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360°-Based Virtual Field Trips to Waterworks in Higher Education

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Abstract: 360° models are a form of virtual reality (VR) that allow the viewer to view and explore a photorealistic object from multiple locations within the model. Hence, 360° models are an option to perform virtual field trips (VFT) independent of time and location. Thanks to recent technical progress, 360° models are creatable with little effort. Due to their characteristics of visualization and explorability, 360° models appear as excellent learning tools, especially when additional didactic features, such as annotations, are used. The subject of this explorative field study is a 360° model of a waterworks that has been annotated for learning purposes. Data are collected from a total of 55 learners in four cohorts from study programs in environmental engineering and urban studies using a questionnaire that included standardized measurement instruments on motivation, emotion, and usability. Furthermore, the eight learners of cohort 1 are surveyed using semi-structured interviews on learning, operation and features of the 360° model. Overall, a very positive view on learning suitability of 360° models in VFTs is revealed. In addition, further potential for development of the 360° model could be identified. The results indicate that VTFs based on 360° models might be valuable learning tools, because of their applicability without great effort on the part of either the lecturers or the students. VFTs based on 360° models might serve as a supplement to conventional learning activities or in self-directed learning activities.

Keywords: 360-degree model; engineering education; virtual tour; virtual reality; panoramic virtual reality; place-based learning; virtual field trip

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1. Introduction

Field trips (FTs) are well established as learning activities [1,2], although FTs tend to be underrepresented in both teacher training [2] and the scientific literature [3]. Benefits of FTs include providing real world experiences, training perceptions, instilling positive attitudes toward the subject matter, lasting improvement in the social structure of the student cohort, and the ability to add variety to teaching with additional instructional approaches [4–6]. FTs are considered experiential and active learning that follows a student-centered learning approach [7]. FTs require careful planning in terms of structure, learning materials, and teaching method; in particular, students should also be briefed [3,8].

Environmental engineering is among the courses in which FTs are a regular part of the curriculum [9–11]. However, the disadvantages that limit the feasibility of FTs apply to environmental engineering as well, such as the distance to be covered, the time required, the costs incurred, the limited number of participants, the uncertainty of the weather, the safety in the object of visitation, or even the complexity in the object of visitation [12,13]. Additionally, during a pandemic—such as the present COVID-19 pandemic—field trips may not be feasible.

The above limitation might be addressed by virtual field trips (VFTs), i.e., the destinations of FTs are transformed into digital representations. At its simplest, a VFT is "an inter-related collection of images, supporting text, and/or other media" [14]. Tuthill and Klemm [6] describe a number of ways to conduct educational VFTs using the Internet, with a focus on multimedia collections and organizational efforts such as school partnerships due to the less advanced state of technology a few years ago [6]. Kingston et al. [15] present a VFT using contextualized video collections.

Qiu and Hubble [16], cited in [12], identify advantages of VFTs as time and location independence and replicability, among others. One of the disadvantages stated is the decreased authenticity and the weaker conveyance of the object's three-dimensional structure. In particular, the three-dimensional structure of the object to be visited may be emphasized by virtual reality (VR) technologies [17]. However, recreating objects to be visited through VR might have disadvantages such as costly software development [17] and possibly reduced authenticity [12]. To mitigate these drawbacks, 360° technology may be employed, since it is considered an easy-to-use entry-level technology for creating VFTs [17].

The artifacts that may be created using 360° technologies include 360° images, i.e., the photographic recording of the environment in all directions as well as 360° videos. Due to the recording in all directions, the term 'spherical' images or videos is also used. Related are 'panoramic' images, which focus on a 360° image along the horizon. In addition to 360° images and 360° videos, 360° models exist as artifacts of 360° technology: 360° models are assembled primarily from 360° images using software such as Pano2VR [18] or web-based platforms, such as Matterport [19]. 360° models allow the pictured world to be viewed from multiple viewpoints and are therefore also called "virtual tours".

360° artifacts are appropriate learning tools. Since 360° technology has become highly affordable due to technological progress, especially in recent years, and has developed into a consumer technology, the creation of 360° artifacts has become achievable with little effort. Therefore, this study investigates the self-created 360° model of a waterworks in a higher education VFT. The research questions (RQs) of this exploratory field study are the following:

- RQ1: To what extent is a self-created 360-degree model of a waterworks suitable as the basis of a VFT for use in higher education?
- RQ2: To what extent are students motivated and what emotions does the VFT evoke?
- RQ3: Does the VFT contribute to learning?
- RQ4: Do specific learner prerequisites prove to be conducive to VFT-related learning?
- RQ5: What additional aspects should be considered when using the VFT?

The rest of the article is organized as follows: The next subsection discusses related work, followed by a subsection presenting the creation of the 360° model. Section 2 presents the results, which are discussed in Section 3. In Section 4, material and methods are outlined, especially the study design as well as the participants of the study. Conclusions in Section 5 end the article.

