A Use Cases Driven Design of a Virtual Anatomy

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Abstract. Anatomy teaching forms a fundamental part in undergraduate medical and dental education. Gross anatomy teaching using post-mortem bodies at the same time causes extensive high infrastructural and personnel resources. Dissection rooms and related mortuary facilities are expensive to operate, hence technical capacities are limited by the logistics involved for providing the basis of high-quality teaching. Virtual tools offer a realistic and immersive learning experience, thereby supporting to better prepare students for their hands-on teaching experience, and hence allowing to enhance the dissection course in an effective way. Furthermore, students can translate their knowledge to other fields in medicine such as radiology or surgery. Even though virtual tools cannot replace hands-on-teaching, it was hypothesized that as a result of using virtual tools accompanying teaching, student learning experience and knowledge gain will be enhanced, thus providing a more effective approach towards teaching delivery. The starting point for the here given project was to evaluate emerging virtual technology with the potential to be deployed in anatomy teaching. We assessed three technical scenarios driven by suitable use cases for individual teaching processes, which will aim to enrich the classical way of anatomy teaching approach by taking advantage of virtual tools. Two scenarios are hybrid, one scenario is virtual asynchronous (but can also be used in a classroom lesson). All three scenarios can also be applied to other fields of science teaching, e.g. engineering teaching by simply replacing the content. In this paper we describe the seven-dimensional use case definition, the technical design of the scenarios and first pilot trials.

Keywords: 3D objects, 3D anatomy visualization, Cinematic Rendering, virtual anatomy, dissection course.

1 Introduction

Anatomy teaching forms a fundamental part in undergraduate medical education. Gross anatomy teaching is commonly conducted based on human corpses, and causes both high infrastructural and personnel resources. Dissection rooms and related mortuary facilities are expensive to operate by expert staff, as a result, room capacities for students are limited by the logistics and technical equipment involved for providing the basis of high-quality teaching. In order to use these facilities in a most efficient manner, virtual tools providing a realistic and immersive learning experience may help support and better prepare students for their dissection lessons. It will also help to translate their knowledge to other fields in medicine including radiology or surgery. On the other side, hands-on teaching on human corpses cannot be replaced by virtual tools. Spatial, haptic and procedural steps involved cannot easily be replaced by virtual technology. However, a virtual 3D representation derived from computed tomography (CT) and magnetic resonance imaging (MRI) enables anatomy teaching based on data from living humans. Virtual approaches are especially relevant for those medical universities which do not own a full-scale anatomy infrastructure for monetary, technical or other reasons. As a consequence, the time students can spend in the dissection room of partnering anatomy departments is often limited and associated to the cost and time of traveling.

It was hypothesized that as a result of using virtual tools accompanying teaching, student learning experience and learning gain will be enhanced, thus providing a more effective approach towards teaching delivery. The starting point for the here given project was to evaluate emerging virtual technology with the potential to be deployed in anatomy teaching. We assessed three technical scenarios driven by suitable use cases for individual teaching processes, which will enhance the classical way of teaching anatomy by taking advantage of virtual tools.

2 Definition of technical scenarios for the virtual anatomy

Based on the related work found and following a consensus process with the partnering Johannes Kepler University Linz, Austria with whom this project will be jointly realized, three suitable scenarios were identified. Two scenarios are hybrid, i.e., students and instructors reside simultaneously within the teaching setting, but without necessarily being located physically at the same location. One scenario is virtual asynchronous (but can also be used in a classroom lesson), i.e., students and instructors reside at different time points and / or different locations 1, 2.

Within the two hybrid scenarios we differentiate between scenario#1 - a lecturer driven 3D live visualization of (living) human bodies (interior) based on CT and MRI scans and scenario#2 - a 3D live video transmission from the dissection rooms of our university to the big lecture room and to our partner university. The virtual asynchronous scenario #3 visualizes 3D scans of anatomical specimens or objects with annotations in 2D in a standard web browser. These items consisted of 3D-scanned models of anatomy dissections, wax models, human bones, and plastinates, which will be annotated by lecturers and made available to students by a learning management system.

As a first step we performed a focused market analysis in close connection to the three technical scenarios we want to implement.

3 Related work

Following the completion of a market research on virtual technology, typical scenarios connected to virtual anatomy were identified a number of items which are related to virtual anatomy: 3D interactive models, augmented reality simulations, virtual dissections, anatomy quizzes and games and video lessons on anatomy topics. In the following chapter we give a brief overview on products and research we found related to our project.

