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AUGMENTED REALITY AS A 3D LAND COVER VISUALISATION TECHNIQUE

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ABSTRACT

Augmented Reality (AR) is an established technique for both 2D and 3D visualisations in several fields such as sports, entertainment or culture (museums). However, in cartography or in GIS, it is still considered as a minor niche visualisation technique. Therefore, the aim of this paper is to present AR as a 3D visualisation method for land cover development. The presented output is a part of a mobile application for Android. Land cover GIS data obtained from historical and contemporary large-scale maps are processed using City Engine, resulting in the creation of several 3D models viewed via augmented reality. Procedural modelling in City Engine is used to visualise 3D land cover data such as buildings or forests (including coniferous, deciduous and mixed). Other land cover types (e.g. arable land, grassland or roads) are displayed as 2D textures. In this way, the user can experience an innovative perspective of land cover changes over time in a study area of Chudenice (a village in the southwest of Czechia). The 3D land cover maps are presented in two time periods (1837 and 2023). The 3D models are accompanied by a map legend, scale, north arrow and title, so that the user can keep track of the current model without the need for additional essential map information.

KEYWORDS

Augmented reality, AR, Land cover, Visualisation, Old maps, City engine, Unity

INTRODUCTION

The development of land use/cover is a topic that is covered from many science perspectives, such as ecology, history, geography or GIS and cartography. Almost every outcome in this specific research sector involves tables, charts or 2D maps [1, 2, 3, 4]. The focus of this paper is to visualise a land cover development in an innovative way and it is redundant to provide the reader (or a mobile application user) a new perspective on this topic. The presented visualisation consists of several 3D terrain models viewed via augmented reality (AR). These 3D models show the development of the study area in two different time periods (Table 1). With AR, user can view the virtual 3D terrain models using a mobile device (a phone or tablet).

The use of augmented reality is rapidly increasing due to the technological evolution, so it is being used not only in cartography, but also in many other domains. The main area of use is still entertainment, such as sports [5], video games [6, 7] or books [8]. Nevertheless, AR is being present in many more serious domains, being culture (e.g. cultural heritage [9, 10, 11], arts [12], museums [13]), medicine [14], education [15], interior design [16] or industry [17, 18].

Land cover/use changes are typically presented mostly as 2D maps (as mentioned above). However, a 3D visualisation of this phenomenon not only gives the reader a new perspective, but can also visualise the terrain more effectively by using the third dimension [19]. The terrain could undergo a massive change during the presented time, therefore it is important to correctly depict its changes in a certain scale. This is quite well possible in a presentation of a contemporary changes or those that have happened in the near past due to the airborne laser scanning and its outputs being very precise digital terrain models (DTM). The older mappings have to rely on a less accurate elevation that had been obtained with older surveying techniques, which often results in a less reliable comparison between two selected time periods [20]. Because of the very minor terrain changes in the study area and the scale of final visualisations, the DMR5G elevation model (data from 2023) provided by the Czech State Administration of Land Surveying and Cadastre (ČÚZK) [21] was used as a basis for both presented 3D models.

Tab. 1 - Time periods of tracked land cover changes with map sources for data comparison

Period	Map basis
1837	Imperial Obligatory Imprints of the Stable Cadastre 1:2,880
2023	Basic Topographic Map of the Czech Republic 1:5,000

Augmented reality

Augmented reality (AR) is defined as a real-time view of a physical world that has been enhanced by virtual information [22] and is a part of extended reality (XR). Other defined branches of extended reality are virtual reality (VR) and mixed reality (MR) as seen bellow in Figure 1. The difference between the types of XR lies in the degree of user immersion in the virtual world based on Milgram's real-virtual continuum (upper part of Figure 2) [23]. Virtual reality offers the most immersive experience for the user as it is presented through a headset that places the user directly in the virtual world. Mixed reality connects the real and virtual worlds, with the use of a headset or goggles, while a greater degree of immersion is still determined by the presence of the user as part of the virtual world. Augmented reality offers the lowest level of user immersion, as it 'only' enhances the real world with virtual elements. In some cases, there is almost no clear distinction between these types of XR, and the borderline cases can therefore sometimes be named, for example, both AR and MR. This claim is also supported by the evolution of technology, which makes the update and re-evaluation of the definitions on which Milgram's scheme is based necessary (lower part of Figure 2) [24].

