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"PARFORCE: Partnership for virtual laboratories in civil engineering"

Intellectual output III - Remote-access experiments in Structural Engineering

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1.   Introduction to IO3

Didactics of e-Learning tools to be implemented in higher education studies and evaluation methods suitable for e-Learning platforms have been thoroughly investigated in intellectual outputs 1 and 2 [27,28], respectively. The focus has been set on assessing electronic educational resources, which have the outmost potential to be devised for conducting remote-access experiments within civil engineering curricula. This report describes a framework that leverages virtual reality (VR) tools for presenting various experiments in form of virtual tours (VT). Extended by the strategic partnership, the VR-based framework is devised for pre-recorded experiment data enabling students to audit laboratory experiments and to interact with pre-defined virtual objects. The proposed framework is presented in detail in Section 4. The rest of the report is structured as follows: Section 2 provides a short background and evaluation of learning objects for virtual learning platforms and respective characteristics, followed by few examples of implemented scenarios, hardware and software requirements. Section 3 introduces partner laboratories and capabilities of the strategic partnership, from which contributions to the case studies have been made. The case studies, i.e. the virtual tours, are described in detail in Section 5. The pilot course, in which virtual tours have been employed as learning objects, as well as the discussion and conclusions on the framework implementation are presented in Section 6. In Section 7, the report concludes with an introduction on the online platform, where virtual tours as project deliverables are made available, and with a discussion on potential further improvements to project outcomes.

2.   Background on remote-access experiments

2. 1.   Didactics measures

Within the last two decades, researchers have implemented and tested new teaching practices in various higher education fields. While conventional teaching methods are still in practice to a certain extent, their applicability and efficiency may be questioned. Educator-centered seminars and using a unified format ("one-fits-all") for the majority of subjects have been proven inefficient in many disciplines [1]. Within conventional teaching methods it is often assumed that students have the same level of learning capabilities, hence, learner-specific tools are mostly neglected. Students with learning difficulties such as dyslexia, autism, different learning speeds, and diverse levels of comprehension are all provided with equal learning objects [2]. Therefore, it should not be unforeseen that many students struggle with course assignments or examinations.

Electronic educational resources have been rapidly evolving and transforming in the recent years with the emergence of new technologies and decentralized learning platforms. E-Learning and hybrid learning methods have revolutionized the modern teaching practice for various higher education disciplines [3,4]. New formats of learning objects have been developed suitable for digital learning platforms. The main characteristics of modern learning objects are reusability, flexibility and interoperability. A reusable or adaptable learning object may be easily adjusted to the teaching-learning process and course requirements or targets. While flexibility offers educators modification opportunities to one learning object entity, interoperability or accessibility describes platform (in-)dependency and different ways one learning object entity can be integrated in the learning environment [5-7]. Moreover, level of granularity and complexity are commonly used to describe a learning object entity. Level of granularity, also referred as "aggregation level", represents the fragments of a learning object entity, if existing, while complexity refers to the preparation load work in terms of time and skills required [8].

A learning object may have the capability not only to be modified by the educator(s), but also by the students, hence, in the last decade interactive learning objects have been integrated in e-Learning platforms. An interactive learning object may be used for individual or group assignments, online examinations, live performance tracking, and adaptive learning scenarios [9].

Today in the Civil Engineering field, decentralized learning platforms commonly use textual and audio-visual learning objects as well as computer-aided designs (CAD). The latter includes various formats of computer-generated models, such as 2D or 3D reconstructions of real environments and parametric models of infrastructures [10]. Similar to conventional learning objects, when searching for learning objects suitable for e-Learning platforms, educators sometimes struggle with finding the right tools assuring that course learning objectives are met. For this purpose, it is important to review main characteristics of learning objects suitable for e-Learning in the field of Civil Engineering.

Textual and audio-visual learning objects are normally prepared by the educator in advance and lack reusability and flexibility parameters. That means adaptivity and modification opportunities for above-mentioned learning objects are limited. Therefore, educators tend not to update course material over semesters and present the older versions with the minimum amount of modifications. Meanwhile, CAD learning objects can be modified easily and can offer various ways of integrating student contributions into the learning process and opportunities to integrate instructional methods such as inverted classrooms [10,11].

For integrating remote-access experiments in the teaching-learning process within civil engineering courses, data recording types, accessibility, interactive capability, and user's view must be assessed. The following ontology describes main characteristics requirements of remote-access experiments.
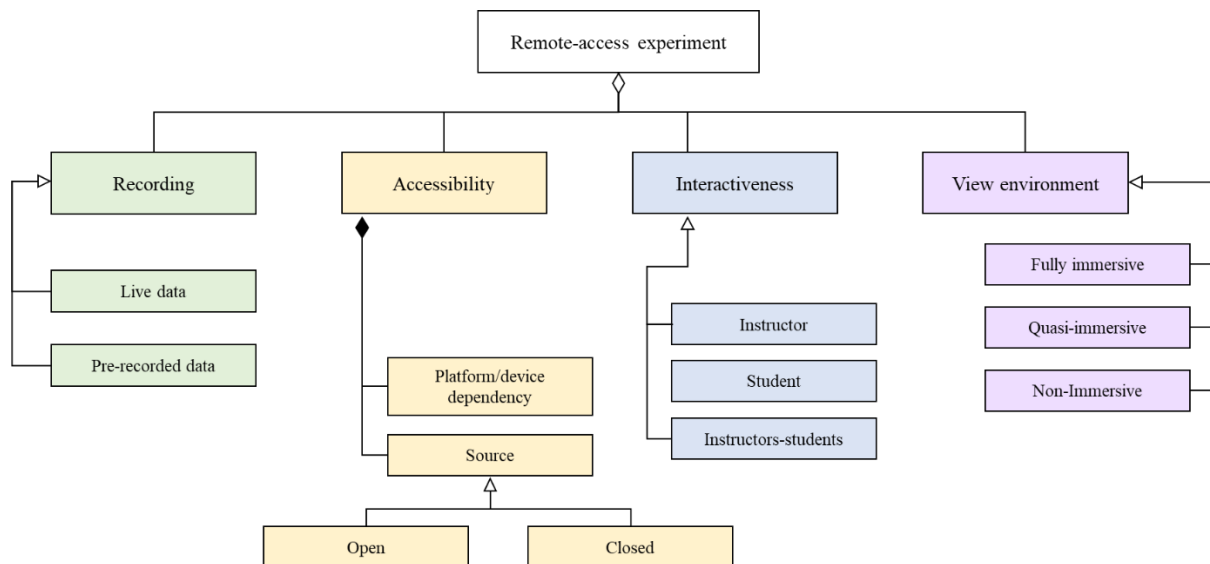
Figure 2.1: Remote-access experiment characteristics

A remote-access experiment may integrate pre-recorded data or live streaming. Pre-recorded data are believed to be more reliable and stress-free, since they can be viewed offline as well as online and have been thoroughly tested by educators in advance with respect to platform compatibility and error-free presentations. Accessibility in terms of platform (or device) dependency and availability must be considered for using the right tools when designing remote-access experiments. For example, if an

experiment can only be viewed online on the web browser and is only provided to authorized users, it is less accessible to students, who do not have stable Internet connections or are not enrolled in the virtual classroom. Remote-access experiments may provide interactions from both sides, i.e. educators and students simultaneously may change the course of an experiment. Interactions can be included as pre-defined control parameters, drop-down menus for different test approaches, or sending and receiving commands to laboratory compliances while running a live experiment. Lastly, the environment, in which remote-access experiments are depicted may be designed as an immersive environment using virtual, augmented, and mixed reality (VAMR) applications. The immersive view when combined with interactions has proven to be more effective in teaching-learning process in various disciplines [12-14].

In the following, few examples of remote-access experiments that have been developed for civil engineering students at the Bauhaus-Universität Weimar are depicted. Figure 2.2 depicts screenshots of a 4-point beam experiment conducted at the experimental facility of the Institute of Structural Engineering. The remote-access experiment is a classical scenario, where pre-recorded (2D) footage of the experiment is synchronized with the sensor data (diagrams) for the whole duration of the experiment. Although this experiment is designed in a non-immersive format with no interaction functions, it has been published online and is accessible for public, making it with respect to accessibility a favorable option. It is worth noting that students may revisit the experiment at any given time and can adjust it to their learning speed [15].
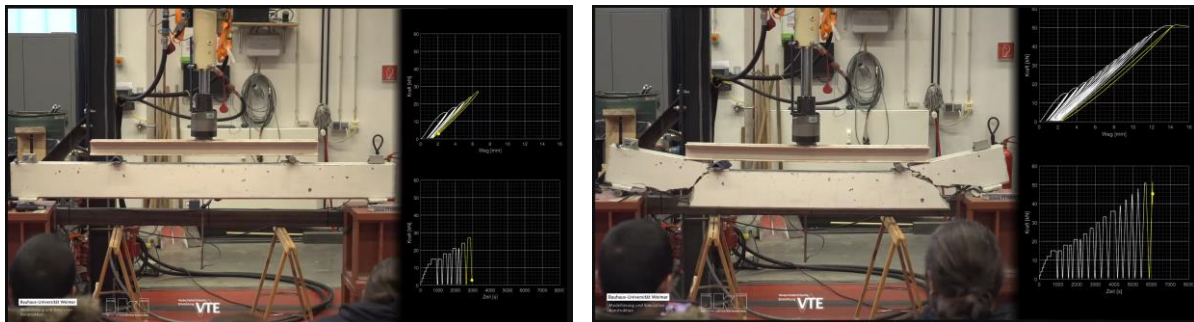
Figure 2.2: 4-point beam experiment [15]

Figure 2.3 shows a screenshot of the 4-point beam element, but in form of rendered point clouds. As the beam was being exposed to various loads, a multi-camera setup was used to take images of the beam over time to monitor crack propagations. This remote-access experiment is using pre-recorded database, is provided online (web-based) but is only accessible to authorized users. Users can choose load cases and view the respective results, also can change the rendering and classification parameters from a drop-down menu. Although the view is designed non-immersive, but users may have interactions with the 3D beam model and change the point of view easily [16].

