Investigating Effects of Animated 3D Point Cloud Simulations on Emotional Responses

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Abstract: 3D simulations are increasingly used in virtual reality laboratory experiments for measuring emotional responses in order to gain a deeper understanding of the perception and judgment of visual landscape quality. Ensuring that these simulations are valid for the intended task is crucial. We demonstrate how we tested animations of a flight into 3D point cloud models of urban areas on the subject of their possible influence on people's arousal response. Furthermore, we provide insights into the technical development and implementation of these simulations. The simulations were set up in a game engine and presented on a head-mounted display. In the experiment, one group first saw the areas in a bird's-eye view followed by a flight down to a pedestrian view. The other group was shown the pedestrian view only. During the presentation, arousal was assessed by measuring skin conductance response and with the Self-Assessment Manikin (SAM) questionnaire. Based on the results we can conclude that the animated flight and the perceived movement that comes with it does not affect the measured arousal response signals. However, further studies are needed to understand the response patterns to the different urban areas. Regarding the animated landscape simulation, the level of detail management of 3D point clouds needs further enhancement in order to provide more consistent transitions between the abstract landscape representation during the flight and the highly detailed perspective at ground level. Alternative approaches such as a combination of 360° videos for the flight and 3D point cloud simulations should be tested.

Keywords: LiDAR-data-based 3D visualization, animations, Virtual Reality, environmental perception; arousal aesponse, physiological response

1 Introduction

Virtual 3D landscape visualizations are frequently used as stimuli in studies for systematically investigating responses to environments in controlled conditions (HIGUERA-TRUJILLO et al. 2017). In these virtual reality (VR) experiments, increasingly not only cognitive statements but also physiological responses of the autonomous nervous system are assessed, e.g. by measuring electrodermal activity (EDA), in order to gain insights into emotional response patterns (MAEHR et al. 2015, HACKMAN et al. 2019, WISSEN HAYEK et al. 2019, YU et al. 2017). It is known that emotions are drivers of decision-making and that there are, inter alia, interactions between cognitive and motivational mechanisms triggered by emotions, which may affect specific judgments or decisions (LERNER et al. 2015). There is also a strong emotional component to landscape values (ULRICH 1986) and the visual landscape quality is influencing people's motivation to initiate creative landscape shaping processes that can contribute to a more resilient development of human-dominated landscapes (GOBSTER et al. 2007, NASSAUER 2012). Therefore, the combined interpretation of people's cognitive and affective emotional responses can help gaining a deeper understanding of visual landscape perception and judgement (ULRICH 1986; PARSONS & DANIEL 2002). However, transferring the insights on people's landscape perceptions derived from VR experiments into the real world is only feasible if the stimuli adequately represent the depicted landscapes. In other words, the cognitive as well as the affective responses must not be biased by characteristics of the simulations (ROHRMANN & BISHOP 2002, HIGUERA-TRUJILLO et al. 2017).

Simulations can only approximate the reality and thus the responses cannot be expected to be identical (ROHRMANN & BISHOP 2002). However, HIGUERA-TRUJILLO et al. (2017) show that particularly 360° panoramas and interactive VR environments presented with a headmounted display (HMD) can provoke quite similar judgments and physiological responses as the physical environment. Further, the level of detail (LOD) offered in the VR environment influences aesthetic landscape judgments (RIBE et al. 2018). Virtual environments consisting of three-dimensional (3D) point cloud data obtained from LiDAR (Light Detection and Ranging) scans have proven to be suitable for representing landscapes while maintaining individual characteristics of a certain location and providing a high LOD especially in the image foreground (SPIELHOFER et al. 2017). When combined with congruent environmental sound, virtual landscape scenes can further increase the level of perceived realism (ROHRMANN & BISHOP 2002, LINDQUIST et al. 2016). Although these findings provide valuable starting points for generating valid stimuli for VR experiments assessing visual landscape quality, the influence of many simulation characteristics on human responses are still unknown. In this paper, we focus on the aspect of movement in virtual reality stimuli and its influence on people's affective response.

