SMARTPHONE-SUPPORTED MAPPING OF LANDFORMS A NEW TOOL IN TEACHING GEOMORPHOLOGY

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With 6 figures
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Summary: Understanding 3D properties of objects is an integral part of geomorphological teaching. This can best be achieved during field trips. However, there are numerous reasons why teaching outdoor might not be possible, either for a group of students or just individuals. 3D models of landforms, either static or interactive, are a great method to improve students learning success, e.g. in a blended learning environment. Preparation of 3D models of individual geomorphological landforms has been so far time-consuming. But since 2020, LiDAR sensors have been integrated into some new smartphones. These systems offer great potential for geomorphological teaching, as they enable simple and cost-effective recording of geomorphological landforms and objects in three dimensions. The smartphone LiDAR systems are suitable for the documentation and 3D reconstruction of objects in the range of several decimetres to metres. By means of three examples, the possible applications of smartphone-based LiDAR systems in the field of geomorphological teaching will be demonstrated. All in all, these smartphone LiDAR systems offer great potential, as they support the understanding of the three-dimensional structure of geomorphological landforms and objects in teaching in schools and universities and thus increase the success of teaching among pupils and students. Furthermore, 3D models make geomorphology more inclusive, e.g. for people not able to conduct field work. At the same time, in research, they offer new opportunities for scientific observation projects, e.g. through the continuous monitoring of geomorphological changes in the context of Citizen Science projects.

Zusammenfassung: Das Verständnis der dreidimensionalen Eigenschaften von Objekten ist ein wesentlicher Bestandteil der Lehre in der Geomorphologie. Dieses lässt sich am besten bei Exkursionen im Gelände erreichen. Es gibt allerdings zahlreiche Gründe, warum eine Lehrveranstaltung im Gelände nicht möglich ist, entweder für eine Gruppe von Lernenden oder auch nur für einzelne. Statische oder interaktive 3D-Modelle von geomorphologischen Formen sind eine hervorragende Möglichkeit, das Verständnis der Lernenden substantiell, z. B. in einer Blended-Learning-Umgebung, zu verbessern. Die Erstellung von 3D-Modellen einzelner geomorphologischer Formen war jedoch bisher sehr zeitaufwändig. Seit 2020 sind in einigen neuen Smartphones LiDAR-Sensoren eingebaut. Diese Systeme ermöglichen eine einfache und kostengünstige Erfassung von geomorphologischen Formen und Objekten in drei Dimensionen. Sie eignen sich für die Erfassung von Objekten im Bereich von mehreren Dezimetern bis Metern. Anhand von drei Beispielen werden die Einsatzmöglichkeiten von Smartphone-basierten LiDAR-Systemen im Bereich der geomorphologischen Lehre aufgezeigt. Insgesamt bieten diese Systeme ein großes Potential, da sie in der Lehre an Schulen und Universitäten das Verständnis der dreidimensionalen Struktur geomorphologischer Formen und Objekte unterstützen und somit den Lernerfolg bei Schülern und Studierenden erhöhen. Darüber hinaus bieten 3D-Modelle die Geomorphologie neue Möglichkeiten für Lernende, welche nicht in der Lage sind an Geländeexkursionen teilzunehmen. Gleichzeitig bieten sich in der Forschung neue Möglichkeiten für wissenschaftliche Untersuchungen, z.B. durch die kontinuierliche Beobachtung von geomorphologischen Veränderungen im Rahmen von Citizen Science Projekten.