Figure 2.3: Project 3D-RealityCapture-ScanLab, BUW (Prof. V. Rodehorst)

Another notable example is using microcontrollers for remotely accessing experimental data. Figure 2.4 illustrates the "shake table" application developed for Android-based smartphones within a student project. The application is used to trigger the shake table and start experiments with the parameter set by the user. Consequently, after vibrations and when the test structure is at rest, the microcontroller on-site collects sensor data (i.e. structural responses) and sends them to the application, reporting back to the user. This remote-access experiment is conducted in semi-live setup, meaning that the data is recorded live but is not transmitted instantly or may not be streamed on the smartphone. The application is only developed for Android phones and is only accessible for authorized users, however provides a high level of interaction to users [17].
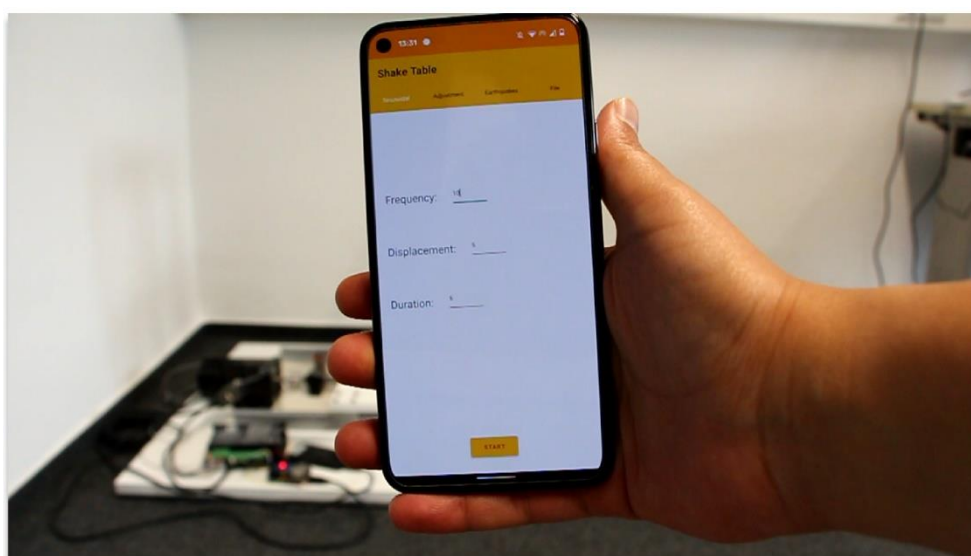

Figure 2.4: The Android-based smartphone application for shake table tests

In the research project AuCity 2, virtual and mixed reality applications have been developed as learning objects for remote-access experiments. Figure 2.5 depicts the virtual room, in which users can try flexural tests on a beam element. Users can have interactions with the virtual objects in this room, e.g. placing weights on the beam and checking the deflections, moving around, selecting items and answering questions. This example of remote unsupervised testing grants users with high interactions and is fully immersive [18]. Another example from AuCity 2 project is the holographic structural analysis experiments shown in Figure 2.6. Users can define virtual objects as an overlay on real objects, assign structural parameters and load cases and select the analysis type. The results are then visible as holograms. Although the holograms are not directly interactive, the user can change pre-defined parameters and the holograms will be updated accordingly [19]
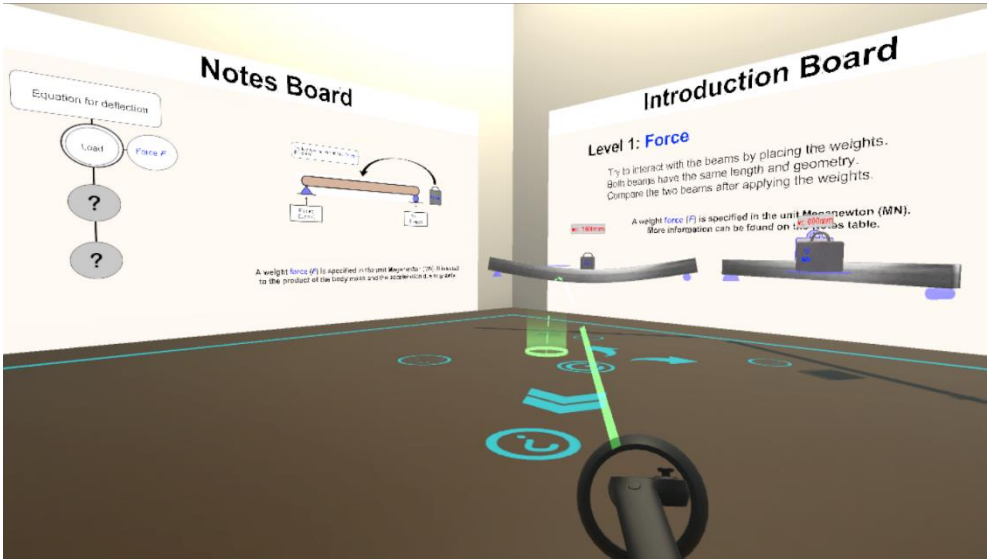
Figure 2.5: VR learning scene for flexural beam and bending moment tests

Each of the above-mentioned implementations of VAMR for remote-access experiments have benefits and shortcomings. As an example of VAMR applications, a virtual tour as learning object offers many benefits: First, in a virtual tour several formats of learning objects may be integrated, such as textual, CAD, audiovisual learning objects. Second, a virtual tour can be viewed on desktop PCs, tablets, smartphones, as well as virtual reality headsets, therefore, a virtual tour is not limited to type of device and is highly accessible. Also, virtual tours may be integrated in any virtual learning platform. Third, in the case of virtual reality, users can experience a fully immersive view, which can give users a feeling of being present at the laboratory. Last, but not least, the virtual tour has many control points or "hotspots" that can offer more interaction with the learning object to the users. Educators can use interactive virtual objects as much as needed (extendable). Therefore, within the framework of PARFORCE project, virtual tours have been considered as the right tool, which can deliver all purposes envisioned for remote-access experiments.
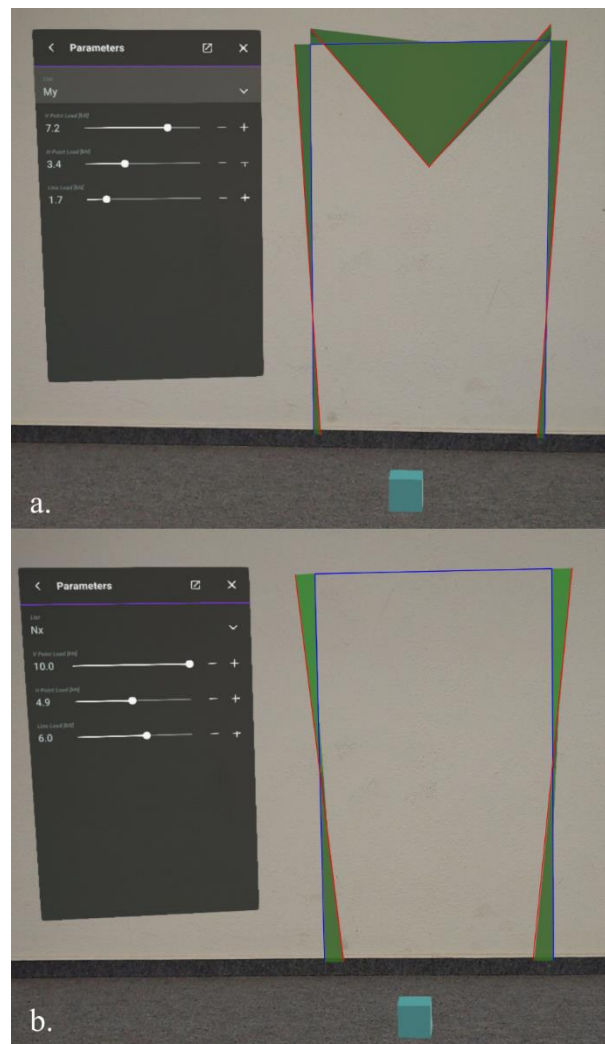
Figure 2.6: Holograms of bending moments (a.) and axial forces (b.) from the linear analysis

2. 2. Virtual tours

Using virtual tours in VAMR application requires preliminary knowledge of suitable data formats, as well as hardware tools, which are addressed in the following.

Footage formats in general comprise images (static frames) and videos (dynamic frames or more than one static frame). Field of view (FOV) is a common parameter in VR that indicates how much of the footage in the virtual environment is seen through one eye or each VR lens. For example, Figure 2.7 depicts FOVs of different VR glasses in comparison to the average field of view for human vision.

The angle of view recorded in each footage depends on camera lenses in general. A wide range of camera lenses exist that based on use cases, one should choose from to match the required FOVs, from 90 degrees to 360 degrees. Monoscopic and stereoscopic 360-degrees footage (images and videos) are the VR formats which have been used in this project. In monoscopic VR, one lens records the intended field of view, which in case on 360-degrees footage, means that one lens is recording one footage with FOV of 360 degrees, and is projecting the footage to both eyes on VR devices. Whereas in stereoscopic VR, two footages are recorded at the same time and are projected to left and right eyes (left and right VR lenses) separately. Two footages (i.e. camera lenses) have slightly different angles, mimicking human

eye position and the interpupillary distance. The stereoscopic VR is also known as 3D VR, due to the fact that by projecting two footages to the eyes, user's brain can calculate depth of field, therefore stereoscopic VR is creating 3D depth. Figure 2.8 shows an example of stereoscopic VR and depth of field. Another common VR format is VR180, which can be analogously described as stereoscopic VR with FOV of 180 degrees. Figure 2.9 illustrates one instance for monoscopic and stereoscopic 360-degree vs. VR180 footages.
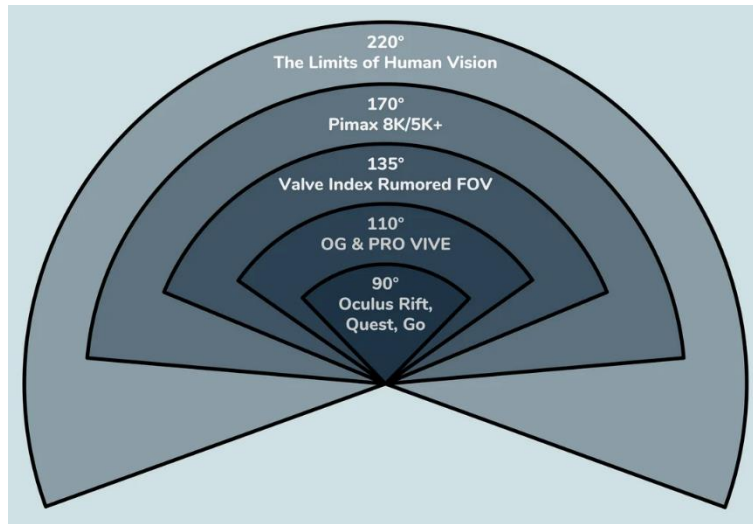
Figure 2.7: FOV of few VR glasses, [20]
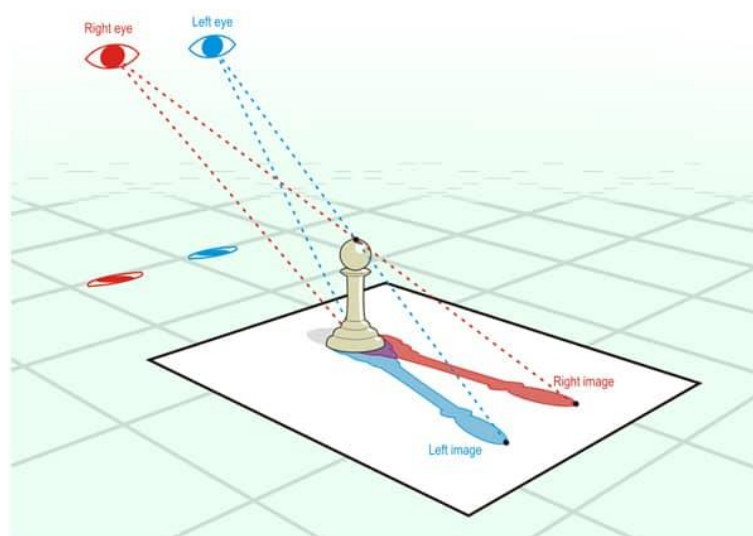
Figure 2.8: Stereoscopic VR, [21]
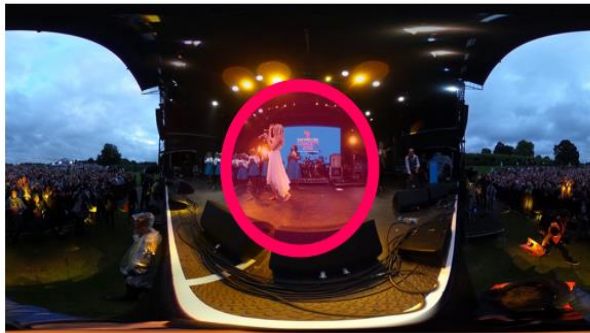
Monoscopic   VR180   Stereoscopic

