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Validity of VR Technology on the Smartphone for the Study of Wind Park Soundscapes

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Abstract: The virtual reality of the landscape environment supplies a high level of realism of the real environment, and may improve the public awareness and acceptance of wind park projects. The soundscape around wind parks could have a strong influence on the acceptance and annoyance of wind parks. To explore this VR technology on realism and subjective responses toward different soundscapes of ambient wind parks, three different types of virtual reality on the smartphone tests were performed: aural only, visual only, and aural–visual combined. In total, 21 aural and visual combinations were presented to 40 participants. The aural and visual information used were of near wind park settings and rural spaces. Perceived annoyance levels and realism of the wind park environment were measured. Results indicated that most simulations were rated with relatively strong realism. Perceived realism was strongly correlated with light, color, and vegetation of the simulation. Most wind park landscapes were enthusiastically accepted by the participants. The addition of aural information was found to have a strong impact on whether the participant was annoyed. Furthermore, evaluation of the soundscape on a multidimensional scale revealed the key components influencing the individual's annoyance by wind parks were the factors of "calmness/relaxation" and "naturality/pleasantness". "Diversity" of the soundscape might correlate with perceived realism. Finally, the dynamic aural–visual stimuli using virtual reality technology could improve the environmental assessment of the wind park landscapes, and thus, provide a more comprehensible scientific decision than conventional tools. In addition, this study could improve the participatory planning process for more acceptable wind park landscapes.

Keywords: noise annoyance; virtual reality; wind park perceptions; soundscape; aural visual interaction

1. Introduction

Wind parks are viewed as the top investment objective in renewables according to European Union (EU) targets, leading to the rapid increase of wind farms across Europe. The installation of new renewable energy in the landscape has reached a critical mass, and is becoming a great issue in Germany and all over Europe [1]. According to a recently accepted survey about energy technology, there were significant differences between the acceptance of wind parks on the national and local levels. This was mainly because of the landscape modification after constructing wind farms [2]. In addition, not-in-my-backyard (NIMBY) syndrome increased the difficulty of the local acceptance of wind farms. The lack of the public's participation in wind park projects has been a key issue for successful wind energy planning, and the EU has encouraged transparency and early involvement in wind energy projects [3]. The procedure for evaluating design from human-centered perspective and the gap between technical potential and social needs should be studied [4].

In contrast to the linguistic methods, using direct presentation of the wind park landscape and digital landscape visualization could improve public participation and enable to receive more responses related to wind energy projects. In addition, the development of technology could enable the designers of landscapes and urban areas to use digital visualization tools for landscape design, planning, and management. Currently, digital landscape visualization is becoming the clearest approach that expresses the designs and planning processes from designers. However, as it is lacking in the demonstration and illustration with regards to depth perception, rendering images, and physical models, traditional landscape visualization does not fully meet the requirements of fast-developing landscapes. For example, traditional visualization media, such as the geographic information system (GIS) maps and photo-realistic images, were difficult for participants to understand. They also might cause confusions or errors in their orientation recognizing [5,6]. Today, researchers are beginning to represent the future landscape in a controlled laboratory by using immersive virtual reality (VR) technologies for participants. In related field work, VR has verified that it can effectively reproduce visual and aural information for participatory evaluation [7–10].

Although the visual images are the dominant human sensory for landscape perception, they only provide partial information and lack another important sensory component: sound information. Thus, a more comprehensive method should be encouraged to evaluate participants' annoyance from the landscape constructions. Manyoky conducted an investigation on the effect of the addition from ambient sounds to the simulations of the perceived realism [6,11]. Unlike traditional demonstration methods, visual–aural stimuli in VR simulations with head orientation can leave users with a feeling of human perception. In addition, the adoption of these technologies for smartphones can enable more members of the public to participate in landscape designs by providing the information via the smartphone, which has been rapidly enhanced in the last decade [12]. The combination of VR technologies of smartphones and audio rendering effects make it possible to perform a new experiment for conducting a reasonable environmental assessment. So far, no studies are made to validate VR simulations of wind park projects on smartphones. This can be demonstrated with applications, with the aid of the Unity 3D game engine. This technology is easily accessible and cost-favorable, and helps the public to communicate with wind park projectors and encourages them to participate, which can help the designers to make educated decisions.

It was also interesting to find that the attitude toward noise of wind turbines has no significant correlation with subjective annoyance [7–10]. This suggested a phenomenon, generally, that people have a bad impression of the noise of wind turbines in mind from first sight, even if they do not have any real experience with wind turbines in the landscape. The noise of wind turbines was masked by surrounding natural sounds or traffic sounds in the background, and presentation of soundscape ambient wind parks could give them different impressions, thus modifying their responses as expected. In addition, the combination of motion and sound were reported to be important for a reliable evaluation of the landscape [13]. Due to the fast developments of computer digital technology, interactive and 3D visualizations can offer new opportunities to improve public communication in the planning stage. The VR technology linking acoustic information enables landscape visualization with a high level of realism, based on geodata with added detailed 3D models and dynamic processes.

The purpose of this study is to apply VR technology pairing aural information to explore the impact of sound on the wind park landscapes. Empirical evidence of the contribution was provided to perceived realism and subjective responses of VR simulations on smartphones. The realism and the relevant factors, i.e., preference ratings and soundscape characteristics in the context of wind parks, were further explored. This study starts with ratings of the realism of VR simulations. Then individuals' general responses (acceptance or annoyance) were evaluated, and the aural–visual interactivity was thus explored. Finally, the soundscape characteristics were explored and compared with the ratings of VR realism.