As part of an investigation on the processes in peri-urban landscapes around European cities, an experiment was intended to be conducted using audio-visual simulations of environments based on 3D point clouds as stimuli to measure people's affective response to different (peri-)urban residential areas. For this experiment, showing merely a pedestrian view of the locations to the participants was considered an insufficient representation of a (peri-)urban area. In particular, the uniform characteristics of the peri-urban landscape in flat terrain is not well represented in the pedestrian view only. Thus, a bird's-eye view needed to be incorporated into the simulations to help participants gain an understanding of the larger landscape context and the dimensions of the investigated areas (cf. KRAAK 2002). To link the two perspectives, an animated flight from the bird's-eye view down to the pedestrian view was implemented.

Movement, like the above-mentioned animated flight, was however expected to negatively affect the signal of the participants' affective responses. Therefore, this study was conducted addressing the question whether an animated flight is a suitable stimulus for the intended physiological experiment. Another part of the investigation was finding a way to visualize (peri-)urban areas on two very different scales in one single 3D model. Especially, as the input data varies greatly in resolution and the size of data can range up to several hundreds of millions of measurement points. Hence, the goals of this paper are (1) to provide insights into the technical development and implementation of the animated 3D point cloud simulations on people's emotional response. Based on the study results we discuss the suitability of the animated 3D point clouds for the intended laboratory experiment. Moreover, we reflect more generally on the 3D simulation workflow and provide suggestions for alternative approaches.

2 Methods

2.1 Development of the Animated 3D Point Cloud Simulations

As stimuli for the experiment, an urban and a peri-urban residential area were simulated. Each of the two environments consists of several components that require a different set of processing steps using different equipment and programs (Fig. 1), all combined in a virtual scene in the game engine Unity (V. 2018.3.3f1, www.unity.com). This scene is a virtual 3D model including a bird's-eye and a pedestrian view as well as a flight between both perspectives.



Fig. 1: Overview of the individual workflow steps and required programs for the different components for generating the Unity scenes of the urban and the peri-urban area

In the following, the process of data collection, post-processing and integration into the Unity scene is described. To represent the environments from a pedestrian view at a high level of detail, LiDAR data was obtained for the two areas with a terrestrial laser scanner (TLS, RIEGL VZ-1000 equipped with a calibrated Nikon D 700 camera). In addition, environmental sound was recorded at each location with an ambisonic microphone (Sennheiser AMBEO VR Mic). At each location, several LiDAR scans were made and during post-processing put together, aligned, and colorized to one comprehensive point cloud using the software RiSCAN PRO (V. 2.3.2; RIEGL). Moving objects e. g. leaves on trees often cause a mismatch between the laser scanned measurement point and its supposedly corresponding colour obtained from the scanner-mounted camera image, which results in white coloured tree crowns. This was corrected by manipulating the images in Adobe Photoshop CC (V. 19.1.5) replacing the white sky with a texturized green surface (Fig. 2). In addition, so-called air points from deflection of the laser beam by highly reflective surfaces, as well as points of passing cars, cyclists, and pedestrians were removed manually. Since it is advantageous for

the visualization to have fewer points in order to keep the project size small and maintain good navigation, the amount of points has been reduced. For each location, the point clouds were manually divided into different landscape elements such as tree trunks and crowns or different parts of the ground. Then, the points were thinned out using Octree filters while applying different settings for the individual elements in order to retrieve a significantly lower but still visually adequate point density. Finally, the processed point clouds were exported from RiSCAN PRO as open format LAZ data, which is a lossless compressed variant of LAS, a binary file format for the interchange of 3D point cloud data.



before Image Modification

after Image Modification

Fig. 2: Left: Photo of a scan position and point cloud of a tree crown colorized with this photo. Right: Photo with the sky coloured green and point cloud of the tree crown colorized with the adjusted photo.