1.1. Related Work

360° artifacts, also called "360VR", have been investigated as learning tools since some years. In the following, aspects of the use of educational 360° artifacts are summarized:

1.1.1. Technical Variants

There are different types of 360° artifacts used for learning purposes. 360° images are single 360° shots that can be explored by the learner. 360° videos can be created without [20] or with camera movement [21]. Both images and videos may be assembled into 360° models using software [22]. Scanners may be utilized to generate 360° spatial models for exploration [23]. Additionally, 360° images or 360° videos may be assembled in an application that does not illustrate a single model but represents a journey between different locations [24]. 3D models generated by scanners [24] or photogrammetry [25], for example, in addition to straight 3D modeling, and aerial photography are also suitable for complementing a 360°-based application [26].

1.1.2. Immersive and Non-Immersive Usage

360° artifacts may be viewed with head-mounted displays (HMDs), among other devices. HMDs allow the 360° artifacts to be explored visually isolated from the environment, and head movements are used to control the section displayed. A higher level of observer immersion is achieved than with personal computer-provided 360° artifacts. In the former case, one speaks of immersive usage [27], in the latter case of non-immersive usage [22]. Immersive usage is said to have a positive effect on learning success, but this effect may be reduced by other factors [28].

1.1.3. Fields of Application

Educational 360° artifacts have a wide range of applications. Izard et al. [29] use 360° images and 360° videos to represent an operating room to provide students with a gradual introduction to surgical practices, some of which may seem shocking at first. The possibility of live streaming is mentioned as a prospect, which should also enable remote surgeries. For training emergency situations in the medical field, Herault et al. [30] describe the use of 360° videos. It is concluded that 360° videos provide students with new interaction opportunities and serve as a complement to traditional teaching. An application for training of work safety on construction sites is presented by Pham et al. [31]: in addition to 360° artefacts, 3D models are integrated as well. Generic use cases of 360° videos in university teaching are described by Feurstein [32]. One particular application is teacher training, in which rehearsal sessions are recorded and both the subject and the audience may be observed in the subsequent analysis [20]. From the field of craftsmanship training, Funk et al. [33] present interactive 360° videos as a training environment for aspiring tile setters. Furthermore, a VFT across a residential area with the learning goal of technical infrastructure planning has been investigated [22]. The positive reception by the students, who would not have visited the residential area without this VFT due to the long distance, is noteworthy. Featuring a demonstration toilet, VFTs to small buildings have been investigated as well [34]: again, positive results emerge regarding emotion and motivation of the students. Argyriou et al. [24] describe an application in cultural heritage education using 360° videos combined with 3D models generated by laser scanners. The application, which is experienced immersively using simple Google Cardboard technology, integrates interactive elements, game mechanics, and mini maps, thus, it represents the development potential of educational 360° artifacts.

1.1.4. Instructional Design and Learning Outcomes

360° artifacts represent media whose successful use in learning contexts depends on consideration of instructional design principles for immersive media, e.g., [35,36]. For example, Petersen et al. [27] investigate an immersive VFT based on a non-interactive 360° video in a climate change learning activity. They find a "positive effect on students' declarative knowledge, self-efficacy, interest, STEM intentions, outcome expectations and intentions to change behavior." Petersen et al. point to the need for prior briefing lowering the cognitive load. An evaluation of the application to increase job safety on construction sites by Pham et al. [31] found significantly higher learning success for the 360°-based application compared to a FT to the construction site. In the field of medicine, an application scenario teaches knot tying skills for surgical operations [37]. Immersive 360° videos are compared to 2D videos, Yoganathan et al. conclude that experiencing 360° videos using smartphone VR headsets, both with and without teacher supervision, leads to better learning outcomes than watching 2D videos.

1.2. Creation of the 360° Model of the Waterworks

As a starting point for a VFT on waterworks, it was necessary to create a 360° model of the waterworks. The creation of the model was based on a step-by-step procedure that mainly followed the phases described by Wohl [38].

1.2.1. Selection of the Object

The waterworks chosen is to be made available as a training waterworks for apprentices to become specialists in water supply technology, an officially approved apprenticeship in Germany. However, a FT to the waterworks involves considerable effort: A coach needs to be chartered for the travel, an employee of the waterworks operator needs to be on site and guide the group of apprentices through the waterworks. There is also the risk of misconduct on-site by apprentices. For these reasons, a 360° model of the waterworks was created that could be used for VFTs without the aforementioned restrictions.