2. Materials and Methods

2.1. Site Selection

Rural landscapes are multiform, and usually generate varied soundscapes with extremely different attributes. To validate the VR simulation on the smartphone for the study of wind park soundscapes, main soundscapes around wind parks need to be explored. Thus, sites with typical soundscapes of ambient wind parks were selected based on the previous studies [14,15]. As a result, seven sites with main characteristics (site 1: high traffic flow, site 2: bird sounds, site 3: motorway, site 4: human sounds, site 5: leisure activities, site 6: medium traffic flow, and site 7: water sounds) were chosen for the case study (Table 1).

After the selection of expected sites, aural and visual materials were prepared for laboratory experiments as described in the following paragraphs, to develop related VR simulations on a smartphone.

Table 1. Elements in the scenarios at each site.

	Sound Features	**Visual Features**								**Description**	**L_{Aeq} [dB]**
Sites		**Wind Turbines**	**Cars**	**People**	**Stream**	**Road**	**Dwellings**	**Trees**	**Sky**		
Site 1	High traffic flow	×	×			×		×	×	Main Avenue with high road traffic flow with a large number of vehicles.	65.3
Site 2	Birds	×						×	×	Location situated in natural environment isolated from sounds of human activity, sounds dominated with bird sounds.	39
Site 3	Motorway	×	×			×		×	×	Location situated in the motorway.	52.5
Site 4	Human sounds	×		×			×	×	×	Location situated in a residential area, sounds included people talking.	50.2
Site 5	Leisure activities	×		×				×	×	Location situated near residential area, with sounds of outdoor activities.	53.6
Site 6	Medium traffic flow	×	×			×		×	×	Location situated in a residential area with medium road traffic flow.	41.2
Site 7	Water	×			×		×	×	×	Location situated in natural environment, with sounds from stream.	43.7

2.2. Aural and Visual Materials

Firstly, a preliminary site survey around wind parks was conducted in the selected seven sites. In order to link ambient sounds with the VR landscape model and avoid complexity of the task, the related binaural recordings of ambient wind parks were made with clear weather from 11:00 a.m. to 3.00 p.m. using a dummy head with a height of 1.6 m and a recorder (DAT 208Ax, Sony (Tokyo, Japan)) at selected viewpoints of these sites. A-weighted sound pressure levels (L_{Aeq}) were measured in 3 min at each viewpoint (Table 1). Each recording point was placed more than 1000 m from the wind park in consideration of the local regulations regarding distance limitations to residential houses [16]. Thus, the noise of wind turbines was not considered in this study.

Subsequently, visual scenarios were made for each site in Unity 3D with the help of 3ds Max modeling software. The modeling procedure and tools used for the laboratory experiment are illustrated in Figure 1. Visual scenarios were created to approach the real landscape, which contained the visual features of each site listed in Table 1. To reach this task, a digital elevation model (DEM), also named height maps, was used to generate the terrain. The digital elevation model recorded the details of height elevation, and the basic ground in the simulated landscape was created to approach the real site. Textures including vegetation, roads, and other elements were then draped over the digital terrain with the help of Photoshop program. As the simulation progressed, the initial ground was covered by textures representing grass and roads etc. Other digital assets, including trees, cars, wind turbines, and other objects in 3D file formats were inserted into the defined areas with the help of the 3dx Max modelling program. The detailed modeling was mostly modeled by hand. With the aim of creating simulations that are close to the wind turbine in reality, the object of wind turbines was required to be dynamic, avoiding the negative effects of static wind turbines [17]. Thus, the scripting for dynamic wind turbines was built on Mono, which was an open-source implementation of the .NET Framework. The basic 3D models inserted above were matched with each actual survey site (wind turbines, cars, people, stream, trees, grass, road, house, sky, etc.) (Table 1 and Figure 2).

Finally, the recorded onsite aural data were uploaded into the unity 3D audio system. Both the aural and visual components of scenarios were combined to make the VR environment as realistic as possible. Unity, herein, supported the deployment to varied platforms. Within this study, a smartphone was used due to its low cost and convenient usage. The tests composed three conditions at seven sites: (1) visual only condition; (2) aural only condition; and (3) combined aural–visual condition. In total, 21 stimuli were thus generated.

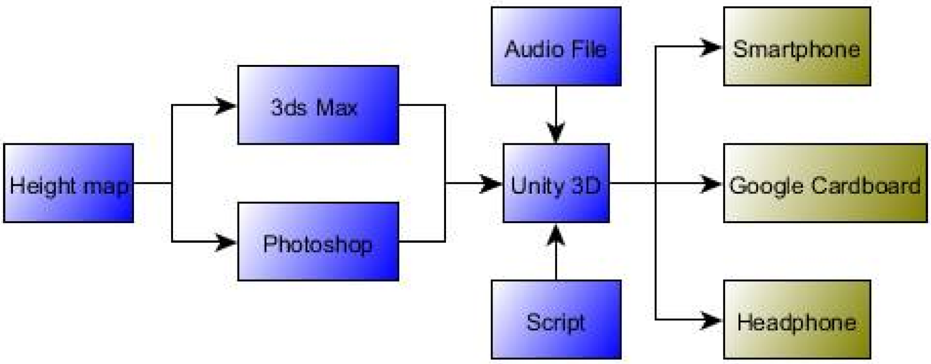

Figure 1. Modeling procedure and tools used.

