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Virtual Reality as a Landscape Decision-Making Tool: the Wind Turbines' Case

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As public projects are more and more committed to sustainable development, users become determinant actors for the decision-making process. This paper aims to make a first step for using Virtual Reality (VR) as an evaluation tool for landscape project. For that, it will evaluate the immersive, interactive and multisensory user's experience of landscape thanks to (VR) and to determine potentialities and biases of such system. We base our work on the particular case of Wind turbines (WT) which are famous for the public controversy they have raised about their visual, acoustic and even social impacts. We compare human perception of a real wind turbine park and of the same virtual one in order to evaluate impacts restitution. An instrumented bicycle is used for in vitro interaction restitution. Results confirm the relevance and importance of human motion restitution in landscape studies; Moreover, the participation of landscape, by multi-sensory modalities and dynamics (e.g. temporal dimension, physical factors, shapes) to construct the perceived space is also shown. Virtual Reality demonstrates good potentials for sustainable landscape studies as a communication and discussion tool, as a required step of the decision-making process.

Keywords: landscape, virtual reality, wind turbines, decision-making, motion

1 Introduction

Sustainability concerns are about favouring a better future to all humans: user is henceforth the purpose of all political, economical and social actions. It means that every action must understand the people for whom the action is directed and answer to their relevant needs. The best way to understand one's desire is to ask him; that is why today, in landscape and urban planning, the user participates as a decision-maker in public projects. He has to express his desired vision of the world by assessing the proposed representation of the project; that means the user must perceive the same world once constructed. In this paper, we propose VR as a new representation and discussion tool for sustainable landscape projects thanks to perception restitution potentialities.

Landscape results from the 'observer-environment' interaction; it is a multisensory perception that changes depending on observer's point of view and motion.[1] Perceptual assessment of rural space rarely uses an immersive and dynamic point of view contrary to some urban methods, which study observer's instant perception through a predefined path. This type of method can be suitable with immersive, multisensory and dynamic landscape experience.

VR has been involved in landscape and environmental planning thanks to immersion and real-time interaction. In this way, real-time virtual landscapes have drawn considerable attention for public participation but most of landscape studies only consider visual perception and visual stimulation for displacement in the space; acoustic perception and natural self-motion (body movement) are seldom used: they are our VR challenges.[2] [3] VR is here proposed as an immersive multisensory and dynamic approach that is able to restore landscape experience and thus it can be a good representation tool for the decision-making process.

1 **Zube E.H.** (1987). Perceived land use patterns and landscape values, Landscape Ecology 1:1, pp. 37-45
2 **Stock C.** and **Bishop I.D.** (2006). Linking GIS with real-time visualisation for exploration of landscape changes in rural community workshops, Virtual Reality 9:4, pp. 260-270
3 **Döllner, J.** et al (2005). Real-time virtual landscapes in landscape and urban planning, Proceedings of GIS Planet'05: 2nd International Conference and Exhibition on Geographic Information, Portugal

4 **Bishop I.D.** & **Miller D. R.** (2007). Visual assessment of off-shore wind turbines: The influence of distance, contrast, movement and social variables, Renewable Energy 32:5, pp. 814-831

WT impacts’ study is the application case of the immersive, multisensory and dynamic approach. Today, international context (Kyoto Protocol) encourages WT which energetic gains are barely contested contrary to impacts: indeed, WT make visual contrast with the rural background and acoustic nuisances in the neighbourhood. That is why, WT impacts have interested many researchers but most of studies remain mono-sensory, non-immersive and non-interactive.[4] Here, we will try to assess WT impacts on landscape by the VR approach; in other words the VR system must render both visual and acoustic impacts. For this purpose, we propose to compare perception of a real WT landscape to the same virtual one using an urban path-based method which tallies with observer’s experience. The comparison of characterized and contextualized perception in both worlds will evaluate potentialities and limits of the VR system.

In the first part of this work, we will first explain the theoretical framework: landscape issues, VR potentials and limitations for public projects, as well as the WT impacts’ studies. In a second step, we will describe the comparative approach; and finally, results will be discussed in order to propose the immersive multisensory and dynamic approach as a discussion tool for landscape and public project.