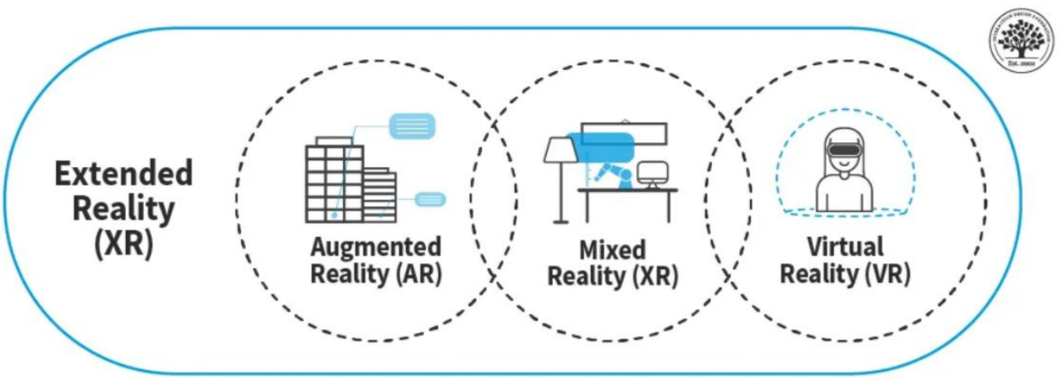

Fig. 1 – Extended Reality scheme [25]

Augmented reality can be divided into several types according to different parameters [26, 27] (e.g. according to display technology or orientation in real space), while the terminology is not clearly established and thus it is possible to encounter different names for the same type of augmented reality (e.g. location-based AR = geospatial AR = GPS AR [28]). To simplify the terminology, this paper only works with a certain subset of augmented reality types. These are the types of AR classifications based on the orientation in real space (markerless AR, marker AR and location-based AR).