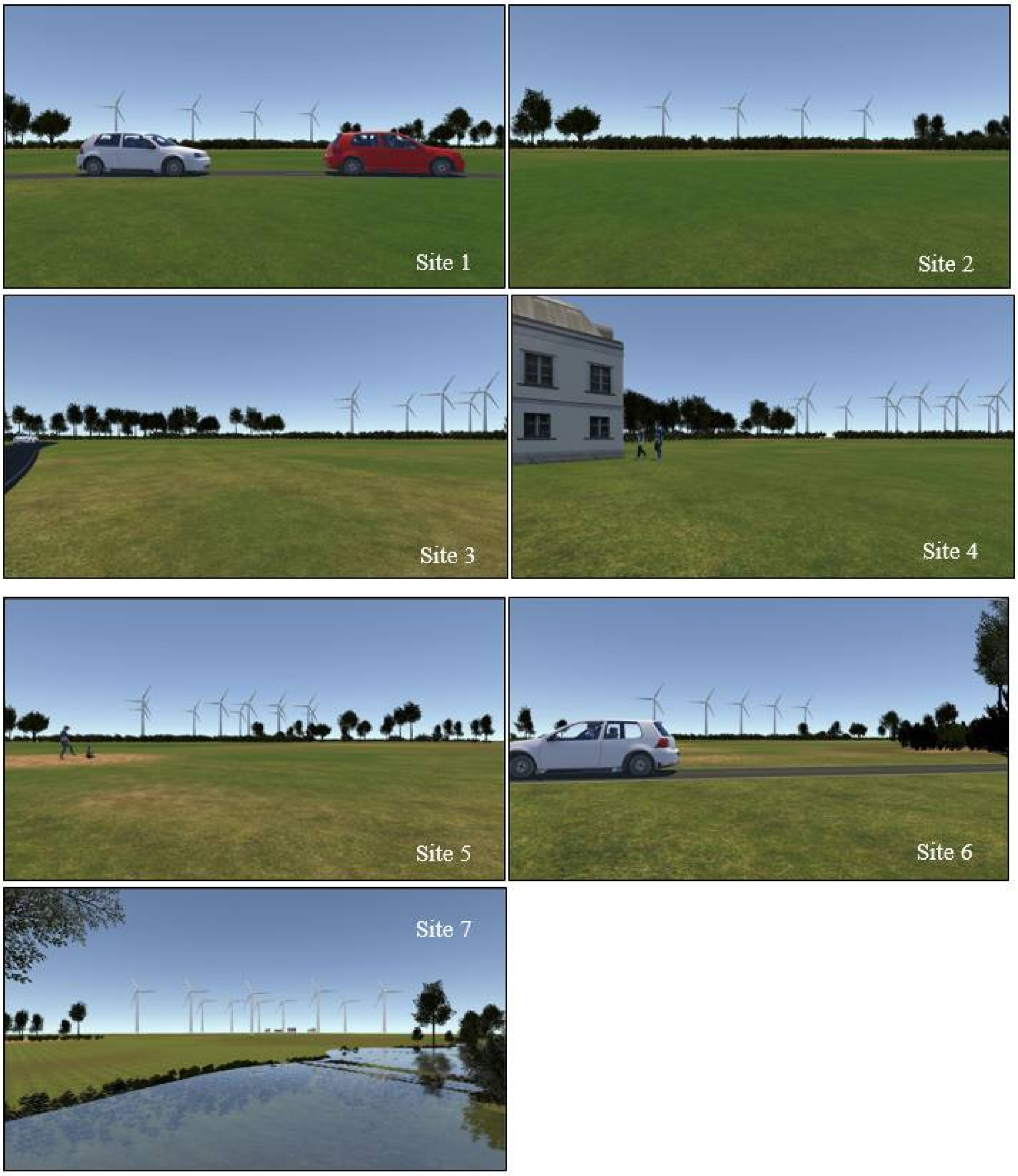

Figure 2. Selected snapshots from the aural–visual simulation at each site, detailed descriptions of each site were listed in Table 1.

2.3. Measures of Subjective Evaluations

To explore the impact of the aural–visual VR scenarios on participants, a questionnaire on the annoyance from wind parks, the realism, and semantical differential tests were assessed. Among them, the annoyance and the realism were rated from "not at all" to "extremely" on a 7-point Likert scale (1 = "not at all", 2 = "low", 3 = "slightly", 4 = "neutral", 5 = "moderately", 6 = "very" and 7 = "extremely"). The semantical differential technique was proposed by former researchers as a test method for linking people's feelings at linguistic and psychophysical levels with the soundscape within multidimensional scales [18–20]. The bipolar adjectives were used for the semantical differential test to characterize the soundscape: pleasant/unpleasant, various/monotonous, quiet/loud, smooth/rough, calming/agitating, comfortable/uncomfortable, open/closed, natural/artificial, order/disordered, and distinct/ordinary were rated on a 7-point scale (Figure 3).