2 Background

2.1 Landscape: the user as a decision-maker in the project

In last decades, landscape has evolved from a passive concept that leads to protect (freeze) the environment to an active tool for planning. This new status is confirmed in 2000 by the European Landscape Convention that promotes the protection, management and planning of landscapes and restores landscape to its central and active role. In fact, the Convention was motivated by the international attention for sustainable development (sustainable landscape) that considers users as an objective of all economical, social and ecological concerns. Since that, the user grows to a preeminent and central part of landscape issues and to a central actor of public projects in decision-making process.

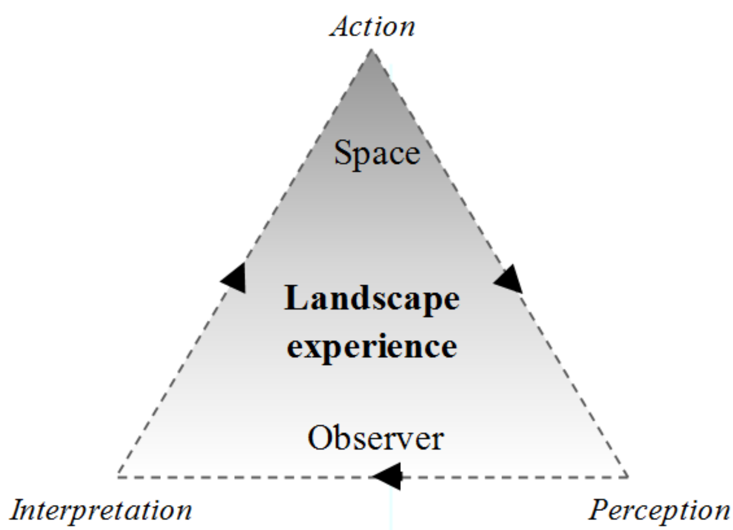

Figure 1 The ‘action / perception / interpretation’ cycle in the landscape experience

In fact, the user also has a central role in landscape concept. Indeed, landscape is resulting of a complex relationship between environment and individual: individual's perception and exploration of space provide him with information from all directions via multisensory modalities and prompt his action.[5] This individual's experience of landscape – also called the 'landscape experience' – is generated by a continuous 'action/perception/interpretation' cycle that re-creates landscape (Figure 1). In this way, the landscape experience is immersive (space), multisensory (perception/interpretation) and dynamic (action/motion) because it involves an immersed observer that interacts with space thanks to his senses and movement. Indeed, the ecological approach of perception showed that the observer's motion enhances perception and links time to space information: while the observer walks, he evolves through a space that offers new shapes and ambiances.[6] We thus assume that immersion, multisensory modalities and motion are required conditions to the landscape experience that any study of landscape must integrate. The user's integration in the decision-making process raises many questions because the user is an inexperienced actor of landscape issues compared to the other specialized actors (designers). One of the major questions is about a representation tool for the communication and the discussion of the landscape project between the different actors. For an inexperienced actor, the representation tool must be on one hand, accessible (all actors can use it), *understandable* (all actors can understand it) and *reversible* (it can be quickly modified); and on the other hand, faithful to the real 'immersive, multisensory and dynamic' landscape experience.[7]

Presently, representation tools have evolved from maps, photographs and photomontages (static visualizations) to animations and interactive virtual environments because today landscape specialists insist on the restitution of the immersive, multisensory and dynamic experience in order to study the landscape.[8] For example, Danahy and Lim et al asserted in their studies that dynamic vision and motion – through real-time interaction – is a better way to evaluate landscape.[9] [10] But most of those methods are mono-sensory (vision) and rely on motion cues that are only visual (moving the user's view from one point to another) which is insufficient to restore real landscape experience because self-motion cues (body movement) are richer than vision cues: visual as well as self-motion cues are important in natural motion sensation.[11] That is why we propose here a multisensory method based on natural motion in order to study landscape.

2.2 Virtual reality: immersion and interaction potentialities and limitations

Since the 90's, VR is finding increasing interest in landscape and environmental planning. VR assets are immersion and real-time interaction because they improve public participation and 'allow rural communities to evaluate possible future landscape scenarios'.[12] Immersive environments that satisfy dynamic visual perception are easily feasible thanks to panoramic projections (looking around, large field of view, 1:1 scale) but other senses are seldom integrated in VR application.[13] Obviously, visual immersion is overriding and is the only aspect of most of virtual studies.[14] However, some researchers like Bishop and Rohrmann proved that acoustic perception coupled to vision improves realism and user's landscape experience.[15]