Figure 2.9: difference between monoscopic, stereoscopic 360 degree and VR180, [22]

There are various professional and consumer cameras on the market for creating VR-compatible images and videos. Based on use cases and ambient conditions, one can choose the right camera for shooting experiments. For example, professional stereoscopic 360-degree cameras cost up to 25000 Euros and are big in size, however they offer more functionalities and are in general more resilient to harsh environmental conditions. Figure 2.10 depicts Insta360 Pro 2.0 camera, which is a professional 360-degree camera with integrated GPS that has been used in PARFORCE project. In contrast to professional cameras, consumer cameras offer ample functionalities and controllers, can also be moved around the laboratory during recordings, and cost up to 1000 Euros.

Figure 2.10: Insta360 Pro 2.0 a professional camera used in this project, [23]

VR glasses are in general three types: Standalone VR, PC VR, and smartphone VR glasses. Standalone VR glasses have built-in screen processor (graphic card, computing processor), cameras and motion sensors for position recognition, and power source; therefore, can operate without the need to be connected to a PC. On the other hand, PC VR glasses can operate only when connected to the PC, since they are using the graphic card and computing processor from the computer (no built-in resources). Mobility (or degrees of freedom), image quality, means of communication, extra available/required hardware (such as hand controllers and base stations), variety of content, and many more parameters should be considered when purchasing the suitable VR glasses for your use case. Smartphone VR glasses are the simplest and cheapest VR glasses comprising only two lenses that can project the VR footage from the smartphone display to user's eyes. A hardware recommendation list for 360-degree cameras and VR glasses is offered in Annex A.

3. Strategic partnership laboratories

This section provides an overview of the strategic partnership facilities and common experiments driven at each facility. Laboratory settings, detailed experiment procedures and result evaluation of experiments driven at each facility are out of the scope of this report. For further information please visit the website of each facility cited at the end of each subsection.

3. 1. Ruhr University Bochum (RUB)

Boundary layer wind tunnel facility is replicated by virtual reality in this project as first virtual laboratory strategy from project partner RUB. This considers the entire environment of a real wind tunnel, examples of the measurements carried out and elaboration of basic wind tunnel techniques needed to conduct an experiment for the purpose of wind engineering education and research. The wind tunnel is 9.4 m long, with a test cross-section of 1.6 m high and 1.8 m wide. The maximum flow velocity is approximately 30 m/s, corresponding to a volume flow of 86 m³/s. The wind tunnel consists two main rooms: (1) A room with the wind tunnel chamber including a large fan, motor and test section; (2) An electrical and instrumentation control room. A special feature of the facility is the simulation of natural wind in the atmosphere under neutral thermal stratification by means of an array of castellated barriers, turbulence generators and ground roughness. The Boundary Layer Wind Tunnel is frequently used to accommodate industrial projects, PhD and visiting researcher, further investigation of wind tunnel techniques, and educational tours for students. Notable experiments carried out in the wind tunnel investigate the wind pressures, static and dynamic wind loads on buildings, aeroelasticity, vortex visualization and pollutant dispersion.

The second strategy is addressed by remote monitoring of a full-scale wind turbine and a wiki-based digital teaching database. Remote monitoring is integrated into a website application for the AIRWIN DEW21 wind turbine in Dortmund. The wind turbine type is Enercon E40 - 500 kW series with 65 hub height and has been measured since 2010. The web application allowed the user to access the monitoring database interface through a common browser. Temporal and statistical measurements such as the acceleration of the wind turbine tower vibration and the power generation can be observed through the application. In this example, the web application was developed using Eclipse Java EE IDE for web developers, Vaadin's Eclipse Plugin 3.0.0 and LAMP stack XAMPP 7.0.8-0 local database.

Additionally, a joint Wiki-based digital teaching database (DigiDat) developed between the Chair of Continuum Mechanics and the Chair of Wind Engineering and Flow Mechanics (WISt) acts as an open-access platform for students and teachers to access the documentation and data of exampled experiments. DigiDat is a form of online website that provides summarized case studies in the related fields, procedure of analysis and a linked online database.

3. 2.   The Institute of Earthquake Engineering and Engineering Seismology (IZIIS)

The Dynamic Testing Laboratory of IZIIS is one of the strategic laboratories in which scientific and applicative investigations in the field of dynamics of structures are continuously performed. The essential equipment in the lab is 3 DOF shaking table, built in 1980, with dimensions 5.0 x 5.0 m and payload of 40t. If properly carried out and interpreted, shake table experiments represent good substitution for information of structural behavior under real earthquakes. Common types of shake table tests are tests for verification of existing mathematical models, or developing new ones; new technological solutions and qualification and proof tests. More than 400 reports have been published related to the conducted experiments on IZIIS 'shake table. Each experiment is unique but the basic steps are common and include: (1) Preliminary analysis, (2) Design of the model, (3) Building (construction) of the model, (4) Mounting of the model on the shake table, (5) Selection and preparation of time histories for shake table tests, (6) Instrumentation of the model, (7) Shake table testing, (8) Processing of the results and (9) De-mounting the model. The experiment goals are wide but might be generalized to learning and understanding seismic performance and safety of structures and their damage and failure patterns. The target groups are external (companies and researchers) and internal (master and doctoral students) whose education in earthquake engineering benefits from experiments outcomes.

In September 2020, the first remote access experiment related to dynamic testing with forced vibration method of infills and masonry structures protected by deformable polyurethanes in seismic areas (INMAPSOL project) was carried out in IZIIS Lab.

3. 3.   University Aveiro (UA)

Based at the Civil Engineering Department of the University of Aveiro and having started its activity in 2007, the Laboratory for Structures and Fire Resistance of the University of Aveiro (LERF) is equipped with a vertical gas furnace with a 3.10 m x 3.10 m free opening, capable of carrying out fire resistance tests to construction elements and products, in accordance with the European regulation. This allows the experimental determination of the fire resistance characteristics according to the functions performed by construction elements, namely, load bearing (criterion R), integrity to flames and hot gases (criterion E) or thermal insulation (criterion I). Fire resistance tests to compartmentation elements (such as walls and doors) and post fire behavior evaluation of structural components and members (such as steel or concrete columns and beams, and timber connections) have been performed at LERF.

3. 4.   University Osijek (UNIOS)

Faculty of Civil Engineering and Architecture Osijek's laboratory has been developing virtual experiments in the students' laboratory experience and class curriculum that involves seismic behavior of RC frames with and without masonry infill walls and openings. The larger scale experiments carried out were the In- and Out-of-Plane behavior test of RC frames with and without masonry walls and openings. The test data was gathered by hardware and by optical measurements. The smaller-scale experiments included tests on masonry walls and their units.

Also, based on those experiments, 3D micromodels were developed. Those models have enabled to manipulation of various parameters, thus offering the opportunity to explore and understand the effects of changes in these parameters on the overall behavior of the micromodels. Also, using calibrated micromodels, an In- and Out-of-Plane load was combined into a single simultaneous action. In addition to aforementioned experiments and models, a Python application that generates graphs and provides load-bearing estimations for RC frames with masonry infill walls, with and without openings of varying sizes and positions was developed. This application, made available as an executable (EXE) file, allows students to explore the effects of infill walls, opening types, and positions on the load-bearing capacity

of RC frames. It has proved invaluable in bridging the gap between theoretical understanding and practical application of knowledge, empowering students to analyze and evaluate civil engineering structures more effectively.
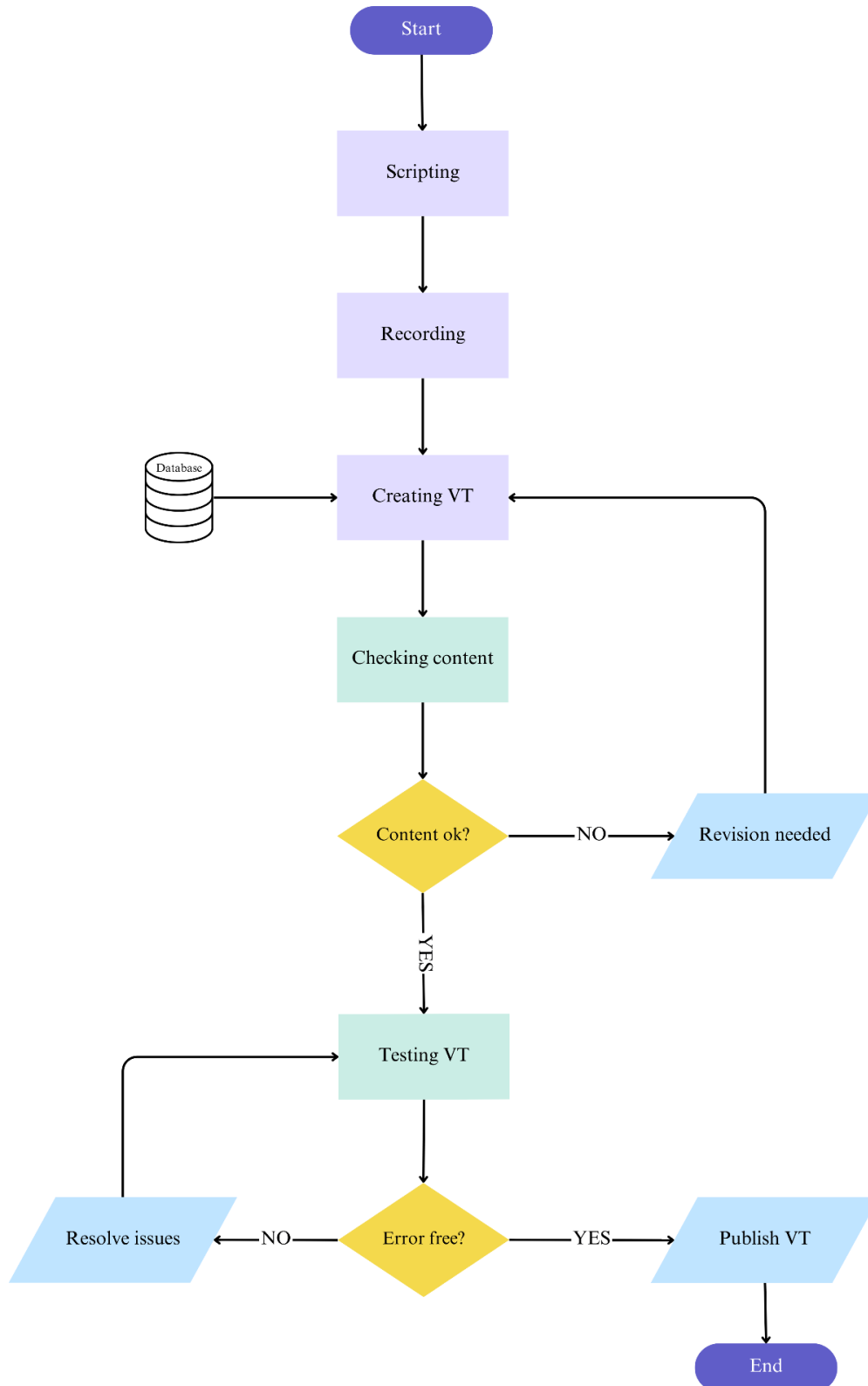