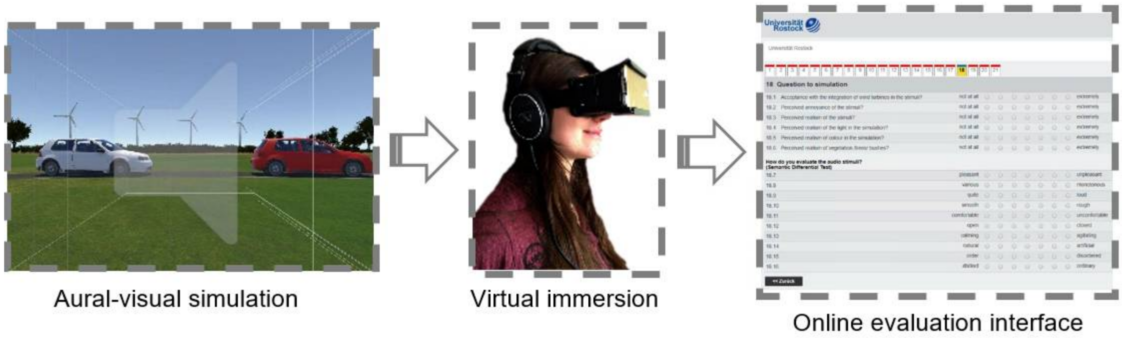

Figure 3. The experimental setting of the aural–visual assessment in a controlled laboratory; participants rated 21 stimuli in total through cardboard/headphones and completed the responses of the online evaluation system.

2.4. Participants and Experimental Precedure

For data collection from individuals for validation of the VR simulations on soundscape analysis of wind parks, a total of 40 volunteer students and staff from University of Rostock (18–35 years: 98%, men: 57.5%, women: 42.5%) participated in the aural–visual assessment of wind parks. All of them had normal hearing and vision. Participants sat in a quiet room (<40 dB) and experienced the aural–visual stimuli in VR simulations. They wore a Google Cardboard headset with an embedded smartphone presented via unity 3D platform. This headset allows the scene view to move in an immersive 360° in response to head movements, and enables a three-dimensional audio environment with the headphone plugged into the smartphone device. Therefore, they could watch the wind park scenarios in VR and experience a similar reality. Aural stimuli were delivered through the headphone (Sennheiser HD598) plugged into the smartphone. The test sound level and the on-site recorded one were set closely to each other before the start of the test.

The experimental questions were presented to the participants on a laptop computer, using EvaSys V7.1 (evaluations system of the University Rostock) (Figure 3). Within this interface, each simulation was performed in 32 s, and the test order was randomized in each assessed condition. Participants evaluated each simulation and were allowed to experience the simulation as many times as they wanted in order to complete the evaluation questions.

3. Results and Discussion

3.1. Realism of VR Simulations

In the visual only and aural–visual combined condition, participants evaluated their realism on a 7-point rating scale. Results showed a highly perceived realism for most participants. Figure 4 shows means and standard deviation of rated realism for all scenarios under the visual only and aural-visual conditions. Perceived realism was mostly (60% of the participants) rated as moderately realistic and realistic under the visual only condition, with rating scores above 5 (close to very realistic). More than half of the participants (59%) rated aural–visual scenarios with scores above 5. The worst realistic scenarios corresponded to site 4 and site 5 with human voices due to “incongruence of human sound and visual content”, according to their comments. Scenarios at site 1 and site 3 with road traffic sound rating scores above 5 were rated as the most realistic. Therefore, with the aid of VR, the aural–visual interactive and dynamic simulations can create scenarios with a high level of realism. The interactivity and dynamics of the virtual environment could support the public’s understanding of wind park projects.

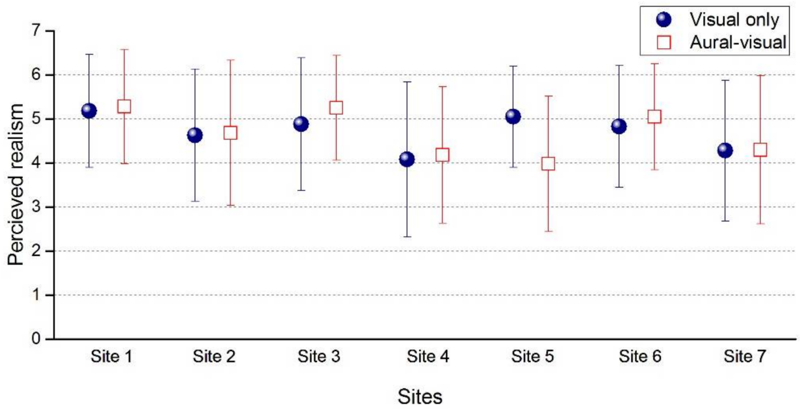

Figure 4. The rated realism of scenarios under visual only and aural–visual conditions at each site.

To improve the simulations, participants rated the seven simulations in the aspects of light realism, color realism, and vegetation realism. Results for each site are listed in Table 2. A significant correlation was found between total realism, light realism, color realism, and vegetation realism ($p < 0.001$). The more realistic the light realism, color realism, and vegetation realism were, the more realism there was in total. The analysis of variance (ANOVA) tests on perceived realism were calculated for different realism metrics (light realism, color realism and vegetation realism) at seven sites. Results confirmed a significant main effect on the realism metrics (F (3, 39) = 5.079, $p < 0.01$).

Table 2. Mean realism and standard deviation in different realism metrics (light realism, color realism, and vegetation realism) under visual only condition.