5 Zube E.H. (1987). ibid

6 Gibson J.J. (1986). The ecological approach to visual perception, Lawrence Elbaum Associates, New Jersey

7 Stock C. and **Bishop I.D.** (2006). ibid

8 Lange E. and **Bishop I.D.** (2005). Communication, perception and visualization. In: Bishop I.D. and Lange E. eds, Visualization in landscape and environmental planning: technology and applications, Taylor and Francis, UK, pp. 3-21

9 Danahy J.W. (2001). Technology for dynamic viewing and peripheral vision in landscape visualization, Landscape and Urban Planning 54:1-4, pp. 127-137

10 Lim E.M. et al (2006). The validity of VRML images as a stimulus for landscape assessment, Landscape and Urban Planning 77:1-2, pp. 80-93

11 Harris L.R. et al (2002). Simulating self motion I: cues for the perception of motion, Virtual Reality 6:2, pp. 75-85

12 Stock C. & **Bishop I.D.** (2006). ibid

13 Lange E. (2001). The limits of realism: perceptions of virtual landscapes. Landscape and Urban Planning 54:1-4, pp. 163-182

14 Coeterier J.F. (1996). Dominant attributes in the perception and evaluation of the Dutch landscape, Landscape and Urban Planning 34:1, pp. 27-44

15 Bishop I.D. & **Rohrmann B.** (2003). Subjective responses to simulated and real environments: a comparison, Landscape and Urban Planning 65:4, pp. 261-277

Few works are dedicated to acoustic simulations in virtual environments even if it is reliable that hearing – linked to vision – improves the scene realism and the user's presence in the digital world.[16] Actually, the main acoustic issue is how to reproduce the same perception of different sounds (wind, vegetation, WT, and others) of an extended space with specific features into a closed space with different features?

A digital landscape experience must also involve real-time interactivity. In fact, natural movement is the main issue of 'user-VR system' interaction because of the scale difference between the virtual environment and the experimental VR facilities. Indeed, existing tracking and display systems are generally limited and constrain the user to move in a small physical area while landscape projects are rather extended. That is why most of virtual environments are based on walkthrough animations, which at least give richer information about human behaviour than a static scene.[17] But natural motion is a particularly potent self-motion cue.[18] Some researchers have used the omni-directional treadmill or the 'cyber-sphere' (Warwick University) to provide natural walking but these technologies remain experimental and expensive.[19] One approach has used an adult-sized tricycle, which has been instrumented to measure the rotation of one of the rear drive shaft and the steering angle: natural movement is provided but the device requires an available large free space.[20]

2.3 Wind turbines' impacts: thresholds of visual and acoustic studies

WT setting up on a territory is not neutral in particular from an aesthetic point of view. That is why many people contest WT impacts on landscape; as a result local authority support participative approach and the user's integration in the decision-making process of the WT project. In fact, conflicts are either visual (wind turbines damage/revalue landscape) or acoustic (nuisances among nearby residents); that is why this section is dedicated to the impacts' context and the limitations of current studies.

Visual impact. The visual aspect is the main feature of WT landscape but this impact strongly depends on distance. That is why some WT guidelines specified three levels of perception (recommended Zone of Visual Influence) that must be considered for each park study (Figure 2).[21] In the *Distant area* (radius greater than 10 km), WT are not always visible because the nearest objects generally draw more attention but in an extended empty landscape vision focuses on WT. The *Intermediate area* (radius between 1 and 10 km) is the most studied perimeter by the photomontages because it consists in an overall view of the park. At this level, WT visually dominate the space because of their height that occupies an important amount of space; and they are also attractive because of their moving blades. For these reasons, visual impact must be considered. In the *Immediate area* (less than 1 km), WT even more dominate visual perception because of their size and the moving blades are visually and acoustically attractive. That means visual and acoustic impacts are very important. According to those three levels of perception, visual impact must be assessed from potentially many points of view whereas actually, only a small set of photomontages from the intermediate area is presented to defend visual impact of new projects. This visualization tool is non-immersive, mono-sensory and static which is far from the real WT landscape experience on site.