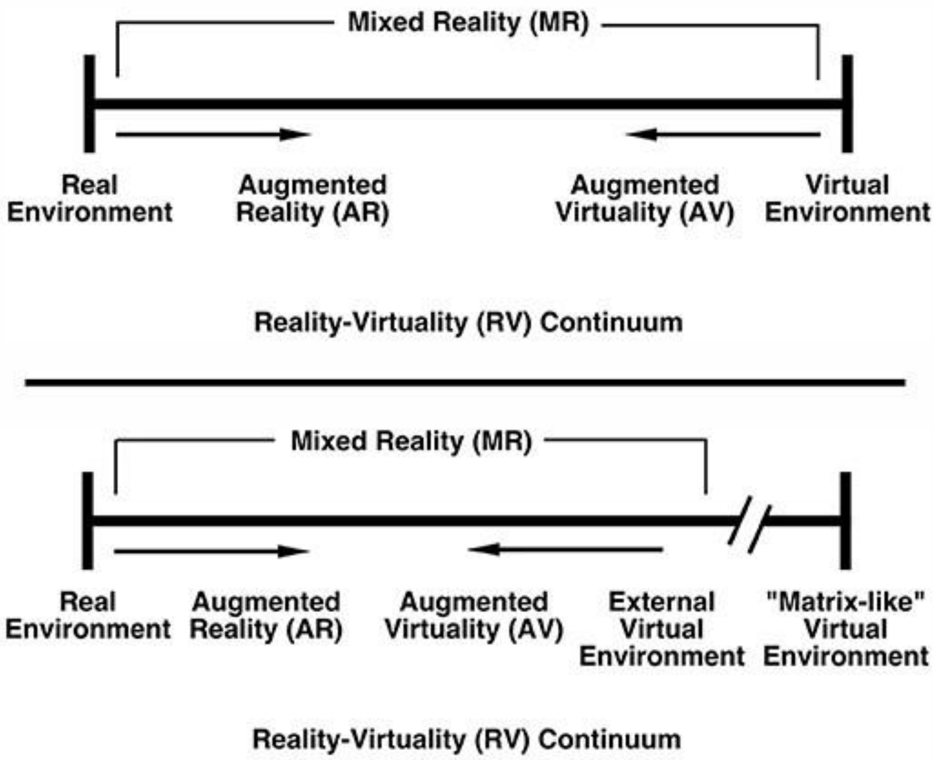

Fig. 2 – Milgram original reality-virtuality continuum (upper part) [23], Milgram revised reality-virtuality continuum (lower part) [24]

The most basic visualisation method for augmented reality is markerless AR, which displays the virtual model based on the user's scan of an environment (e.g. a table or floor). Once the environment has been scanned, the virtual element can be placed in space and can be therefore moved (on scanned horizontal or vertical planes), rotated or resized.

Marker AR places the virtual object based on the recognition of a specific marker [29]. The object is directly tied to this marker. The applications are then divided into those that allow the user to move, rotate and resize the object - as in the previous case. The second type of applications uses the marker as an anchoring element that directly defines the size, rotation and position of the virtual model. In this case, the displayed virtual model is directly tied to the marker.

Location-based AR visualises the virtual model in a predefined location in the environment (e.g. city street or field) [30, 31]. Therefore, the model cannot be displayed at a different location using this method, as it is tied to a specific location.

Study Area

The study area of a Chudenice is located in the south-western of Czechia on the border of the Domažlice and Klatovy district (Figure 3). The municipality consists of four cadastral communities Chudenice, Lučice, Bezpravovice and Slatina and its area is approximately 25 square kilometres. According to the latest census from 2021 [32], the population of the village was 733 inhabitants. The figures in the text (Figures 5-7) are depicting AR models visualising the cadastral community Chudenice.

The first mention of Chudenice dates back to 1291 [33]. Until the end of the Second World War, the area was under administration of the Czernin family from Chudenice [34]. During this period, several cultural buildings were built here, making Chudenice a popular regional tourist destination. The most important buildings are the Old Czernin Castle, the Museum of Josef Dobrovský, the Church of St. John the Baptist, the Castle of St. Wolfgang and the Bolfánek observation tower (built on the ruins of the Church of St. Wolfgang) [35].