Keywords: Geomorphology, teaching, 3D models, LiDAR, smartphones

1 Introduction

Geomorphological research and teaching thrives on the three-dimensional (3D) observation of objects. Only when all three dimensions are taken into account, is it possible to gain a deeper understanding of landform relationships and the underlying geomorphological processes. Therefore, field trips are an essential part of most geoscience curricula. In many cases, however, full 3D observation in the field is not possible, e.g. for reasons of time, logistics or due to the organisational effort. Furthermore, not all students are able to attend field trips, e.g. due to physical limitation (Cooke et al. 2018, Feig et al. 2019, Anadu et al. 2020, Giles et al. 2020). The COVID-19 pandemic has also exposed the importance to explain geomorphological forms digitally (Bond & Cawood, 2021). Usually, pictures, sketches or maps are used for this purpose. However, especially the interpretation of contour

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lines and the development of a three-dimensional idea of an object in the mind is a difficult task for the untrained (Bond & Cawood 2021, Krüger et al. 2022). Specifically, the estimation of dimension and the construction of a mental 3D model from 2D images is challenging for many students (Wu & Shah 2004, Chen et al. 2015). However, in physical geography, as in many other disciplines, visuospatial thinking is related to success and participation (Hegarty 2014). Studies have shown, that interactive 3D representations result in significantly better learning results (Carbonell Carrea et al. 2018, Carbonell Carrea & Bermejo Asensio 2017, Bond & Cawood 2021, Krüger et al. 2022). Thus, 3D models of landforms are used to improve the understanding of landform formation (Carbonell Carrea & Hess-Melder 2019). Especially interactive animations are beneficial to train spatial understanding (Cohen & Hegarty 2014) and are supported by a playful learning atmosphere (McGowan & Scarlett 2021). Due to these positive effects, 3D models are a useful component of a blended or active learning environment (Bond & Cawood 2021, Fryirs 2022). Additional teaching material, e.g. 3D models, become furthermore important as students are more diversely qualified, requiring new educational approaches (Day 2012). On the other hand, digital skills are an important requirement for many professions. However, these requirements are hardly meet by current geography educational curricula (Peter & Sprenger 2022).

In recent decades, three-dimensional representations of the Earth's surface in the form of digital elevation models (DEM) or digital surface models (DSM) have become increasingly common. A DEM basically represents the bare surface, while a DSM include objects like vegetation and buildings. Modern DEM/DSM are based on airborne LiDAR systems. LiDAR - Light Detection and Ranging - records the earth's surface by reflecting infrared laser beams and determining the time of flight (Maas 2005, Höfle & Rutzinger 2011). With a resolution of up to 1 m per image point, the DEM of the German state surveying offices are, as far as they are available free of charge, excellently suited for the representation of geomorphological landforms and landform groups on the landscape level. These include, for example, river terraces, maars, but also anthropogenic forms such as opencast pits or mining dumps. For smaller landforms in the range of several metres or even in the submetre range, such datasets are not useful. But it is precisely at this level that many important geomorphological processes take place. Here, the use of terrestrial laser scanning (TLS) is suitable for the creation of small-scale surface models. Further possibilities arise from the photogrammetric analysis of photographic images, e.g. from drones or ground photographs using structure from motion - multi-view stereo (SfM-MVS) approaches (James & Robson, 2014). With these methods, it is possible to create DSMs with a resolution down to the subcentimetre range. However, SfM-MVS calculations require relatively complex processing steps (James et al. 2019), while terrestrial LiDAR systems are expensive, with prices ranging from 15,000 to over 100,000 €

2 Smartphone LiDAR

Technical progress in the capabilities of smartphones has led to these devices increasingly supporting geographic research, e.g. through the implementation of accurate global navigation satellite systems (GNSS), high-resolution cameras or an accurate digital compass (Tavani et al. 2022). A LiDAR system is installed in some smartphones and tablets since the year 2020, which provides another possibility for creating 3D virtual models of geomorphological objects. Currently, such systems are installed in the mobile phones IPhone 12Pro and 13Pro as well as in the IPad Pro 2020. For a brief technical description of the sensor, please refer to Luetzenburg et al. (2021) and Tavani et al. (2022). Initial scientific studies have shown possible applications in the field of forest inventory (Gollob et al. 2021, Mokroš et al. 2021) and in the documentation of coastal cliffs (Luetzenburg et al. 2021, Luetzenburg 2022). In contrast to the classic TLS with ranges of up to several hundred metres, however, the distance measurement only extends to a maximum of 5 m. Our own tests and other studies (e.g. Tavani et al. 2022) indicate an optimal measuring distance of maximum 2 m. However, these 'simple' LiDAR systems are also excellently suited for use in teaching or the documentation of objects. They can be used to record geomorphological forms three-dimensionally and prepare them for teaching in different ways. Furthermore, they offer students and pupils the opportunity to deal intensively with the landforms during practical recording in the field. At the same time the data can be processed directly in the field and viewed in a virtual 3D environment (see Fig. 1), thus, substantially differing in use from the

