VRsurv: A virtual planning and educational tool for surveying tasks

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Key words: Virtual Reality, geodetic concept creation, gameful design

SUMMARY

Today's typical surveying tasks, like staking out or monitoring, take place in a dynamic and fully 3D environment with many dependencies on other objects. Obstructions and disturbances of the line of sights must be foreseen often at a very early stage of a project. Also, the high precision of modern surveying instruments requires a detailed evaluation of systematic effects to fulfil nowadays accuracy demands.

In order to compete with these requirements, the planning environment for modern geodetic network design needs to be in 3D and object orientated to cover the relations and dependencies between relevant object groups within the monitoring scenario. Moreover, it should be capable of processing meshed reality capture data sets and design models from architects to serve as a basis for feasibility studies of the concept.

Such a geodetic 3D planning tool is realized with the experimental software VRsurv at the Institute of Engineering Geodesy and Measurement Systems (IGMS) of Graz University of Technology. Fully operational virtual surveying equipment can be placed in an interactive 3D environment. Therefore, a modelled total station can turn and steer onto prisms and the line of sight is automatically checked for obstructions, optimal prism orientation or automatic aiming issues.

Technologies from the entertainment industry have been applied on geodetic task to perform quality checks in near real time. The software was developed in the coding environment Unity with the usage of Virtual Reality (VR) technology as a human computer interface. The VR gear should overcome the limitations of conventional 3D viewers in complex 3D scenarios and provide the user an immersive first person view on the data. The usage of VR is also beneficial for educational purposes in student courses.

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1. INTRODUCTION

Digitalization and innovation in surveying offices is an important process to keep up with the demands of nowadays building projects. A mayor goal of every surveyor is to reduce the time and cost intensive field work by optimizing the number and location of needed setup points for the geodetic instruments. This can be accomplished on the one hand by the usage of state-of-the-art surveying equipment as well as the execution of a sophisticated concept creation of the planned measurement campaign.

Especially in complex three-dimensional urban environments the measurement planning can be challenging. Due to high dynamic working environment of modern building sites many logistical aspects for instrument placement and operation are gaining more importance such as an obstacle free line of sight, the continuous power supply of permanent installations or the safety of the installation itself. However, conventional construction plans are often unable to represent the 3D scenario sufficiently and do not provide a reliable data source for planning purposes.

Therefore, an important part of the conventional network design are onsite inspections, to investigate the scenario live and in person in order to reveal all possible limitations and critical issues.

A problem of onsite visits is the observable state of the building process. If the current state of the building project does not represent the future monitoring scenario, it is nearly impossible for a geodetic expert to foresee interferes with the planned measurement design.

In this case it has to be relied on virtual datasets. Delivering the mounting points of geodetic instruments with the required level of detail and to make up all design decisions virtually is nearly impossible with state-of-the-art geodetic software solutions at such an early stage of the project.

The need for an adequate 3D working environment has also attracted more attention during the global Covid19 crisis when travel regulations have strictly limited onsite visits for more than two years now. Many experts had to adapt to virtual data sets that were provided by recent 3D laser scanning data, drone photogrammetry or result from Building Information Modelling (BIM) (Eastman et al. 2011) from the planning stage.

This publication introduces an interactive and object oriented 3D software for the concept creation of survey tasks. The user can import, interact and export complex datasets in an intuitive Virtual Reality (VR) environment. These VR devices use enclosed displays without a connection to the real surroundings to enable a first person view on arbitrary 3D models. Not only can the user switch between location and time through the data set, he also obtains similar impressions as he would capture on site.

A strong focus has been placed on the accurate simulation of systematic effects that can reduce the achievable measurement accuracy. The benefit of the software VRsurv is that the simulation of sensor effects is carried out on the bases of the loaded 3D environment. This enables a customized quality investigation for a specific simulated scenario. Therefore, the quality investigation for logistic problems as well as for accuracy investigations can take place on higher level of detail with the usage of fully functional virtual surveying equipment (fig 1).