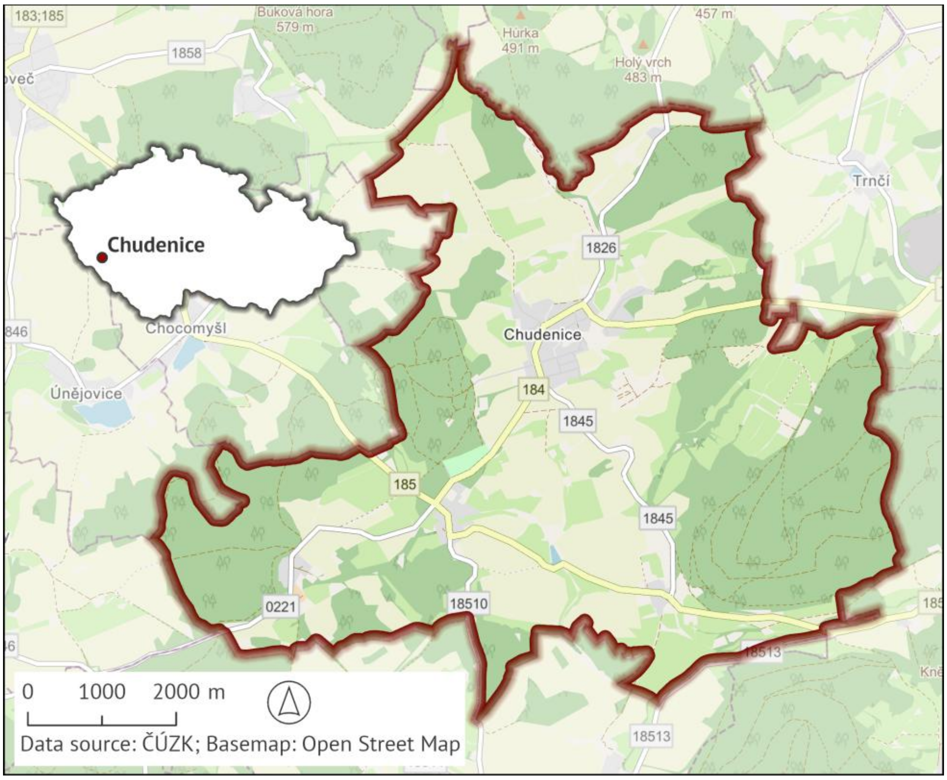

Fig. 3 – Map of the study area

METHODS AND RELATED WORKS

Land cover changes are observed in two time periods, as shown in Table 1. The monitored types of land cover and its specification are described in Table 2 below. These are the land cover types that can be distinguished on both of the used map basis, historical (1837) and contemporary (2023). Some of the land cover types are visually merged for achieving a better interpretation and comparison at a given map scale. For example, used historical map distinguish three types of grassland (meadow, pasture and garden). Contemporary map uses only two of them (meadow and garden). Therefore, some way of adjusting the distribution and merging certain land cover types into larger groups was needed for a clearer overview on the area of interest, as visualised in Table 1.

This paper is concerned with the use of markerless AR for 3D cartographic visualisations, which is a method that is also described in a paper by Halik and Wielebski [36].They have developed a web AR application showing peaks of Polish mountains based on a digital terrain model (DTM) with an orthophoto map as a texture. The 3D models are supplemented with a scale, cardinal direction arrows and map labels making the map fully readable and informative with no need for any additional description. The presented models can be visualised both in a web browser and in augmented reality (if viewed on a mobile device). This approach allows the user to choose their way of viewing 3D scenes, which makes the application flexible in its visualisation methods, so it can be examined by a larger amount of users and not only by those who want to use the AR experience. However, the aim of this paper is to visualise 3D landscape in augmented reality only, so the web application is not being developed at the moment.

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Tab. 2 - Monitored land cover types derived from maps at a given time period

Type	Stable Cadastre (1837)	Basic Topographic Map of the Czech Republic (2023)
Arable land	Arable land	Arable land
Grassland	Meadow Pasture Garden	Meadow Garden
Forest	Coniferous, deciduous and mixed forest Park	Forest Park
Water body	Water body River	Water body River
Built-up	Built-up space	Built-up space
Other	Path and road Yard Barren land Graveyard	Path and road Yard Barren land Graveyard Farm area

Another approach in a 3D landscape visualisation was presented by Lázna [37]. He used both marker and markerless AR for showing 3D scenes. Firstly, the markerless AR method works in a standard way of placing the 3D model after a plane detection is completed. Similarly, to the previous example, the models are created on a base of DTM with a texture from aerial imagery. Lázna is presenting several different cartographic models but most of them lack any additional map information such as a scale or labels. The result is presented as a mobile application developed in Unity, which is an approach that is carried with Chudenice AR presentation as well. His second presented method, the use of marker AR, is utilized for showing virtual models placed on a 3D printed relief after recognising a QR code. This method seems to be exciting because it connects the real physical model with virtual elements, which is an approach that should be more studied in the future due to its possible implementation in museums or education [38, 39].

