational Benefits: Improved engagement, enhanced understanding of complex subjects, and practical skill development.
Technical Advantages: Cutting-edge technology providing a unique, immersive learning experience.
Limitations: Addressing potential technical challenges, learning curve for users, and resource allocation.

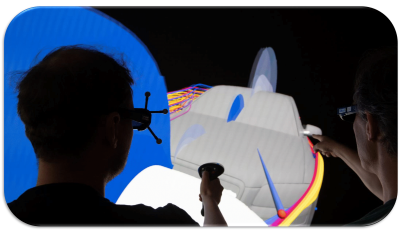
Visual Roadmap



Next steps

Immediate Plans: Implementing pilot programs and workshops, integrating feedback for improvement.
Long-Term Goals: Expanding the use of DAVIS across various disciplines, promoting research and development in XR technologies.
Call to Action: Encouraging participation from students and educators, fostering a community of innovation and learning.

Demo Screenshots



TECHNISCHE UNIVERSITÄT WIEN

234.139 Multidisciplinary Planning 2023W
XR in Teaching

Markus Haferl
Alexander Schmidt

XR Concept of Railway Simulation

XR in Teaching

Lecture Information

- 232.029 Railway Simulation
- Civil Engineering – Master's programm
- Winter semester and summer semester
- 16 Participants in groups of each 4 persons

Classroom Setting

- VR Glasses for all participants
- Accompaniment by teaching assistent
- Seminar room with large open area

Role model projects:

- Experimental model railroad laboratory in Germany Slovakia, Czech Republic
- Real-life models of railroad infrastructure
- VR Railway teaching research projects in China

Next steps

- Decision on realization
- Researching the available options
- Programming of VR application with inputs from Opentrack
- Testing → Launch

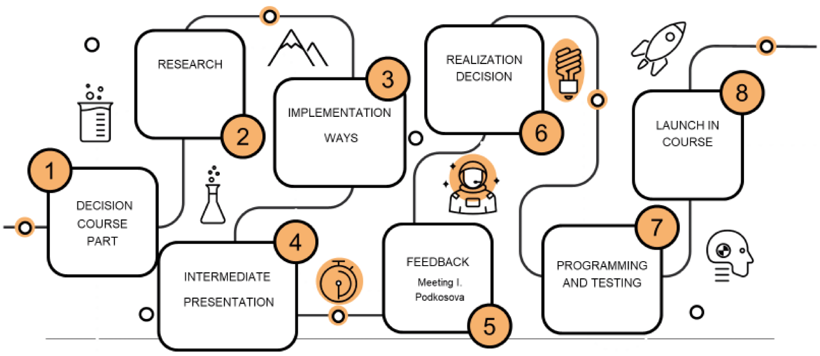
Technical requirements/Platform concept

- Programmed application for input
- VR-Simulation with VR-Glasses
- Data interface

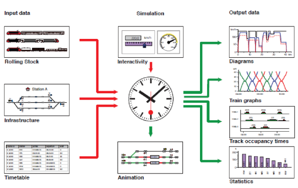
Main benefits and limitations

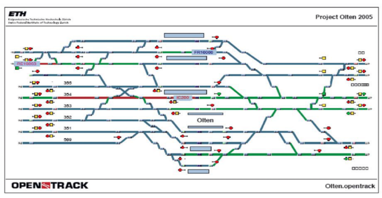
Better understanding through visualization
Optimized learning effect
Improvements of the model
Limited area and time
Restricted speed range
No longitudinal slopes

Visual Roadmap



Demo Screenshots





XR in surface-chemistry

Make cutting edge research in surface-science more accessible for students, by using XR technology.