Fig. 4.1: Flowchart of the proposed framework for creating virtual tours

4.   The proposed framework

The strategic partnership aims at granting access to specialized laboratories and specific tests listed in the previous section. Students enrolled at each university or institute can benefit from facilities and expertise offered by the strategic partnership and can extend their practical knowledge using experiments that are not locally available. For developing virtual laboratories of the strategic partnership, virtual tours have been recognized as the most suitable tool, as described earlier in Section 2. For delivering realistic view of laboratory environments and enabling interactions with experiments, footage from laboratory and running experiments are recorded in VR compatible formats and are later combined with supporting information and experiment data using a VT-maker software. The framework for creating VT of laboratory experiments is depicted in Figure 4.1 and is explained in detail in the following subsections. Within the proposed framework three actors are considered: Educators (and laboratory technicians), who essentially deliver the scientific content and respective experiment data, the VT developer, whose main task is creating the VT and the virtual platform, and users or viewers, i.e. students.

4. 1.   Scripting

The first and most important step for creating a VT is to define learning objectives of the experiment and laboratory conditions. To offer the VT developer an overview of what is to be expected, the educator must identify experiment goals and learning outcomes including expected experiment results. Moreover, the experiment procedure, laboratory conditions and ambient conditions should be described. This process is called "scripting" and is iteratively done by the educator and the developer until a mutual understanding of the whole test procedure is reached. Within the script, the educator can describe their expectations from the VT to the developer in detail, for instance by answering following questions:

- Laboratory and ambient conditions
  - What is the size of the test field?
  - How many points of interest are existing for this experiment? What is the location of point(s) of interest?
  - Are objects moving around in the test field? If yes, how often and how fast?
  - Are the any locations in the laboratory that must be avoided due to safety or confidentiality purposes?
  - Are safety regulations of the laboratory important for remote viewers? If yes, please specify them. What type of equipment are present for hazard control?
  - Who is present at the laboratory and which responsibility one has?
  - How are the light exposure and ambient noise conditions at the laboratory? What can be done to remove any distracting elements from the laboratory during test recording?

- Experiment procedure
  - What is the goal(s) of this experiment?
  - What is the procedure of this test? i.e. how do we achieve the goal(s) of this experiment?
  - What do we measure? What kind of data are to be collected/recorded?
  - How do we measure experiment data? What kind of equipment and data acquisition systems are present at the laboratory?
  - What is the process of preparing a test structure? What type of test structure is being tested? How long does it take to prepare a test structure?
  - Educator's expectations according to the theoretical knowledge or past events: What do you expect from this test according to the experiment goal(s)?
  - Are there multiple tests to be recorded? How long is the duration of each test?

o Does the experiment setup change between each test round? If yes, do the points of interest shift?

o Is it necessary to record the test over the whole duration of it? i.e. are there any time slots, when the experiment field can be discarded by remote viewers?

o Post-processing experiment data: What kind of data formats are to be used for presenting experiment data? i.e. what kind of data are to be integrated in the VT?

o Interactions: what kind of control points or "hotspots" are envisioned for the VT? How can students interact with the VT content?

o E-Learning measures: What are the criteria for tracking the student performance? Are there any quizzes included? How many trials one user has for the VT? Is there a time limit?

Any supporting information that is not listed in the first draft of a script may be added later. However, educators and VT developers must invest time and patience in the scripting process, simply because the script is the baseline for deciding upon software and hardware requirements, as well as the layout of the VT.

4. 2.   Recording

Once the script is completed, the VT developer can choose the right tools for recording the experiment. In this project, panoramas and videos in monoscopic and stereoscopic 360-degree formats are employed for recording experiments. Camera locations are set in a way that points of interest are in focus and ambient distractions are minimized. If necessary, studio lighting setups (light sources, reflectors and diffusors), audio recording systems, and background curtains can be used to improve ambient conditions and the focus on the test area. The script helps educators and VT developers to identify points of interest. Cameras can be moved all the time, but for the VR view too much movement can cause motion-sickness in users. Therefore, it is recommended to have at least a fixed point of view in the laboratory. Although one existing setup does not fit all experiments and laboratory conditions, it is recommended to keep a point of view fixed during the whole experiment and prepare more footage using one or more cameras from different angles and viewpoints. Thus, the developer has more data to choose from when preparing the VT. Also, since most of the experiments are costly and are conducted by one round (e.g. in the case of destructive tests), there is no opportunity to retake footage if the setup is not efficient. For this purpose, it is recommended to evaluate the laboratory conditions and to try the full setup one time before the experiment is to be conducted.
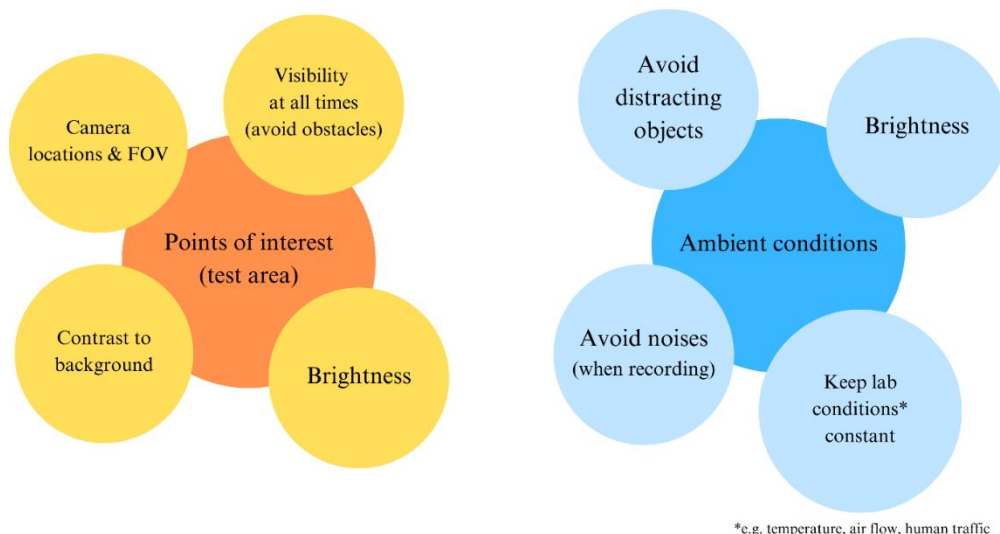
Fig. 4.2: Important measures before you start recording

4. 3.　Creating VT

After conducting an experiment, the VT developer starts preparing the recorded footage for the VT-maker software. The post-processing phase includes initially stitching 360-degree panoramas and videos, but also color corrections, noise reduction (visual and/or audio noise), selecting frames (videos), and if needed, combining different viewpoints in one video. The developer collects all the experiment data and supporting material from the educator. At this point, the developer follows the script step-by-step to put the 360-degree footage in order and to assign the logical order of appearance and functionalities to hotspots. In general hotspots can be divided in two categories: Hotspots that change the point of view and hotspots with eLearning functionalities. The latter includes pop-up information windows (including images, videos and text), albums (sliding images/text), quiz cards, and download buttons for experiment documentations. Changing point of view can be defined as switching between panoramas and videos, or as hopping from point to point in the laboratory on each panorama. CAD models, 2D/3D footages, PDF files, excel sheets, and many more data formats can be integrated in virtual tours. If internet connection is available, websites and links to online learning platforms and external eLearning material can be integrated in the virtual tour, too. It is worth noting that the functionalities depend on the VT-maker software tool in use, therefore, it is recommended to take required functionalities into consideration when purchasing a VT-maker software. Figure 4.3 depicts the functionalities (or actions) offered by the 3DVista Virtual Tour Pro, which is the software used in this project for preparing virtual tours.

Figure 4.3: Screenshot of hotspot actions from 3DVista Virtual Tour Pro [24]

4. 4. Checking content

Essentially, the virtual tour is to be confirmed with respect to the content before being published. Even though the VT developer has followed the script step-by-step, the virtual tour is to be approved by the educator at least one time, to make sure that the content aligns with learning objectives described in advance. Often some extra data are to be added or replaced, therefore a revision may be required. This step c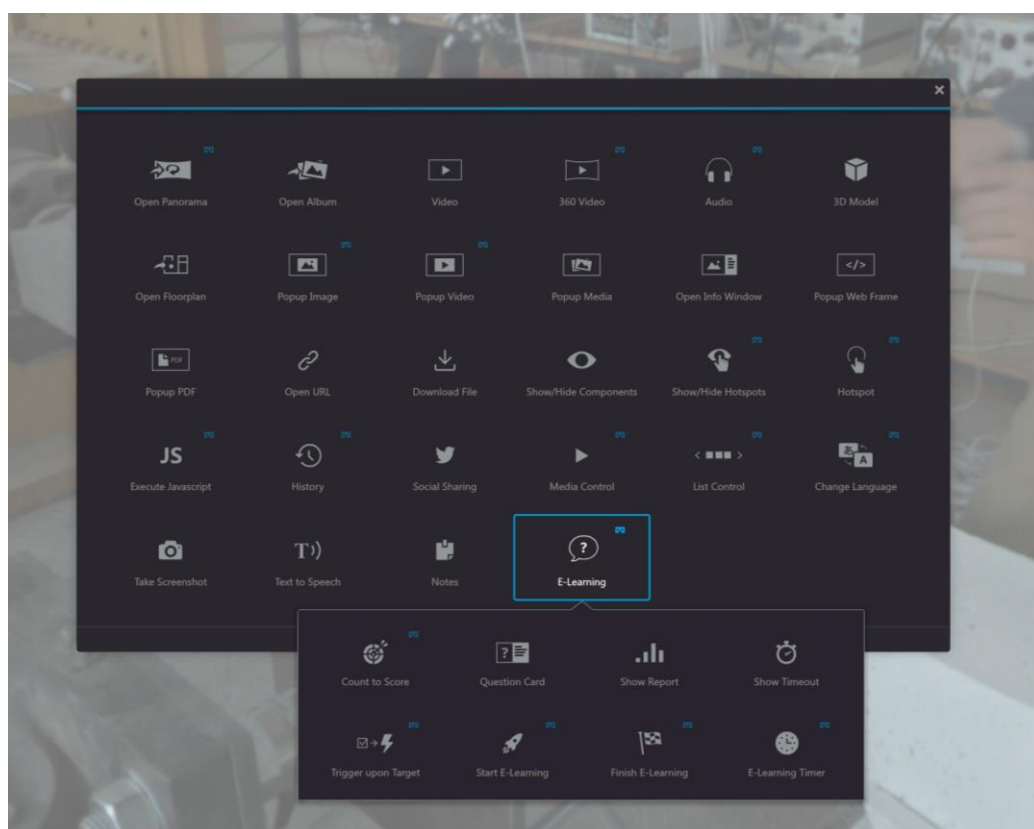an be repeated even after publishing a virtual tour as well, for example in cases where further course assignments are to be integrated or temporarily eLearning functionalities are to be (de)activated within a virtual tour.