Visualisation of the virtual model on a 3D printed terrain model is also described by Zhang et al. [40]. Their work is concerned with the use of AR as a 3D flood visualisation method and it presents the developed method as an innovative way of displaying the threat of natural disasters in AR, which can be helpful in avoiding the threat or lessening the consequences of flood. Another great example of 3D cartographic visualisation in AR is a connection between AR and printed school atlases, which is described by Schnürer et al. [41]. Their work presents 2D and 3D visualisations of thematic cartography maps that are enhancing printed school atlas with virtual elements such as charts or maps. Similarly to most of other mentioned works, this one is developed using Vuforia engine and Unity. Schnürer et al. had to solve a problem with an AR visualisation on a curved double-sided atlas map, which they resolved by anchoring a virtual object to the page with the biggest recognized part of the map.

3D Cartographic scenes in AR should always follow the rules of cartographic visualisations. In this case, a 3D cartographic scene is understood as a large scale cartographic visualisation of a landscape scenery complemented with schematic vegetation and buildings procedurally or manually modelled. As was mentioned before, not all works handle this topic correctly. Therefore, it is very important to make sure that the presented model is well recognisable, so the user does not lose track of its details or the position of viewed area in map. This can be done in several ways, but the most straightforward approach is to label the model well, as described by Halik [36, 42]. The labels can be minimalistic and user can toggle their visibility, so the labels could be turned on only if necessary. As the user moves the mobile device around the presented object, the labels should be always facing the camera, so they are well readable from every angle.

Processing of GIS data

The GIS data were obtained from historical and contemporary large scale maps (Table 1). The historical maps were manually vectorized and the contemporary map was already obtained in a vector format. Firstly, the historical maps had to be georeferenced. The Imperial Obligatory Imprints of the Stable Cadastre 1:2,880 were georeferenced on identical points with the use of affine transformation resulting in residuals around 3 meters. The State Map 1:5,000-derived was georeferenced with the use of projective transformation based on four corner points of the map sheets with residuals around 4 meters. The used methods of georeferencing are described by Cajthaml [43, 44], Janata [45] or Balletti [46]. As for the contemporary map, the Basic Topographic Map of the Czech Republic 1:5,000 in vector format was used for obtaining large scale land cover data. The forest composition data (coniferous, deciduous and mixed) were derived from CORINE Land Cover 2018 [47].

The 3D terrain is based on a DMR5G elevation model, which is a very precise elevation model provided by the Czech State Administration of Land Surveying and Cadastre. This model is measured by the technique of airborne laser scanning with a mean elevation error between 0.18 m (exposed ground) and 0.30 m (forested ground) [21]. The terrain was converted into TIN and simplified relatively to the scale and visualisation use of the final virtual 3D models. All GIS work was done in ArcGIS Pro 3.2.

