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Preparing 3D Point Clouds as Stimuli for Landscape Preference Studies: Lessons Learned

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Abstract: Representational parameters of landscape simulations can influence people's perception and preference judgements. Therefore, it is crucial to test their effects systematically. The goal of this paper is to answer a few key challenges encountered when preparing 3D point cloud stimuli for landscape preference studies in order to make an informed modelling choice. We present lessons learned from preparing 3D visualizations of landscapes with renewable energy systems, which served as stimuli for a laboratory experiment investigating landscape preferences. With a series of four small studies we tested the stimuli's suitability for purpose with regard to: (1) The placement of the renewable energy infrastructures on the landscapes and their representation; (2) the effect of seasonal aspects on preferences; (3) the presentation media (panoramic projection or head-mounted display); and (4) the display type (animated or static) and presentation form (simultaneous or sequential). The results of the first study show that designing landscape scenarios collaboratively with experts is important as they have a critical view on both, the technically realistic visualization of the landscape change and its representation. The 3D point cloud models were an appropriate means for this task. Further, audio-visual simulations presented with head-mounted displays can contribute to a higher level of immersion. The other two studies focusing on the effect of the seasonal aspect as well as the display type and presentation form revealed that the effect of the investigated aspects on stated preferences was not significant in the context of our study. The insights can inform other 3D visualization processes in relation to crucial aspects to be considered when generating stimuli using 3D point clouds.

Keywords: LiDAR-data-based 3D visualization, Environmental perception, Level of realism, Presentation media, Visualization types, Presentation forms

1 Introduction

3D visualizations provide valuable means for landscape planning and design with public participation. However, generating 3D visualizations includes many modelling choices on aspects such as the level of detail and interactivity or the presentation forms due to technical limitations or editorial decisions. Yet, it is not known, what the impact of these choices is on people's experience of the represented landscape and on the decisions they make (NASSAUER 2015). Therefore, the effects of 3D visualizations on people's perceptions and preferences need to be better understood and tested systematically (DANIEL & MEITNER 2001; NASSAUER 2015). The goal of this paper is to answer a few key challenges encountered when preparing 3D point cloud stimuli during a visualization process of landscapes with infrastructure of wind energy and photovoltaic (PV) systems in order to make an informed modelling choice. A special focus is on 3D visualizations based on point clouds.

During a visualization process many questions arise, which require a decision from the visualizers. The question on the level of detail, for example, needs often to be answered at the beginning of a visualization task. APPLETON & LOVETT (2003) show that the ground and especially the foreground needs a high level of realism, but the effect on the viewer's rating seems to be scene dependent. RIBE et al. (2017) found that the experiential perception is a

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major factor affecting acceptability ratings of wind farms in different landscapes, recommending that visualizations should have a very high level of perceived realism. However, there are still many other open questions regarding the preparation and presentation of 3D visualizations, e. g. concerning the effect of seasonal aspects, animation, or displays.

In our case, the visualizations served as stimuli for a laboratory experiment investigating landscape perceptions and preferences by measuring people's affective and cognitive responses. The affective responses were taken into account because it is known that purely objective landscape measures fall short due to a strong emotion related to landscape values (ULRICH 1986; MAEHR et al. 2015). A series of four small studies was conducted to test the effects of these stimuli with regard to different aspects: (1) How to visualize realistic scenarios of a mix of renewable energy systems in different landscapes based on point clouds? The mix had to be integrated into the scenes presenting feasible patterns and appearances of wind turbines and PV panels. Which approach is suitable for this visualization task? (2) Which presentation media should be chosen? – Study participants should perceive and imagine the landscape represented by the visualizations. This may be fostered by supporting a higher level of immersion into the landscape, i. e., the feeling of being present, which can be achieved, e. g., with large-sized image projections or head-mounted displays (BISHOP & LANGE 2005; WISSEN HAYEK et al. 2016). Are there any differences in people's perception of the landscape between these presentation media? (3) How much does the seasonal aspect matter in touristic, alpine areas for the perception and evaluation of the energy landscape scenarios? – The scene of the alpine tourism landscape contained skiing facilities and usually more people visit this area in winter than in summer. Therefore, the choice of the seasonal aspect and its impact on the people's perception of the energy scenario was crucial to investigate. (4) What is the effect of animated or still images? And shall the visualizations be presented simultaneous or sequential? Should the wind turbines need to be rotating and the clouds moving or not? The movement of scene elements may support the perceived level of reality (LOVETT et al. 2015). However, it may also focus the attention and distract from watching the whole scene. Further, it was not clear whether the scenarios should be presented simultaneous for direct comparison or sequential. We wanted to know if these decisions have an effect on the people's affective responses and their stated perception of the landscape.