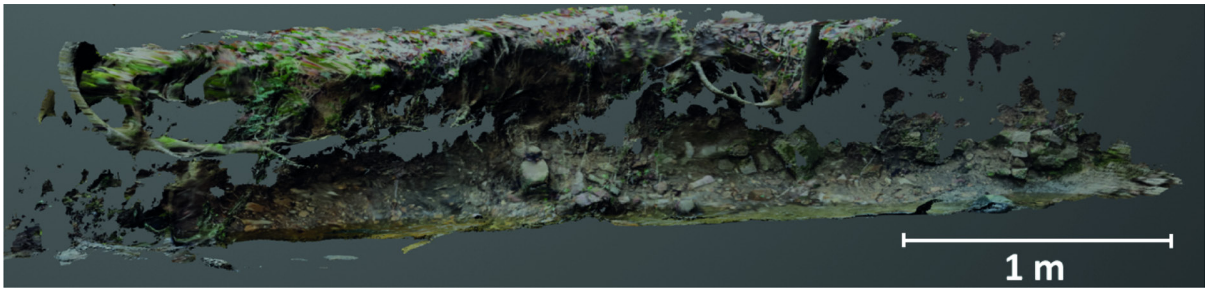

Fig 1: Cut bank with missing data in the 3D model due to small roots and leaves

classic TLS. The processing time rarely exceeds 5 minutes even for models with a size of more than 1,500 m², which was the upper storage limit for the used IPad Pro 2020.

There are now many free software tools for PCs and apps for smartphones for creating and viewing 3D models. The possible use of LiDAR sensors in mobile devices for geomorphological education is shown in more detail in the following with three examples. The scans were carried out with an IPad Pro 2020 and the free 3D Scanner App. The app has also been used successfully in other studies (see Gollob et al. 2021, Luetzenburg et al. 2021). The topographic information is recorded via the point cloud and the texture via photographic images with the camera. Both data sets are combined and stored together. Simple measurements, e.g. of the size of objects, can also be taken directly in the app. An initial review of the data and a check for completeness of the measurement can already be done on site in the app and is available in a few minutes. Problems in detecting surfaces with LiDAR arise especially with leaves and small branches. Here it is often not possible to capture a clear surface. Overhangs, e.g. on cut banks (Fig. 1), or crevices in rocks can also often not be consistently imaged. Other problems are caused by highly reflective surfaces such as water, due to the reflection of the electromagnetic radiation away from the sensor. Optimal images, on the other hand, are often obtained from dry rock surfaces. In addition, the orientation of the scanner in relation to the sun, especially in clear skies, can also influence the quality of the recording. Furthermore, repeated scans of the same area might result in considerable distortions (Fig. 2).

A variety of file formats are available for advanced processing using additional software tools. In the following, two free software tools will be discussed as examples. However, there are a large number of other software tools with a similar scope of services. The open source software Blender in its current version 3.0 is suitable for a pure representation with possible post-processing of the surfaces. For further processing, the software enables, among many other options, the creation of various lighting sources including shadow casting as well as animation for films. A suitable format for further processing of the data from the 3D Scanner App is OBJ. The topographic information and the texture can be processed separately. For the compilation of DSM, which can be used in Geographical Information Systems (GIS), the open source programme CloudCompare was used. The data sets were exported from the 3D Scanner App as a point file (xyz colour). CloudCompare was originally developed for processing TLS point clouds, among other things. Additionally, the 3D models can be stored and exchanged in free repositories such as Sketchfab (www.sketchfab.com) directly via the 3D Scanner App.