RESULTS

3D Land use models

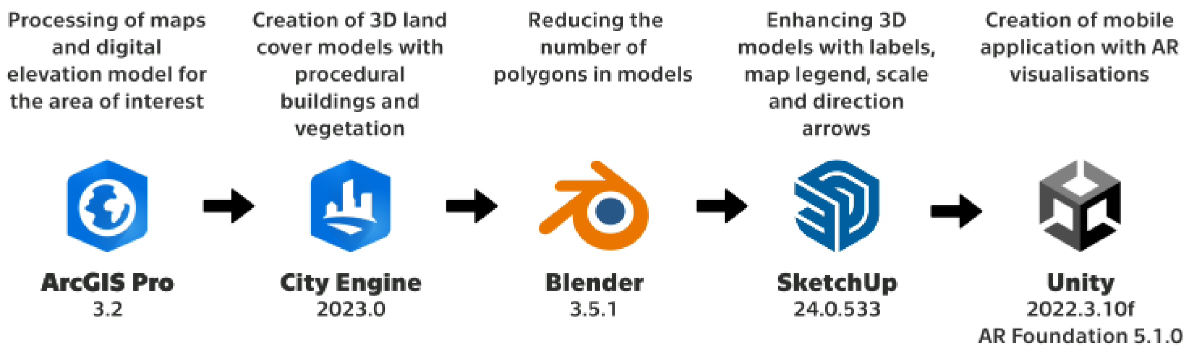

Fig. 4 – Workflow chart including used software versions

When the process of vectorization was completed, the vector data in shapefile (.shp) format were imported to City Engine (version 2023.0), where the data were used as a basis for procedural modelling. The schematic workflow chart of the data processing is shown in Figure 4. Procedural modelling generates 3D models based on rule files (.cga). These rules automatically apply a set of predefined rules for each 3D object (etc. house, tree, road) and use these rules randomly on the dataset at a set ratio. For example, user can define that 25% of the modelled houses will have hip roof, 35% will have pyramid roof and the rest will have gable roof. However, this set of rules is applied randomly or based on certain attributes of the geodata. Using .cga rules, procedurally modelled were simplified houses, forest areas and avenues based on methods described by Janovský et al. [48], Watson et al. [49] and Kitsakis et al. [50]. For a more immersive visualisation the height of a terrain was multiplied by the ratio of 1.5. Different models were generated for both tracked time periods depending on the vector land cover shapefiles.

Fig. 5 – Details of land cover 3D model

The generated 3D land cover model was then exported to Blender (version 3.5.1), where the terrain mesh had to be compressed [51] due to its visualisation on mobile platforms, which require a lower number of polygons (in 3D models) for a smoother presentation. This was done by Decimate modifier in Blender resulting in a significant decrease in a number of used polygons. Due to optimalisation of the 3D model for mobile platforms, the models of procedurally generated trees had to be also simplified, as seen in Figure 5. The coniferous trees were simplified more easily thanks to their pyramid shape. However, the deciduous trees are harder to generalise due to their rounded crown, which can be triangulated much trickier when compared to the coniferous trees.

In CAD software SketchUp (version 24.0.533), additional map information was added, such as the map scale, labels, legend and cardinal directions. The labels show the name of a viewed area and a reference year. The map legend describes the types of land cover with schematic 3D overlays (trees or buildings). Under the map legend the map scale and data sources are situated (Figure 6). Both 3D models are labelled in Czech language because they are prepared to be viewed mostly by the Czech users. Also, some of the more important or interesting buildings, such as Bolfánek observation tower (Figure 5), were modelled manually using CAD. At this point, both models were ready for visualisation in augmented reality.

Visualisation in a mobile application

From CAD software, the models were imported to Unity game engine (version 2022.3.10f) in .fbx format, which is considered as the most convenient because of its good compatibility with Unity. This step was followed by application testing, which resulted in a several repeated steps of optimalisation of the visualised models due to the limits of mobile device performance. As the test device, Samsung A14 5G (2023) was chosen, which is a lower-class device, therefore if the application runs well on this device, it is considered to be working fine on most of the current mobile phones or tablets. The AR Foundation library (version 5.1.0) with plane detection was used for the AR visualisation and it was supplemented by additional C# scripting.