4. 5. Testing VT functionalities

Last step before publishing a tour is to assure that the virtual tour is accessible without any technical issues on the displaying device. Whether designed for desktop PCs or virtual reality glasses, device compatibility of virtual tours must be double-checked to assure the content integrity, functionalities of hotspots, and audiovisual quality. For this purpose, the developer tests virtual tours multiple times on different devices. Sometimes, a hotspot that is available on desktop version is not appearing on the VR version or is replaced due to different scaling (pre-defined in the VT-maker software). Another potential issue is when the projected ray from hand controller on VR glasses (or hand gestures) cannot activate the hotpots due to the difference between the depth of field (of the hotspot and the projected ray).

4. 6. Publishing

After checking the content and testing accessibility, the virtual tour can be published and shared with users. Depending on the VT-maker software, a virtual tour can be published for desktop PCs, smartphones and tablets, as a web-based application (accessible online and/or offline), or as a VR application compatible with VR glasses. To decrease device and platform dependencies and to increase accessibility, it is recommended to publish a virtual tour in diverse formats. VR glasses due to high costs are often not at user's disposal, however, the VR format can offer a full immersive view of the real laboratory setup and are therefore recommended as one of the formats when creating virtual tours.

5. Virtual tours as PARFORCE products: Case studies

The virtual tours as remote-access experiments are described in this section. These virtual tours are published on the "360-degree.education platform" [25], which is a publicly-accessible web-based education platform. The links to the virtual tours can be found here [26].

5. 1. Wind tunnel experiments

The virtual tour of the wind tunnel facility at the Ruhr-University Bochum, Institute of Wind Engineering and Fluid Mechanics (WiSt), has in total 14 scenes, i.e. Panoramas, which visualize the whole facility, from outside the building until inside the wind tunnel chamber. There are two different laboratory experiments introduced in this virtual tour, the boundary layer test of the grouped cylinders and the free-vibration and forced-vibration tests of the horizontal cylinder.

The tour includes hotspots that provide information to students such as:

- Viewing course material and slide shows
- Description boxes on top of the real objects
- Technical sheets of the equipment in the laboratory
- Video guide around the wind tunnel hall
- Video footage of the running tests from different angles
- Theoretical knowledge on laboratory tests

Apart from the information hotspots, two scenes have been equipped with quiz hotspots to assess the interim knowledge of users about the presented VT content. Users can try quizzes as many time as needed, since quizzes are not defined as embedded assignment and will not be evaluated. The timer and score display are defined only for users to track their performance. Since users cannot move in real environment around, arrows on the ground and doors on the walls are defined as hotspots, which can take the user from one scene to another. The VT has been published in desktop and VR versions and have been provided to students. Few screenshots from the tour (in desktop version) are shown in Figures 5.1 to 5.4. For further information about the VT, please visit the PARFORCE website [26].
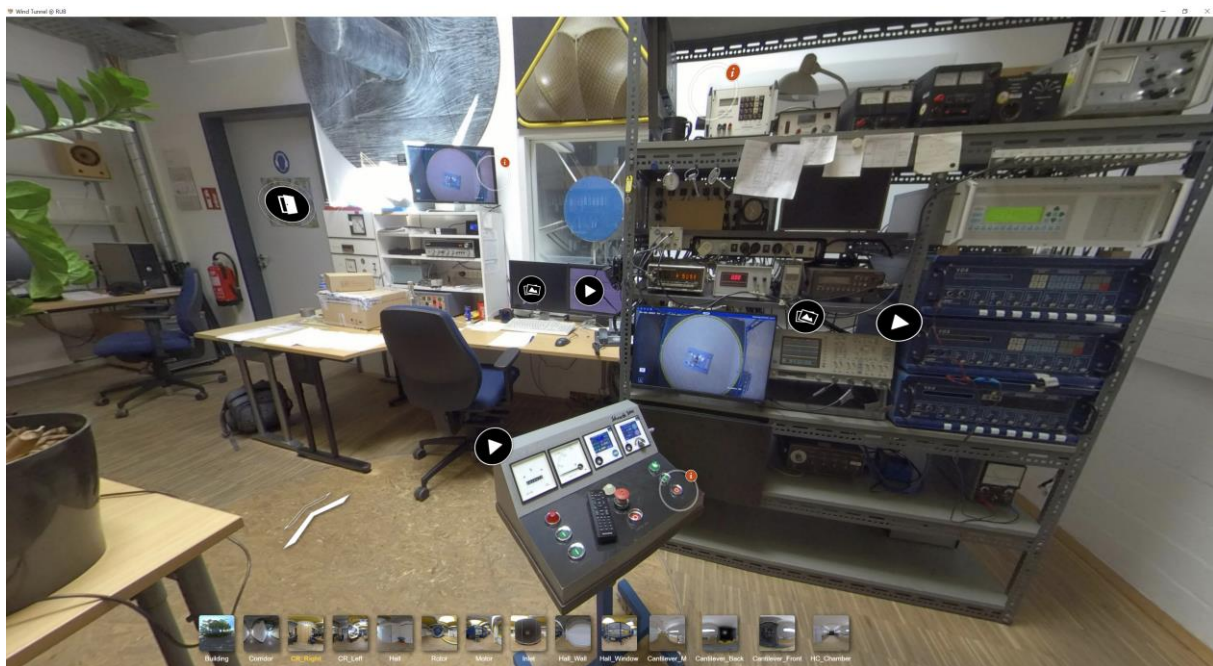
Figure 5.1: Control room scene of the VT from the wind tunnel facility at RUB, WiSt
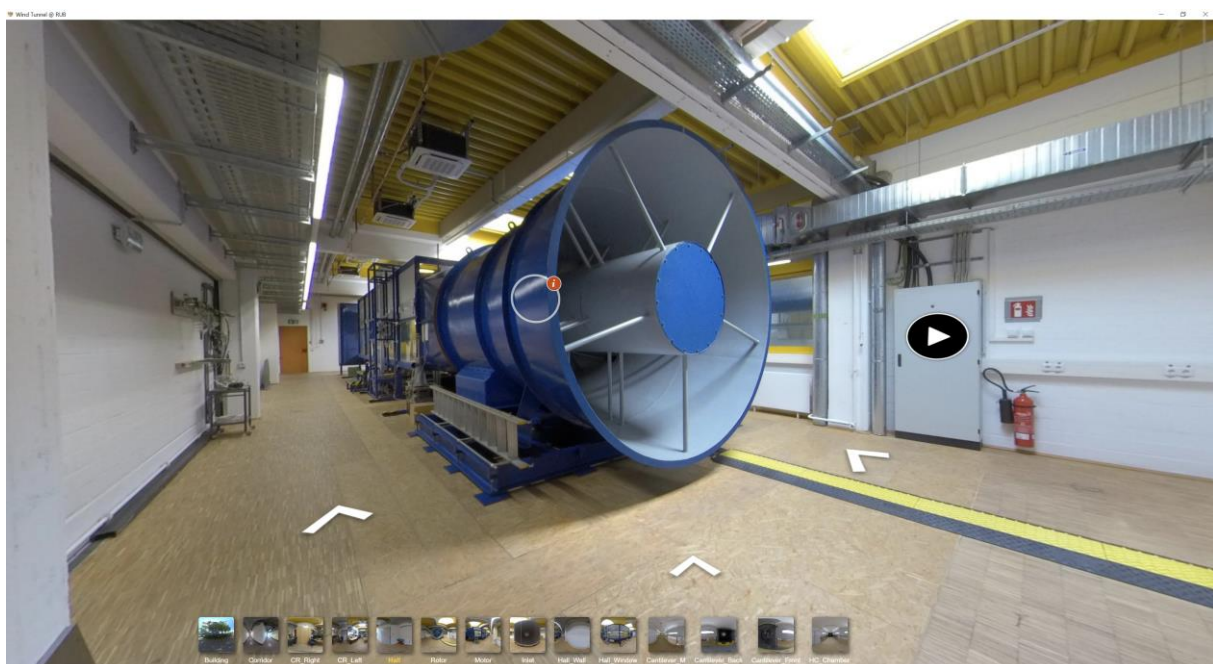
Figure 5.2: Rotor scene of the VT from the wind tunnel facility at RUB, WiSt