16 Tsingos N. et al (2004). Perceptual audio rendering of complex virtual environments. In: International Conference on Computer Graphics and Interactive Techniques, ACM Siggraph, USA, pp. 249-258

17 Bishop I.D. et al (2001). Assessment of path choices on a country walk using a virtual environment, Landscape and Urban Planning 52:4, pp. 225-237

18 Allison R.S. et al (2002). Simulating self motion II: A virtual reality tricycle, Virtual Reality 6:2, pp. 86-95

19 Darken R.P. et al (1997). The omni-directional treadmill: a locomotion device for virtual worlds, Procee-dings of the ACM Sym-posium on User Interface Software and Technology, Banff, Canada, ACM Press, New York, pp. 213-221

20 Allison R. S. et al (2002). ibid

21 University of Newcastle (2002). Visual Assessment of Wind-farms: Best Practice, Commissioned Report F01AA303A, Scottish Natural Heritage, Scotland

Acoustic impact. WT produce both mechanical and aerodynamic noise but only the blade-wind friction propagates to hundreds meters around and disturbs neighbours; it must enforce relative ratios of background noise levels that are used in France (1995/04/19 Decree). In the compulsory Environmental Impact Assessment, WT acoustic issue is presently addressed by technical studies, which are not understandable by inexperienced users.[22] Few studies however tried to assess acoustic perception: as an illustration, Pedersen and Waye used questionnaires to show that the annoyance risk was enhanced among inhabitants who see turbines from their dwelling and among those who live in a rural area by comparison with a suburban area.[23] Furthermore, they demonstrated that perception focuses on the WT noise because of its incongruity with the background sounds. Most of acoustic inquiries quantify annoyance and do not qualify perception.

Visual and acoustic perception is required to assess WT impacts on landscape. It is maybe easier to separate visual and acoustic studies but we think that senses' interaction tallies with real-life experience and gives richer sensory information. Indeed, some studies showed the influence of visual factors on acoustic nuisances' perception.[24] But in digital WT studies on landscape, visual assessment is still the most studied.[25 26]

2.4 Conclusion: an immersive, multisensory and interactive approach for landscape study

Thanks to sustainability, the user's main role in public spaces is recognized; that is why the user is nowadays a principal actor in the decision-making process. At this step, the represented project must be easily understandable and must restore the real perception as when the project is constructed. For that, the best way is user's immersion in the represented project in order to interact – thanks to his senses and motion – with the multisensory and dynamic space.

Since the 80's, immersion and interaction with space are used on site by some urban approaches through the experience of walking: the *wayfinding* method or the commented city walk method solicits a pedestrian in order to walk, observe and describe the space by his own words; that ensures the characterization of the inhabited space and the contextualization of the pedestrian's perception.[27 28] We choose the *commented walk* method to study the landscape experience in real and virtual environment because it has showed great potentialities in real landscape and in VR-based ambient daylighting study.[29 30]

Immediate area *Distant area* *Intermediate area*

Figure 2 Three different visions of the WT landscape depending of perception levels

3 Method

The aim of this paper is to assess VR potentialities in order to be a valid tool for decision-making process in public projects, especially landscape ones. It must

22 Sénat C. et al (2005). Calculate noise of wind farms. Proceedings of First international meeting on wind turbines noise: Perspectives for Control proceedings, Germany

23 Pedersen E. & **Persson W.K.** (2006). Exploring perception and annoyance due to wind turbine noise in dissimilar living environments. Proceedings of Euronoise 2006, Finland, EAA, Acoustic Society of Finland and VTT

24 Pedersen E. & **Larsman P.** (2008). The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines, Journal of Environmental Psychology, to be published

25 Bishop I.D. & **Miller D.R.** (2007). ibid

26 Thogersen M.L. & **Nielsen P.** (2003). Virtual reality modelling of wind farms including the countryside, Proceedings of 2003 European Wind Energy Conference, EWEA, Spain

27 Passini R. (1984). Wayfinding in Architecture (Environmental Design, Vol. 4), Van Nostrand Reinhold, New York

then restore – like in real context – immersive, multisensory and dynamic landscape experience. Applied to the WT impacts' study, the VR method must restore visual and acoustic perception. That is why the comparison of perceived impacts between the experience of an immersed user *in situ* and *in vitro* is required. The objective is not only to have the same perception (characterization) but also the same perception conditions (contextualization). The discussion of those conditions will highlight potentials and limitations of the VR method.

3.1 Tasks' procedures and analysis

The *in situ* and *in vitro* surveys are similar; they are composed of *commented country walks* and questionnaires. This type of qualitative method gets interesting results with about 20 persons.[31] [32] In our study, 18 persons have participated in the *in situ* survey and 19 persons *in vitro*.[33] Every survey took about 45 minutes. The *commented country walk* is based on perception verbalization: the participant, accompanied by the investigator, is required to walk along a predefined path, to observe and to describe what he feels. The comments are video filmed and audio recorded. After the immersive experiment, the user is asked to answer to a questionnaire with open questions.