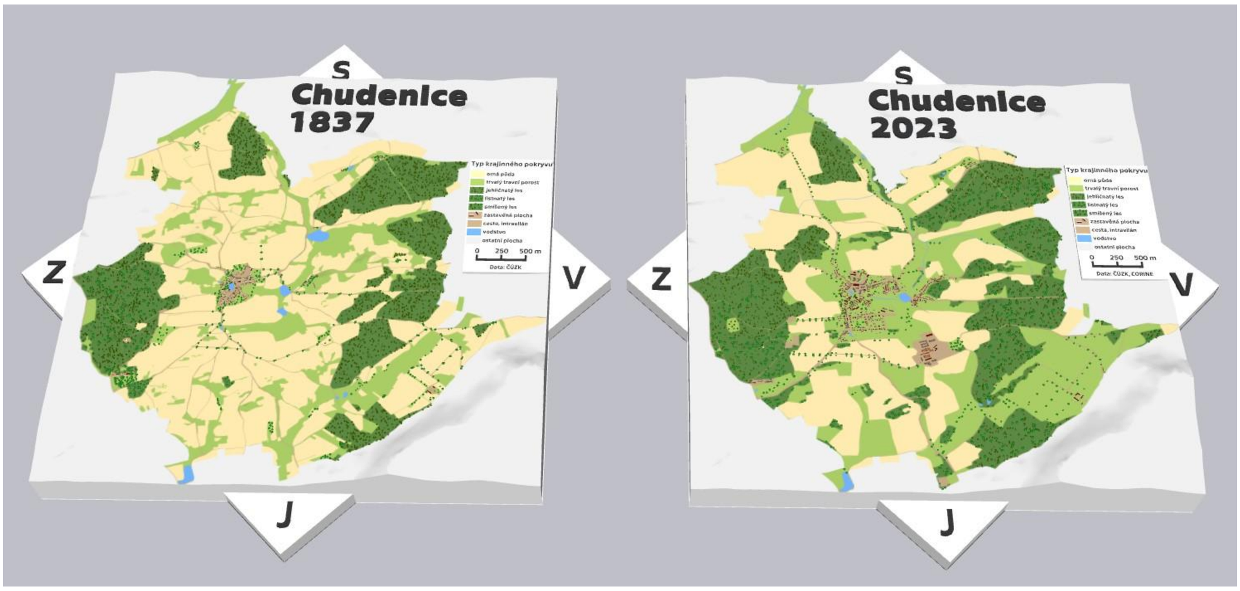

Fig. 6 – Comparison of final 3D models with land cover in 1837 (left) and 2023 (right)

The final application firstly scans the surroundings and detects any horizontal planes (e.g. table, floor) using the AR Plane Manager (AR Foundation component). In the second step, the user can visualise the 3D cartographic land cover model by tapping on the detected plane, after which the model appears (as seen in Figure 7 - left side). Now, the user can rotate, move and scale the model using finger gestures (pinch or swipe). Using the button on the top left side of the screen, all scanned horizontal planes can be hidden making the model glued to its current position. However, it can be still rotated and scaled with finger gestures (Figure 7 - right side). By locking the position of the model, the user can interact with the model without accidentally moving it, so the details or the map legend can be viewed in a larger scale.

Fig. 7 – 3D land cover visualisation in AR

DISCUSSION

The aim of this papers is to present the possibilities of visualising the development of land cover on a 3D terrain in augmented reality using native mobile application. As mentioned before, there are lot of different approaches for 3D cartographic visualisations in AR but all of them have to share two essential characteristics, which are key for the user experience and proper visualisation. The first one is a visual legibility of the model, which plays a huge role in understanding the map depicted on the 3D model (e.g. well readable text, recognizable colours or symbols). The second important characteristic is the preservation of cartographic principles, meaning that even the AR 3D model should be full-featured map with map scale, labels, legend and north orientation (if necessary).

When compared to work of Halik and Wielebski [36], the models presented in this paper share the same method of geographic orientation described by four triangles with symbols of a given cardinal direction. This seems to be the easiest way of describing the orientation of a 3D AR map. Additionally, the map legend and the map scale can be presented directly on the model regarding the shape of the Chudenice cadastral community. Also the scale of presented models is quite similar in this paper compared to their work. Both papers refer about large-scale 3D maps, which means that some details can be still preserved at this level of detail (forest composition, smaller land units, narrow pathways or types of buildings). Halik and Wielebski use orthophoto as the model texture, which could make the 3D model more visually appealing and realistic. On the other hand, the use of vectorised land cover used in this paper can give the user better awareness of the real use of certain land units throughout the whole area. Halik and Wielebski utilize the map labels very well because labels on their model aways follow the user's camera which makes the map very well readable from different angles. This feature should be incorporated to Chudenice AR map in the future.