Lecture Information & classroom setting:

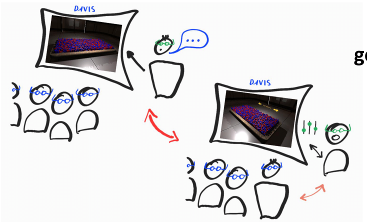
165.008 Physik/Physikal.-chem. Praktikum

type: LU (laboratory exercise)– 9.0 ECTs
- field of study: 033 290 technical chemistry
- year: BSc. - 5th semester
- XR supervisor: Johannes Zeininger

lecture structure: multiple groups and sessions in a chemical laboratory

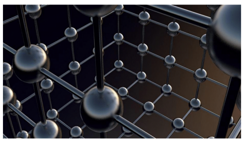
students: up to 30 per group

goals of lecture:
- showcasing to students the invisible world of chemistry
- teaching chemical knowledge, e.g. surface chemistry



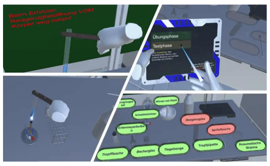
goals for the future:
- special lecture unit, once per group to teach state of the art technology and research (in the DAVIS Lab)
- let students experience surface chemistry, by manipulating reaction input parameters live in the simulation model

What are other universities doing?



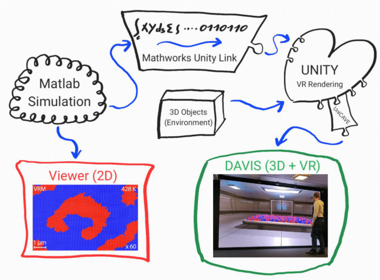
Uni Kassel – work in progress

NC State University – VR lectures



Uni Salzburg – general chemistry

Platform Concept



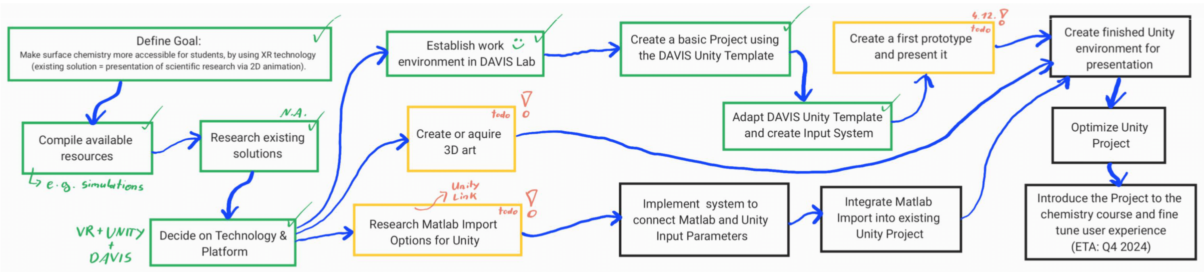
VR
- visualization of nano-scale -> AR does not add benefits
- Synergies with the DAVIS Lab

DAVIS Lab
- easy access for small groups of students (up to 30)
- equipment available (stereo glasses)

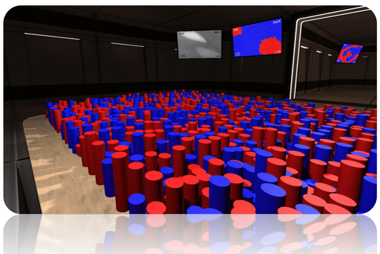
Unity3D
- easy visualization and animation of 3D objects
- supports many standards and file formats (e.g. stereo rendering)
- good integration with DAVIS Lab (Unity Template)

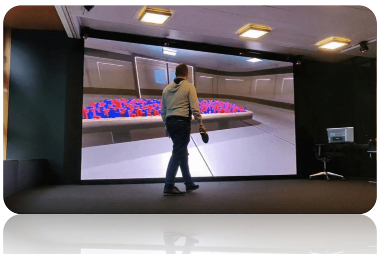
Main benefit: Add an additional dimension for parameter visualization of chemical surface reactions.