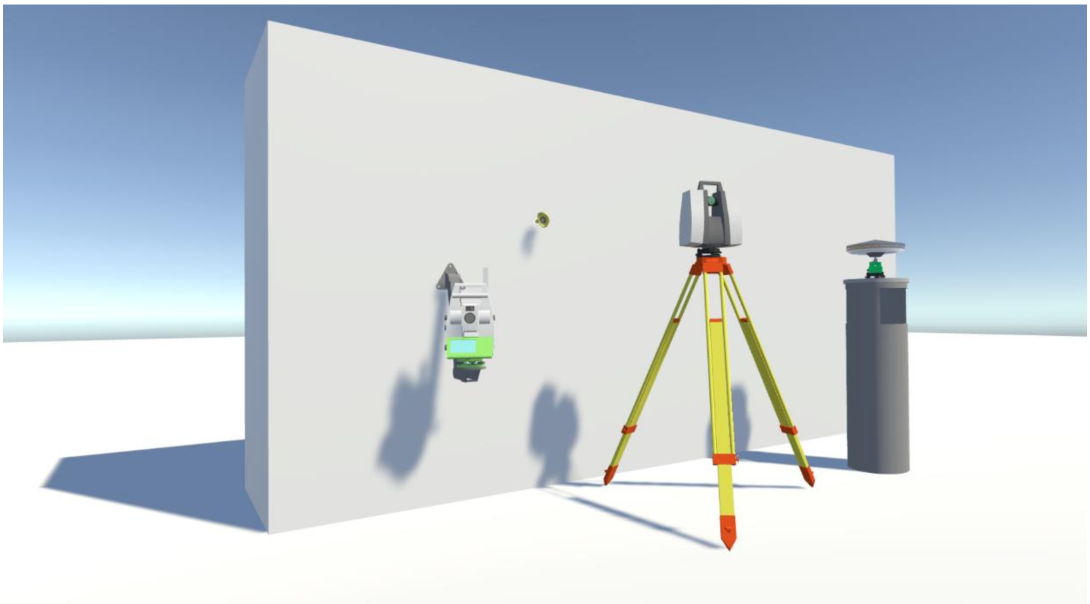

Figure 1 Virtual representations of modelled surveying equipment

2. GAMEFUL DESIGN OF TECHNICAL SOFTWARE SOLUTIONS

The entertainment sector has always been an early adopter for advances in computing and visualization techniques to provide new content to the audience. Gaming developers have found many approaches for adequate human computer interface because it has always been a central element for their success and selling factor as well. Therefore, decades of experience can be found in this industry in presenting and interacting with 3D datasets approved for an inhomogeneous audience with different backgrounds.

In state of the art videogames the level of detail of virtual urban environments has often reached a comparable state as their real counterparts. Also the data structure and modelling principles in many game productions follow similar principles as the digital twins of real building projects. Therefore, it is not surprising that software developing environments, which are originally designed for the production of video games, like Unity, the Unreal Engine or the CRYENGINE offer a suitable object oriented 3D coding environment. This is attractive for custom software solutions in technical applications far beyond the entertainment sector. It can already be seen in the emerging BIM methods that interdisciplinary will be a key feature for future data environments throughout all technical sectors.

The process of integrating game elements in a non-game context is summarized as Gamification by the definition given by Detering et al in 2011. This term has gained popularity in the last years and is often mentioned in the context of digitalisation. Due to the vague definition it covers many aspects of ”games” and is also often associated with the concept social skill and achievement systems to boost the motivation of the workforce and to increase productivity.

To distinguish between this negative social association and the beneficial adaption of software approaches for technical applications the more precise term gameful design (Detering 2015) is more adequate to describe the developed geodetic software presented in this paper.