Figure 5.3: Chamber entrance scene of the VT from the wind tunnel facility at RUB, WiSt
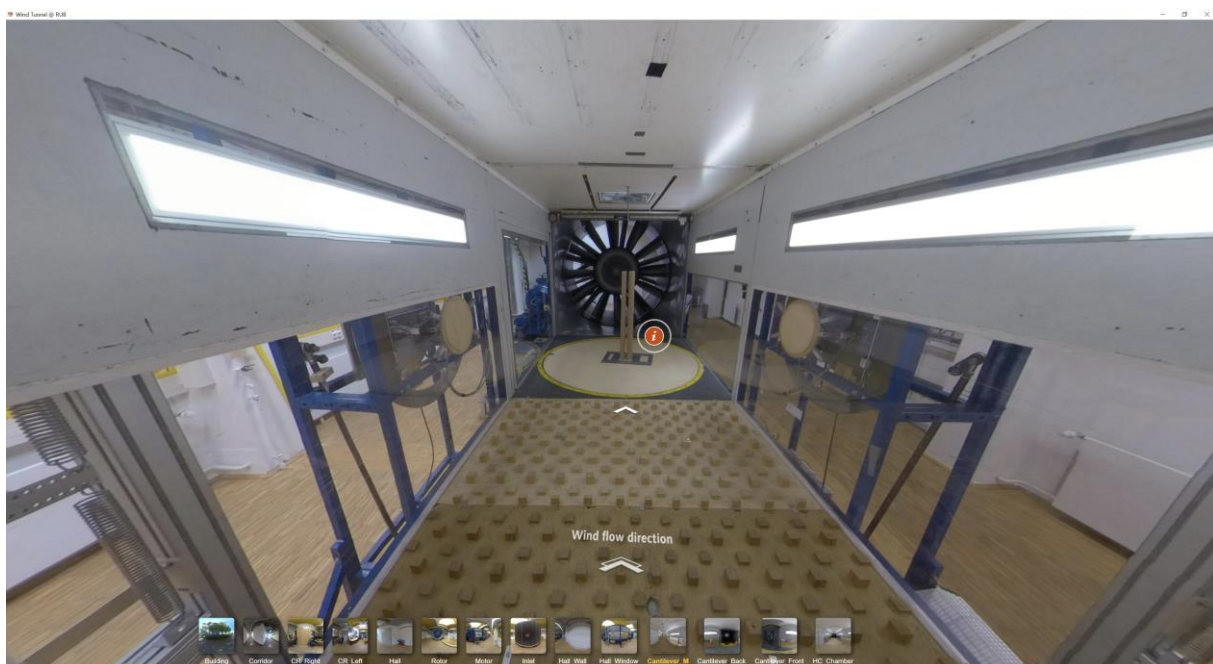
Figure 5.4: Inside chamber scene of the VT from the wind tunnel facility at RUB, WiSt

5. 2.   Gypsum board fire resistance test

The VT from the fire resistance test facility at the University of Aveiro, Department of Civil Engineering, depicts a fire resistance test, which was conducted on a gypsum plate wall. The objective of this test was to evaluate the integrity to flames, hot gases, and thermal insulation with respect to criteria of standard fire resistance classification. It is worth noting that the ambient conditions and test setup at this facility are not suitable for huge attendance, therefore, fire resistance tests are conducted under safety restrictions and only technical staff are allowed to audit experiments in person.

The VT of the fire resistance test has in total 13 scenes, including three 360-degree videos. The scenes are organized in a way that by moving around the virtual room, users can view time steps of the experiment as it has been conducted in real life (as a sequential view). Therefore, the VT begins at minute 0 (first scene) and ends after 77th minute (the last scene). A 360-degree video at the end of the test reviews the whole experiment that was conducted in 77 minutes in 7 minutes. The information hotspots embedded have above all the following functions:

- Showing the construction of the gypsum board wall
- Depicting the exposed side of the wall before and after test
- Describing the equipment and data acquisition system at the laboratory
- Showing raw sensor data and footage from thermal cameras
- Depicting the final results and tables related to the fire classification

The VT has been published in desktop and VR versions and have been provided to students. Few screenshots from the tour (in desktop version) are shown in Figures 5.5 to 5.8. For further information about the VT, please visit the PARFORCE website [26].
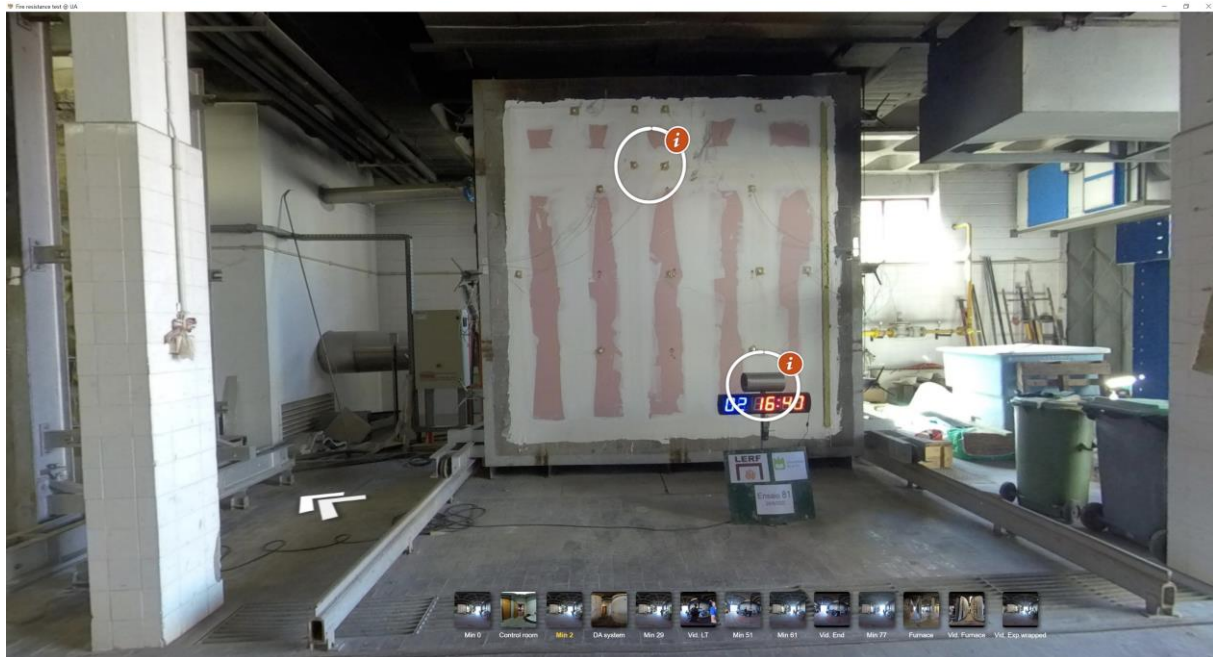
Figure 5.5: Minute 2 scene of the VT from the fire resistance test at UA

Figure 5.6: 360-degree video of minute 25 of the VT from the fire resistance test at UA
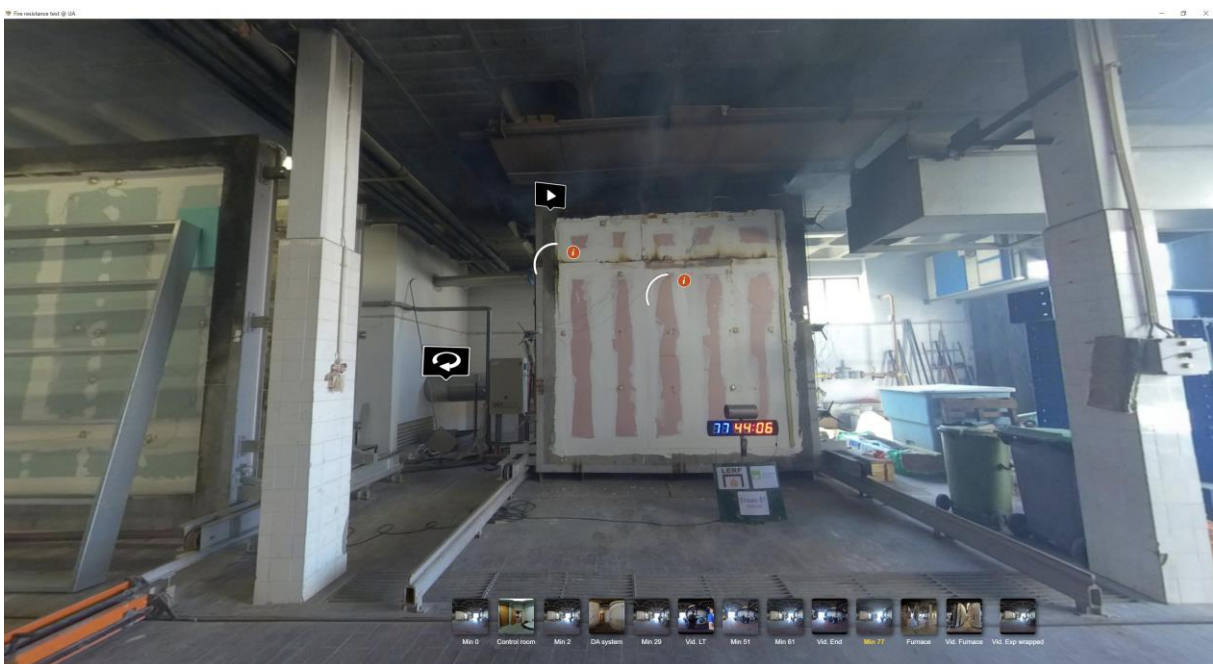
Figure 5.7: Minute 77 scene of the VT from the fire resistance test at UA (test ended)
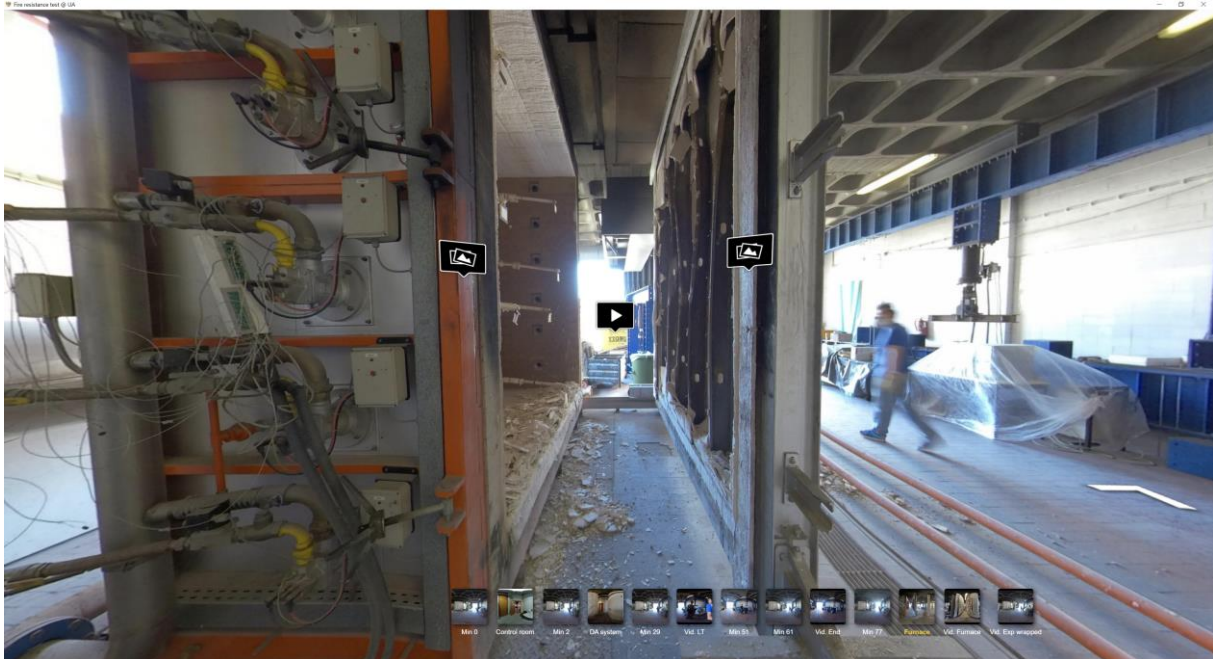
Figure 5.8: Furnace scene of the VT from the fire resistance test at UA (test ended)

5. 3.   Quasi-static test of polyurethane repaired reinforced concrete column hinges

The VT of the quasi-static test has in total 4 scenes, including 3 panoramas and one 360-degree video. Panorama footages are conduced from the column element at the beginning of each test, once from the column without damage at the hinge area, and once after the damaged element from the first test is repaired by polyurethane material and is about to be tested again under the same load cases. The third panorama scene depicts the whole test setup from another viewpoint. Figure 5.9 shows the screenshot from a panorama scene at the beginning of the test, before the column element has undergone damage around the hinge area. In this figure, it is noticed that the column element is not straight, specially around the middle vertical line. The reason is that the screenshot is made from the VR version of the VT, and the panorama originally is a stereoscopic footage from this scene. This means that to the naked eye, the stereoscopic footage may not seem straight or in the case of Figure 5.10, it may seem blurry.