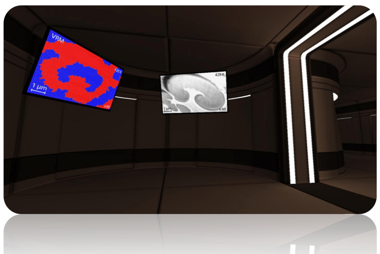
Roadmap & Next Steps



Demo Screenshots



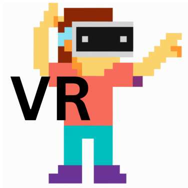




Ensar Yabas (11809077)

XR in Teaching

Visualize your environment in VR



Course Information

- Associate Prof. Dipl-Ing Dr.techn. Gottfried Mandlburger
- Bachelor course in Environmental Engineering
- ~90 students

Technical Requirements

- 3D Mesh Assets
- Unity3D
- Davis Lab

Classroom Setting

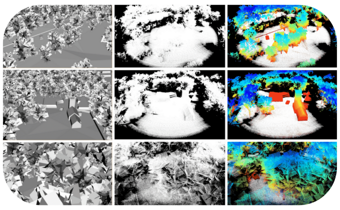
- Groups of 20-25
- Groups in Davis Lab

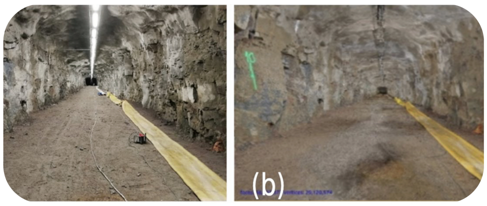
Benefits

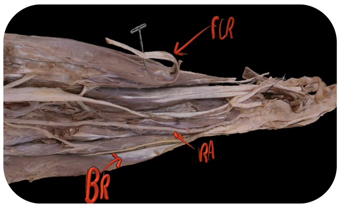
- Immersive
- New technologies
- Engaging

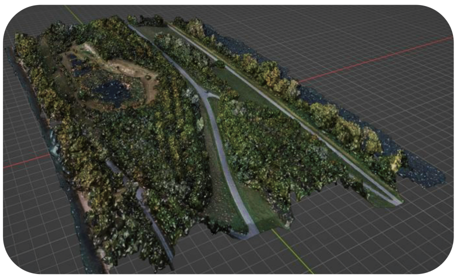
In the Industry

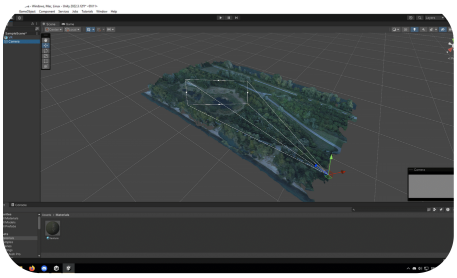
- Same technology used
- Scarce information about usage