The audio-recorded comments highlight the 'instant' perception, the participant's behaviour and the motion role in perception. We use the *discourse analysis* method to examine the transcribed comments: it is a qualitative approach and a deconstructive reading and interpretation of a text.[34] In our case, it emphasizes the perception characterization and contextualization because it aims at revealing the motivations and actions involved in the comments.[35] We classify the discourse within three topics: WT (visual, acoustic, and other features), landscape (visual and acoustic features) and VR system biases (modelling, immersion and interaction) (Table 1). The analysis is done simultaneously with transcription and video projection in order to include user's behaviour (influence of context, stop points, visual attraction, etc.), which could not be deduced from the transcribed comments.

The video recordings highlight the user's behaviour that is not verbalized in the discourse. They are watched at the same time with audio recordings. For example: the user is silently moving forward and the camera is fixed on the blades at the same time (visual attraction).

The questionnaires identify the 'remembered' perception after the commented walk and bring out the path features that marked the most the participant. Here, the analysis is statistic. It is a way to get a quick general idea of results before the comments' analysis. The questions are about: 1/ *landscape*: visual and acoustic attraction in the path; 2/ *WT*: visual and acoustic impact; 3/ *path structure*: path division in sequences according to landscape aesthetics; and 4) VR *system*: the *In vitro* questionnaire contains questions about modelling, immersion devices and interaction devices.

3.2 Investigation site: Plouguin

Real site. The study park is installed in Plouguin (France) since 2004 and surrounded by flat agricultural fields and few hamlets. The 7 WT are streamlined with smooth shapes and coloured with light grey-blue in the high part and with a green graduation in the base; that makes them original and recognizable. The

28 Thibaut J.P. (2001). La méthode des parcours commentés. In: Grosjean M. and Thibaud J.-P. (eds.) L'espace urbain en méthodes. Editions Parenthèses, Marseille, pp. 79-99

29 Jallouli J. & **Moreau G.** (2009). An Immersive path-based study of wind turbines' landscape: a French case in Plouguin, Renewable energy 34:3, pp. 597-607

30 Tahrani S. & **Moreau G.** (2008). Integration of immersive walking to analyze urban daylight ambiences, Journal of Urban Design, 13:1, pp. 99-123

31 Thibaut J.P. (2001). ibid

32 Tahrani S. & **Moreau G.** (2008). ibid

33 Jallouli J. & **Moreau G.** (2009). ibid

34 Gee J.P. (2005). An introduction to discourse analysis: theory and method, Routledge, New York

35 Frohmann B. (1992). The Power of Images: A Discourse Analysis of the Cognitive Viewpoint, Journal of Documentation 48:4, pp. 365-386 park is easily accessible from 2 main roads. For this park, the intermediate and the immediate areas are the most important levels to study because in the distant area, the nearest objects draw more attention. 2 paths tally with those areas and are frequently visited by tourists and inhabitants: Path1 is at the WT feet and Path2 is 0.5 to 2 km far from the park (Figure 3).

Virtual site. The digital world was built thanks to 3D Max and GIS data. Vegetation was the main issue of modelling: in order to optimize easy real-time navigation, we decided to use 2D planar vegetation textured by photographs taken on site. This option gave preference to a monoscopic projection because stereoscopy would accentuate the reading of 2D plans succession. The digital Path1 has a grey sky while Path2 has a blue sky in order to respect the weather conditions in real surveys. The 3D model was then exported to Virtools that manages the interaction part of the experiment.