Very important decision to consider in the future work is whether to use native mobile application built in Unity or to visualise AR models using web browser (using WebXR) as mentioned by Halik and Wielebski [36]. WebXR is easy to use for the user as they do not have to download a standalone mobile application. All they need is a standard web browser capable of visualising AR (e.g. Google Chrome or Safari), which is very convenient. On the other hand, this kind of visualisation only allows less complex models to be shown because everything is rendered via web browser. This also means that users need to have a good (and stable) internet connection, otherwise the application will not function. Although the native mobile applications require to be downloaded from Google Play or App Store, they can be viewed offline and can handle much more complex visualisations. With the use of native applications, the augmented reality can be more stable as well, which minimizes the model drifting in AR. More complex stable AR tracking methods are also (at the moment) only available through a native mobile application.

As Halik and Wielebski [36] mention, the combination of real world and virtual model create an immersive experience for the user. This experience can be enhanced by connecting the visualised models with printed maps (or map atlases) as described by Schnürer et al. [41]. The possibility of viewing 3D land cover models in AR on top of a 2D printed map (or a 3D printed model [37, 40]) will be the aim of author's future research because it is an interesting way of adding more map information that enhances the 2D/3D printed map with both static and animated cartographic data visualisations. The immersion and connection between physical and virtual environments is something that only augmented reality is capable of. Therefore, it is essential to explore its possibilities within thematic cartography and geovisualisation more deeply. AR can not only stand as another method of digital maps visualisation, but it can also visualise elements that could not be added (for different reasons) to printed 2D map. These can be interactive charts, infographics or audiovisual materials complementing and enhancing the physical printed 2D static map.

None of the above-mentioned works utilize procedural modelling for generating buildings or vegetation in AR, which is a feature that adds details to the whole 3D model, although the generated outputs are mostly schematic copies of real world. Most of the houses are procedurally generated, only few important models are created using CAD as seen in Figure 5. Although procedural modelling can be used widely in web based or VR applications rendered on a regular computer or laptop (as seen in works of Janovský et al. [48], Watson et al. [49] and Kitsakis et al. [50]), its implementation in AR can be problematic mostly due to large number of generated polygons. This can lead to problems with stability and with lagging of the AR visualisation viewed through a mobile device, which is not (in most cases) comparable in its performance to computers or laptops. Procedural modelling combined with land cover map is the core part of this paper because there can be found only little information in visualising this kind of 3D map in AR among other studies. In the future, this approach can be enhanced by adding more levels of detail for every procedurally generated object. This will lead the way to optimize this visualisation so it can be available also through using a web browser. Another way to improve and enhance the visualisation is to make it more immersive using interactive information about the map such as attributes for a selected polygon or building.

CONCLUSION

This paper is concerned with the use of augmented reality as a visualisation technique for 3D land cover cartographic models. Because the AR visualisation has its specifics, mostly as it is directly tied to a mobile device, the use case of this method may differ and certain data visualisations are more suitable than other. The land cover data are well suited for being viewed via AR because the data is well visually recognised. However, the biggest issue of the presented technique is the scale of the viewed area. It is fundamental to select smaller area, otherwise the schematic landscape elements or buildings would not be clearly visible until the model is properly scaled. However, if the model would be scaled too much, it can lose track of the scanned horizontal plane, resulting in its drifting, which can make the user experience displeasing. The larger the area is, the sparser the schematic 3D landscape (mostly trees or other landscape elements) need to be due to hardware limitations of the mobile devices. The best example for this kind of visualisation is a mountainous area (because the plasticity and the depth of the model is then depicted better without no need to manually adjust the "Z factor" - scale of vertical axis). By following this, the model depth is increased while the visual proportions remain similar. Nevertheless, the topic will be studied further, and its results will undergo user feedback to help validate the best approach of a 3D land cover visualisation in AR. The emphasis will be mostly on adjusting the level of detail, number of polygons, used colours and a size of area of interest. The advantages and disadvantages of using web or native applications for this sort of AR visualisation should also be part of future research.

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