1.2.2. Didactic Concept

In a waterworks, a process of water engineering consisting of multiple steps is carried out transforming ("treating") raw water into drinking water. The didactic concept requires the determination of the target group initially. In this study, the target groups were the above-mentioned apprentices for water supply technology and students of the bachelor's degree study programs in urban studies and environmental engineering. Furthermore, the didactic concept for the 360° model of a waterworks needs to define, which process steps are to be shown, which technical components are to be demonstrated in more detail and which information on the components is to be integrated into the model. Additionally, the form of the information annotated is to be defined, for example text, pictures, graphics, or videos. This information was defined for both target groups. The 360° model considered further in this article refers to the target group of students in bachelor's degree study programs. The didactic concept was created in a workshop together with a lecturer with an effort of two person days. Afterwards, it was checked by an employee of the waterworks operator for the exclusion of security-relevant recording details, which should not be visible in the publicly accessible 360° model.

1.2.3. Recording Concept

Based on the didactic concept, a recording concept is developed, which, after selecting the recording device determines at which points of the object recordings have to be made. Aspects to be considered include, among others described in [39–41], also the maximum distance between two recording points and especially the definition of the transitions between the different parts of the object, these are in the waterworks, for example, the transitions between the individual floors as well as technical details to be covered, if necessary. The recording concept was created by an expert for audiovisual media with an effort of one person day.

1.2.4. Image Recording

For the recording itself, an on-site visit to the waterworks was required. For the few outdoor shots, for example, attention had to be paid to the weather. The audiovisual expert was accompanied by an employee of the waterworks operator and worked through the recording positions. The recordings at a total of 78 recording points, on average 25 in each level as well as some outdoor recordings, were carried out within two working days. The Insta360 One X consumer camera was used for recording. The waterworks operator's employee was also helpful in identifying details to be excluded in the imaging process, which were mentioned in the recording concept.

1.2.5. Post-Processing

The post-processing of the images was carried out by the content management system itself, the commercial software platform Matterport [19] has been used. The platform automatically handled the stitching of the various images, i.e., the creation of the 360° model from the 360° images. A total of 74 annotations (text, graphics, images, and videos) defined in the didactic concept were added. The model is accessible at https://my.matterport.com/show/?m=q7aL5aMud1a, accessed on 25 August 2021. The implementation required three person days of a student assistant.

1.2.6. Validation

The 360° model (Figure 1 shows a screenshot) was first validated by the study lead for completeness of content, by an employee of the waterworks operator for exclusion of security-relevant details, and then for learning appropriateness within the study described here.

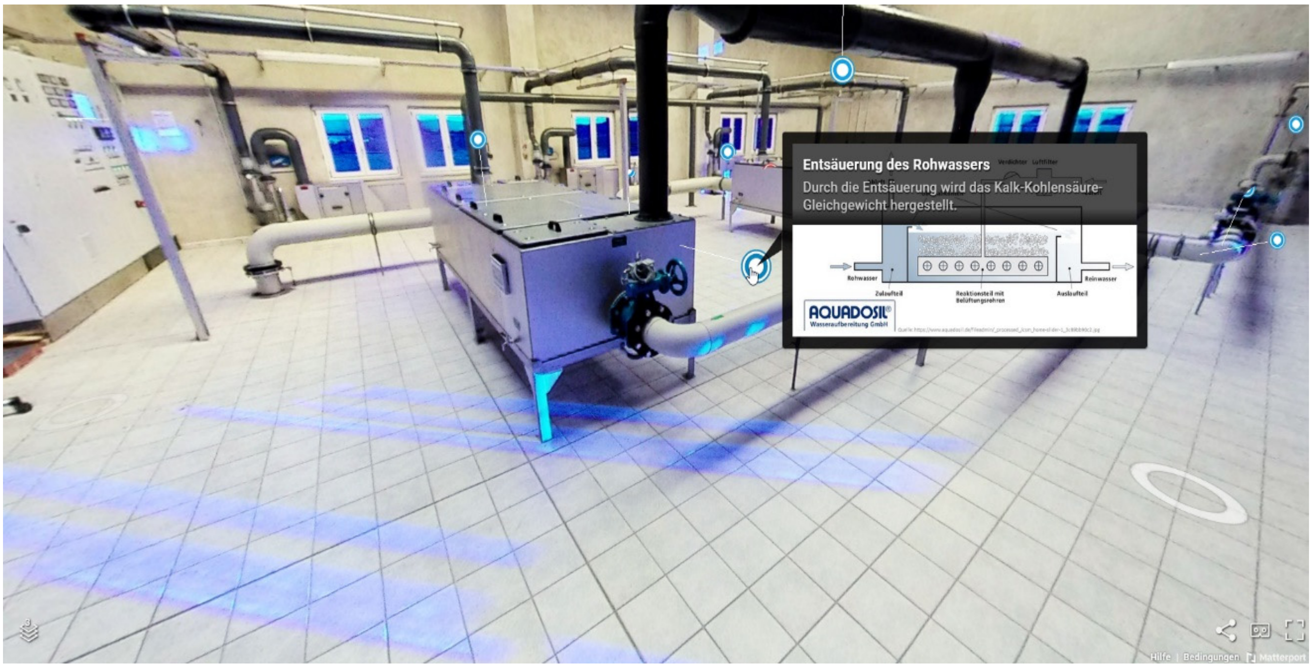

Figure 1. 360° model of the waterworks: view of the upper floor with deacidification devices and annotation.