In connection to scenario #1 the young Austrian startup company Augmentomy [3] offers an augmented reality (AR) solution for teaching anatomy. Originally targeted for medical doctors the technology developing focus turned to medical education due to strict and difficult to implement restrictions in medical software and hardware. The startup company began in 2023 with the development of augmented reality software for Qualcomm AR glasses. A first prototype of the software was demonstrated to us in March 2023. Users wearing Qualcomm AR glasses were presented a virtual skeleton with options to visualize muscles, vessels, bones and organs. A typical use case for this application was a small-scale classroom setting offering interactive collaboration. For the scenario required with 480 students, this software cannot be used in an efficient way due to the need of expensive AR glasses.

The research project nARvibrain [4] of the university of applied sciences FH Joanneum in Austria aims to merge structural and functional neurological imaging data. The project develops assistance systems for diagnosis and treatment of brain tumors by usage of AR technology. Again, the use case is very different from our requirements, by putting the focus on assistance of medical doctors rather than on undergraduate education. Also, the hardware required would be not affordable for 480 students in parallel.

Furthermore, a number of medical simulation programs exist including HoloScenarios. This simulation was developed by the well-known simulation company GigXR [5] in collaboration with the Cambridge University hospitals. The software provides a realistic simulation of the entire patient care journey, from assessment and diagnosis to appropriate intervention and escalation of care, but there is no direct connection to anatomy and anatomy in education. Hence this software is more suitable in a later stage of the medical education, where students are already in their clinical years.

For scenario #3 a number of web based platforms were assessed capable of distributing 3D objects, including Online 3D viewer [6], 3D Vault [7], CG Trader [8], Visibly Body [9] and Sketchfab [15]. The only platform meeting our requirements was Sketchfab. It offers an easy to use annotation interface for lecturers, an upload for new objects, an embedded code which allows seamless integration in our learning management system Moodle, privacy settings and offers reasonable pricing for academic institutions. Other solutions presented were too costly, failed offering the addition of own objects and/or annotation of them, or failed providing a protected access link to the objects.

4 Definition of seven-dimensional use cases

In parallel to the three technical scenarios which were given in section 2 we defined nine use cases, integrating these scenarios within teaching anatomy. This was a mission critical step in this project, because it guarantees the involvement of the actual users of the system, the teachers, right from the beginning. This was considered as very important, since involving lecturers already at an early stage grants a user oriented and user-friendly design of the technical infrastructure. Therefore, use cases were defined in seven dimensions, in order to cover all issues involved with the use case and also to directly connect it to the technical realization. The seven dimensions include a description of the use case, its priority, logistic approach and time consumption, frequency of application in teaching, technical pre-requisites and requirements, necessary personnel resources and costs.

4.1 Seven dimensions

All use cases we defined were based on a well-structured template and consisted of the following seven dimensions:

1. Short description: Briefly outlines the use case and the learning goals.
2. Priority: here the values high, medium and low can be applied. In general, all use cases should be implemented throughout the project, however, if it comes to a shortage on resources, prioritization would be needed.
3. Time line and time resources (connected to 2): in this section the storyboard of the use case was described in detail. This is done in relation to the time given. So, for e.g., a typical 45-min lecture an exact time plan has to be stated.
4. Frequency of use: here the lecturer indicates how often the use case will be used during his lessons, e.g., in 10% of all lectures within a specific semester.
5. Technical prerequisites and requirements: which technology will be needed in order to implement this use case in practical teaching? Is there any other material needed in order to realize this use case such as dissections, wax models, bones, or plastinates?
6. Personnel resources required: Which lecturer at the institute will concretely be responsible for this use case and its implementation? Which personnel is needed next to the lecturer in order to implement this use case? E.g., technical support, preparation of dissections
7. Costs of the use case: here all costs in connection with the implementation of the use case have to be stated. Costs are divided in one-time investments (e.g., hardware costs for 3D visualization) and continuously appearing costs such as technical support personnel, maintenance costs etc.

4.2 Main use cases

Due to the page limitation we cannot describe all nine use cases in very detail in this paper. Only the technically most challenging use cases will be outlined. The planned technical implementations of the use cases will be given in section 5.

