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3D Point Clouds for Representing Landscape Change

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Abstract: Along with increasingly rapid changes of our present landscapes, exchangeable land use patterns are evolving that lead to decreasing identification of the people with their environment. To evaluate people's perceptions of and reactions to possible future landscape development scenarios, we aimed to develop realistic-looking landscape depictions from a pedestrian perspective, including environmental sound. With this, we faced the challenge of how to most effectively and efficiently visualize potential landscape change scenarios. In this context, LiDAR (Light Detection and Ranging) data are a promising resource to create realistic landscape depictions. We present an innovative workflow combining 3D point cloud data collection and modelling with audio recordings for visualizing scenarios of landscape change. The focus is laid on the visualization process and the integration of various geographic data sets. In the discussion of the resulting workflow we consider strengths and weaknesses of our solution regarding data collection, as well as technical and ethical issues. Overall, the presented approach looks promising, but still requires a great deal of manual labor. We recommend to further develop the visualization workflow, for example, by speeding up the data acquisition process of the point cloud data, and by further automatization of the data processing steps.

Keywords: LiDAR, 3D landscape visualization, audio-visual simulation, high level of realism

1 Introduction

We are currently observing increasingly rapid changes of our present landscapes. Along with these developments, exchangeable land use patterns are evolving that lead to people's decreasing identifications with their surroundings, and thus to people feeling less comfortable in their own environment (ANTROP 2005). To support a development of identity generating landscapes, systematic measurements of how the public feels about possible landscape changes are necessary (JORGENSEN 2011). Realistic-looking landscape visualizations from a pedestrian perspective, including environmental sound, are suggested as suitable stimuli for such empirical studies (LINDQUIST et al. 2016, MANYOKY et al. 2016). The challenge, however, remains how landscape changes can be visualized as effectively and efficiently as possible. Specifically, the visualization of several time steps of alternative development scenarios require additional amounts of stimuli development work, in which an automated visualization workflow would be particularly desirable. In this context, increasing LiDAR (Light Detection and Ranging) data availability might offer a promising data source for rapid stimuli development (SHEPPARD 2004, LIN et al. 2014).

The objective of this paper is thus to present an innovative workflow combining LiDAR data-based 3D point cloud modelling with environmental audio recordings for visualizing scenarios of landscape change. The focus is laid on the visualization process and the combination of various geographic data sets. The approach is demonstrated on a study site located in the peri-urban municipality of Erlinsbach (at the Canton Aargau / Solothurn border) in the northern parts of Switzerland. A possible future landscape development scenario including two

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time steps (the years 2025 and 2050) needed to be visualized for this location. In the following, we present a four-step data processing workflow, as a proof-of-concept that includes 1) LiDAR and audio data acquisition and processing, 2) the modeling of possible landscape changes, 3) the rendering of the visualizations, and lastly 4) the integration of the visualizations with the audio data. We then compare the strengths and weaknesses of our solution, and further discuss the potential of using LiDAR data for realistic 3D landscape visualization. Particularly, we offer considerations that should be considered regarding this kind of data, including technical and ethical issues associated with the development of such audio-visual landscape depictions for future empirical studies with participants.

2 Methods

A key challenge for realistic-looking 3D visualization is to simulate landscape at high fidelity. This is often difficult, due to time-intensive and costly workflows for geometry updates, and the adequate 3D model creation of landscape features, including buildings and vegetation (Richter & Döllner 2014). We propose to develop such depictions of landscape changes with LiDAR data, and implement a workflow including four major steps (Fig. 1): (1) Cantonal LiDAR data (ALS) and terrestrial laser scanning (TLS) data are gathered and integrated into one single point cloud to produce a realistic 3D scene of the current landscape state. Furthermore, environmental sound is recorded in the field that enables a simulation of the ambient acoustics, additionally increasing the level of perceived realism of the virtual landscape (Lindquist et al. 2016, Wissen Hayek et al. 2016). (2) Two future states of a possible landscape change scenario are semi-automatically developed by applying a procedural approach for generating new settlement patterns on given parcels. These are then integrated into the 3D point cloud model constructed in step one. Vegetation is directly manipulated within this model. (3) Scene renderings are produced next, displaying a short walk through the study site in which the current state and the future changes can be perceived, respectively. (4) Scene videos are combined with the stereo audio files recorded at the study site to further enhance the realism of the modelled landscape. In the following, more detail of these four steps is presented.