3. VIRTUAL REALITY IN THE FIELD OF GEODESY

The first VR headsets have already been developed in the 1960s, however due to the state of available computers and graphic cards these devices have been only subject to a small user group. Beside their immanent attraction to researchers the VR devices mainly served as props in science fictions movies for a long time due their futuristic image. The industry received a real boost in the last decade when advances in home computing enabled manufacturers like HTC or Oculus to produce VR headsets for the mass market. (VirutalRealitySociety 2017)

Nevertheless, the usage of VR gear in geodesy is not well established until today and only few commercially available software products are supporting the technology. Although the technology is assumed as mature since leaving the Gartner hype cycle of emerging technologies in 2018 (XRtoday, 2021), the majority of geodetic VR approaches are still experimental concept studies and are missing real use cases.

At the beginning, it has been laser scanner distributers like Faro (Faro Scene) or Leica (Cyclone VR) who have quickly added VR viewers for visualization purposes to their software to keep up with the entertainment sector. However, most of these attempts were aimed for demonstration purposes at fairs and conferences and where soon put out of service again.

The benefits of VR applications arise from a real integration into existing workflows for data interaction and analysis. This has been clearly demonstrated in collaborative projects with archaeologists, crime scene investigators and first responders.

Motivated by their success also many geodetic departments have than started to experiment with VR applications for geodetic purposes, as seen in the data investigation and analysis for the Arctic Clyde (Lütjens et al 2019). Especially for complex underground scenarios with overlapping geometries VR driven investigations have revealed the limitations of conventional 3D viewers for mining and tunnelling applications (Traxler et al. 2019).

In analogy to the VR training simulations of first responders, geodetic departments also tried to digitalize the hardware and labour intensive training of surveying students. One of the first geodetic educational tools has been the software from Michigan Technological University (Levin et al. 2020) for the training of surveying students in civil engineering. The software simulated a field survey and points could be measured with a virtual surveying pole. The measured points were evaluated with regards to point spacing and distribution for the derivation of digital terrain models.

Today several educational VR field simulators are available, which place a huge emphasis on the simulation of proprietary instrument field software like the simulator of South instruments (South 2021). A similar project is also the VRscan3D (Popovas et al. 2021) application, which was originally aimed in teaching Ukrainian students laser scanner field software and producing realistic point clouds for demonstration purposes of post processing approaches

4. GEODETIC SIMULATION SOFTWARE VRsurv

4.1 Functionality of the software

The experimental software kit has been developed with the game engine Unity (2019.3.3f1) for the VR headset HTC Vive Pro. The main purpose of the software is the simulation of systematic effects for quality investigations of future surveying scenarios. Moreover, it should be an easy to use tool for the definition of mounting methods and setup points for geodetic instruments at an early stage of the building process. This should be accomplished with a high level of detail in 3D modelling and the implementation of the mechanical functionality for all objects.

At the beginning of the simulation the user must import an adequate representation of the intended monitoring scenario. For performance reasons the simulation requires a meshed as-built model from a reality capturing method or an exported conceptual model from a planning or BIM software in the common obj-format.

The user can select surveying equipment from a virtual product catalogue and place it directly into the 3D scene. For future 3D simulation software an exchangeable object format for surveying objects would be beneficial to extend the interoperability, as it exists in BIM processes with the Industry Foundation Classes (IFC) (buildingSmart 2022). However, the IFC format would only be partly applicable in this regard, as it only covers geometry, attributes and relations. The needed real time functionality of the objects had to be established with developed and attached C# routines for every object. During the object placement the legs of the tripod adjust themselves automatically to the ground or the total station is able to turn and steer at target points when selected.

This enables sophisticated collision controls between objects and the environment, obstructions in the line of sight and violations of designated safety areas and restricted mounting spaces. All line of sights in the network configuration are stored in a database and are evaluated according to implemented restrictions in near real time. The line of sight is colour-coded and the user gets instant visual feedback on the quality of the selection. This should raise awareness of possible accuracy issues in the current selection and motivate the user to readjust the measurement configuration.