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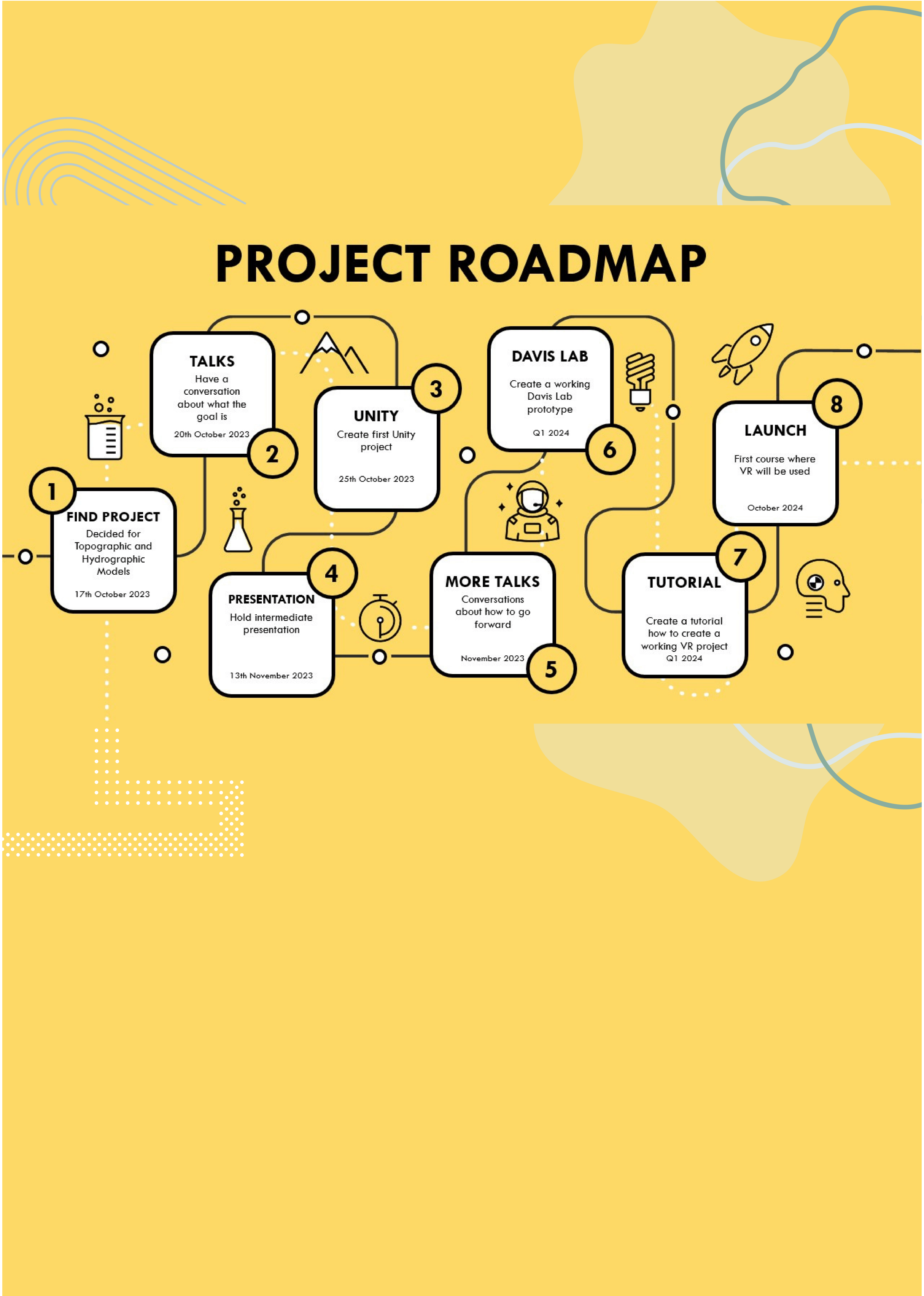
XR in Teaching


PROJECT ROADMAP
1
FIND PROJECT
Decided for Topographic and Hydrographic Models
17th October 2023
TALKS
Have a conversation about what the goal is
20th October 2023
2
UNITY
Create first Unity project
25th October 2023
3
PRESENTATION
Hold intermediate presentation
13th November 2023
4
MORE TALKS
Conversations about how to go forward
November 2023
5
DAVIS LAB
Create a working Davis Lab prototype
Q1 2024
6
TUTORIAL
Create a tutorial how to create a working VR project
Q1 2024
7
LAUNCH
First course where VR will be used
October 2024
8

Laura Hahn, 12019801
Elias Zechner, 11919541

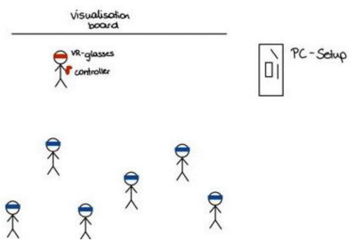
XR in Teaching

XR in Industrial Building Design

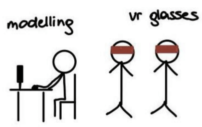
Lecture Information
234.161 Industriebau – master's course
lecture & correction meetings
tasks: design, construction, technical building information

Classroom Setting

presentation in Davis Lab



decision making tool



What are other universities or industries doing? What is the state-of-the-art software?

