Authoring Educational 360° Models

Experiences from Higher Education in Environmental Engineering

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Abstract: The continuous progress of 360° technologies in recent years has considerably reduced the effort required for creating 360° models. Educational 360° models may now be authored by instructors themselves. However, the quality and usability of 360° models still depend significantly on experience gained from previous authoring of 360° models. Thus, this article summarizes the experience gained during authoring of eleven 360° models from 2018 to 2022 for higher education in environmental engineering. The experiences are structured following a process model inspired by Wohl 2019. Four cameras and four software packages have been used for authoring the eleven 360° models. Based on the eleven 360° models, authoring principles and generalizable experiences are provided to guide the selection of approaches and design elements, as well as hardware and software equipment, for authoring of 360° models.

Keywords: 360-degree, escape room, desktop VR, 360VR

1 Introduction

The market for 360° cameras, i.e. cameras recording simultaneously in all directions, is predicted to grow at annual rates of over 20% until 2030 [Pr21] . Although the consumer and entertainment sectors are seen as the primary drivers of growth, 360°VR is also increasingly being used in educational scenarios. One 360°-based medium frequently being used in educational scenarios is 360° video. For example, in synchronous educational scenarios, 360° videos are used for online lecturing [HH20] . In teacher education, 360° videos are implemented to facilitate reflection [Fe19] or to increase self-efficacy [TvB20]. Frequently, 360° videos are also used in medical education (e.g., [Ul21], [Pi18]). 360° videos are seen as highly conducive to learning processes [Ra22]. For example, 360° videos in preparation for outdoor labs can significantly increase learning effectiveness [Bo20]. Brivio et al. [Br21] compared 360°VR and model-based VR and found no differences in terms of presence, anxiety, and positive emotions. In addition to 360° videos, **360° models or 360° environments, i.e., the software-assisted combination of multiple 360° images into a visual model in which the viewer can take multiple viewpoints**, are

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also applied in educational scenarios. If 360° videos may rather visualize actions and are therefore used to teach skills [IJP17], 360° models or 360° environments are used for virtualization of field trips. For example, wetland ecological systems [OCT21], construction site security [Ph18], or waterworks [Wo21b] may be visited virtually. Virtual field trips based on 360° technology are also used in construction education [WM20].

Aiming to enable non-participating students to experience impressions of research project field trips to Asia, we started integrating 360°-based media as virtual field trips into our graduate and postgraduate environmental engineering courses in 2018, first as 360° videos, followed by 360° models. We previously summarized the state of the literature on 360° video development at that time [We19b]. Lampropoulous et al. conclude in their literature review on 360° videos in educational scenarios that instructors typically do not have the necessary skills to develop 360° videos [La21]. Although instructors have not taken the lead in our authoring processes either, we have found in recent years that instructors easily may initiate and lead the authoring processes, especially in higher education institutions. With access to digital-savvy academic assistants in particular, as well as in the context of academic theses, the authoring of decent 360° models for educational purposes becomes feasible. This article summarizes the experiences we have made in authoring 360° models and may thus aid in getting started with own authoring of 360° models. The article is structured as follows: The next section describes the used cameras and software as well as the authored 360° models. The following section 3 covers the principles guiding the authoring as well as our experiences. Subsequently, principles and experiences are discussed and summarized in section 5.

2 Cameras, Software Packages and 360° Models

The cameras and software packages we used are listed below. Primarily, the development of requirements and scope of services over time is illustrated. The aim is not to evaluate the respective software packages and cameras, but instead provide an overview of the applied soft- and hardware. We are aware that the cameras and software packages used are subject to a fast technical development and are therefore outdated rapidly. Nevertheless, with the description of usage decisions we believe to present relevant principles for future developments as well.

2.1 Cameras

Authoring of 360° videos started in 2018 via the consumer camera **Insta360 One X** (in the following referred to as C1, approx. € 500). The capabilities of this low-end camera became visible in 2019 when we found that the camera also supports professional platforms for 360° models such as *Matterport* [Ma20] by calculating 3D recordings using photogrammetry. The second camera purchased in 2019 was the **Kandao Obsidian GO** (C2) to also enable stereoscopic 3D recordings. The purchase decision was guided by the low price (about €2000) compared to other full 3D cameras. However, it turned out to be challenging to handle in post-processing (especially with the stitching software *Kandao Studio*). The third camera purchased in early 2021 was the **Matterport Pro2 3D 360** (C3) (ca. € 3500), which allows true depth recording through an infrared sensor in indoor scanning. Finally, also in 2021, the fourth camera **Insta360 Pro 2** (C4, ca. € 4500) was acquired, which is characterized by a better image quality-especially a better video quality (8K compared to 4K for C3), by a more convenient handling through a wireless remote control and by a much simpler post-production.