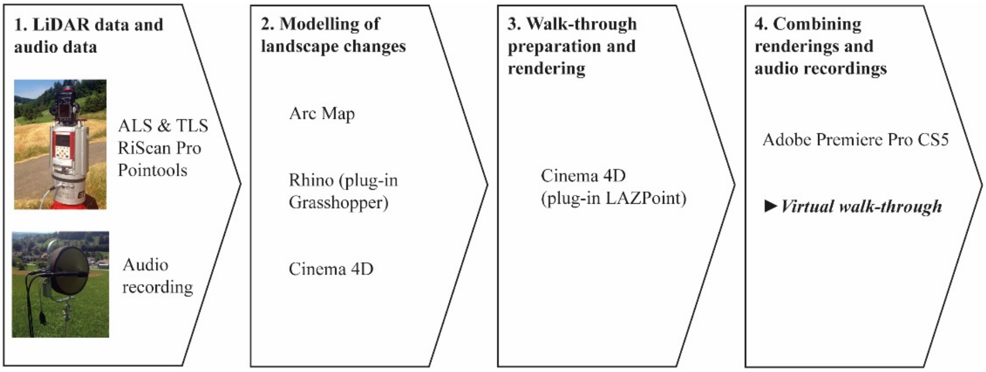

Fig. 1: Workflow and employed software to generate the audio-visual landscape simulations for the virtual walk-through in the landscape development scenarios

2.1 LiDAR Data and Audio Data Acquisition and Processing

3D point clouds can be obtained from different data sources, such as aerial and terrestrial LiDAR scans (RICHTER AND DÖLLNER 2014) which can be distinguished regarding their suitability for visualization at different spatial scales. Data from aerial laser scanning (ALS) provide a wide coverage of an area, but at a rather low resolution. Hence, they are most useful for overview visualizations. In contrast, the data from terrestrial laser scanning (TLS) offers point clouds a high resolution which in turn are useful for depicting landscape features in the fore- and middle grounds of a scene. However, dense 3D point cloud datasets, resulting in large 3D model sizes, pose additional challenges for data processing. An effective combination of different LiDAR data types at varying resolutions is desirable for visualization of landscape change.

LiDAR Data from Aerial Laser Scanning (ALS)
We acquired Cantonal LiDAR data obtained by aerial laser scanning during March/April 2014. We selected an area of 2×2 km^2 at a density of 4 points per m^2, and a height accuracy of 15 cm. The Canton of Solothurn also provided us with aerial images with a resolution of 12.5 cm for the same area. We colorized the LiDAR data with these high resolution aerial images that we merged to an orthophoto mosaic using Esri's ArcMap (http://desktop.arcgis.com/en/arcmap). We merged the image mosaic with the LiDAR point cloud by assigning an RGB value to each point using the LIS (LASERDATA, www.laserdata.at) software. The resulting point cloud depicts the landscape scene in acceptable manner for the overview perspective. However, due to the coarse resolution of the points, the landscape looks fragmented in close-up views. The scene was then exported in ASCII format. We acquired additional LiDAR data using a terrestrial laser scanner. This to increase the resolution of the point cloud for the area in the landscape where we wished to generate a walk-through from a pedestrian perspective, thus, to depict landscape features in the fore- and middle ground of the scene.

LiDAR Data from Terrestrial Laser Scanning (TLS)
In preparation of the data collection in the field, we first determined the path of the walk-through in the scene. Suitable scan positions in the landscape were identified respectively, and saved at a grid distance of approx. 80-100 m using Google Earth, and printed as 2D map, to be taken into the field. We scanned the current state of the landscape of the study site, focusing on the settlement border and the vegetation. For this we used a TLS RIEGL VZ-1000, together with a calibrated NIKON D700 camera mounted on top, which we employed to take pictures synchronized with the scan. On two days during the summer 2016, we scanned fourteen positions.