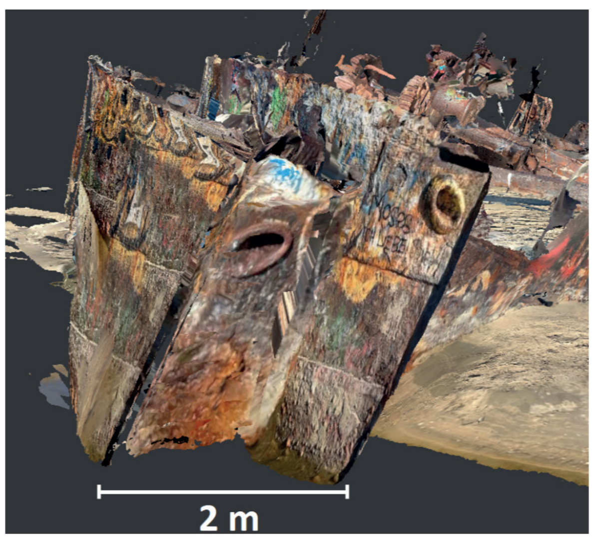

Fig. 2: Distortions of the bow of a shipwreck due to repeated scanning

3 Examples

To demonstrate possible applications of the smartphone LiDAR systems, three different landforms were selected. The examples vary in size and complexity. The first example of the sunken lane is illustrating the option to measure the size of a landform to recognise scale and size relationship. The second model is an example of weathering processes actively shaping a rock. The last example is a time-series from a small creek and is illustrating the complex interaction of erosion and deposition in a fluvial environment.

The first example is a sunken lane in the Aachen Forest (Fig. 3). The Münstergracht was formed mainly in the Middle Ages in loosely consolidated Cretaceous sands (Aachen and Vaals sands). With a length of more than 40 m and a height of 20 m, the size is at the upper limit of the device's capacity for a single scan for the used IPad Pro 2020. However, the maximum area that can be scanned depends on the size of the overlapping scanning area and the scanning resolution. The model of the sunken lane was recorded by scanning multiple tracks parallel to the slopes. In contrast to the classic 1 m resolution DEM of the German land surveying offices, which are regularly used to explain the formation of hollow ways, this model also contains surface images. The possibility to digitally rotate and measure the model gives students a faster and especially better understanding of this geomorphological form.

A 3D model of a rock (Zyklopensteine) was created in the Aachen forest in the border area to Belgium and was processed with Blender (Fig. 4). The rock is composed of quartzitic sandstone that formed in the Cretaceous Aachen sands (Walter 2010). After the sands were eroded, the more resistant quartzitic sandstone remained. Weathering resulted in rounded edges over time and the formation of tafoni. The former rock stratification can still be recognised by the spatial arrangement of the tafoni. Tafoni are formed by water seeping into the rock and migrating back to the surface following sediment boundaries or zones of weakness. On the outside of the rock, the rock-forming