Figure 5.9: Column scene of the VT from the quasi-static test at IZIIS (before damage)

Figure 5:10: Setup scene of the VT from the quasi-static test at IZIIS (before damage)

Figure 5.11 shows the panorama scene of the repaired column element at the beginning of the quasi-static test. The 360-degree video has been employed to show an overview of the laboratory and test setup, as well as providing users with an understanding about how slowly the column element is moving during each cycle of loading.

The information hotspots embedded within this VT have above all the following functions:
- 2D footage from the hinge area, before and after crack propagation
- Close-up view of cracks and test equipment, including data acquisition systems

- Diagrams of loading cases at the end of each test
- Time-lapses of column element deflections at the end of each test
- Raw data of the sensor recording at the end of each test

The latter hotspot is designed as a "download button", meaning that at the end of the tour, students have to download the raw sensor data. This function helps educators with coupling the VT as a learning object with other course activities and assignments, i.e. if students want to access the raw sensor data to work on an assignment based on them, they have to try the VT at least once on the desktop. The VT has been published in desktop and VR versions and have been provided to students. For further information about the VT, please visit the PARFORCE website [26].

Figure 5.11: Column scene of the VT from the quasi-static test at IZIIS (after being repaired)

Figure 5:12: A panorama scene of the VT from the IZIIS facility showing the shake table

6.   Application within the PARFORCE M.Sc. Pilot course

The implementation of virtual tours as a supplementary learning object within a blended learning pilot course marked a significant advancement in the conventional learning experience, especially in relation to the project work (see the module guide in Table 6.1). The pilot course aim at facilitating the practical application of students' theoretical knowledge. Virtual tours provided were employed to describe laboratory setups, experiment procedures, and to visualize complex structural response under various loading conditions such as wind, earthquakes, and fire. This interactive and immersive approach made it considerably possible for students to extend their practical knowledge by auditing experiments that were not available at their home universities.

Table 1: Module guide of the pilot course.

Experimental testing based on impact and resistance: wind, fire and earthquake						Module-No.: …	
Semester No.	**Frequency of the module offering**	**Duration**	**Type of module**	**Credit points (ECTS)**	**Language(s)**	**Student workload**	
3	annually in Winter Semester	1 Semester weekly	Elective compulsory	6	English	180hs, Thereof: 60hs attendance time, 60hs project work 60hs self-study and exam-preparation time	
Recommended course requirements	**Course program**	**Form of examination / Duration of examination**			**Teaching and learning methods**		**Responsible for the module**
B.Sc. Basics in: - signal processing - dynamics - matlab or python	NHRE other	Project presentation (oral), 50% Project report, 50%			Lecture (L) Project (P)		…
Course content							
Lectures: (hybrid format) Theoretical background about experimental testing based on impact and resistance with focus on wind, fire and earthquake; testing facilities and technical equipment; demands on specimens and scaling requirements; arrangement of sensors; application of equivalent impact/action (e.g. forces) in pseudo static and dynamic testing; physical interpretation and presentation of experimental data; Project: Training of modelling and analysis methods; study of code requirements and their application to different structural systems; evaluation of structural performance for wind and seismic action; Tools: Matlab or Python; SAP2000 Workshop / Excursion (presence): Training in and practicing presentation skills; visit of construction sites; networking; Date: from 24th to 31st of March 2023 Place: Weimar and Bochum							

The pilot course was designed with a focus on the practical application of civil engineering, where the consequences of various loading conditions were derived and studied. The course content was primarily driven by the observation that both earthquakes and winds apply lateral forces on buildings, thereby prompting a comparative study between two loading scenarios. It is worth noting that while earthquakes and winds generate dynamic forces with unique characteristics, these loading scenarios are often approximated by static loadings in the simplified methodologies typically employed in building design codes. It is a widely accepted notion that these two forces don't necessarily need to be considered concurrently, underscoring the importance of identifying the governing lateral load provisions in any design problem where both forces are applicable. However, such a comparison holds validity only under a specific set of conditions and might not account for the impact of certain crucial variables, such as geographic location, on the relative significance of earthquake and wind forces on a country-wide scale.

The course was structured to include integrated lectures throughout the semester, employing blended learning (see Table 6.2). This approach allowed for the incorporation of digital tools and resources (including virtual tours), enhancing the learning experience while maintaining the benefits of face-to-face interactions. The in-person training week at the end of the course provided opportunities for immediate feedback and in-depth discussions, enhancing the teaching-learning process. The students also visited the Dillenburg branch of the Westphalia highway, during which a group of 25 students observed the A45 replacement project for the Bornbach and Bechlingen viaducts. The goal of the excursion was to combine analytical and practical knowledge enabling students to enhance and develop practical problem-solving skills.

Overall, the pilot course, with a blend of lectures, project work, and excursion, served as a model for digital collaborative learning, demonstrating the potential for enhancing educational outcomes.

Table 6.2: Overview of integrated lectures.

Wind I: Physical modelling of wind effects at structures	**Fire I:** Introduction to fire safety in buildings	**Earthquake I:** Experimental mechanics – fundamentals
Wind II: Evaluation techniques (processing of measurement signals)	**Fire II:** Requirements for fire resistance tests to construction products	**Earthquake II:** Remote access experiments in Earthquake Engineering
Wind III: Example of a wind tunnel experiment	**Fire III:** Experimental practice in laboratory	**Earthquake III:** Large scale shake table test experiments of RC and masonry buildings
Wind IV: Vortex Induced vibrations	**Fire IV:** Analysis and evaluation of the test results	**Earthquake IV:** Experimental research in earthquake geotechnical engineering – element and model tests

At the end of the pilot course, students were asked to participate at a survey. The (anonymous) survey categorized different aspects of the pilot course focusing on the online lecture contents, presence week activities, and project work content and procedure. The most important section of the survey focused on students' feedback on virtual tours. Almost 90% of students had tried at least 2 virtual tours on desktop PCs. These students have rated the content of virtual tours (desktop version) 4 out of 5 and have reported that they did not have any technical difficulties viewing the tours. Less than 10% of the students did not try virtual tours on VR glasses at all. They have listed various reasons, such as device unavailability and not feeling comfortable wearing VR glasses. From the remaining students (91%), 70% had not ever tried VR glasses for any purposes (such as gaming) before. In total only 6% of students reported issues with VR glasses, such as motion sickness, blurry images, uncomfortable setting. When asked about the quality of footage, students rated the footage quality on VR glasses higher than the desktop version (41%). Around 70% of students agreed with the statement that "*the immersive footage made me feel I was in the laboratory and I was comfortable with standing close to the objects*", which is, e.g. in case of fire resistance test, an important feedback. The majority of students (88%) responded that they would like to try the virtual tours on VR glasses again.

7.   Conclusions and outlook

The present report has focused on the proposed framework for implementing virtual tours as remote-access experiments. Use cases extended by the strategic partnership as well as results from the pilot course have been briefly discussed. It has been proven that virtual tours not only can enhance the learning process but also can provide a unique perspective on the practical implications of theoretical concepts, thereby bridging the gap between theory and practice. The implementation of VR tours in the pilot course stands as a model for collaborative teaching and learning, demonstrating the potential of digital intellectual effort in an educational setting. The virtual tours as PARFORCE project results are published as web-based tours on the public education portal 360-degree.education [25]. Using a public web-based platform increases accessibility, hence, any user that has internet access can benefit from PARFORCE virtual tours as free online learning objects. Educators may integrate PARFORCE virtual tours within their course curricula and may access other VT versions on demand.

Virtual tours are currently designed for the single user view, which may be potentially extended for simultaneous multi-user views, hence, a collaborative virtual laboratory may be achieved in the near future. Moreover, live streaming functions may be added to virtual tours, e.g. the student performance may be monitored and an opportunity to ask for instructions may be supported. Lastly, VR-related comfort may be increased, i.e. interactions with hotspots to be improved or to be replaced with hand gestures. Also, parameters related to footage clarity and stability that can easily lead to issues such as motion sickness may be further investigated.

8. References

[1] Vezirov, T.G., & Bakmaev, A. (2019). Pedagogical Capacity of Multimedia Laboratory of Educational Resources in Specialists Training Within the Conditions of On-Line Learning.

[2] Liu, J. (2020). Online Teaching Practice and Reflection Based on the Perspective of Learners.

[3] Chen, P., Yang, K., Liu, Z., & Zhang, B. (2021). Research on Online Teaching Practice of Specialized Course. 2021 2nd International Conference on Big Data and Informatization Education (ICBDIE), 629-633.

[4] Li, Y., Zhang, L., Tian, Y., & Qi, W. (2022). Research on Teaching Practice of Blended Higher Education Based on Deep Learning Route. Computational Intelligence and Neuroscience, 2022.

[5] Nabizadeh, A.H., Gonçalves, D., Gama, S.P., Jorge, J.A., & Rafsanjani, H.N. (2020). Adaptive learning path recommender approach using auxiliary learning objects. Comput. Educ., 147, 103777.

[6] Matar, N.A. (2011). Adaptive learning objects repository structure towards unified E-learning. International Conference on Information Society (i-Society 2011), 404-410.

[7] Karampiperis, P., & Sampson, D.G. (2006). Adaptive Learning Objects Sequencing for Competence-Based Learning. Sixth IEEE International Conference on Advanced Learning Technologies (ICALT'06), 136-138.

[8] IEEE Standard for Learning Object Metadata (2020). IEEE Std 1484.12.1-2020 , vol., no., pp.1-50, 16 Nov. 2020.

[9] Montoya, D.M., Vargas, J.E., Giraldo, J.S., & Hincapié, N.C. (2020). Developing a Pedagogical Method to Design Interactive Learning Objects for Teaching Data Mining. Journal of Educators Online, 17.