Overall, the four studies were conducted with different intentions related to the general topic of informed visualization choices. In the following, the results of the four studies are briefly presented. Then we discuss these results with regard to the lessons learned. The insights can inform other 3D visualization processes in terms of crucial aspects which require special attention.

2 Investigating Visualization Choices

2.1 Realistic Visualizations of Renewable Energy Infrastructure

The aim of the first study was to create realistic visualizations of wind energy and photovoltaic (PV) systems in two landscape scenes (KESSLER 2017). For this purpose, a site analysis concerning spatial planning regulations was first carried out in Esri's ArcGIS to design the layout of the energy systems' distribution. Subsequently, 3D objects of the wind turbines and PV panels were placed in a virtual 3D model of the landscape scenes in Cinema 4D (Maxon) and renderings of selected views were created (Fig. 1). Following the approach of SPIEL-

HOFER et al. (2017), 3D point clouds were used as base data in order to obtain a highly realistic representation of the actual landscape. The foreground as well as built objects were depicted with a very high level of detail. Wind turbines and PV panels were placed in the form of 3D objects into these scenes. In a third step, these visualizations were evaluated by 10 experts for wind and/or solar energy based on a questionnaire. This included the renderings and a set of questions regarding the layout and the representation of the energy systems in the landscape scenes.

The results show that a GIS analysis was a straight forward approach to develop initial scenarios, which met professional standards. However, in the case of wind farms, more attention must be paid to the layout. On the one hand, the wind turbines must be placed in such a way that they take full advantage of the wind; on the other hand, the wind farm must appear as a unit. These aspects were not fulfilled by the visualized scenario shown in Fig. 1 on the left. It was designed in 2D to achieve maximum wind yield. However, the experts judged it as unrealistic because the distances between the turbines (although placed technically correctly) appeared too close to each other with an uneasy overall pattern. Furthermore, the experts judged the PV panels as too intrusive (Fig. 1, right) and the overall colour concept of the visualization appeared inconsistent.

Regarding the approach for expert evaluation, the questionnaire turned out useful. Though, in a later phase of the scenario design, workshops with experts and with the project team were more effective in providing direct comments on the scenarios and developing the final layouts together. For this phase, the point cloud model proved beneficial: for the experiment, comparable patterns of renewable energy systems in different landscapes had to be generated. Hence, the distances from the viewpoint to the wind turbines and PV panels had to be almost the same in every scene. To achieve this, being able to move the highly detailed foreground scans to the required distance in the point cloud model was very helpful. This was a legitimate solution in our case, because generic landscapes had to be depicted and not specific locations.

Fig. 1:
Left: Visualization of a potential wind farm scenario with a high spatial concentration of the wind turbines. Right: Visualization of a mix of integrated and non-integrated PV panel types distributed on the roofs in the landscape scene. (Renderings: LAURA KESSLER & RETO SPIELHOFER 2017).

2.2 Presentation Media: Panoramic Projection vs. Head-Mounted Display

In the second study, it was systematically examined if participants perceive and evaluate a landscape scene presented with a head-mounted display (HMD) differently than presented with a panoramic projection (GLANZMANN 2018). Again, 3D visualizations based on point clouds were prepared implementing Cinema 4D. This time it was an alpine area characterized

by tourism infrastructure such as ski lifts. For the presentation with the HMD, a 360° image of the landscape was rendered, whereas for the panoramic presentation three images with a focal length of 50° each were rendered and projected on three screens (Fig. 2).

In a laboratory experiment with 31 students, 16 participants perceived the landscape with the HMD and 15 participants saw the panoramic projection. Afterwards all of them rated the landscape aesthetics and answered a questionnaire with 5-point Likert scale questions concerning their feeling of being present in the scene, the perceived degree of their involvement and of the realism of the virtual landscape.