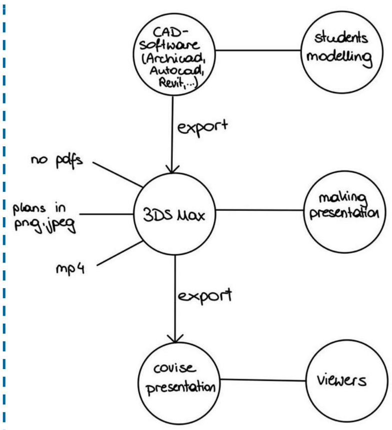
BIM Flexi Tool
- immersive decision making tool
- based on Rhino
- realtime changes

Data Visualisation Center (Davis Lab)
- Revit plugin „Covise": direct modelling
- 3DS max: visualisation program

The Wild
- multiple people, same modell
- 3D modelling in VR, floorplans
- enable and disable layers

Cave
- since 2000
- beamer projects images on wall
- limited capabilities

technical requirements / platform concept



Main benefits and limitations
+ immersive
+ decision making
+ VR modelling
+ open source software
- modelling only on pc
- bad shading

Visual Roadmap

Installing Software
- Revit 2023
- Covise

if Revit is installed first, Covise should implement automatically

Already available
- Top down view
- Set viewpoints
- Walkthrough
- 3D Section Cuts
- Activate/deactivate layers

Implementation
- Display Floorplans
- Display Pictures (pdf/png)
- Show actual Room name with m^2

Future Features
- Tablet UI
- Shading

Preparation
- same point zero
- same GIS data (surrounding)

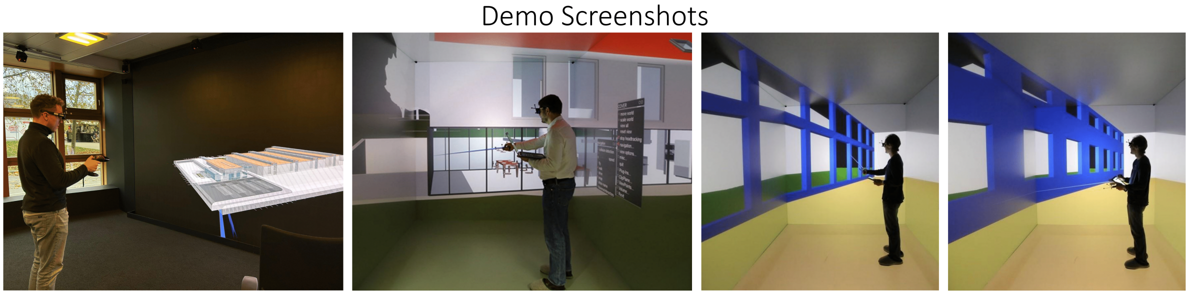
Modelling
- Revit on PC
- decision making in VR
- attention to layers

Decision making
- Covise Davis Lab
- BIM Flexi Tool
- group sessions

Final Presentation

next steps
- implementation in Davis Lab
- cooperation with Uwe Wössler
- teach students about the program and implementation
- let students book time slots in Davis Lab
- let students use implementation
- do presentations in Davis Lab