2.2 Software Packages

Each of the above cameras comes with dedicated software for generating and stitching of the taken images. For post-processing, especially stitching to a 360° model and the integration of further information, four different software packages or platforms (abbreviation: "S") have been used so far. **S1:** We started with the provision of simple 360° videos without further information added on the platform **Vimeo** (e.g., [We19a]). **S2:** Based on the capabilities of C1 we provided the first 360° model of the P-Bank in 2019 with little recording and post-processing effort on the commercially established platform **Matterport** [Ma20] [Wo21a]. Using Matterport required a monthly subscription (approx. € 10 / month). Only a limited range of cameras is supported, data is stored on vendor servers, and exporting data for further processing as point clouds requires an extended monthly subscription including a per-model cost. **S3:** In 2020, when the visualization of an entire city quarter led to the requirement of being able to link outdoor shots to a 360° model [Sp20], we used the software **Pano2VR** [Ga20] (educational license: € 70). Furthermore, Pano2VR also supports the integration of custom content such as photos and videos. 360° models authored with S2 load such content exclusively from external internet services, such as *Flickr* or *Vimeo*. Similarly, Pano2VR supports the consumption of stereoscopic footage on VR glasses using the *VR Tourviewer* software [3D22]. S2 likewise enabled the use of VR glasses, but there were limitations in the user experience, such as distorted perspectives and only a slight 3D perception. Pano2VR allows customization and programmable extensions and is therefore particularly suitable for users with programming skills. Few design templates are included in the delivery. **S4: 3DVista Virtual Tour Pro** (S4) [3D21] is currently used as additional software. The software (approx. € 500) offers a more convenient operation during post-processing as well as an easier generation of offline tours. In addition, a videoconferencing tool and an e-learning tool are integrated. S4 also offers the preparation of 3D versions for VR glasses.

2.3 360° Models

In the following Table 1, the 360° models (abbreviation "M") are described with name, year of creation, software and camera used and the learning goals. Where available, evaluations are mentioned. Models M1 to M5 and M11 are currently freely accessible on https://www.360-degree.education [Ba22] while free accessibility is planned for models M6, M7, M9 and M10. Fig. 1 provides a visual impression of M4. Model M8 will only be accessible on request.

#	Object	Learning Goal	S / C
M1	Padma-Bridge (2019): 360° video of traveling on a speedboat at the Padma Bridge under construction in Bangladesh, available at [We19a]	On-site experience of a giant transportation infrastructure project	S1 C1
M2	P-Bank (2019): 360° model of the P-Bank, a mobile show toilet [Wo21a]	Awareness that phosphorus is an essential and finite resource	S2 C1
M3	Informal Settlement Bangladesh (2019): 360° model of a sanitation facility in an informal settlement in Bangladesh	Awareness about social components in development aid projects	S3 C1
M4	Tiefengruben Waterworks (2020): 360° model of a waterworks [Wo21b]	Process steps of water treatment	S2 C1
M5	Neues Bauen am Horn (2020): 360° model of a city quarter on infrastructure planning [Sp20]	Principles of sewage disposal	S3 C2
M6	Photocatalysis (2021): 360° model of an experimental facility of pollutant removal from wastewater by photocatalysis	Design of experimental facilities and wastewater sampling	S2 C3
M7	Umpferstedt Composting Plant (2022): 360° model of a medium-sized urban composting plant	Functioning of a composting plant and awareness raising for the biowaste-producing consumer	S4 C4
M8	Leipzig Wastewater Treatment Plant (2022): 360° model of a metropolitan wastewater treatment plant including functional buildings.	Process steps of wastewater treatment	S4 C2
M9	Rohrbach (2021): 360° model of a village of 200 inhabitants	Planning of rural wastewater systems	S3 C2
M10	Hamburg Jenfelder Au (2022): 360° model of a city quarter	Functioning of resource-oriented sanitation systems	S3 C4
M11	Bauhaus 2050 (2021): Selected sites of Bauhaus Universität Weimar on climate neutrality connected in a single model	Approaches for a university to achieve climate neutrality	S3 C4

Tab. 1: Overview of 360° models

3 Principles and Experiences

The following sections are structured according to a process model for authoring of 360° videos proposed by Wohl [Wo19]. For each phase, we describe the principles we applied and the related and – and to our belief generalizable – experiences that occurred during the authoring of one or more 360° models.

1. Object Identification. Objects recorded so far include a) buildings with emphasis on indoor shots (e.g., M2, M4, M6) but enriched by outdoor shots, b) sites with buildings (e.g., M5,) without indoor shots of the buildings, and c) sites including buildings with equally weighted outdoor and indoor shots (e.g., M3, M7, M8, M9, M10, M11). In M9 and M11, remote locations are connected by transitions. Organizationally, it must be ensured that the project team includes a stakeholder, such as the operator of the object or a lecturer, who provides expertise regarding the learning goals and also is able to determine the extent to which the 360° model may be used freely for teaching or even be publicly accessible.