The sound recordings were processed to congruent sound sequences for the two urban areas using the digital audio workstation Reaper (www.reaper.fm). These sequences were arranged in a data flow system to so-called patches using the software Max 8 (https://cycling74.com). During the experiment (cf. section 2.2), this Max patch was triggered from the Unity scene with open sound control (OSC) signals for playback of the respective sound sequence on five loudspeakers connected to a PC through a MOTU 896mk3 audio interface.

For developing the bird's-eye view, point clouds of airborne laser scanning (ALS) obtained from administrative data were used. The LAZ files were opened in the software CloudCompare (V. 2.0.1 64 bit, https://www.danielgm.net/cc) and cut to the required perimeters of the urban areas. Then, the data was classified into ground, buildings, and vegetation and colorized with orthophotos using the software LIS Pro 3D (www.laserdata.at). The vegetation points were imported into Unity with the Unity plug-in "Pointcloud Viewer and Tools" from

the Unity Asset Store. Since the ALS data provided only points of the roofs, these were further processed with LIS Pro 3D's "City Modeller" function to 3D building models. The models were exported as shape files (shp) and colorized as well as converted to 3D building models (FBX files) in Esri's City Engine (V. 2017.1). The FBX objects were then imported into Unity and manually aligned with the terrestrial point cloud model. For the surrounding landscape, given the flat topography of the study area, a simple plane was inserted and colorized with orthophotos of the respective area, which had been exported from the software QGIS (www.qgis.org) to JPEG files. Next, the LAZ files of the point cloud data were imported with the above mentioned Unity plug-in. For representing atmospheric conditions, a sky dome was added gained as object from the Asset Store. Due to the reflectivity of the windows the point cloud data were erroneous and not sufficient for a realistic representation at a close view, so for these windows a Unity object with a reflective surface was generated.

Finally, a camera path for the flight from the bird's-eye to the pedestrian view was generated with the Unity plug-in "LeanTween Editor" (V. 0.950). The starting point was set at 520 m above ground and in 900 m distance from the viewpoint of the pedestrian view. A Bézier curve with a slope of -30° was defined, which ends horizontal to the ground. During the flight, the dense TLS point clouds caused a flickering image display. To overcome this problem, these point clouds were not shown until two meters before the end-point. Closing in on the end-point, the TLS data were made visible using a script "Activate Point Cloud" and at the same time, the abstract ALS data were hidden with a script "Hide Point Cloud" (Fig. 3).



Fig. 3: View at the start of the flight-path (1), during the flight (2), two meters before landing on the ground (3), and when exploring the scene at the pedestrian position (4) of the simulated urban residential area

2.2 Laboratory Experiment

The experiment was conducted in an audio-visual lab (AV Lab) with 44 adult participants (19 women, 24 men, 1 diverse; aged between 21 and 60 years; 30 people aged between 21 - 30 years). The participants were distributed into the two groups "Flight" and "No Flight". Within the groups the order in which the two environments were presented was pseudo-ran-

domized by assigning half of the participants in each group to see the urban environment first and the other half to see the peri-urban environment first before experiencing the respective other environment (Fig. 4).



Fig. 4: Study design with two experiment groups "Flight" and "No Flight" showing the timeline for the experiment

There are several ways to measure emotional, not consciously controllable responses to visual stimuli. One of the three dimensions of emotion is arousal, for which according to BRADLEY & LANG (2000), skin conductance is a good index when seeing pleasant or unpleasant images. We measured electrodermal activity (EDA) by placing sensors (ADInstruments Powerlab 8/35 and GSR Amp, low AC voltage of 75 Hz) on the second finger phalanx on ring and index finger on the inside of the left hand, and recording the electric conductivity of the skin (measuring range at 0-40 μ S, measuring frequency of 1kHz) using the software Lab-Chart (V. 8.1.13). The participants were instructed to rest their left hand on a table during the experiment (Fig. 5, right).