Use case (UC) #1 “networked learning between the Medical University of Graz and Johannes Kepler University Linz”: in this use case, first, a 3D live video streamed from the dissection rooms of Medical University of Graz presented by a lecturer demonstrating regional anatomy on a human prosection will be transmitted. In the second part a 3D visualization of the same dissection will be transmitted from a lecturer of Johannes Kepler University, but this time based on a CT/MRI scan mostly from individuals living at the time of the imaging. In between, students will have the chance to interact with the lecturers on both locations by using a voting software. This use case uses the technical scenarios #1 and #2 and is the most challenging use case in technical terms. It combines a live 3D video transmission over the internet with a live cinematic rendering transmission and visualization at two geographically dispersed locations. Due to these high technical requirements this use case also has high demands on involved personnel (2 lecturers plus technical support staff at two locations) and on hardware and software licensing costs.

UC#2 “local virtual anatomy” and #3 “operative access on musculoskeletal system” are technically sub use cases from UC#1. UC#2 uses the technical scenario #1 in order to only locally visualize 3D representations based on CT/MRI scans instead of a synchronized display in two remote locations. UC#3 uses the technical scenario #2 in order to transmit a 3D live video from the dissection rooms at Medical University of Graz to the Johannes Kepler University in Linz, however, without combining with scenario #1. Technically speaking, both use cases use a part of the technology needed to implement UC#1 and have therefore lower requirements in terms of personnel and technical resources.

UC#4 “frontal lectures within anatomy modules” and UC#5 “correlation of head/neck regions based on 3D videos with 3D live rendering” both combine the technical scenarios #1 and #2, but again only locally at one university. As a special addon, the technical requirement exists to replay before recorded specifically selected 3D videos from dissections. This technology requires 3D recording infrastructure. Throughout the project the feasibility of this use case will be investigated, since it requires extensive storage space and a special software.

UC#6 + #7 “Annotation of 3D objects in biomechanics and osteology in hybrid / virtual asynchronous teaching”, UC#8 “3D scans of dissections in human medicine for self study” and UC#9 “3D scans of fragile huge preparations for self study” are all related to the technical scenario #3. These use cases aim to give all students access on the huge collection of preparations, wax models, bones and plastinates by using standard web browsers and visualization of 3D objects. This involves a 3D scan of the objects, a proper annotation by the lecturers and a proper platform for distribution. This will be described in more detail in section 5.4.

5 Technical implementation

In this chapter we describe the results of the technical feasibility study on the three technical scenarios and the first implementations. Starting from the technical workflow we then describe each technical scenario in more detail.

5.1 Technical workflow

Within **Fig. 1** we depicted the technical workflow for all three scenarios of our planned virtual anatomy environment. In the graphic you can see the main technical components and the main communication / data paths.

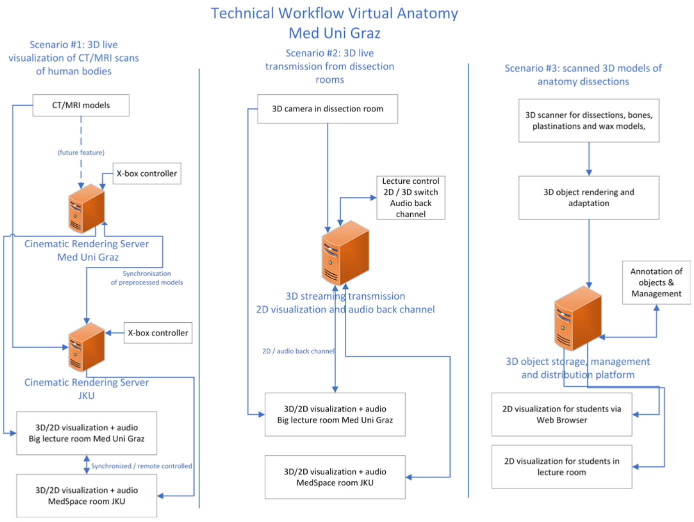

Fig. 1. Technical workflow for the three technical scenarios of the virtual anatomy

5.2 Scenario #1 - A lecturer driven 3D live visualization of (living) human tissues based on CT and MRI scans

Scenario #1 will be based on cinematic rendering, a novel and emerging technology for the post-processing of medical imaging data [11] with a commercial rendering software [13] and a 3D projection technology installed in a huge lecture room. Didactically, the scenario is designed for the teaching of a large student cohort, offered the content in a classroom setting in 3D via special passive or active shutter glasses. The visualized 3D content will be presented by the lecturer with a x-box controller based on live renderings from CT and MRI models of humans. This enables case-based teaching, e.g., by visualizing a vertebral fracture of a person fallen from a horse, its actual effects on the person and the proper therapy. Additionally, a 2D version will be streamed so students may follow the lesson from home, which classifies this scenario as hybrid.