2. Results

In addition to the results of all participants, the comparison between the two majors is particularly interesting. Students of environmental engineering are in their professional work involved in the planning and operation of water treatment processes. In contrast, students of urban studies must integrate water supply into urban planning and are therefore more interested in general information, such as capacity and operational requirements of a waterworks. Furthermore, attention is paid to the differences between male and female students. Before the differences regarding study program and gender of the participants were tested, all variables were examined for normal distribution using the Shapiro–Wilk test. It showed, that only two of the variables are normally distributed. Accordingly, Mann–Whitney tests were conducted for the results for motivation and emotion according to these groupings. The following three measures for motivation, emotion, and usability were each part of the questionnaire and were collected following the VFT.

2.1. Motivation

Student motivation was measured using the *Questionnaire for Current Motivation* (QCM) [42]. The QCM consists of four subscales (*Interest*, *Challenge*, *Probability of Success*, and *Anxiety*), composed of a total of 18 items. The subscales show questionable to good reliabilities (Interest: Cronbach's $\alpha = 0.768$; Challenge: $\alpha = 0.618$; Probability of Success: $\alpha = 0.716$; Anxiety of Failure: $\alpha = 0.811$). Since the subscales only consist of four to five items and this study was conducted with a relatively small sample size, which both can lower the values of Cronbach's α [43], all sub-scales were included in the analysis. It is found that students report a high *Probability of Success* regarding completing the VFT. The reported *Anxiety*, on the other hand, is at a low level (Figure 2).

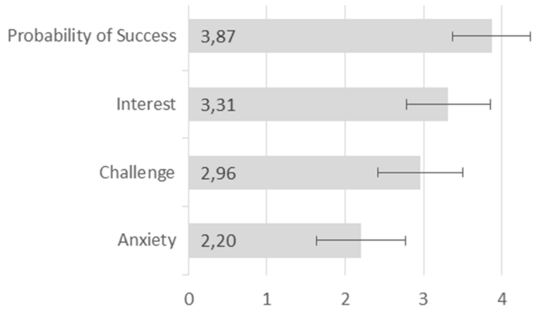

Figure 2. QCM: Subscales (five-point Likert scale, $n = 55$).

Comparing the values of the four subscales with regard to the study programs, it becomes clear that the m proximity to the topic is also reflected in the interest for the VFT: The *Interest* of environmental engineering students (Mdn = 4.20) is significantly higher than that of urban studies students (Mdn = 3.00; U = 98.50, z = −4.42, $p < 0.001$). However, no significant differences were found with respect to the other three subscales.

Another pattern shows for the effects shown in a comparison between female and male students. Here, no significant differences in *Interest* reported as well as *Anxiety* reported could be found. With regard to the subscale *Probability of Success*, significantly lower values were found for female students (Mdn = 3.75) than for male students (Mdn = 4.00; U = 497.50, z = 2.05, $p = 0.041$). Along with this, female students (Mdn = 3.38) feel significantly more *Challenge* than male students (Mdn=2.75; U = 209.00, z = −2.853, $p = 0.004$).

2.2. Emotion

To measure participants' emotion, the *Achievement Emotions Questionnaire* (AEQ) [44] was administered. The AEQ measures the emotions of joy, hope, pride, anger, fear, shame, hopelessness, and boredom. The actual questionnaire includes more than 100 items. To reduce this to an operable set of items, the eight items of the learning-related emotions of the sample questionnaire given by Pekrun et al. [44] were included in the questionnaire of the study.

The results show that especially the emotions with positive connotations reached high scores (≥3.8) among the students (Figure 3). Emotions with negative connotations were rated lower overall (≤2.4). Looking at the individual emotions in relation to their respective majors, urban studies students reported significantly higher scores for boredom (Mdn = 3.00) than environmental engineering students (Mdn = 1.00; U = 508.50, z = 3.01, $p = 0.003$). No significant differences were found regarding the other emotions. No significant effects were found regarding the gender of the participants in the study.

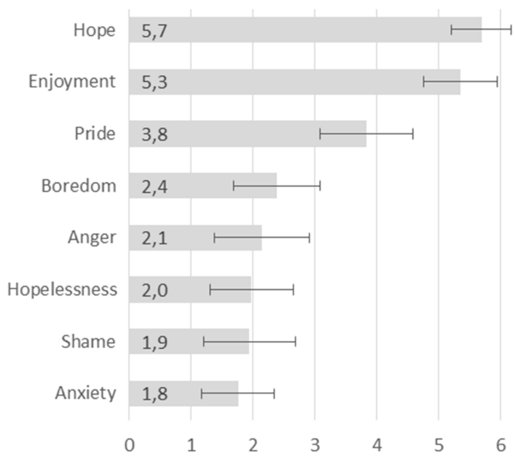

Figure 3. AEQ: Subscales (seven-point Likert scale, $n = 55$).