In addition, we recorded what emotional response was stated by the participants. For this we used the so-called self-assessment manikin (SAM; BRADLEY & LANG 2000). The SAMquestionnaire consists of three 9-point-scales with graphic figures representing different stages on these scales. Each of the three scales corresponds to one of the dimensions of emotion: valence (from unhappy to happy), arousal (from relaxed to excited), and dominance (from out-of-control to in-control). In contrast to the skin conductance measurements, the SAM can show whether an arousal response is positive or negative (BRADLEY & LANG 2000).

For measuring the baseline of the EDA, the participants saw first a fixation cross for 20 seconds and then a relaxing video of nature scenes for four minutes. After the baseline video, the participants did the SAM-rating on a tablet computer, stating how they currently felt. Then, the first 3D point cloud simulation was presented on an HMD (HTC Vive, resolution of 1080×1200 pixel per eye, frame rate of 90 Hz, 110° field of view). The prepared environmental sound sequence was played back as 5.0 surround sound with five loudspeakers. The group "Flight" saw a bird's-eye view of the environment for 15 seconds followed by a flight of 17 seconds to the pedestrian view. During the flight, generic wind sounds were audible, blending with the environmental sound when approaching the ground. Both groups

perceived the pedestrian view for 122 seconds. Subsequently, the participants rated again their current emotional status with the SAM. After this, they saw the second environment according to the group specifications (Fig. 4). This part of the experiment took about 12 - 15 minutes per participant depending on the group.

At the end of the experiment, the participants filled out an online questionnaire on their perception of the bird's-eye view, the flight, and the pedestrian view (level of realism and immersion; duration), and on the comfort of the HMD and the skin conductance measurement. The overall procedure, including an introduction, an informed consent, and a familiarization of the participants with the HMD took about one hour.



Fig. 5: Set-up in the AV Lab. The experimenter controls the desktop PC for running the experiment. The participant with the head-mounted display and sensors on two fingers, is surrounded by five loudspeakers playing the sound of the respective scene.

The whole experiment was set up with the framework EVE, Experiments in Virtual Environments (GRÜBEL et al. 2017) running in the software Unity. This framework offers an interface between the visual stimuli, the measuring instrument as well as recording software of the physiological arousal and a MySQL database. After each run of the experiment, timestamps were automatically generated by EVE and placed at defined events during the experiment, e. g. at the start and end of the baseline video as well as of the pedestrian view, which are the relevant response windows for data analysis (Fig. 4).

The EDA data was processed with the software MATLAB (V. R2016b) running the script Ledalab (V. 3.4.9, www.ledalab.de) for downsampling the data from 1 kHz to 10 Hz, and decomposing the phasic and tonic signals with a continuous decomposition analysis. From the phasic EDA, the number of skin conductance responses (nSCR) per second was calculated and normalized with each participant's baseline response. Based on HACKMAN et al. (2019) we assumed that the perception of the virtual environments led to a general increase in nSCR.

In order to analyse whether the flight led to a short-term carry-over effect, i. e., higher arousal due to the movement, the response window of the pedestrian view was divided into two parts of 61 seconds each and the respective normalized nSCR values per second were calculated. The nSCR values, the SAM data, and the data of the questionnaire were statistically analysed using IBM SPSS Statistics (V. 25).

3 Results

Concerning the core research question of the experiment we found that the group "Flight" did not have an overall higher arousal response than the group "No Flight" (Mann-Whitney-U-Test, peri-urban area: p = .681; urban area: p = .418). The group "Flight" showed slightly higher differences in the nSCR values between the urban and the peri-urban scene (Wilcoxon-Test, p = .301) than the group "No Flight" (p = .931), however, these were statistically negligible within the groups. The comparison of the differences in the arousal response of the first and second half of perceiving the pedestrian view revealed a significant difference for the group "No Flight" for the urban area (Wilcoxon, z = -3.547, p = <.001), with a strong effect (r = .77) according to Cohen (1977). In contrast, between the urban and the peri-urban area there are no significant differences between the groups "Flight" and "No Flight" regarding the nSCR values neither for the first nor the second part of perceiving the pedestrian view.