Based on a technical criteria list we did a market analysis on possible 3D visualization technologies suitable for a huge lecture room with 480 students. There are two principal technologies, each of them with two variants:

- 3D Projector with active or passive shutter glasses
- LED wall with active or passive shutter glasses
- Native 4k 3D projectors were less costly than a LED wall, and offer a well-established, durable technology with numerous applications world-wide. However, 3D projectors also suffer from drawbacks, including: they produce quite a lot of noise and heat, they are very heavy – hence a ceiling mount may not always be possible, and they cannot offer the same contrast / brightness level as LED walls do. There is a significant difference in brightness loss when using passive instead of active shutter glasses. According to the underlying investigations the brightness loss is up to 70% when using passive shutter glasses.

LED walls, an example can be seen in **Fig. 2**, are not a new technology, however, the usage of a 4k 3D visualization in combination with LED walls is currently cutting-edge technology and not many vendors on the market do exist who can provide the necessary technology. The decisive technical element here is the proper controller, which can drive all the single displays in parallel and this with a resolution of 4k, and with 120 Hz (60 Hz for each channel – left eye, right eye). However, all our technology research released, that LED walls are the future for visualization in lecture rooms. In smaller lecture rooms LED panels are already state of the art technology right now. For our specific installation the LED wall offers a number of advantages: since we cannot completely darken the huge lecture room, contrast and brightness are an important issue, and no projector can cope with the brightness and contrast offered by a LED wall. LED installations are not as complicated as projector installations, which might even take seats in the lecture room when it has to be mounted on the ground. Furthermore, the lifetime of the LED wall is expected to be much longer than of a projector, which loses brightness faster over a period of usage time than LED walls. This is due to the fact that a set of spare panels should be bought together from the same production batch to have exactly the same panel characteristics in the likely case that some of the panels fails its operation. LED walls are meant to be used with active shutter glasses. But there exists a possibility to use them with passive shutter glasses as well which involves a special foil to be attached on the panels. This technology, however, is not well established so far, we could find only one vendor worldwide, and one application for a live concert. All in all, the advantages for LED walls better meet our specific requirements. It was therefore decided to proceed with this technology in combination with active shutter glasses.

Fig. 2. LED wall example installation in a lecture room

Additionally, to the 3D visualization within the big lecture room we will transmit a 2D live stream via our open source based lecture recording and streaming system [5]. Technically this will be realized by just submitting one channel (e.g. only the left eye). The live stream extends the hybrid teaching provided of our university for the students in order to give them a maximum of flexibility. Students may watch the lessons also from home or any other place with an Internet connection. Live streams will be provided in 2D, technically only one channel (left eye) will be streamed.

Actually, active shutter glasses were not our preferred solution due to the fact, that they are more expensive than passive shutter glasses and they require a battery which must be regularly loaded. Since we have 480 students and glasses, this is an enormous technical but also logistical expense. For the loading process we decided to buy inductive loading cabinets which offer space for simultaneously loading up to 192 glasses. Since a cable connection is not necessary, the manual efforts for the loading process are significantly reduced.

With regards to software we will use a commercial rendering software from Siemens [13], which will be installed on a standard high-end server with a state-of-the-art graphic card (Quadro RTX A6000) in order to render the two images (left and right eye) in real time in 4k and with a 60 Hz frame rate.

The control of the software – hence the main user interface for the lecturer - is performed via a standard x-box controller. The lecturer can use the sticks of the x-box controller to navigate through the model and may choose which layers (e.g. muscles, bones, veins) to be displayed. According to the movements of the lecturer the software generates in real time the 3D images which will be sent to the LED wall controller and furthermore displayed. Students will see the 3D effect by using active shutter glasses. In the following some examples are shown how it may look like – the images are from Ars Electronica Center in Linz, where such a system is already installed for many years and recently it was also used for teaching anatomy by our partner university.