The Questionnaire User Experience (QUX) [45] was used to survey usability (see also next section). This questionnaire aims to measure user experience and contains, amongst other, three items for measuring emotion (Figure 4). The three emotions measured received values slightly above the average, while the highest value was achieved by the motivation *motivated*. This may be seen as a further indication of the strongly motivated participants.

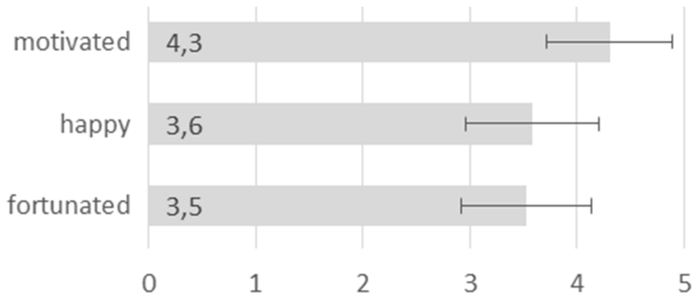

Figure 4. QUX values (six-point Likert scale, n = 55).

2.3. Usability

To determine the extent to which students feel comfortable using the 360° model, usability was assessed using the Questionnaire User Experience (QUX) [45]. In addition to the emotions already described in the previous section, the QUX includes the survey of non-functional characteristics, functional characteristics, and an overall assessment. Since the goal of the usability measurement was to evaluate the usability of the 360° model, regardless of learner prerequisites, no inferential statistical analysis was performed for this measurement.

The evaluation of the non-functional characteristics of the digital tool is done in polarity profiles. For all polarity profile items (*boring—thrilling*, *unattractive—attractive*, *inferior—valuable*, *ordinary—professional*, *inconvenient—convenient*, *drowsy—activating*, *uninspired—creative*, *uninteresting—interesting*, *creates a negative image—creates a positive image*, *unappealing—appealing*, and *unaesthetic—aesthetic*), there were comparatively uniform and high average values between 7.0 and 8.0 on a scale of 1 to 10 points. The lowest average value was found for the item *inconvenient—convenient* with 7.0 (2.08), while the highest value of 8.0 (SD: 1.43) was found for the item *uninspired—creative*.

The functional characteristics (Figure 5) also had consistently high scores. The operation of the 360-degree model can be learned easily. Lower values, but still above the middle of the possible rating, are found for the clarity of the software ("The information I am looking for is easy to retrieve", "The layout is very clear", "I quickly reach my goal").

The overall rating regarding the usability of the 360° model also tends to be positive: The statements "I would recommend the software to others" receives an agreement of 4.7 (1.21) on a six-point Likert scale, followed by "I would use the software again" (4.5, SD = 1.41), "The software appeals to me" (4.4, SD = 1.20), and "I find the software as beautiful" (4.1, SD = 1.22). In summary, the results do not indicate any major difficulties in using the 360° model.

2.4. Learning

2.4.1. Self-Assessment

The questionnaire asked participants for a self-assessment of their knowledge of waterworks before and after the VFT. Knowledge before the VFT was rated 3.33 (SD = 1.846) on a 10-point Likert scale from *1: nothing* to *10: expert*, and knowledge following the VFT was rated 7.45 (SD = 1.358). Pairwise t-Tests revealed significant effects for the entire cohort as well as in the respective subgroups for gender (female, male) and study program (environmental engineering, urban studies) in each case (Table 1).

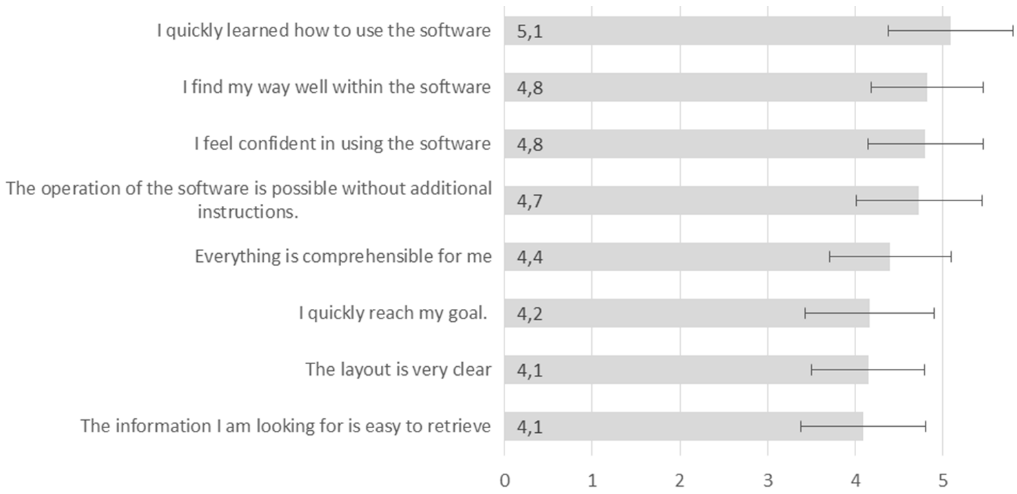

Figure 5. QUX: Functional characteristics (six-point Likert scale, $n = 55$).