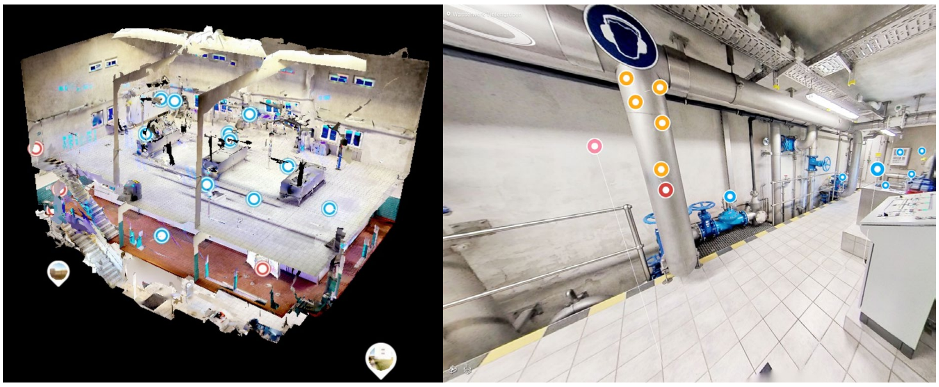

Fig. 1: Waterworks Tiefengruben (M4): Doll house view (left) entry perspective (right)

2. Didactic Concept. A didactic concept was created for the 360° models of all objects except M1 before recording. In a document, all points of interest (POIs) and the annotations assigned to these POIs were described. The walk-through sequence should also be defined. For example, for the waterworks (M4), the POIs were defined along the flow direction of the water. *Annotations.* Annotations are a means of didactic preparation of 360° models. Annotations may be text, graphics, sound, or video annotations. For example, short videos featuring interviews with stakeholders, have proven to be useful annotations for conveying information (e.g., M2). Graphic highlighting, known as signaling in multimedia learning theory, has also been positively evaluated [Ma09]. One particular video annotation is a short spoken introductory at the beginning (M6 and later version of M4). *Guidance.* Free exploration of 360° models may overwhelm a part of the students [Wo21b]. Hence, opportunities for learner guidance might be integrated into 360° models. Guidance may be provided, for example, by displaying the next viewpoints to be taken, providing a concise direction or adding maps indicating the standing location. The escape room metaphor is similarly suitable for guiding learners through a 360° model [Kr21]. Digital escape rooms may be implemented in a low-tech manner using a 360° model and a web-based form [VSB20]. Furthermore, color-coding as well as systematic captioning of annotations are a means to guide the exploration. In M6, for example, the different aspects of an experimental setup are distinguishable by the color of the annotations.

3. Recording Concept.

Selection of Recording Points. Recording points are selected along the POIs defined in the didactic concept. In some cases, one POI may require more than one recording point. Also, for the transitions between POIs it may be advantageous to interpose several recording points ensuring that the students have visual contact to the next recording point at any time. The rule is to create as many recording points as necessary, but as few recording points as possible.

Media selection. It must be decided which recording points will be shown as a 360° photo and which as a 360° video. Videos are preferable when showing dynamic sequences regarding learning goals, photos allow faster post-processing and also require less bandwidth when deployed. For didactic reasons, sections of 360° videos were used within 360° photos in some models. The blending of photos and videos is particularly supported by S4. In M8, videos are used to illustrate the dynamics of the water being cleaned. In M7, the delivery process and the screening of organic waste is also illustrated through videos. Sound recordings increase the immersion significantly and require little effort (e.g., M5).

Selection of Camera and Software. The selection of the software to author the 360° model is seminal for important properties of the 360° model. If a platform like S2 is used, there are permanent subscription costs. Software such as S3 and S4 require dedicated server space, which also leads to costs. Data protection regulations of the object operator might exclude platforms. For example, M8 is considered critical infrastructure, therefore, it is not publicly available and hosted on a server in Europe. Access for educational uses is only provided on a temporary basis upon request. In the meantime, we have rented a dedicated server in a German data center for providing the 360° models authored with S3 and S4. This server will also be available to third-party 360° models [Ba22]. The selection of the camera is influenced by the object to be imaged: 360° scanners are suitable for indoor spaces; 360° cameras are more suitable for outdoor spaces. A minimum distance of the camera to the object should always be considered as well. In M6, for example, the room is so small that minimum distances that have to be maintained visually affect the quality of the images.