Demo Screenshots



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XR in Teaching

A.4 AR-supported Teaching Content

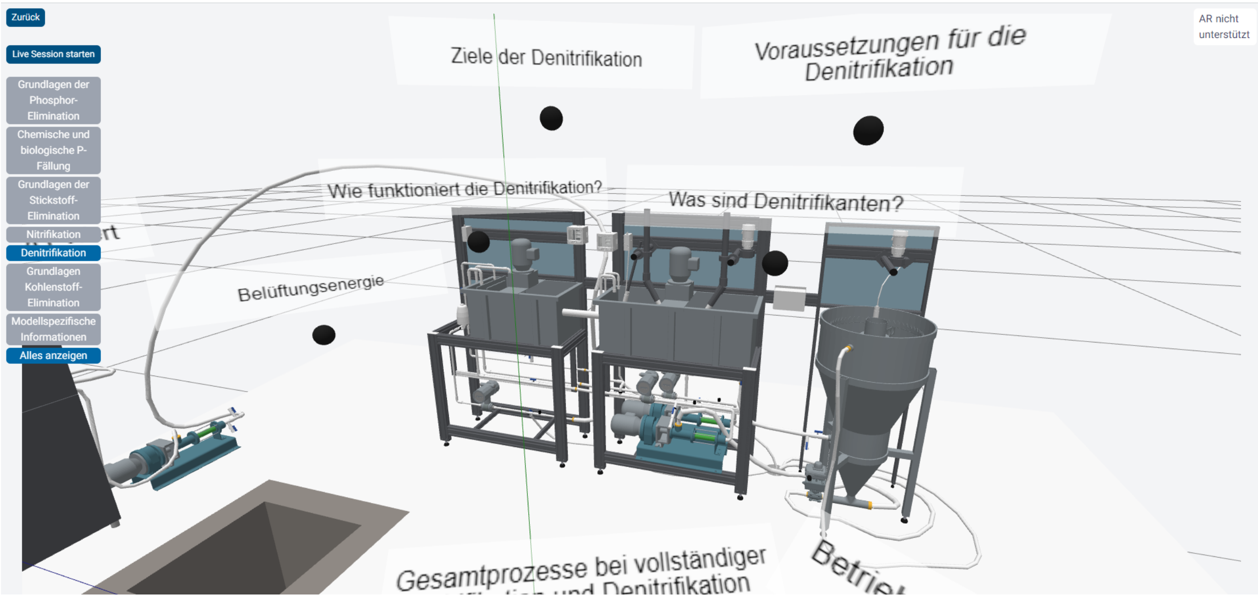

Figure 38: Model sewage treatment plant made during a bachelor thesis together with E226-01