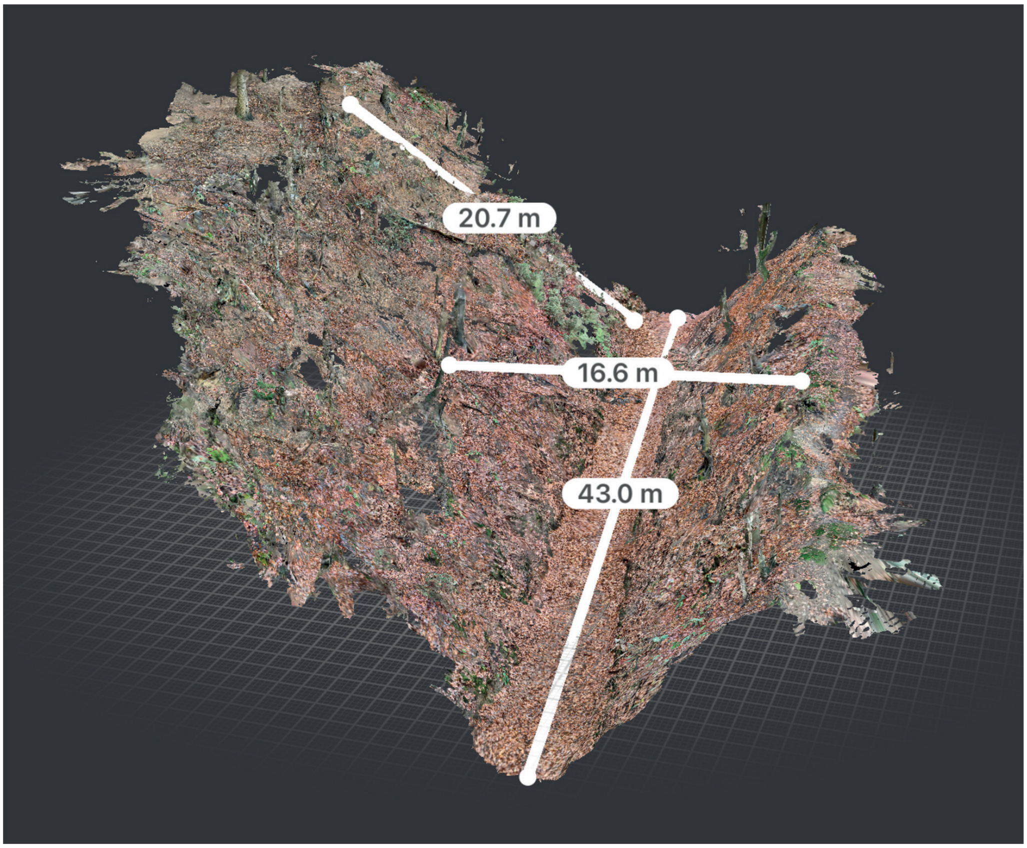

Fig. 3: The Münstergracht - a sunken lane in the Aachen Forest with simple distance measurements in the 3D Scanner App.

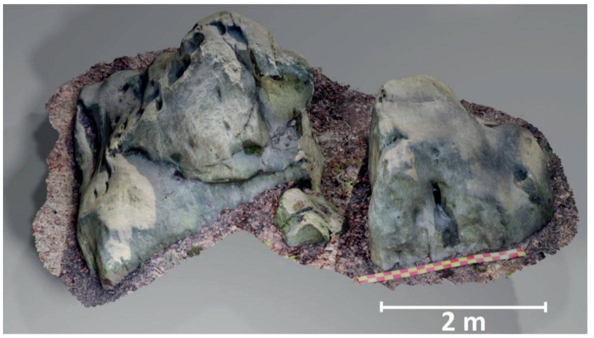

Fig. 4a: Quarzitic sandstones in the Aachen Forest in 3D view

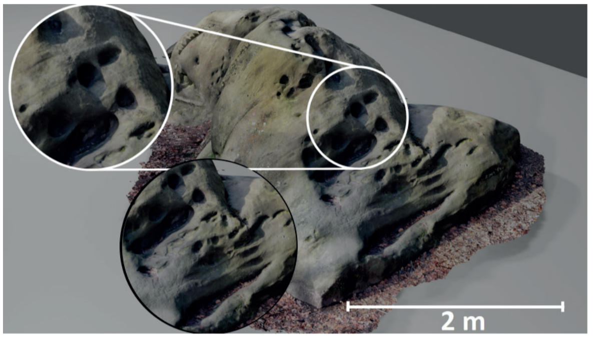

Fig. 4b: Tafoni following the sedimentary layers

minerals are dissolved. Since the exit point of the moisture is always in the same place due to the internal structure, a hollow form is formed here over time. All these points can be derived relatively easily by students from the 3D model.

With software tools like Blender, the teachers can add labels to the 3D models, and on the other hand the learners can approach the form in a playful way. In contrast to 2D illustrations such as drawings and pictures, which are often difficult for the untrained eye to interpret in a geomorphological sense, 3D models can present spatial relationships more easily and thus more comprehensibly.