Main implemented limitations for the totals station simulations are demonstrated in figure 2. The basic requirement of an obstacle free line of sight can be seen in figure 2a. With the principle of ray casts, collisions between each line of sight and the imported environment are computed and evaluated dynamically. In figure 2b the evaluation of incidence angles from several setup points can be seen. Laboratory investigations have shown that the reachable measurement accuracy directly correlates with the prism orientation (Lackner et al. 2016). On the basis of the surface normal of the environment and the network configuration the optimal prism orientation is computed during the placement. The user has to define the accuracy demands of the surveying task and the corresponding operation range for the prism types are set automatically. All line of sights that have critical incidence angles on prisms are indicated with red colour. Another critical issue can be seen in figure 2c, the disturbances of the automatic aiming process due to close proximity of target points. To investigate this effect, the virtual total station is equipped with an abstracted automatic aiming process. An emitted light cone is reflected by the prism object and a virtual camera evaluates the target configuration in the field of view of the instrument. If more than one prism appears in the narrow search cone the probability for malfunctions are increased and therefore the line of sight would be also indicated in red.

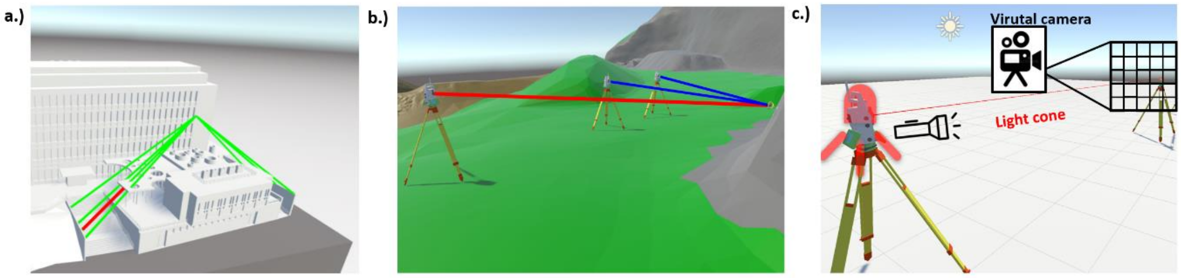

Figure 2 (a) Collision control (b) evaluation of incidence angles (c) virutal automatic aiming process

Most of the features of the software are optimized for the simulation of conventional surveys and permanent installations with total stations. To cover also the co-working with other instruments during a measurement campaign also basic GNSS and laser scanning simulations are implemented. However, due to the used software environment (Unity) the laser scanning capabilities are on a smaller extend compared to the VRscan3D project (Popovas et al. 2021), which bases on the UnrealEngine.

4.2 User interaction in 3D environments

The approaches for interaction within a VR application are predominantly object orientated. By selecting the objects through colliders or by user input their functionalities are activated. After the placement they automatically start to interact with other linked objects and vice versa. Beside the VR headset the user is also provided with two handheld controllers for interacting with objects. The user with the equipped VR gear can be seen in the upper left window in figure 3a. The left hand controller is equipped with a virtual laser pointer to steer at virtual objects or buttons (see figure 3c). By pressing the trigger on the controller, buttons and objects are activated, context menus are opened or additional object information can be accessed.
The product catalogue (3b) with buttons for each surveying device is attached to the right controller. After selecting an object from the catalogue the gear can be placed with the laser pointer (3c) directly into the scene. By selecting already placed objects with the laser pointer, a context menu (3d) for editing attributes or activating functionalities is opened.