Using RiScan Pro (RIEGL, www.riegl.com), a processing software for 3D laser scanners, we colorized the point clouds of the fourteen scan positions with their respective photos. This step also included co-registration and cleaning of the point clouds from scanning errors and noise in the data, incurred, for example, by swarms of insects, which were surrounding the TLS during some of the scans. Also lens flare effects on a few of the taken photos had to be retouched using Adobe Photoshop (http://www.photoshop.com). This post-processing resulted in a point cloud of approx. 300 million points, each assigned with their location and height (X, Y, Z) coordinates, and their respective RGB code from the photos. The mean density of the TLS point cloud was approx. 1550 points per square meters. Next, we integrated the two point clouds obtained at different spatial resolution.

Combining ALS and TLS Data

For integrating the ALS and TLS data into one single point cloud we chose the software Bentley Pointools (www.bentley.com), which is known for processing large amounts of point clouds. Nevertheless, dealing with the entire TLS landscape model turned out to be difficult for two reasons: Firstly, the point density of the scene was too high for smooth processing in Bentley. Secondly, because of the different days and daytimes of the TLS data acquisition, the data was heterogeneous in color and light intensity, which caused an inconsistent landscape image. These data challenges led to the following visualization strategy: Only important details in the foreground, like building façades at the settlement border and vegetation close to the views along the walk through path were visualized with the TLS data. The background, i. e., the topography, streets, buildings, and vegetation seen in the distance, were represented with the ALS data. With the Bentley 'Pointools' editing tools, the required points of the detailed objects were cut out from the TLS data and placed into the ALS point cloud at their respective position. This resulted in a final point cloud of about 30 million points, that is, approx. ten times fewer points compared to the initial TLS data.

Audio Recordings

We recorded the stereo audio atmosphere with a Jecklin-type disc (see Fig. 1), consisting of two omnidirectional microphones, separated by an acoustically muffled disc (FRIEDRICH 2008), and a two-track audio recorder (Sound Devices 702T). Recorded audio files (WAV) provide the correct stereo signal for reproduction via two loudspeakers. The sound recording positions were chosen along the planned path of the walk-through, in approx. 30-35 m. We created an audio file with a recording of the environmental sounds of approx. 2 minutes at each selected position along the walk-through path.

2.2 Generic Modeling of Landscape Changes and their Integration into the Point Cloud Model

For developing the future landscape development stages «Vision 2025» and «Vision 2050», a generic, procedural visualization approach was chosen. Based on the data set of the cantonal and communal spatial development strategy, possible future settlement parcels at the settlement border were extracted in Esri's ArcMap as GeoJSON files, to be imported into the software Rhino (www.rhino3d.com). With the plug-in Grasshopper (www.grasshopper3d.com), a visual programming environment within Rhino, the distribution of the buildings, their dimensions, and typology were calculated based on the rules of the construction and zoning ordinances of the Canton of Aargau. The vector dataset was then imported into and texturized within the Cinema 4D software (www.maxon.net). This resulted in polygonal, texturized, 3D building models, representing the landscape changes in the two selected scenarios[1]. The polygonal buildings (Fig. 2a) appear rather edgy in the smooth point cloud model. We thus decided to also render the buildings as point clouds (Fig. 2b).

We first employed the point renderer Krakatoa C4D (Thinkbox Software, www.thinkbox-software.com/krakatoa-c4d), a plug-in for Cinema 4D, to transform polygonal models into point clouds. This option was abandoned to avoid having to deal with different RGB value formats in the final point cloud. Instead of 8-bit integer, which range from 0-255, Krakatoa

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[1] Alternatively, we could have chosen Esri's CityEngine for the procedural modeling of the buildings (http://www.esri.com/software/cityengine).

uses the floating point format. The LAZPoint plug-in for Cinema 4D offered a more straightforward alternative. The planned buildings were thus represented with colored points, and integrated into the point cloud model of the current landscape situation. From Bentley Pointools (see Section 2.1), we thus imported the data with LAZPoint into Cinema 4D. In the next step detailed below, we developed the different views of the landscape, as a result of the development scenarios along a virtual walk from a pedestrian perspective.