Sites	Aspects	Realism	
		Mean	**SD**
Site 1	Light	5.1	1.03
	Color	4.75	1.26
	Vegetation	4.65	1.39
	Total realism	5.18	1.28
Site 2	Light	5.03	1.16
	Color	4.78	1.37
	Vegetation	4.48	1.60
	Total realism	4.63	1.50
Site 3	Light	4.88	1.32
	Color	4.75	1.45
	Vegetation	4.55	1.71
	Total realism	4.88	1.51
Site 4	Light	4.83	1.38
	Color	4.75	1.30
	Vegetation	4.58	1.52
	Total realism	4.08	1.78
Site 5	Light	5.1	1.17
	Color	4.8	1.24
	Vegetation	4.68	1.53
	Total realism	5.05	1.15
Site 6	Light	4.9	1.32
	Color	4.63	1.46
	Vegetation	4.3	1.60
	Total realism	4.83	1.38
Site 7	Light	5.05	1.22
	Color	4.8	1.26
	Vegetation	4.43	1.68
	Total realism	4.38	1.69

3.2. Aural–Visual Interactions in VR Simulations

In the visual only and aural–visual combined conditions, participants evaluated their acceptance on a 7-point Likert scale. The mean values of the acceptance evaluated for each site for 40 participants are presented in Figure 5. The evaluation of acceptance of wind parks were conducted in two conditions (visual only and aural–visual conditions), since the aural stimulus was not synthetic but came directly from original binaural recordings. This study intended to avoid confusion and fatigue on the part of the participants in rating these parameters. The data were calculated by a two-way ANOVA test in these two conditions, and seven sites were independent of each other. Acceptance was the dependent variable.

Results showed a statistically significant main effect located at the site (F (6, 39) = 11.75, $p < 0.001$). No significant main effect was found between two conditions. It could be seen that all of the investigated sites were rated as highly accepted areas for wind parks. This included site 1, with rated acceptance by a score of 5.15; site 2, site 3, site 6, site 7 were 5.38, 5.23, 5.2, and 4.58, respectively. Of all the sites, site 4 and site 5, where human activities took place nearby, had scores of approximately 4, and were rated the least accepted sites.

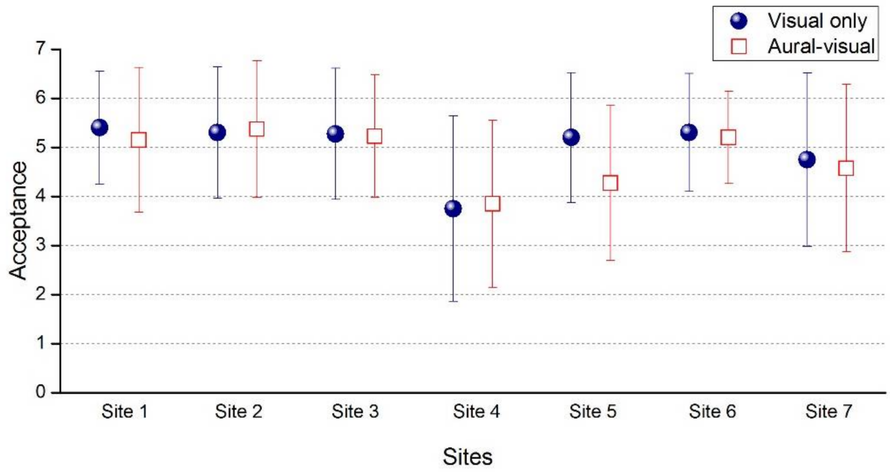

Figure 5. Acceptance under visual only and aural–visual conditions at each site.

The results indicated that participants had a relatively high acceptance for wind parks at rural sites, but the addition of human activities could decrease the acceptance for wind parks. People might find wind parks to be clean and meaningful constructions when they were "not in my backyard". Otherwise, wind turbines might be considered to be ugly and annoying constructions, which converted the natural recreational areas to industrial sites. This study could suggest that planning of wind parks must be restricted near sites of human activities.

Furthermore, participants rated the general annoyance of the simulation under aural only, visual only and aural–visual combined conditions. The ANOVA annoyance test scores were calculated for three conditions (aural only, visual only, and aural–visual conditions) at seven sites. Results showed a statistically significant main effect was in the condition (F (2, 39) = 20.00, $p < 0.001$) and sites (F (6, 39) = 77.49, $p < 0.001$), and also a significant interaction effect was in the condition versus sites (F (12, 43) = 22.10, $p < 0.001$). Mean general annoyance scores in three conditions were plotted in Figure 6. It was found that annoyance at most sites (site 1, site 2, site 6, and site 7) in the aural–visual condition was closer to the results of the aural only condition than the visual only condition. This result illustrated the fact that the addition of the visual information did not significantly change the perceived annoyance, which may be because of the similarity of the rural environment. In addition, the presentation of visual simulations was not as complex as that of the real site, because detailed visual modeling by hand is time consuming. In this study case, aural information was more influential than visual information with regards to the wind park landscapes.