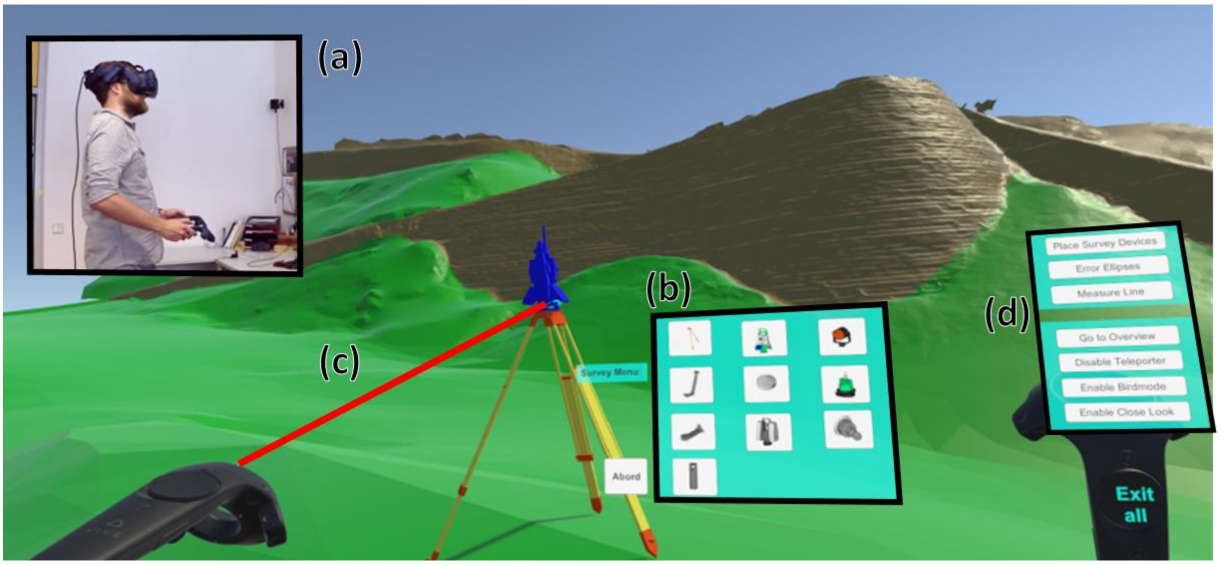

Figure 3 VR interaction: (a) User with gear (b) product catalogue (c) virutal laser pointer (d) context menu

The VR gear supports a real scale movement in the virtual scene, although the dimensions of the room are limiting the capabilities. To navigate the user’s point of view beyond these limits, three additional methods for navigating have been implemented. The user can move along the surface with the controllers, a teleporter can be enabled to jump to locations and the user can “fly” freely through the 3D environment (Danyluk et al. 2019).
Moving along the surface provides a very precise movement and the most realistic experience for users. However, only areas which would be also accessible for a pedestrian on the site can be accessed in the 3D model by this method. In this mode gravity is applied to all objects in the scene and the movement is controlled with the joysticks of the handheld controllers. This method is inspired by video games from the ego perspective.
Accessing areas which are out of reach can be done with the teleporter. By pointing with the laser pointer of the right hand controller at the scene, the user jumps to the desired location. This method is the most common approach in modern day VR simulations because teleporting reduces the causes of motion sickness dramatically (Chang et al. 2020), and has a positive effect on the long term usage. However, it limits the degree of freedom for player movement.
The most popular method is the “fly” mode in VR applications. To have a better overview on the scene the user can decide to disable gravity and fly freely through the model. Although this free mode is often required by the users, it has a rapid motion sickness effect on untrained personal and does not support long term usage.

4.3 Working principles of the software

The software VRsurv is a mixture between a VR software and a conventional desktop application, because the usability depends on a balanced combination of both approaches. For the integration of the software into existing workflows, options for import and export of data in open formats have been implemented. The user starts the application in a desktop loading menu, which is operated with mouse and keyboard. Here 3D models can be loaded in the obj-format to import a 3D environment or restricted areas. Also coordinates and polylines can be imported as ASCII lists, to highlight points and lines of interest or to automatically place a predefined set of prisms.

After the import of all required datasets the user can place the VR gear on the head and a preview of the loaded data is visualized in an overview mode. By pointing with the laser pointer on the preview the user jumps in VR from overview mode into the real scale first person mode and can start to place objects and to interact with the environment.

When an optimal setup is found and the quality checks fulfil the requirements, the user can switch back to the desktop and export the setup coordinates as an ASCII list again to pass them onto third party software or to a contractor. If the exported setup is altered by the third party software, it can be reimported into VRsurv for additional quality checks. This process can be iterative.

The workflow is described in more detail by the flowchart of figure 4. The red arrows are indicating all actions that are carried out automatically by the objects, whereas blue arrows indicate the manual actions carried out with the VR and the black arrows indicate all actions on the desktop with mouse and keyboard input.