Table 1. Self-assessment of knowledge: pretest, posttest, and *t*-Tests.

Subgroup	Pretest M (SD)	Posttest M (SD)	Paired *t*-Test
All	3.33 (1.846)	7.45 (1.358)	t(54) = −17.046, $p < 0.001$
Female	3.00 (1.356)	7.38 (1.299)	t(25) = −15.785, $p < 0.001$
Male	3.62 (2.178)	7.52 (1.430)	t(28) = −10.107, $p < 0.001$
Environmental Engineering	4.05 (1.802)	7.95 (1.146)	t(19) = −12.706, $p < 0.001$
Urban Studies	2.91 (1.755)	7.17 (1.403)	t(34) = −12.561, $p < 0.001$

Self-assessment of pre-VFT knowledge is significantly greater for environmental engineering students than for urban studies students (t(53) = 2.278, $p = 0.027$). This difference was also found for post-VFT knowledge (t(53) = 2.109, $p = 0.040$). No significant differences were found between male and female students.

2.4.2. Pre- and Posttest

In the pretest, the 29 participants who completed the test achieved an average of 79% (SD = 16.7%) of the points, taking an average of 5:52 min (range 1:02 min to 27:07 min). The posttest was completed by 62 participants with a mean of 92% (SD = 11.6%) of the points in an average of 4:55 min (range 0:37 min to 27:43 min).

Considering the 27 participants who completed both pretest and posttest, similar figures emerge: 80% (SD = 15%) of the points were achieved in the pretest and 94% (SD = 11.9) in the posttest. Only the time in which the tests were completed differed more clearly: the pretest took an average of 6:05 min, whereas the posttest was completed after an average of 3:58 min.

2.5. Qualitative Results

The questionnaire of the cohorts 2–4 included an open question for further comments on the use of the 360° model in the context of the VFT, which were also answered by a total of 33 participants. A qualitative content analysis [46] of the responses was conducted by two experts. In the event of discrepancies in the assessments, consensus was reached by discussion between the two experts in each case. Furthermore, a semi-structured interview was conducted with each of the eight participants of the first cohort by one of the two experts mentioned above asking guiding questions on general assessment of the VFT, on learning, and on operating the 360° model itself. Although the experts felt that the answers to the open-ended questions appeared to be blunter, the interviews allowed asking follow-up questions. The interviews were journaled by written key words. The results were also reviewed in a qualitative content analysis by the two experts. A comparison of the two content analyses showed that the two sets of results overlapped to a large extent. Therefore, the results of both sources were subsequently combined. Finally, the following four categories were identified:

2.5.1. Overall Rating

Whenever an overall rating was expressed in the qualitative feedback, it was exclusively positive; a total of 13 times a positive overall impression was mentioned ("In general, however, it was fun and is a nice alternative to studying!", P29). The VFT was described as an alternative to FTs (n = 5). The overview provided by the VFT was praised (n = 2) as well as the good supplementation of the lecture by the VFT (n = 4). The possibility of preparing and supplementing a FT with the help of the VFT was also pointed out (n = 5). Further mentioned was the consistently satisfactory quality of the information conveyed compared to a guided FT, as well as the possibility of being able to attend the VFT several times, regardless of time and place ("You have more time, you get everything, you can look at it as long and often as you want.", P11). The VFT allows for self-directed learning, such as the unrestricted roaming within the model reported by one participant retrieving specific information. One participant also reported taking notes during the VFT. Two participants said that the content was more tangible and understandable in the model than in a written description ("A nice new form of learning away from the theoretical lectures, the components and processes of the waterworks became more tangible for me this way.", P7; "But in conclusion, a 3D model helps to explain the process much better than a mere diagram. Also moving around the room makes you feel how large certain parts are and how large overall the waterworks is.", P31). A total of five participants explicitly mentioned that the model supported learning. ("So, during the visit I mentally went through the flowchart from the lecture. [...] In the tour, I also kept jumping back and forth to look up certain things", P8). However, it was also stated by five participants that existing knowledge was strengthened rather than new knowledge was acquired. Once the VFT was described as a sufficient learning experience, once also the excellent utilization of the technology potential in the context of the COVID-19 pandemic was stated.