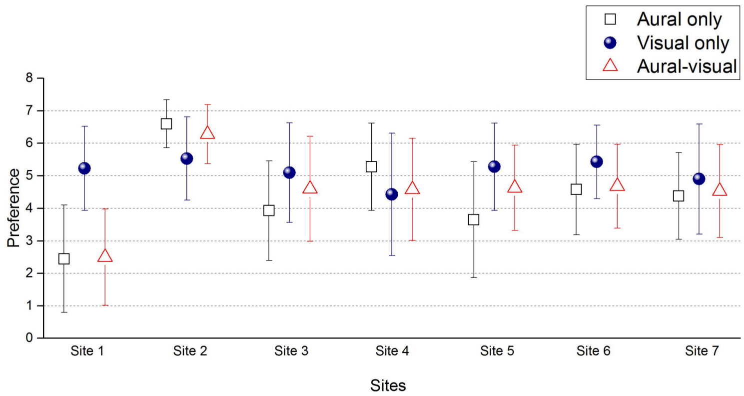

Figure 6. Perceived annoyance with wind parks under aural only, visual only, and aural–visual conditions at each site.

As could be seen, the addition of aural information decreased the annoyance with the simulation for most sites, except site 2 with dominant natural sounds (birds). Conversely, a significant decrease was shown at site 1 with dominant mechanical sounds (traffic). Finally, site 2 with dominant bird sounds was the most preferred site, and site 1 with dominant traffic noise was the least preferred one. Results indicated that the aural information played an important role for the annoyance of the wind park simulation. Further the addition of human sounds, traffic sounds, or water sounds in the rural region had a negative influence on the preferences of wind parks, while the addition of bird sounds brought a positive effect to the preferences.

The relationship between realism and annoyance was analyzed; however, there was no significant effect. The reason was that, in the specific wind park projects, when the realism of landscape was relatively strong, the primary interactive factor for the annoyance of wind parks could be another important factor, such as the sound pressure level [21]. Overall, the addition of sound increased the realism of the simulations; however, incongruence of the aural and the visual information could have a strong negative impact on it.

3.3. Soundscape in Multidimensional Scales in VR Simulations

In the VR method in the soundscape study, perceived realism was further explored with soundscape factors. Therefore, a method of the multidimensional scales was used to assess the soundscape at linguistic and psychophysical levels, and determined how the different semantical scales were linked to one another. According to the semantical descriptors, participants rated the seven scenarios. The mean ratings of the bipolar adjectives of the semantical description are shown in Figure 7. Site 3, site 4, site 5, site 6, and site 7 remain in the middle of the radar circle, except the metric of open/close. However, site 1 located in the outer circle and site 2 located close to inner circle of the radar plot are clearly seen. At the same time, as described above, site 1 with dominant traffic sounds and site 2 with dominant natural bird sounds were rated as the least preferred sites and most preferred sites, respectively. These results are somewhat consistent. They confirm the importance of the semantical characteristics of an ambient soundscape on perception of wind park landscapes. The relationship between the semantical metrics and perceived annoyance will be discussed in the coming paragraph. Furthermore, site 1 was found to be quiet, distinct, natural, open, calming, smooth, and comfortable for the participants, while site 2 was found to be the opposite of site 1. This could be explained by the fact that people prefer landscapes with bird sounds to those with traffic sounds.

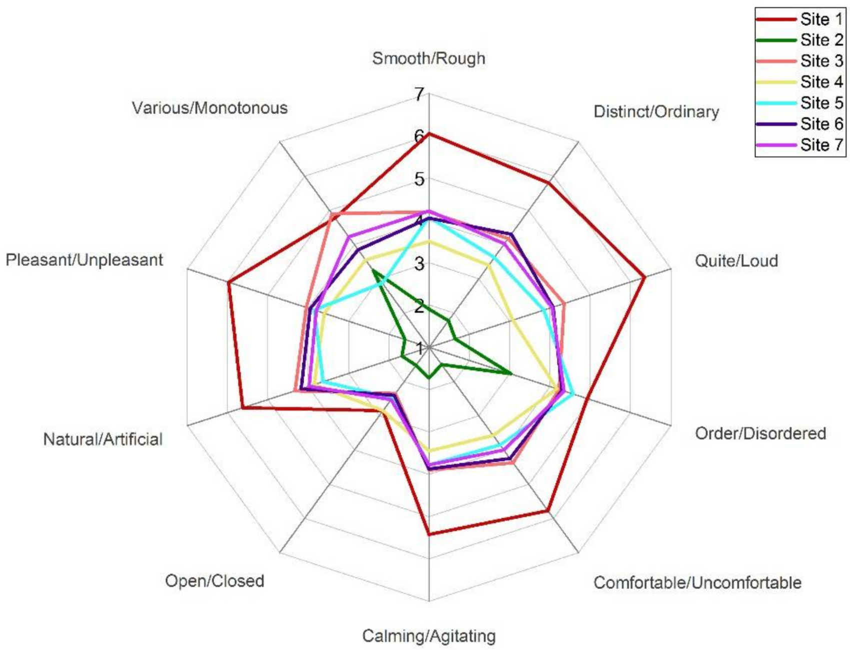

Figure 7. Mean ratings of the simulations for bipolar adjectives of soundscape semantic description.