The option of exporting ASCII coordinates with quality information is only a basic functionality and the object orientated coding environment supports also more complex implementations of logistic computations as it can be seen in emerging BIM processes in the constructions sector. VRsurv already computes accurate drilling locations for the mounting of surveying consoles, which can be exported along with the setup coordinates. A possible feature for future versions can be the export of detailed equipment lists and equipment costs by adding the required attributes to the objects.

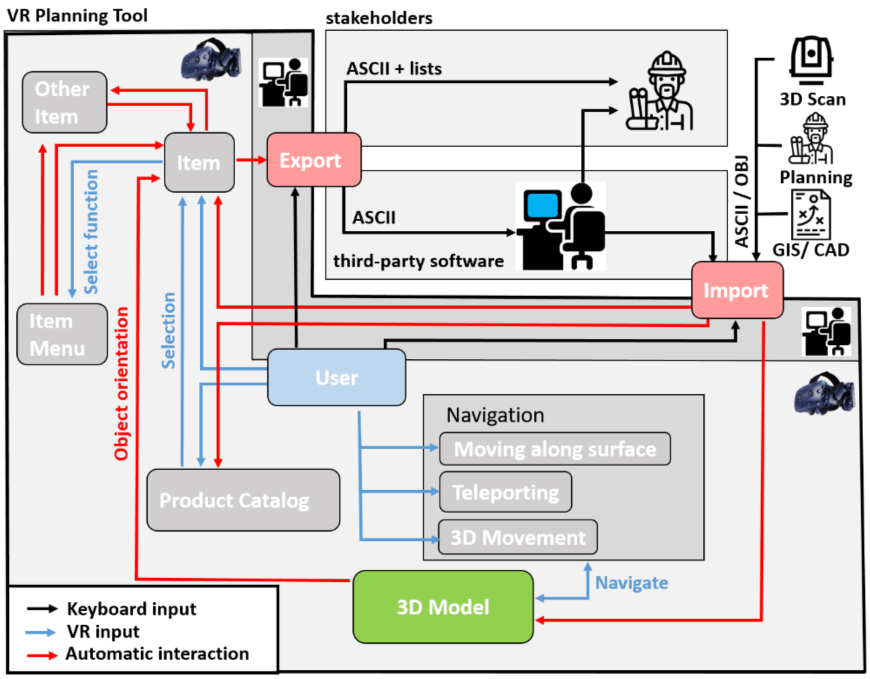

Figure 4 Flowchart of the VRsurv application

5. PLANNING OF A MEASURMENT CAMPAIGN FOR REMOTE TEMPLE COMPLEXES

The usability of the software for planning as well as for educational purposes can be demonstrated by the example of a recent project, the surveying of remote temple complexes. Due to the high number of relevant structures in this project and the limited access to the region the time needed for the capturing of the temples has to be optimized in advance. Also the accessibility in the temples themselves is limited and the survey should not interfere with the daily life of the monks.

In a prior campaign the sites have already been investigated by a team from the Institute of Architectural Theory, History of Art and Cultural Studies of Graz University of Technology (Auer et al. 2013) and they have constructed approximate virtual representations from these sites based on their sketches and ruler measurements (figure 5a). Although the models have a low geometrical accuracy, the complex topology of the temples with narrow corridors, small doors at multiple levels is represented very well.

With the Virtual Reality application these models will be the foundation for the detailed measurement planning of the highly accurate geodetic surveying campaign for the documentation of the real geometry of the buildings and the detailed paintings and sculptures. The setup points for the reference traverse can be planned in advance (figure 5b) as well as the placement and mounting possibilities of reference targets. Therefore, an approximate number of total stations setups and scan setups can be foreseen to predict the measurement time needed at each location.

The complexity of the temples is a challenging environment and does not occur in the everyday life of a surveyor. To discuss also such scenarios with students for educational purposes, which cannot be part of a standard survey training, the VR application can be used. Students can enter the VR simulation and try out surveying this scenario virtually. Afterwards the students can be introduced to the dataset from the actual field work to provide them with a ground truth. In the classroom differences between their planned measurement setups and the real measurements will be discussed, which adds an interactive part to the theoretical part teaching program.