2.5.2. Positive Aspects

The positive aspects include the designation of the VFT as diversification in the daily learning routine (n = 5). The free movement allowed in the 360° model was also praised (n = 3) ("It is pleasant to be able to move freely through the building. However, it is then necessary to figure out for oneself the linear flow of the water treatment.", P5) as well as the additional media, such as videos, texts and graphics (n = 3). The appropriate information (n = 4) was also complimented, for example the included information about the history of the waterworks. However, this aspect seems to be very subjective, so there were also comments that called the information too little as well as too much. Furthermore, positively commented was the good combination of visual impressions and schematic drawings (n = 2). The ease of use was also noted positively four times. The assessments are likewise not uniform with regard to the handling of the 360° model, which was also mentioned in the category of problems.

2.5.3. Problems

The most frequent problem mentioned was the need for a guided tour of the 360° model or further aids to orientation, as the students had to find their way through the 360° model themselves (n = 10). Three times, the 360° model and the annotations were also described as confusing. However, the flow of water through the waterworks was mentioned as an orientation aid. Nine mentions criticized the domain-specific information available as insufficient, and once the information was described as excessive. Five times the technical navigation in the 360° model was mentioned as challenging. Three times it was noted that, compared to a guided FT, no questions could be asked and thus the interactivity was limited.

2.5.4. Suggested Improvements

The most extensive category constituted the improvements suggested. To solve the problem of orientation, the numbering of the points of interest to be visited was frequently suggested (n = 7), alternatively, the coloring of points of interest already visited was also proposed (n = 1). In total, the optional feature of a guided tour was mentioned four times ("I would have liked to have a kind of automatic tour in the form of numbered points of interest as a supplementary feature. In addition, a schematic map would have been helpful, which, would have simplified 3-dimensionally and clearly illustrated the water flow of the waterworks.", P49). For the multimedia content of the 360° model, further graphics with 2D overviews including room layout (n = 3) were also mentioned as explanatory videos (n = 3), as well as background music (n = 1). Providing an offline version was also named once as a remedy for a poor internet connection. Another suggestion was the integration of a narrative covering the entire tour. Additionally missed was a technical instruction manual for the 360° model (n = 1) and a step-by-step guide for the visitor of all VFT points of interest (n = 1). Other suggestions included establishing multidisciplinary 360° models (n = 1) and a library of 360° models (n = 3). Specific to this three-story waterworks, the possibility of choosing floors (n = 1) was suggested, as well as doing the VTF collaboratively in a group (n = 1).

3. Discussion

The 360° model was deployed in four cohorts for use in a VFT; only cohorts 1 and 4 represented a repeat of the course after one year. Thus, three distinct contexts of use resulted, differing by intended degree (master's degree or bachelor's degree) and by discipline (environmental engineering or urban studies). In all three contexts of use, the VFT was evaluated positively: the qualitative surveys characterized the VFT as an innovative learning activity, which was reflected in the quantitative measures. The VFT is performed with comparatively positive emotions and motivations conducive to learning by students (RQ2). Both self-reported learning measures, as well as pre- and post-test, indicate that the VFT is supportive of learning (RQ3). Usability is consistently rated as good, although the qualitative results still suggest potential for enhancement. Basically, 360°-model based VFTs are a promising learning tool that is suitable for supplementing teaching with virtual on-site experience. Thereby, both replacing existing FTs during a pandemic with a few trade-offs as well as enhancing learning experiences by means of a set of VFTs—e.g., provided by a library of 360° models—is conceivable to improve the quality of teaching (RQ1).

From the perspective of learner prerequisites (RQ4), the group of participants—which was heterogeneous due to multiple cohorts from different majors and degrees—was unable to identify any dedicated learner prerequisites that were particularly conducive or detrimental to the VFT. The heterogeneity of the group was evident, e.g., in comparably high standard deviations of self-reported prior knowledge. Gender-specific effects could be demonstrated, confirming findings already reported in the literature [47]. Significantly varying scores for emotions were also detected regarding the course of study, but these did not result in significant effects on the self-reported learning outcomes.

As the qualitative analyses have shown, there is further potential for extending 360° models as foundation for VFTs (RQ5):

- **Increasing Interactivity:** One conceivable option of advancing the 360° model is coupling it with simulations that are controlled via interactive operating elements in the 360° model. Chatbots might also be used, for example, to interview virtual persons.
- **Collaboration**: In this study, the participants each entered the 360° model individually and in part experienced problems with orientation and navigation. One option to improve learning success would be the use of collaborative learning scenarios, i.e.,

walking through the 360° model takes place in a group. The generally identified potential of collaboration in learning scenarios [48–50] has also already been leveraged, specifically for VFTs with the help of 360° models [22].

- **Guided Tour:** Many of the participants felt overwhelmed in free exploration of a 360° model and suggested offering a mode of a guided tour through the 360° model. The mode of free exploration, as explored in the study, should continue as an alternative. The mode of a guided tour is to be advocated from the point of view of the theory of multimedia learning. For example, the segmentation principle [51] suggests a gradual introduction of learning content. It also lends itself to comparison with pedagogical agents [52]. Virtual escape rooms [53,54] are a variant of setting goals and thus providing guidance, which may simultaneously increase motivation of the students.
- **Visual Guidance:** 360° models are deemed to not be ideal for learning processes due to their diversity of detail; for example, 360° models contradict the fish tank principle [55], which is considered to be conducive to learning. A possible remedy is directing attention through visual cues [56].