Fig. 2:
Left: Participant perceiving the landscape with a head-mounted display (Photo: Patrick Lehmann, 2018). Right: Setup of the panoramic projection in the laboratory.

The nonparametric Mann-Whitney U test (BORTZ & SCHUSTER 2010) shows that compared to participants perceiving the panoramic projection, the participants with the HMD stated a significantly higher feeling of being present ($z = 2.274$, $p = .02$, $r = .41$) and a higher involvement ($z = -2.721$, $p = .01$, $r = .49$) in the scene. This seems to have an influence on the aesthetics rating, because the median value was higher for the HMD group ($\tilde{x} = 4.5$, SD = 0.719) than for the group with the panoramic projection ($\tilde{x} = 4$, SD = 0.756). Regarding the perceived level of realism, the resolution of the images (as seen in the photo on the left side in Fig. 2) and the gap between the individual images during panorama projection (Fig. 2, right image) were criticized. Furthermore, some participants mentioned that they were missing environmental sounds to better immerse into the landscape.

2.3 The Effect of Seasonal Aspects on Preferences

The third study investigated the preferences for wind energy infrastructure in the previously presented alpine tourism landscape at different seasons. A preference study with 62 participants (71% men and 29% women; 20 – 66 years old, mean age 26.5 years) was conducted. Audio-visual simulation of the alpine tourism landscape with and without wind turbines in summer and in winter were prepared as described in section 2.1. For a realistic foreground visualization, terrestrial laser scanning data was acquired with a RIEGL VZ-1000 in summer and with a FARO Focus^{3D} X330 in winter. The latter was necessary because it is capable to scan also highly reflective surfaces such as snow. Furthermore, following the approach of WISSEN HAYEK et al. (2018), ambisonic sound recordings were made at the viewing location in summer and in winter.

In the experiment, participants watched two short videos of 30 seconds each with the audio-visual simulations of the landscape with and without wind turbines either in summer or in winter (Fig. 3). Then, they rated the perceived landscape with a questionnaire and provided

short oral statements (1-2 minutes) on their perceptions. Finally, they answered socio-demographic questions.

Fig. 3:
Panoramic projection of the alpine tourism landscape in summer (left) and in winter (right) (Photos: ANDREA WÜST 2018)

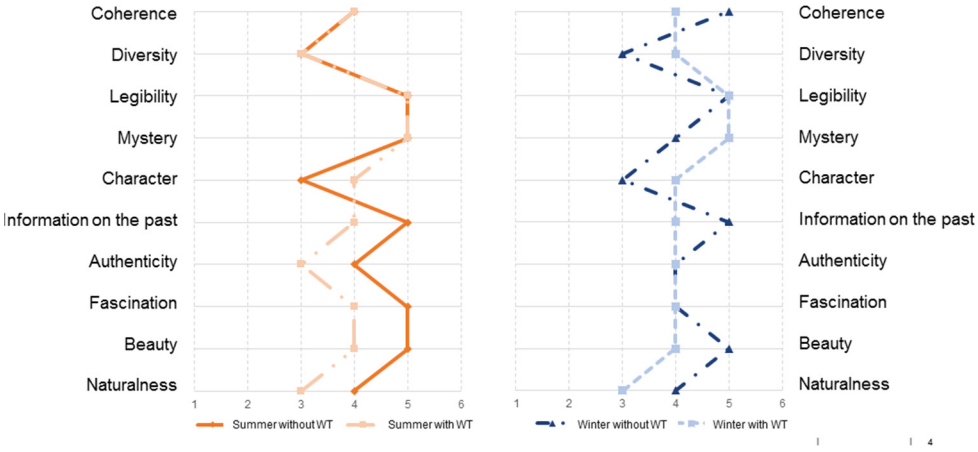

Fig. 4: Perceived quality ratings of the landscape scenes in summer (left) and in winter (right). (Source: ANDREA WÜST 2018)

The results show that wind turbines have an impact on the perception of the landscape (Fig. 4). However, there are no significant differences between the perception of the summer and the winter landscape with wind turbines. Only a slight trend indicates that, in this landscape, wind turbines are more preferred in winter than in summer (WÜST 2018).