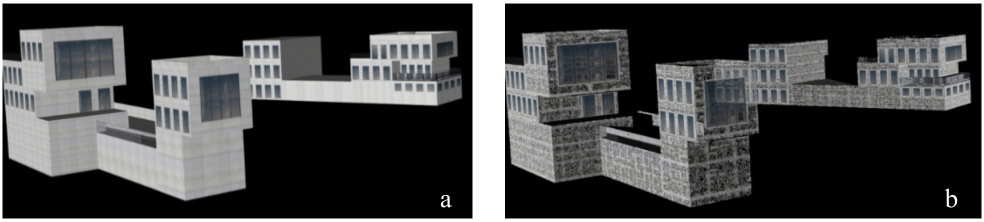

Fig. 2: Polygonal (a) vs. point cloud building models (b)

2.3 Preparing and Rendering a Walk through the Virtual Landscape

Although Bentley Pointools does provide a rendering function, the available lighting options and the settings to represent the sky are inadequate for realistic landscape depictions. Furthermore, the settings for defining a camera path are inferior to the functions provided by Cinema 4D. Therefore, the latter software package was used to prepare the final landscape scenes. The setup of a camera path is straightforward in Cinema 4D. However, a typical visual characteristic of point cloud models limits this approach. The closer one moves towards the points, the more the points spread apart, thus resulting in a foreground with rather low scene resolution. This is in direct contrast to current design guidelines for realistic 3D visualization. Landscape perception studies typically recommend highest levels of detail in the foreground of a scene (LANGE 2001, APPLETON et al. 2005). As a solution to this problem, we added a digital elevation model (DEM) of the area, at 0.5m spatial resolution, obtained from the Canton of Solothurn, and draped the ortho photo mosaic (see Section 2.1) on top. This terrain model provided a smooth and always visible surface, onto which we placed the point cloud. Following that, we adjusted the lighting settings, and added a naturalistic-looking sky. To increase realism, the sky was texturized with clouds and a background, adding some occlusion. Finally, 1650 pictures per scenario were rendered along the pre-defined virtual landscape walk-through. In a last step, videos had to be produced from the renderings (in *.png format), and combined with the audio recordings (see Section 2.1).

2.4 Generating the Audio-visual Simulations

The renderings were imported into Adobe Premiere Pro (http://www.adobe.com). We set the display duration of the individual renderings to 30 frames per second in the video. Audio tracks were also added to the video content. To give a natural impression of the environmental sound at the study site, the audio recordings were mixed. Natural sounds including birds and the wind are audible during the walk-through, as well as human-made sounds from cars, and noise from a construction site. Finally, three video files, including 55s of audio-visual landscape scenery along the walk-through were exported in 1280 × 720 HD mp4 format.

3 Results and Discussion

A pedestrian can now observe landscape changes from the current situation (3a) and the «Vision 2050» development state (3b) because of our presented workflow (Fig 3.).

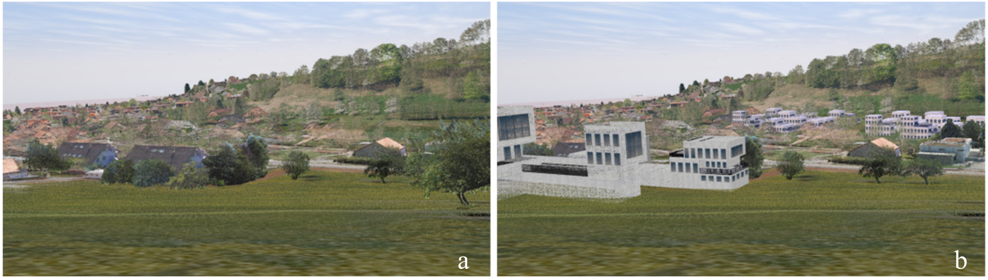

Fig. 3: Still images from the walk-through in the virtual landscape showing the current situation at the study site (a) and the state of the «Vision 2050» (b)

One might ask now whether the use of LiDAR data is worthwhile for 3D visualization of landscape changes. We have identified several issues associated with the preparation of such audio-visual landscape depictions, concerning data acquisition, technical challenges, as well as ethical issues, discussed in more detail below.

TLS scanning in the field is rather a time-consuming endeavor. We only later realized that not all the collected data were indeed necessary for the final visualizations. Scanning on multiple days with different lighting conditions can cause additional post-processing issues of the point cloud, especially regarding colorization. This means that careful preparation of the planned field work is necessary, to be able to collect desired data with minimal delays. As timing is critical, we recommend to identify which specific features need to be collected, and at which resolution, ahead of time. This to be able to prioritize the scans, and thus to limit the number of scans to those that are necessary. This would probably make it feasible to gather all the scans on the same day, for such a small study site as in our study (i. e., approx. 500 m^2). The time for data acquisition is indeed a critical issue, because of the seasonal changes in the vegetation. This means that visualizations that involve acquisition of LiDAR data need to be planned well in advance to be able to scan the environment when landscape features are in desirable conditions.