Another possible application is the creation of time series. Such a time series, which documents changes caused by fluvial processes, was created on a small river section in the Aachen Forest (Fig. 5). Three models were recorded between the beginning of December 2021 and the beginning of February 2022 and show the reactivation of an old meander loop at the creek Beverbach. The data sets were exported from the 3D Scanner App as a point file and processed in CloudCompare. In CloudCompare, the data sets of the different dates were coregistered with each other, and, then the elevation data and the texture were exported as a terrain model and image, respectively. The final representation as DSM with artificial shading was done in the GIS software QGIS (Fig. 6).

On the basis of the three models, different fluvial erosion and accumulation phases can be seen. A first overflow of the stream to the north has led

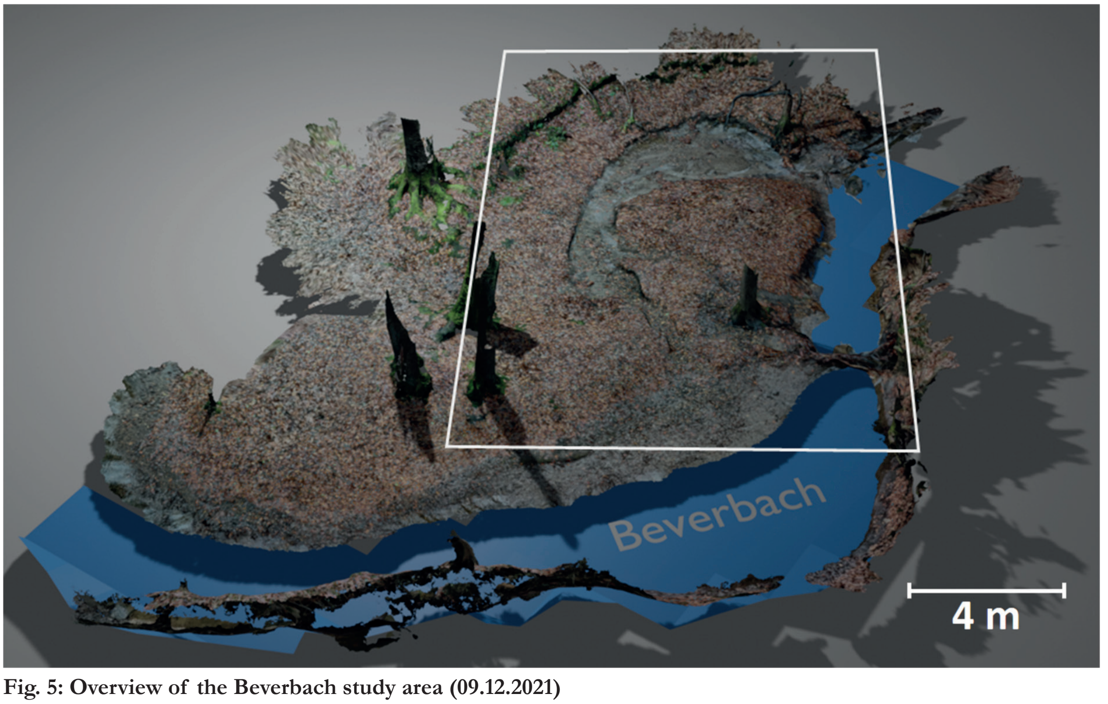

Fig. 5: Overview of the Beverbach study area (09.12.2021)