2.4 Display Type and Presentation Form

The goal of the fourth study was to investigate the influence of the display types, which is animated or still images, and of the presentation forms, simultaneous or sequential, on perceptions of and affective responses for landscape types (SCHWERI 2018). 3D simulations of wind parks in three different landscapes of Switzerland (Jura, urbanized Plateau, and alpine tourism landscape) were generated. Thereby the same 3D point cloud approach was applied as in the other studies presented before. In a laboratory experiment with 74 students (45 % = men, 55 % = women; 19 – 29 years old, mean age 21.5 years), we measured the affective responses by participants' skin conductance and the stated landscape preferences depending

on the display types and the presentation forms of the simulations. The participants were always presented a pair of landscape types and had to choose the landscape they preferred. In addition, we asked them to rate the landscapes as well as to answer questions on their landscape perception.

The results show that neither the display types (static or animated) nor the presentation forms (simultaneous or sequential) had a significant effect on the participants' choices of the preferred landscape. Hence, we regarded both types and forms as appropriate for investigating stated landscape preferences in our laboratory experiment and in a related online study. However, both types and forms showed effects on the affective responses.

3 Lessons Learned

In this section, we focus on the lessons learned from the different studies. Regarding the development and visualization of realistic scenarios of a mix of renewable energy systems in different landscapes, the collaborative approach with varying level of participation proved successful. The fine-tuning of the scenarios with the experts employing the 3D visualizations was very important for defining an actually realistic layout of the renewable energy systems in the landscapes. Whereas in the beginning of the visualization process the questionnaire was very efficient to gather structured feedback, in later phases, workshops with experts or other stakeholders turned out more efficient to make final design decisions together. Furthermore, the experts' stressed that the colours chosen for the energy systems are very critical. Overall, it seems to be crucial to establish colour concepts for such landscape visualizations (see also RIBE et al. 2017).

The test of the different presentation media's influence on the people's landscape perception showed that compared to a panoramic presentation, a head-mounted display leads to a higher involvement, a stronger feeling of being present, and a higher perceived level of realism. Whereas this was shown already by, e. g., WISSEN HAYEK et al. (2016), we also identified that these effects seem to have an influence on the aesthetics rating. In addition, participants recognized environmental sound as missing. This suggests that audio-visual simulations may be preferable stimuli for perception-based visual landscape quality studies – ideally with movement of the user in the virtual space (ECHEVARRIA SANCHEZ et al. 2017).

As seasonal aspects did not influence participants' preferences, we decided to neglect this effect in the main experiment. However, because of identified tendencies for higher preferences of wind turbines in alpine tourism landscapes in winter, further investigations on local scale might be advisable, where the seasonal aspects in combination with the respective land use activities are taken into account. Point clouds turned out suitable for preparing rather realistic simulations of seasonal aspects, but the terrestrial laser scanner needs to be capable to scan, e. g., reflective surfaces.

Finally, our results show that animated or static simulations or simultaneous or sequential presentations of stimuli do not influence landscape preferences. However, as affective responses were affected by these visualization choices, we need to better understand how affective responses contribute to the emotional process of decision-making and what influence the display types and presentation forms have in this context. In addition, a comparison with

affective responses to the real landscape would be valuable, in order to see how they differ from the ones measured in the laboratory.

4 Conclusion and Outlook

Stimuli using 3D point cloud visualizations can be prepared in various ways. We present in this contribution four different studies investigating important issues encountered while preparing the stimuli. The four studies provide concrete starting points for critical reflection of possible effects of modelling choices. Moreover the results stress that the specific purpose of the visualization is pivotal for deciding if the setting of a certain visualization aspect (e. g. only one seasonal aspect) is appropriate. This means that such study results must be interpreted thoughtfully when transferring them to other cases, considering the respective context. For fostering informed visualization choices, an overview of what is already known should be established and iteratively enhanced with new findings. A central repository of these findings could support generating 3D visualizations in an informed manner and help ensure that actually the represented landscape and not technical visualization characteristics are affecting, e. g. preference judgements. This is crucial, because otherwise recommendations based on the results of studies conducted with 3D landscape visualizations might be misleading.

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