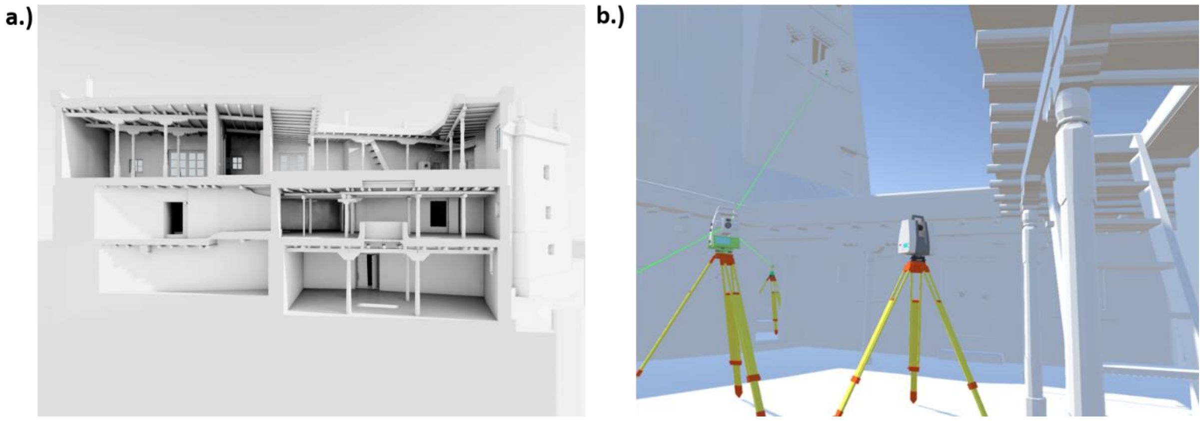

Figure 5 (a) virtual model from (Auer et al. 2013) and (b) placement of surveying equipment in the VR application

6. SUMMARY

Geodetic software solutions have to adapt to the complex 3D working environment of modern building projects. Also does the BIM process in the construction sector show the benefits of object orientated environments. The developed software VRsurv demonstrates how a modern working environment for the Surveyor 4.0 could look like.
The usage of VR gear supports the perception of a human user for 3D content with the first person view. Therefore, the human expert can rely on the knowledge and intuition in a comparable way as an onsite visit. Nevertheless, the software package is not aimed to outdate onsite inspections or practical teaching programs, it should be seen as an augmentation that can be used when conventional approaches reach their limits.
For the development of the software the game engine has been a valuable tool which supports the required flexibility with the coding interface for C# routines. Also the software has shown that Unity supports all frequently used geodetic datatypes and conventional workflows can easily be implemented. However, the implementation of a common exchange format for geodetic objects for further software developments will be a key issue. This will also be a topic for BIM process, when the project models will be used as asset models for maintenance purposes after the construction phase. The integration of structural health information will also require exchangeable 3D sensor entities.

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BIOGRAPHICAL NOTES

Peter Bauer graduated with an M.Sc. in Geomatics Science from Graz University of Technology (TUG) in 2018. He is currently working as an University Assistant at the Institute of Engineering Geodesy and Measurement Systems at TUG with his research focus on the design of geodetic monitoring installations and the integration of VR technology into geodetic workflows. In 2021 he has been awarded with the Heinrich Wild award for his research.

Prof. Werner Lienhart is the head of the Institute of Engineering Geodesy and Measurement Systems at TUG. His research focus is on development of new sensor technologies and evaluation strategies for the monitoring of infrastructures using contactless and embedded sensors. Before his work at the TUG he was product manager at Leica Geosystems in Switzerland and responsible for the development of new surveying instruments. Werner Lienhart is also president of the Austrian Geodetic Commission, vice president of the International Society for Structural Health Monitoring of Intelligent Infrastructure (ISHMII) and Chair Elect of the Commission 6: Engineering Surveys of the FIG.

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