Figure 39: Bottom outlet of a retention basin made by students

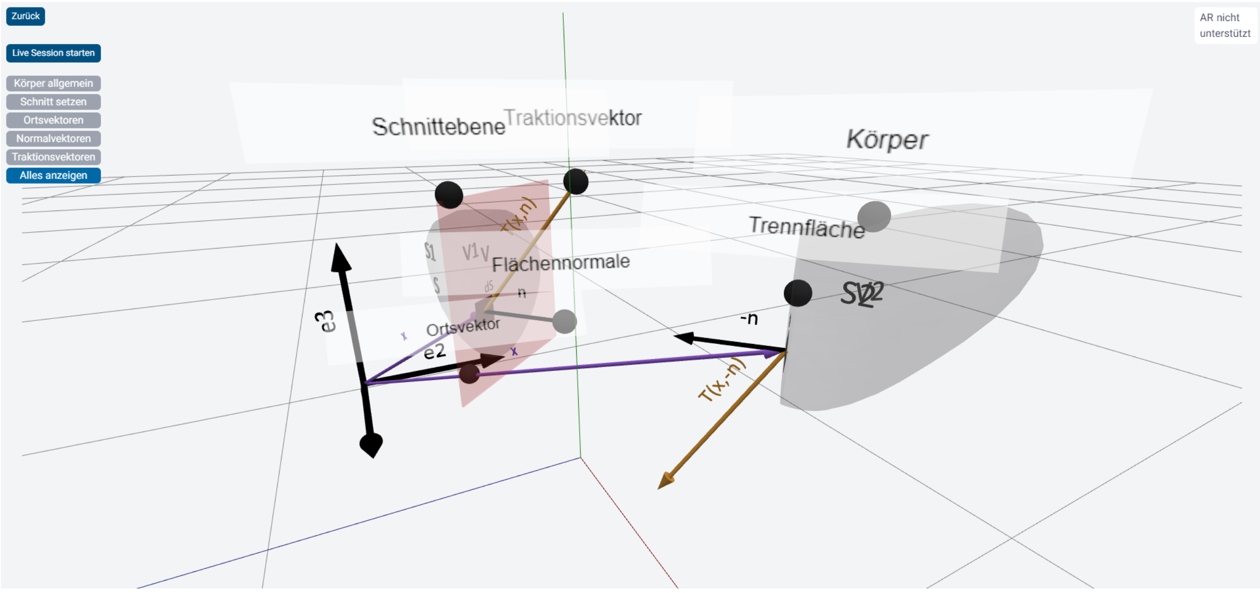

Figure 40: Free body principle made with ArchiCAD

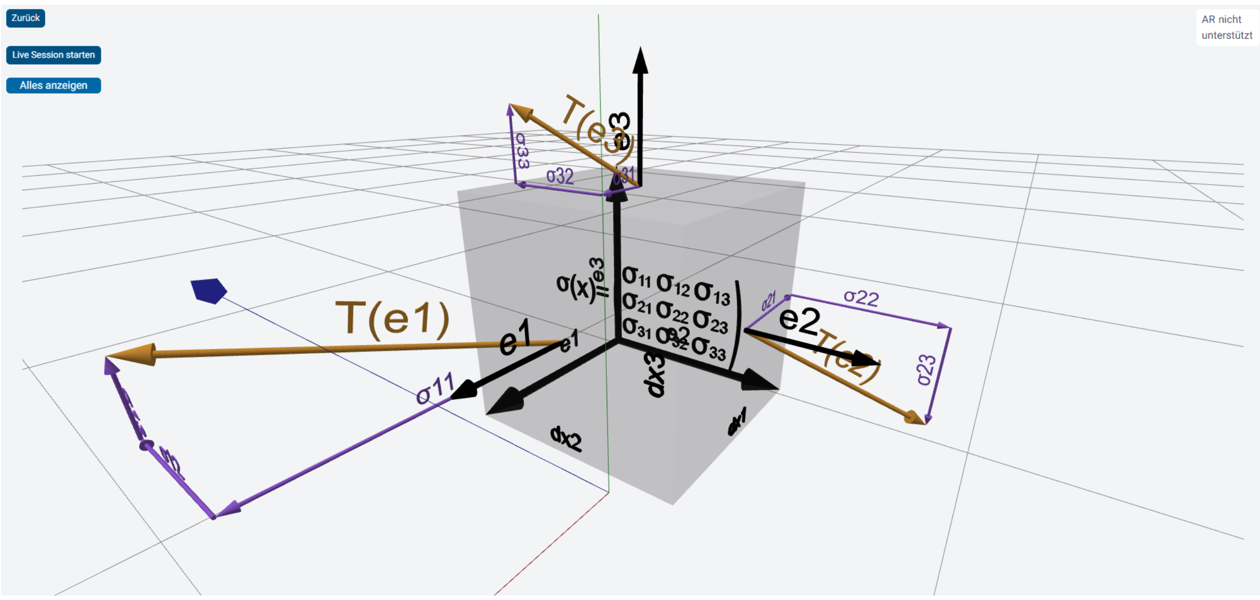

Figure 41: Cauchy stress tensor made with ArchiCAD

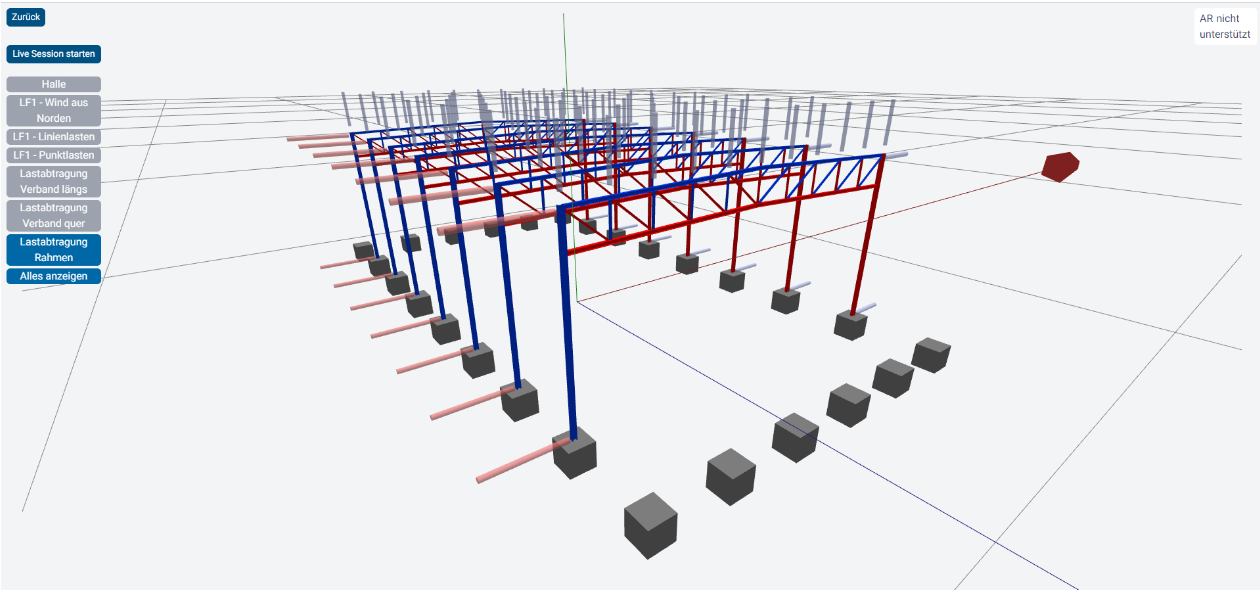