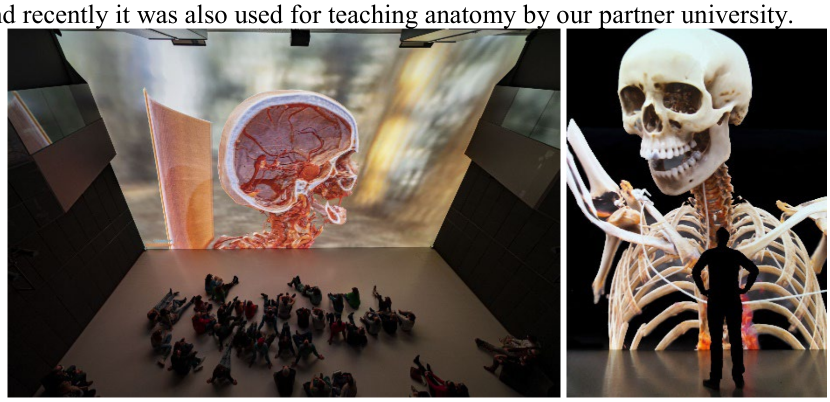

Fig. 3. Cinematic rendering – virtual anatomy. Photo by Ars Electronica / Robert Bauernhansl, CC BY-NC-ND 2.0 (https://creativecommons.org/licenses/by-nc-nd/2.0/legalcode)

5.3 Scenario #2 - 3D live video transmission from the dissection rooms

The didactical background of this scenario is to give the students of our partner university, which has no dissection room space, the opportunity to see a prosection on a human corpse as realistic as possible. This complements the anatomy education of the students of our partner university who have in this stage of their study only virtual anatomy lectures. It also presents steps of preparation and follow up before and after attending the dissection rooms for student hands-on experience.

Scenario #2 will be based on a 3D camera mounted on a crane and placed on a cart, see **Fig. 4** for the current 2D solution. The goal is to conduct a live transmission of a dissection commented by a lecturer to the lecture room and to our partner university. 3D visualization in the lecture room again will be achieved by special passive or active shutter glasses. Technically this scenario has two challenges: one is the selection of a proper 3D camera, the second one is the long-distance transmission over the Internet.

Fig. 4. Crane mounted camera for filming in the dissection rooms

For the 3D camera, two technical solutions exist: mirror rig technology or side by side rig, see also **Fig. 5**. Mirror rig technology offers the advantage to film in the macro range, hence for small objects in a very high level of detail. This technology is often used in medical applications, e.g., in neurosurgery where the doctor must have a 3D view of very small parts in the human brain during the surgery procedure. This technology is expensive, cameras are in the price range of 50k€ or higher owing the fact that the mirror rigs are individually manufactured. The side-by-side rig technology consists of two standard cameras mounted on a rack. Due to usage of standard components, this technology is much cheaper. However, it has the disadvantage of not being able to film in the macro range. For monetary reasons, the side-by-side technology was the chosen option, assuming that it would be sufficient for the given purposes. To ensure this, a test installation will be fostered during the bidding process.

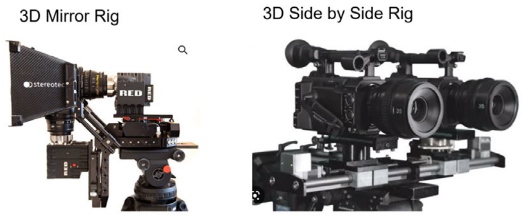

Fig. 5. 3D camera technologies mirror rig and side by side

The second technical challenge in this scenario is the real-time and fully synchronous long-distance transmission of the two 4k streams in 60Hz of the 3D camera (left and right eye) over the Internet to our partner university. The main issues here are the delay which must be in the range of 300ms (otherwise bidirectional communication is very difficult) and the synchronicity of the two streams left and right eye, otherwise the 3D effect will be lost (left eye would see different content than right eye). For minimizing the delay specific hardware encoder exist. With regards of the delay a first rough calculation is 160ms (encoder) and 4 times the round-trip time of 6 – 8ms, which will result in ~200ms which is an acceptable range. For the synchronous transmission over the Internet there exist two technologies.

- Stereo amorph transmission: the images of both channels will be encoded in a single frame, which guarantees a 100% synchronous transmission but enables only half resolution (4k → 2k)
- Frame sequential transmission: left and right channel will be encoded in sequential frames, which again guarantees 100% synchronous transmission but in this case the frequency will be halved from 60 Hz to 30 Hz.

It was decided to use the frame sequential technology so to achieve the maximum possible resolution for our display. A 30Hz frame rate should still be sufficient for the human eye and hence an acceptable quality loss.