The principal component analysis (PCA), a statistical method was proposed to explore communalities in collected soundscape semantical data, and Kaiser–Meyer–Olkin (KMO) was applied within PCA to verify the adequacy of the data and the factor loadings [18–20,22]. The PCA with varimax rotation was thus chosen to extract the orthogonal factors (Table 3). Three factors were determined to explain their variance. Component 1 was extracted to explain 42% of the variance, which had high positive loadings for "smooth/rough," "distinct/ordinary," "quiet/loud," "order/disorder," "comfortable/uncomfortable," and "calming/agitating." This component could represent "calmness/relaxation" as demonstrated by former researchers [20]. Component 2 was extracted to explain 16% of the variance, which had high positive loadings for "open–closed," "natural–artificial" and "pleasant–unpleasant." Thus, it could be relevant to "naturality/pleasantness." Component 3 was extracted to explain 11% of the variance, and it had high positive loadings for "various/monotonous," which could be related to "diversity." These three components retained orthogonality, which also explains 69% of the variability in the original ten dimensions.

Table 3. Principal component analysis (PCA) of the bipolar adjectives of soundscape semantical description (Eigenvalue > 1, Kaiser–Meyer–Olkin (KMO) index = 0.725, Bartlett's test of sphericity $p = 0.000$, N = 40).

Component	Component 1 (42.4%)	Component 2 (15.6%)	Component 3 (11.4)
Smooth–rough	0.874		
Distinct–ordinary	0.858		
Quite–loud	0.841		
Order–disorder	0.692		
Comfortable–uncomfortable	0.679		0.468
Calming–agitating	0.659	0.451	
Open–closed		0.836	
Natural–artificial		0.695	
Pleasant–unpleasant	0.458	0.601	
Various–monotonous			0.919

After factor analysis, the strongest factors for explaining the impact on the annoyance with wind park landscapes were achieved. In addition, further analysis of Pearson's correlation among these factors, perceived realism, annoyance, and psychoacoustic factors were conducted and listed in Table 4. Mean perceived realism in the aural–visual condition and four psychoacoustic metrics including loudness, sharpness, fluctuation strength, and roughness, were obtained through Artemis (Head Acoustics) Software, and were applied for the correlation analysis. Results showed that "diversity" was related to the perceived realism. "Diversity" of soundscape had a stronger impact on the perceived realism than the others. In order to enhance the reality of the landscape, varieties of soundscapes should be considered. Results also indicated that the factors "calmness/relaxation" and "naturality/pleasantness" were correlated to psychoacoustic metrics "loudness" and "fluctuation strength." Annoyance with wind parks was significantly correlated to "calmness/relaxation" and "naturality/pleasantness" of the soundscape, marking the importance of "calmness/relaxation" and "naturality/pleasantness" in the evaluation of wind park landscapes.

Table 4. Correlation coefficients for semantical factors, psychoacoustic metrics, annoyance and perceived realism.

Factor	Calmness/Relaxation	Naturality/Pleasantness	Diversity
Perceived realism	0.401	0.339	0.759 *
Loudness	0.841 *	0.790 *	0.561
Fluctuation strength	0.756 *	0.672	0.294
Roughness	0.916 **	0.843 *	0.571
L_{Aeq}	0.782 *	0.794 *	0.431
Annoyance	0.964 **	0.971 **	0.594

** = $p < 0.01$. * = $p < 0.05$.

4. Conclusions

One of the key challenges in the communication of landscape design proposals is the adequacy of simulation. The virtual environment of this study provided a fixed viewpoint in which the user could explore the simulated environment in 360 degrees. The addition of sound information on the simulated virtual environments contributed to a sufficient evaluation of wind park landscapes.

Most of these VR simulations on the smartphone were rated from relatively good realism to high realism under the aural–visual condition. The developed aural–visual VR simulations on the smartphone is thus proved to be a valid method for the study of wind park soundscapes. In addition, it was found that light, color, and vegetation realism could enhance the simulation experience.

The ratings of acceptance of wind parks indicated the high agreements with conducting wind park projects, but the addition of human activities could decrease the acceptance of wind parks. It was found that the aural information played an important role in perceived annoyance, and the addition of human sounds, traffic sounds, or water sounds in the rural region had a negative influence on the preferences for wind parks. There was a relatively large number of residents against wind park projects. Using VR technology to supply the public with a virtual environment of the wind park landscape could be considered the primary means of communication with the public.

Furthermore, results of soundscapes in multidimensional scales confirmed the importance of the semantical characteristics of ambient soundscapes on perception of wind park landscapes. The strongest components for evaluation of wind park landscapes were "calmness/relaxation" and "naturality/pleasantness." In addition, "diversity" of the soundscapes were found to have a strong impact on the perceived realism.

The results could be used for comparison for other validation studies based on aural–visual interaction simulations [23]. This method with the addition of spatial sound information could contribute significantly in enhancing the environmental assessment of the wind park landscapes, and thus provide a more comprehensible scientific decision than conventional tools, such as GIS maps and photorealistic images. This study could contribute to giving guidance to produce such VR scenarios on the smartphone in the landscape study in an intuitive and brief way. Also, this study could improve the participatory planning process for more acceptable wind park landscapes, which should be further studied in future research.

The modeling of visual objects, such as roads, trees, and wind parks, could be automatized depending on their spatial distribution and the related georeferenced data. The aspects of complexity of scenarios should be further improved, as the detailed modeling by hand is time consuming. Research studies on experiencing the scenarios with the context of landscape planning in consideration of aural and visual information are mostly virtual 3D scenarios. A future study of a more convenient and cost-favorable method combining GIS data with a high level of realism can be developed.

Author Contributions: All the authors conceived and designed the experiments; Tianhong Yu performed the experiments, analyzed the data and wrote the paper."

Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

References

1. Kontogianni, A.; Tourkolias, C.; Skourtos, M.; Damigos, D. Planning globally, protesting locally: Patterns in community perceptions towards the installation of wind farms. *Renew. Energy* **2014**, *66*, 170–177. [CrossRef]
2. Bertsch, V.; Hall, M.; Weinhardt, C.; Fichtner, W. Public acceptance and preferences related to renewable energy and grid expansion policy: Empirical insights for Germany. *Energy* **2016**, *114*, 465–477. [CrossRef]
3. Hills, J.M.; Michalena, E. Renewable energy pioneers are threatened by EU policy reform. *Renew. Energy* **2017**, *108*, 26–36. [CrossRef]
4. Cowell, R. Wind power, landscape and strategic, spatial planning—The construction of 'acceptable locations' in wales. *Land Use Policy* **2010**, *27*, 222–232. [CrossRef]
5. Lewis, J.L.; Sheppard, S.R.J. Culture and communication: Can landscape visualization improve forest management consultation with indigenous communities? *Landsc. Urban Plan.* **2006**, *77*, 291–313. [CrossRef]
6. Manyoky, M. Developing a GIS-based visual-acoustic 3d simulation for wind farm assessment. *Int. J. Geo-Inf.* **2014**, *3*, 29–48. [CrossRef]
7. Yu, T.; Behm, H.; Bill, R.; Kang, J. Audio-visual perception of new wind parks. *Landsc. Urban Plan.* **2017**, *165*, 1–10. [CrossRef]
8. Iachini, T.; Maffei, L.; Ruotolo, F.; Senese, V.P.; Ruggiero, G.; Masullo, M.; Alekseeva, N. Multisensory assessment of acoustic comfort aboard metros: A virtual reality study. *Appl. Cognit. Psychol.* **2012**, *26*, 757–767. [CrossRef]
9. Jiang, L.; Masullo, M.; Maffei, L.; Meng, F.; Vorländer, M. A demonstrator tool of web-based virtual reality for participatory evaluation of urban sound environment. *Landsc. Urban Plan.* **2017**, *170*, 276–282. [CrossRef]
10. Ruotolo, F.; Maffei, L.; Di Gabriele, M.; Iachini, T.; Masullo, M.; Ruggiero, G.; Senese, V.P. Immersive virtual reality and environmental noise assessment: An innovative audio-visual approach. *Environ. Impact Assess. Rev.* **2013**, *41*, 10–20. [CrossRef]
11. Manyoky, M.; Wissen Hayek, U.; Pieren, R.; Heutschi, K.; Grêt-Regamey, A. Evaluating a visual-acoustic simulation for wind park assessment. *Landsc. Urban Plan.* **2016**, *153*, 180–197. [CrossRef]
12. Gill, L.; Lange, E. Getting virtual 3d landscapes out of the lab. *Comput. Environ. Urban Syst.* **2015**, *54*, 356–362. [CrossRef]
13. Lindquist, M.; Lange, E.; Kang, J. From 3d landscape visualization to environmental simulation: The contribution of sound to the perception of virtual environments. *Landsc. Urban Plan.* **2016**, *148*, 216–231. [CrossRef]
14. Pedersen, E.; van den Berg, F.; Bakker, R.; Bouma, J. Response to noise from modern wind farms in the netherlands. *J. Acoust. Soc. Am.* **2009**, *126*, 634–643. [CrossRef] [PubMed]
15. Torija, A.J.; Ruiz, D.P.; Ramos-Ridao, A.F. Application of a methodology for categorizing and differentiating urban soundscapes using acoustical descriptors and semantic-differential attributes. *J. Acoust. Soc. Am.* **2013**, *134*, 791–802. [CrossRef] [PubMed]

16. Plehn, M. Wind Energy in the Baltic Sea Region 2. 2012. Available online: www.windenergy-in-the-bsr.net (accessed on 12 June 2015).
17. Bishop, I.D.; Miller, D.R. Visual assessment of off-shore wind turbines: The influence of distance, contrast, movement and social variables. *Renew. Energy* **2007**, *32*, 814–831. [CrossRef]
18. Kang, J.; Zhang, M. Semantic differential analysis of the soundscape in urban open public spaces. *Build. Environ.* **2010**, *45*, 150–157. [CrossRef]
19. Axelsson, Ö.; Nilsson, M.E.; Berglund, B. A principal components model of soundscape perception. *J. Acoust. Soc. Am.* **2010**, *128*, 2836–2846. [CrossRef] [PubMed]
20. Sudarsono, A.S.; Lam, Y.W.; Davies, W.J. The effect of sound level on perception of reproduced soundscapes. *Appl. Acoust.* **2016**, *110*, 53–60. [CrossRef]
21. Szychowska, M.; Hafke-Dys, H.; Preis, A.; Kociński, J.; Kleka, P. The influence of audio-visual interactions on the annoyance ratings for wind turbines. *Appl. Acoust.* **2018**, *129*, 190–203. [CrossRef]
22. Sudarsono, A.S.; Lam, Y.W.; Davies, W.J. The validation of acoustic environment simulator to determine the relationship between sound objects and soundscape. *Acta Acust. United Acust.* **2017**, *103*, 657–667. [CrossRef]
23. Jian, K. From dBA to soundscape indices: Managing our sound environment. *Front. Eng. Manag.* **2017**, *4*, 184–192.