Figure 42: Steel hall made during the course “UE Steel Construction” with Allplan

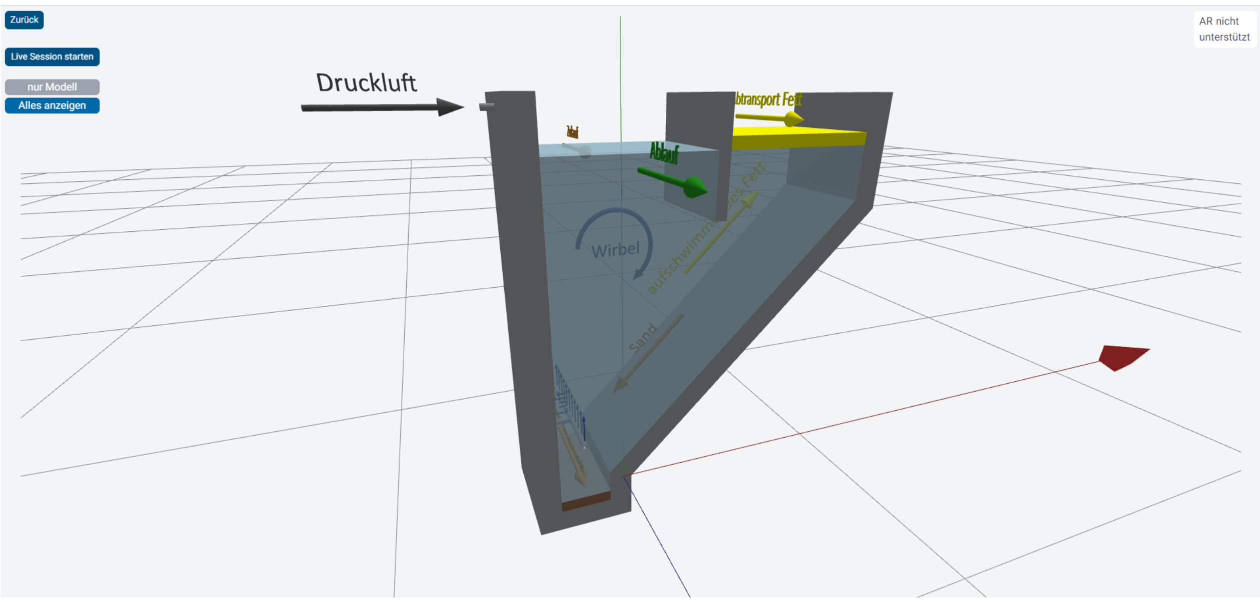

Figure 43: Functionality of a grease separator in a wastewater treatment plant made with ArchiCAD

Figure 44: Formwork teaching scene made with Blender using glTF

Figure 45: Apollo 11 capsule in AR-supported Teaching using glTF