5.4 Scenario #3 – Visualization of 3D scans of anatomy objects within a standard web browser

The main didactical purpose of this scenario was to offer undergraduate medical students an interactive 2D access on 3D-scanned anatomy objects within a standard web browser. For this purpose, a number of wax or cast models, bones, prosections or plastinates have been selected and 3D scanned by means of a 3D software [14]. The models were then processed with this special 3D software, generating a final 3D object file. This 3D object file is uploaded into a web-based software platform [15]. This allows on the one hand annotations by lecturers to be made, and on the other hand an embedding of the objects into the learning management software Moodle. Students can access and interact with these objects by usage of a standard web browser from any place with an Internet connection.

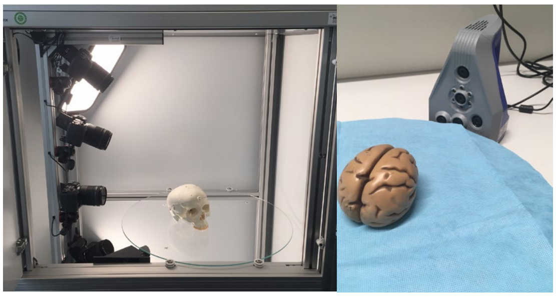

Fig. 6. Scan 3D box and the Artec Space Spider 3D hand scanner

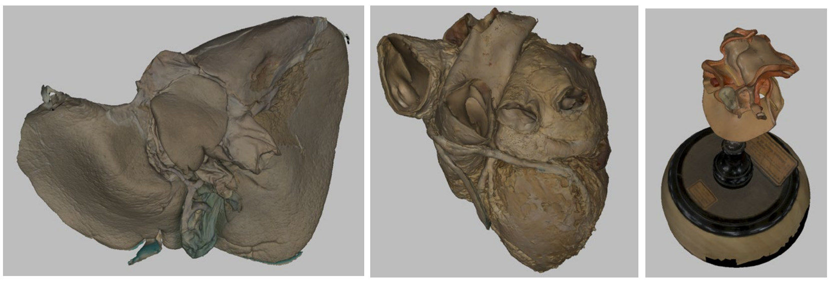

Fig. 7. Examples of 3D scans of anatomy objects (liver, heart, middle ear)

In technical terms, this scenario is comprised of a 3D scanner, 3D processing software, storage and a 3D objects distribution platform. For 3D scanning currently a handheld Artec Space Spider [16] is used, see **Fig. 6**. Additionally, we will use a Scan 3D box, see again **Fig. 6**, which was built by an Austrian research and development center in the field of medical technology [12], specifically to meet the needs of neuro surgeons, hence can scan only objects with the size of approximately a head. However, this scanner is much more precise and faster, and is intended to be used for smaller objects.

The requirements for storage we have calculated are about 5 TB. All in all, 100 objects shall be scanned with an average file size of 500 MB. The storage is attached to a backup system in order to avoid loss of data.

For the distribution platform we selected Sketchfab [15] for the reasons given in section 3. It offers an easy to use 2D interface for students in any standard web browser and can be easily integrated into our learning management system Moodle. Hence the objects can be used for virtual asynchronous teaching (self study), synchronous, hybrid and classroom teaching (lecturers show the objects during the lesson and explain them). Some examples of objects scanned so far are given in **Fig. 7**.

6 Summary, Conclusions and Recommendations

The here presented approach of defining use cases in seven dimensions, covering thoroughly technical issues, personal resources and costs involves users of the system right from the start. This approach helps prevent unfavorable expensive scenarios not being used by lecturers.

For scenario #1 and #2, currently, the project is in the phase of a technical feasibility analysis. Acceptance criteria for the scenarios were first defined. Now possible technology for 3D presentation and recording is systematically investigated, and advantages and disadvantages listed and how they correlate with the acceptance criteria. Cost follow up is further considered, including license fees, hardware replacement, etc. and of course calculate the full costs for implementation in relation to the financial resources we have been provided. Based on these structured results, the decision will be made on which technology will be used. The start of implementation is expected in spring 2024.

With regards to scenario #3, a first prototype has readily been set up with the application of the full workflow from scanning, annotating and presentation to the students. A software platform has been installed for annotation, and currently the time resources to be invested by lecturers for annotation are estimated. The first pilot trial of scenario #3 is expected to be run by winter semester 2023/24.

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