Transitions. The recording points should be in visual range allowing users to better orient themselves when moving from recording point to recording point. If this is not possible, transitions should be used to provide an impression of the distance. Transitions include drone flights (M11) or movements, such as car rides in time-lapse (M9).

4. Recording. Conducting the recording in pairs has proven to be efficient: One person operates the camera; the second person directs based on the recording concept and documents the camera shots. Knowledge of the camera's orientation is important for post-processing. For sound recordings, this information should also be spoken into the recordings by one person. Prior preparation of the recording location reduces superfluous details from a didactic perspective. Preparations include, for example, removing objects that are not relevant to learning and reducing the viewing area by closing doors.

5. Post-processing. Post-processing tasks include mainly stitching the recordings together and retouching relics of the photo shoot (such as tripods or dead spots). Post-processing may take a lot of computational power, especially for 360° videos. For stitching, all camera manufacturers provide dedicated software. The *Insta360 Stitcher* software delivers particularly convincing results. For retouching the photos, we used the *Affinity Photo* software. The post-processing work is limited by the features of the software used: *Annotations.* Annotations consisting of text and image, or video are possible in S4, but are supported by S3 as well at a higher effort. *Overviews*. Overlayed maps or aerial images facilitate the overview and have been positively evaluated in our evaluations so far. Map overviews in S3 and S4 show the respective viewpoint and viewing direction. *Augmentation.* Augmentations may be incorporated into the models for better visualization. In M10, for example, contiguous pipeline paths in the pump house are highlighted when hovering with the mouse pointer, allowing for easy identification of pipeline paths. *Stand-alone apps.* The online provision of 360° models is only a convenient solution when there is a resilient Internet connection. However, for showing 360° models in areas and countries with instable internet connections it becomes essential to generate stand-alone apps.

6. Model Validation. Model validation should be carried out jointly with the domain stakeholder in the project team to check the factual accuracy of the information presented and to ensure that no sensitive information is published by the 360° model. Also identified are opportunities for improvement that may be incorporated into a next version of the 360° model. For example, in M4 there is an area that is not accessible due to technical problems of the post-processing.

4 Discussion

The case studies presented are from the field of environmental engineering, i.e., the application contexts focus on the representation of buildings and their environments. For other application contexts, such as for water safety training [Ar21], teacher training [Fe19], or tiler training [Fu19], the guidelines need to be extended: further application contexts result in different requirements, for example, in teacher training it is important to recognize the facial expressions of persons, in 360° models for environmental engineering persons usually need to be shown for privacy protection reasons in a way that they cannot be identified.

During the last years, we could observe a maturation process for 360° technology: the technology offers increasingly new features at falling prices and less and less software expertise is required for the implementation. The lack of accessibility of 360° models, i.e., the inaccessibility for people with certain disabilities, must be mentioned as a limitation.

To improve 360° models a continuous evaluation with teachers and students is advised. The focus should particularly lie on the content and the approaches to communicate it, as graphics might not be suitable for each end-devices. Also improving aspects linked to navigation may support the contextual understanding.

Guidelines for the media didactic design of 360° models are outside the scope of this article, as are any applicable rules of instructional design. In both cases, we have been guided by the generally applicable rules of media didactics in the 360° models presented and their use scenarios [Ke18], [Ni08], [Ye20]. We have explored a range of didactic scenarios, whose comparative characterization in a publication is pending. Currently, small-group-based model walk-throughs outside of formal teaching activities are the most commonly used didactic scenario. A frequently referenced feature distinguishing use is immersivity versus non-immersivity. Although the software used also supports the creation of immersive 360° models, we have generally evaluated non-immersive use. The predominant non-immersive use results from the requirement of easy accessibility. VR headsets are not found in sufficient numbers among students, nor are they available in necessary quantities at our institution. Non-immersive use admittedly forfeits the advantage of immersion. However, we still believe that the spatiality of the objects depicted is well conveyed by 360° models in comparison to 2D media.

Low-threshold 360° technology was supported by the competencies on software literacy, media design, multimedia learning design, and instructional design available in the authoring team. Due to the affiliation of the authoring team to an institute of environmental engineering, a substantial part of the domain content could be developed by the team itself. However, the definition of the learning goals and the validation of the 360° model were always conducted jointly with the domain experts.

5 Conclusions

Authoring of educational 360° models has become feasible through powerful cameras and software by dedicated teachers themselves. Our experiences from eleven 360° models allow the following conclusions: Growing into the authoring process is a viable path. The experience of authoring one 360° model provides the foundation for developing another 360° model. While new camera models tend to offer advancement in image quality and recording organization, software is vital to the content and interactions offered in 360° models. Between conventional media-based learning and field trips, 360° models enable a class of learning activities of their own. The presented principles and experiences might facilitate the own creation of educational 360° models.

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