The same is true for audio recordings, which also need to be made at suitable days, and on appropriate times of the day. For our study, we only used audio recordings gathered directly in the field, using a simple stereo recording approach, to increase the vividness and authenticity of the simulated landscapes. However, for more sophisticated ambient environmental sound recordings and reproductions, a calibrated surround sound recording might be necessary.

We were challenged by the mixture of different software packages required to collect, and process the data to be visualized, and to set up the development scenarios, respectively. There was no single software package that was suitable for conducting the entire workflow from data processing to generation of the audio-visual scenarios. We pushed the limits of all used software packages as much as possible for the problem at hand, until we were forced to move on to another package that offered a solution or a missing function to complete a task. This required us to perform a great deal of manual processing in between of the different steps, particularly for the cleaning and pre-processing of the point cloud data, then for selecting and isolating desired landscape elements. A more automatic, GIS-based, and (semantically-driven) process for these steps would have been preferable. For example, the point clouds could be classified into different thematic layers including the terrain, the vegetation, the buildings, and other landscape features, which can be already done with point cloud processing software such as LIS (LASERDATA, www.laserdata.at).

Another area for improvement of the workflow and the visualizations is the effective and efficient combination of point clouds with GIS-based vector data to increase foreground detail while retaining the coherence of the land surface. Whereas, overall, the data integration works quite well, the foreground detail in our resulting simulations is still rather low. Based on the findings of MANYOKY et al. (2016) it remains to be seen whether our achieved level of detail might be sufficient for landscape perception studies, especially when focusing on emotional responses. One might explore the use of game engines, not only to increase the level of detail or the fidelity of the visualization, but also the dynamics of the depicted landscape features such as the grass in the foreground. Plug-ins including «Point Cloud Viewer and Tools» for the Unity game engine (https://unity3d.com) allow for importing LiDAR data directly into a scene and overlaying the data onto a terrain model, in similar fashion as we reported earlier using Cinema 4D. A further advantage of using game engines for display is the option to not only increase the visual fidelity of the visualization, but also to heighten the perceived immersiveness, e. g., when shown on various kinds of Virtual Reality (VR) presentation types. Head mounted displays, for example, have already shown to increase viewers' engagement with a depicted landscape (KULIGA et al. 2015, WISSEN HAYEK et al. 2016).

Nevertheless, our presented workflow seems suitable to generate landscape depictions with a high degree of visual realism. However, SHEPPARD (2004) reminds us to be careful with such highly realistic landscape renderings, because they can influence viewers' emotions and attitudes in potentially unwanted ways. Particularly when it comes to visualizing and assessing future landscape development scenarios, one unresolved question is whether and how the depictions should include planning uncertainties, e. g., new buildings could be rendered with non-realistic methods, to communicate this uncertainty (ZANLOA et al. 2009). As KULIGA et al. (2015) suggest, highly realistic-looking visualizations can also cause so-called "uncanny valley" effects, i. e., a negative emotional response to a depiction, which looks almost, but not quite truly realistic. This might even provoke negative feelings of eeriness, simply due to the graphic properties of a scene, but not necessarily due to its semantic content. Empirical follow-up studies with participants are necessary to evaluate the adequacy of the developed visualizations, for example, to study people's emotional responses to the shown landscapes.

5 Conclusion and Outlook

We presented a workflow to create audio-visual landscape stimuli using LiDAR data and in-situ audio recordings for future empirical studies to investigate people's perceptions and reactions to future landscape changes. The proposed workflow still generates about the same amount of work compared to conventional visualization approaches that replicate all landscape features with virtual 3D objects. In our visualization workflow, only new landscape features need to be fully modelled in 3D, thus modeling time is reduced, but data collection and processing of the LiDAR data requires a significant amount of time and resources. The technical aspects of the workflow could be further simplified and accelerated, for example, during data acquisition of the TLS data, and by considering further automatization of the data processing stages.

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