[10] González-Lluch, C., Vergara, M., Bayarri-Porcar, V., Bellés, M.J., & Gracia-Ibáñez, V. (2021). APPLICATION OF FLIPPED METHODOLOGY IN COMPUTER AIDED DESIGN TEACHING. ICERI2021 Proceedings.

[11] Dagman, A., & Wärmefjord, K. (2022). An Evidence-Based Study on Teaching Computer Aided Design in Higher Education during the COVID-19 Pandemic. Education Sciences.

[12] J. Wermann and B. Pohn (2022). VR Training for Laboratory Environments, 2022 International Conference on Software, Telecommunications and Computer Networks (SoftCOM), Split, Croatia, 2022, pp. 1-6.

[13] Try, S., Panuwatwanich, K., Tanapornraweekit, G., and Kaewmoracharoen, M. (2021). Virtual reality application to aid civil engineering laboratory course: A multicriteria comparative study. Comput Appl Eng Educ. 2021; 29: 1771– 1792.

[14] Lohre, R.; Bois, A., Athwal, G., Goel, D. 2020. Improved Complex Skill Acquisition by Immersive Virtual Reality Training: A Randomized Controlled Trial. The Journal of Bone and Joint Surgery 102(6):p e26, March 18, 2020.

[15] 4-point bending test conducted at the laboratories of the Institute of Structural Engineering, Bauhaus-Universität Weimar. Available at: https://www.uni-weimar.de/en/civil-engineering/institute/iki/; Accessed: 2023-07-07.

[16] 3D-RealityCapture-ScanLab of the Chair of Computer Vision in Engineering, Bauhaus-Universität Weimar. Available at: https://www.uni-weimar.de/en/media/chairs/computer-science-department/computer-vision/research/3d-realitycapture-scanlab/; Accessed: 2023-07-07.

[17] Structural Health Monitoring Laboratory of the Chair of Computing in Civil Engineering, Bauhaus Universität Weimar. Available at: https://www.uni-weimar.de/en/civil-engineering/chairs/computing-in-civil-engineering/research/shm-laboratory/; Accessed: 2023-07-07.

[18] Tasliarmut, F., Vogt, A., Montag, M., Zander, S., Koch, C. (2022). Conducting user studies in engineering education during the COVID-19 pandemic in Proceedings of the 2022 European Conference on Computing in Construction.

[19] Mirboland, M., Tasliarmut, F., Abrahamcyzk, L., Koch, C. (2022). A mixed reality application for holographic structural analysis experiments in Proceedings of the 2022 European Conference on Computing in Construction.

[20] CodeF53 (2019). Comparison of the Horizontal FOV of different headsets. Available at: *Reddit*; https://www.reddit.com/r/ValveIndex/comments/b9lp7t/comparison_of_the_horizontal_fov_of_different/; Accessed: 2023-07-07.

[21] What is the difference between monoscopic and stereoscopic VR? Available at: https://immersionvr.co.uk/blog/monoscopic-vs-stereoscopic-360-vr/; Accessed: 2023-07-07.

[22] Virtual Reality (VR) and 360 Videos 101 — A Beginner's Guide. Available at: https://medium.com/visbit/virtual-reality-vr-and-360-videos-101-a-beginners-guide-70bbade8e39; Accessed: 2023-07-07.

[23] Official website of insta360 products; insta360 Pro 2.0. Available at: https://www.insta360.com/product/insta360-pro2/; Accessed: 2023-07-07.

[24] Official website of 3dvista products; 3dvista Virtual Tour Pro. Available at: https://www.3dvista.com/en/products/virtualtour/; Accessed: 2023-07-07.

[25] Education Portal "360° Education", virtual learning experiences and excursions (German: Bildungsportal "360° Bildung", virtuelle Lernerfahrungen und Exkursionen). Available at: 360-degree.education; Accessed: 2023-07-07.

[26] Parforce: Partnership for virtual laboratories in civil engineering. Available at: https://www.uni-weimar.de/en/civil-engineering/international/strategic-partnerships-erasmus/; Accessed: 2023-07-07.

[27] Winkelmann, U., Kurniawati, I., Höffer, R., Braungardt, K., Penava, D., Apostolska, R., Kähler, U., Mirboland, M., Hasan, P.L., Salzinger, J., Kalender, C., Abrahamczyk, L. (2023). Instructional Design Guide: Didactics of Media Learning Environments, University Handbook, ERASMUS+ Strategic Partnerships 2020 for "Digital Education": Partnership for Virtual Laboratories in Civil Engineering (PARFORCE).

[28] Kähler, U., Cerejeiras, P., Pereira, I., Lopes, N., Hasan, P.L., Apostolska, R., Höffer, R., Penava, D., Abrahamczyk, L. (2023). Methods and algorithms for digital learning tools evaluation guidelines for evaluation, Report on intellectual output 2 (IO-2), ERASMUS+ Strategic Partnerships 2020 for "Digital Education": Partnership for Virtual Laboratories in Civil Engineering (PARFORCE).

Annex A: Hardware recommendation list

The present list offers recommendations for hardware tools to be used for producing VR footage and displaying the produced content on VR glasses.

360°/180° degree VR cameras

- 360° camera (Monoscopic footage only)

#	Name	Intended for	Price	Availability	Top features
1	Insta360 One X2	Consumer	+ From 500 Euros (only the camera) + different kits/accessories available	In stock	- Live streaming - Video quality up to 5.7K @ 30 FPS
2	Kandao QooCam 8K Enterprise	Consumer / Prosumer	+ From 1.600 Euro	In stock	- Highest tested video quality (8K @ 30 FPS) - Live streaming at 8K (highest available in the market in the consumer category)
3	Ricoh Theta X	Consumer /Prosumer	+ From 999 Euro	In stock	- Best and the newest Ricoh product - Live streaming quality 4K @ 30 FPS
4	GoPro Max	Consumer	+ From 490 Euro	In stock	- Video quality 6K - suitable for beginners - good for 360 videos
5	Ricoh Theta Z1	Consumer	+ From 1.300 Euro	In stock	- Best for 360 Images and panoramas - Image quality and reliability is high -
6	Trisio Lite 2 VR 8K	Consumer	+ From 400 Euro	In stock	- - Best budget camera for 360 images
7	Insta360 One RS twin edition	Consumer	+ From 500 Euro	In stock	- Together with One X2, the best consumer cameras for 360 videos

8	Labpano Pilot One EE (512 GB)	Consumer/Prosumer	+ From 2.000 Euro	In stock	- Direct connection to Google Street View - Can upload footage to google drive - On the top 5 list of 360 cameras for 2022

Cameras mentioned above, mostly come with on-board stitching functions or with a proprietary stitcher for desktop. In case you would like to try stitching the footage on your own, the "Adobe After Effects" software is recommended.

- 360° camera (Monoscopic + Stereoscopic)

#	Name	Intended for	Price	Availability	Top features
1	Insta360 Pro 2	Prosumer	From 5.000 Euro (basic kit), Premium kit for 6000 Euro	In stock	- Best Profi camera within a low-budget - Live streaming 8K 30 FPS - on-board stitching for 4K videos - Video quality at 8K for 3D
2	Mosaic51	Prosumer	From 20.000 Euro	In stock	- High resistance against harsh environment - up to 12 K resolution - High dynamic range, suitable for street view mapping
3	Kandao Obsidian Pro	Prosumer	From 2.100 Euro (standard kit)	In stock	- 12K 3D videos - max. Live streaming quality 8K @ 30 FPS - 8 APS-C lenses (other alternatives have max. 6 lenses)

- 360°/180° camera (Monoscopic in 360°, Stereoscopic in 180° mode)

#	Name	Intended for	Price	Availability	Top features
1	Kandao QooCam	Consumer	From 299 Euro	In stock	- 3 wide angle fisheye lenses - 4K @ 30 FPS video quality
2	Z Cam K1 Pro	Prosumer	From 4.200 Euro	In stock	- Only 180° §D footage - Cinematic usage - 6K @ 30 FPS output quality - Live streaming at 4K @ 60 FPS

VR and MR wearables

Standalone VR goggles have on-board screen processors, batteries, sensors/cameras for spatial orientation and position recognition. 6 degree-of-freedom (6DOF) goggles include rotations along 3 axes and allow user to walk around in the real world, whereas using 3DOF goggles one can only tilt their head and look around. PC VR goggles require to be connected to a (high-end) PC, base stations for tracking the real world, and controllers. Wired connections hinder the usage of PC VR goggles with respect to mobility and specific applications. However, PC VR goggles provide better image resolutions. Standalone goggles are preferred over PC goggles, if the computation/rendering burden is not high and if the mobility of users, the ability to use the goggles anywhere is of great importance to the developer. It is worth noting that the standalone goggles are normally cheaper than PC VR goggles. In the following, the leading hardware in VR are listed.

- Standalone glasses

#	Name	Intended for	Price	Availability	Top features
1	Oculus (Meta) Quest 2	Consumer/Prosumer	From 410 Euros (128 GB)	In stock	+ Glasses + hand controllers + Best budget standalone set - Field of view: 90˚ - Facebook product (requires a FB account!)

| 2 | HTC Vive Focus 3 | Prosumer | From 1400 Euros (kit) | In stock | + Best standalone VR kit

+

- limited to specific enterprises/VR applications games

+ |
| 3 | Pico Neo 3 Pro (eye) | Consumer/Prosumer | From 700 Euro | In stock | + Standalone AND PC

+ hand controllers included

+ built-in eye tracker (EYE version) |

- PC VR glasses

#	Name	Intended for	Price	Availability	Top features
1	HP Reverb G2	Consumer/Prosumer	From 500 Eruo (only glasses- currently low availability) From 650 Euro (+ hand controllers)	In stock	+ High image resolution for PC VR glasses + Field of view: 114˚
2	HTC Vive Pro 2/ Eye	Consumer/Prosumer	From 800 Euro (only glasses) From 1400 Euro (full kit: hand controllers + base stations)	In stock	+ Highest image resolution for PC VR glasses (5K) + Field of view 120˚ + better processor than the older version (HTC Vive Pro) - the Eye version has built-in eye tracker
3	HP Valve Index VR	Prosumer	From 1650 Euro (kit)	In stock	+ Gaming monster PC VR kit + Field of view 120˚ + Finger tracking
4	HTC Vive Cosmos XR	Prosumer	From 600 Euro (only glasses), 1000 Euro (kit)	In stock	+ high resolution + supports many applications (suitable for business)

Another category of VR goggles are smartphone VR headsets, for which one needs to insert the smartphone inside goggles, and use the screen of smartphone. The goggles only have two lenses which project the footage for each eye from the smartphone screen. Therefore, the image quality is dependent on the smartphone screen quality. One can use these headsets for leisure, either for playing games or visiting virtual tours.

- Smartphone VR headsets

#	Name	Intended for	Price	Availability	Top features
1	BoboVR Z6	Consumer	From 50 Euros	In stock	+ Smartphone VR headset: ONLY works with a smartphone in it, has no display! Similar alternatives such as BNext VR headsets exist