Limitations of the study result from the single point in time of the survey, which was after the completion of the VFT. For example, the recommended use of the QCM instrument [42] calls for use immediately before or during the learning activity. Therefore, participants were asked to hypothetically imagine re-executing the learning activity for assessment purposes. It is reasonable to assume mild differences in scores measure compared to use consistent with the recommendation; for example, the subscale *Probability of Success* scores are likely to be modestly elevated after the learning activity has already been successfully performed once. Overall, however, it should be assumed that no substantial distortions have arisen because of the survey's point of time.

For further use of VFTs, additional didactic scenarios might to be defined. In this study, students were given the task of exploring the 360° model with the aim of successfully passing a subsequent test. Additional didactic measures are considered, such as forming groups, keeping protocols, or accomplishing predefined tasks. Proven recommendations on VFTs without 360° models [6] should also be taken into account when developing didactic scenarios. It is also necessary to assess to what extent specific scenarios, as well as specific annotations added to the 360° model, support different target groups. Such a necessity is suggested by the significant effects on students of different majors with respect to emotion and motivation that have been measured.

4. Materials and Methods

4.1. Study Design

After completion of the 360° model, the study was conducted as an exploratory field study. The students were instructed to take part in the study at a time of their choice during a period of one week following the lectures on water treatment. As a prerequisite for operating the 360° model, students were required to use either a personal computer or a tablet. The first step was a pretest, which consisted of five questions selected from a pool of 15 questions about water treatment. The second step comprised the exploration of the 360° model of the waterworks limited to 60 minutes. The aim of the exploration was familiarization with the details of the waterworks to achieve the best possible result in the third step, the posttest, in which again five randomly selected questions from the pool already utilized in the first step had to be answered. The final step was completing a questionnaire consisting of validated measurements of motivation [42], emotions [44], and usability [45], as well as containing some additional items, including perceived knowledge about waterworks. All participants were informed about the study nature of the learning activity and gave their written consent to participate in the study. Participation in the study was voluntary. The questionnaire was completed anonymously, and demographic information could only be gathered from the responses to the questionnaire. Therefore, there is no attribution of questionnaire data to the results of the pre- and posttest.

4.2. Participants

4.2.1. Sampling

Courses, in which water treatment was a learning objective, were selected for participation in the study. Students were approached partly through messages via the learning management system of the university and partly by short presentations in lectures of the respective courses. Table 2 shows the cohorts taking part in the study.

Table 2. Cohorts.

No.	Degree	Major	Course	Term	Size
1	Master	Environmental Engineering	Drinking Water Treatment	Summer 2020	8
2	Bachelor	Urbanism	Urban Engineering: Water	Winter 2020	35
3	Bachelor	Environmental Engineering	Urban Water Management	Winter 2020	4
4	Master	Environmental Engineering	Drinking Water Treatment	Summer 2021	8

4.2.2. Demography

A total of 55 students participated in the study. Gender: 53% (29) of the students identified as male, 47% (26) as female. Major: 36% (20) of the participants studied environmental engineering and 64% (35) in urban studies. There were 71% (39) bachelor students and 29% (16) master students. Age: 44 % (24) students indicated the age of 22/23 years, 29% (16) 20/21 years, 16% (9) 24/25 years, 4% (2) 26/27 years, and 7% (4) were older than 27 years.

5. Conclusions

Virtual field trips (VFTs) using 360° models offer the possibility of realizing field trips (FTs) in a standardized way, independent of time and place, also in the context of self-directed learning. Due to technological progress in recent years, the creation of 360° models is meanwhile achievable with rather little effort. VFTs also require little time and resources on the part of lecturers, and they also place rather low technical and organizational demands on the learners. VFTs can therefore be developed and applied at low barriers, i.e., on the initiative of single lecturers. The present study investigated such a VFT on a waterworks using a 360° model as a learning activity in higher education. The quantitative results showed positive values for motivation and emotion of the students. The usability of the 360° model was also rated as proficient. The learning outcomes determined by self-assessment and pre- and posttest indicate the learning effectiveness of the VFT. Overall, a 360°-model-supported VFT has to be seen as a promising learning activity, which on the one hand can replace FTs to a large extent during a pandemic such as COVID-19; and on the other hand, in the form of a library of 360° models, support self-directed learning. Thus, 360° model-based VFTs may lead to a qualitative improvement of formal and informal education. Although the current VFT on a waterworks was positively received, the qualitative part of the study identified several options for further development of the VFT and its underlying 360° model. Implementing these options will contribute to establishing VFTs as a learning tool not only in higher education.

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