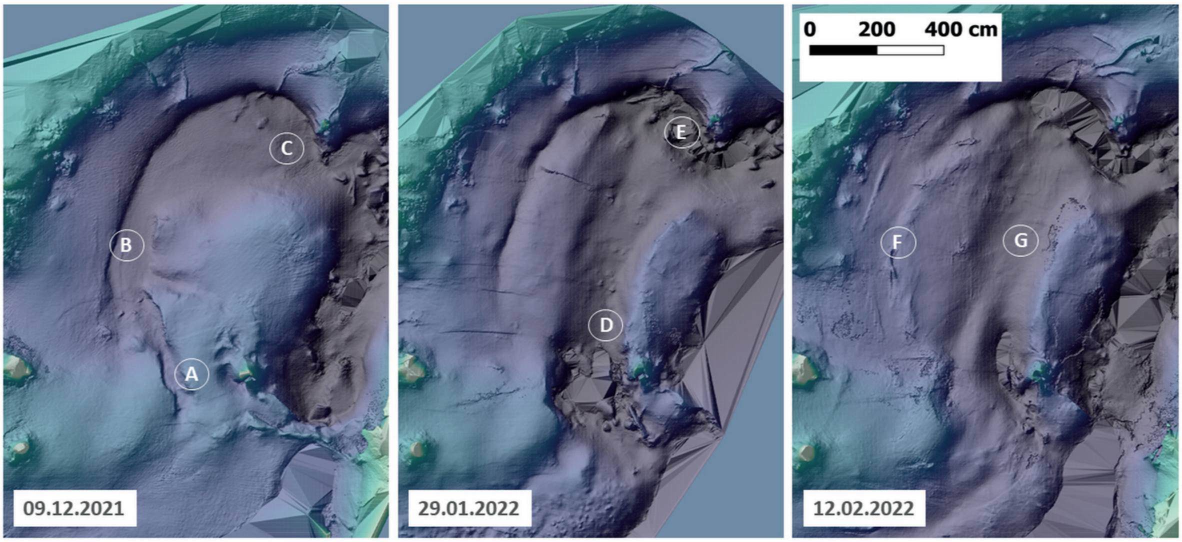

Fig. 6: Development of a new stream arm at the Beverbach, illustrated in the shaded digital terrain model. The large triangular areas represent water surfaces. No exact surface data could be obtained here.

to the reactivation of an old meander loop. The low embankment (A in Fig. 6) was cut like a gorge by about 22 cm and the first erosion in the old meander arm was box-shaped (B). After a short transport distance, the material was directly deposited again at the northern end of the old meander in the form of a small alluvial fan (C). The model of the 29th of January shows a much stronger and wider incision. The main channel (D) has shifted to the east and the original channel has been filled in. The erosive force and higher transport capacity has also led to the clearing of the alluvial fan at the end of the old meander arm (E).

In the third phase, the last remains of the original channel were also filled in (F). The eastern channel (G) has become shallower in parts and has shifted even further. Overall, this example shows very dynamic fluvial landscaping in a small area that took place in approximately just two months.

4 Conclusion

As shown in the three examples above, smartphone LiDAR systems are capable of generating 3D models of geomorphological objects for research and teaching. The size can range from individual geomorphological objects to small landform assemblages covering several m². There are various free open source software tools for processing the geomorphological 3D models available. These models can be used in support of lectures or in the preparation of field trips, e.g. in a blended learning environment. The recording of geomorphological objects in the context of school and university courses might increase interest in such landforms through playful elements and, thus, lead to an increasing learning success. Consequently, the students can discover the special features of different geomorphological forms independently with 3D programmes. Another possibility is to create short animations with the corresponding explanations. Furthermore, 3D models make geomorphology more inclusive, e.g. for people not able to conduct field work. Thus, the use of 3D models can significantly improve geomorphological education.

It will be exciting when such LiDAR modules become established in further and more cost-effective end user devices. In research, smartphone-supported LiDAR system might increase the number of geomorphological monitoring sites dramatically. Furthermore, this would also enable more extensive Citizen Science projects, e.g. for the observation of locations with high geomorphological dynamics such as impact slopes on rivers or the formation of erosion gullies.

Acknowledgments

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Software used

3D Scanner App: https://3dscannerapp.com/
Blender 3.0: https://www.blender.org/
CloudCompare: https://www.cloudcompare.org/main.html
QGIS: https://www.qgis.org/de/site/

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