The ratings of the Self-Assessment Manikin (SAM) for the three emotional dimensions did not differ significantly between the groups. However, regarding the differences between the two areas, in both groups the ratings for the valence dimension differed significantly and with a strong effect ("Flight": z = -1.998, p = -0.46, r = .42; "No Flight": z = -2.021, p = .043, r = .44). Concerning the arousal dimension, only the differences in the ratings of the group "No Flight" are significant (z = -2.451, p = .014) and with a strong effect (r = .53). No significant differences were shown for the dimension dominance. Overall, the group "Flight" showed higher nSCR values and higher arousal in the SAM-rating for the urban area than for the peri-urban area, whereas the pattern is the opposite in the group "No Flight".

The questionnaire revealed that the pedestrian view was rated slightly more realistic by the group "Flight" than the group "No Flight". Both groups could immerse themselves quite well into the environment of the pedestrian view and stated that they got a good understanding of the presented type of urban area. The animated flight, in contrast, was rated less positively regarding the above aspects. Moreover, whereas both groups perceived the duration of the pedestrian view as good, the group "Flight" considered the flight duration good but rated the bird's-eye view as too short. The majority of the group "Flight" appraised the transition between the flight and the pedestrian view as rather unpleasant. Participants mentioned particularly the low LOD of the 3D buildings as well as the sudden appearance of the highly detailed 3D point clouds at the pedestrian view as disturbing (Fig. 3).

4 Discussion and Conclusions

With regard to the emotional responses on the animated 3D point cloud simulations, i. e. the flight from bird's-eye view to pedestrian view, compared to the non-animated simulations, we neither found effects on the physiological arousal responses nor on the cognitive SAM-ratings. Based on these results we can conclude that in general the animated 3D point cloud simulations are suitable stimuli for investigating the affective response to different types of (peri-)urban areas. However, when comparing the responses on the different urban areas, the two groups showed different patterns in their responses. The design of the experiment was not sufficient to understand why this occurred. In order to enhance the understanding of the physiological response patterns regarding positive or negative effects of the visual urban quality, more data on the participants' cognitive landscape assessment would be helpful, e. g., about the perceived quality of the landscape structure (WISSEN HAYEK et al. 2019). Further-

more, a combination of different methods for physiological responses, e. g., eye tracking or measuring the heart rate and pupil size, may be useful for supporting data interpretation (HIGUERA-TRUJILLO et al. 2017). When using further methods for measuring the physiological response to urban areas with 3D simulations, the effect of the flight on these measures needs to be analysed, too. Furthermore, the results must not be generalized to the whole population or to all types of landscapes as we only tested two types of urban areas and the results were obtained with a small sample of mainly young, well-educated adults used to digital applications and trained in reading spatial landscape patterns.

Technically, the quality of the flight was not satisfying the participants. Although the bird'seye perspective was appreciated for gaining an overview, the LOD of the 3D simulation and particularly the transition from a low to a high detailed representation of the environment were rated negatively. A LOD needs to be provided, which matches the view distance, and the viewing duration needs to be better harmonized between the different perspectives. As an alternative approach, a sequential presentation, separating the different levels of detail as in a cinematic change on sceneries, should be tested. This might reduce the expectations of a perfect transition between an abstract and a realistic representation. However, for preparing stimuli to investigate effects of a broad range of urban areas, also other, less time consuming visualization approaches, such as 360° videos taken with Unmanned Aerial Vehicles (UAV) for the flight should be taken into account. 360° panoramas have been proved as valid stimuli for investigating the participants' psychological responses, whereas virtual 3D simulations with a high level of detail were better suitable for measuring the physiological responses (HIGUERA-TRUJILLO et al. 2017). Further testing of such 3D visualization workflows and of the suitability of the resulting stimuli for the intended purpose is required. Only then, it can be ensured that the results of such experiments can support recommendations for the improvement of visual landscape quality.

Acknowledgements

This study was carried out in the scope of the ERC project GLOBESCAPE (Research Grant: 757565). The experiment was approved by the ethics commission (EK 2018-N-125).

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