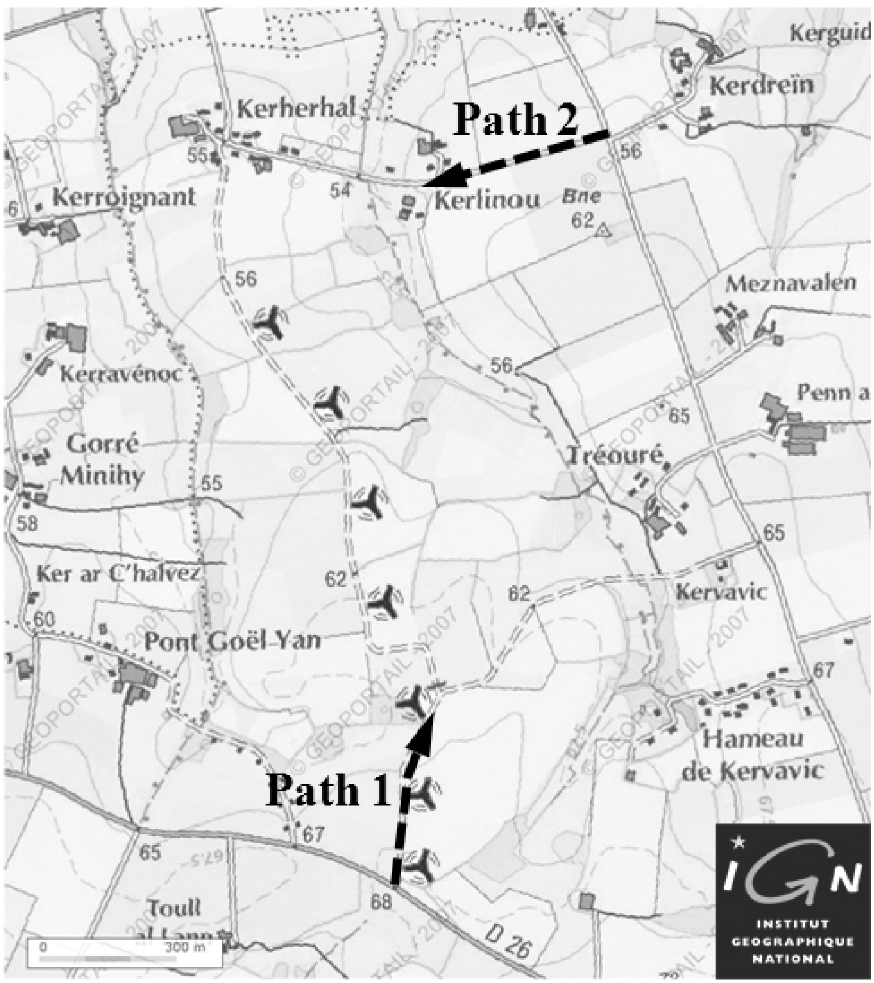

Figure 3 The studied paths (© GEOPORTAIL 2007)

36 Fuchs P. et al (1999). A theoretical approach of the design and evaluation of a virtual reality device, Proceedings of Virtual Reality and Prototyping'99, France, pp. 11-22

3.3 VR application: an instrumented bicycle for a natural motion

Virtual study protocol. The developed VR application is based on a design and evaluation method that outlines 3 levels of immersion and interaction (I²) in order to build a VR application: 1/ *the functional I²* define the tasks that have to be performed in the virtual environment.[36] In our case, there are 3 tasks: the user observes the virtual landscape while he is walking along a path and talking to the investigator beside him (real world). 2/ the *mental I²* describe how the user is implicated in the virtual environment. In our case, they will be validated by the comments. 3/ the *sensory-motor I²* define the 'user-VR system' physical relation (devices). In our case, they are determined by visual and acoustic devices (immersion) and by motion devices (interaction).

VR application. The virtual world behaviour includes: 1/ *visual perception*: the blades' rotation. 2/ *acoustic perception*: the different sounds (blades' noise, road traffic, birds and wind) were recorded on site and implemented in virtual paths with respect to reality. In Path1, 3 sounds were associated to 3 objects (blades' noise/blades, road traffic/road and birds' noise/central object in the path); the blades' noise was pitch-defined in order to match with a medium rotation speed (12 revs. per minute). In Path2, the WT were not heard in the *in situ* surveys then only birds' noise and road traffic were implemented. In both paths, every sound has a sphere of acoustic influence and decreases at a certain distance like in the real paths (Figure 5). Spatialized sound is also used in order to cope with a real landscape experience. 3/ *perception in motion*: we assumed that an instrumented bike could be a solution: motion would be natural. We also assumed that biking (*in vitro*) is different of walking (*in situ*); that is why we fixed maximum biking speed at 7 km/h. To cope with a very limited budget, we simply used the opto-mechanical sensors of 3 mouses that were plugged to the PC and implemented natural motion with a Virtools building block. Rotations of the rear wheel and of the handlebar were measured to provide realistic natural motion to the user. A third mouse wheel has been fixed on the handlebar and used to control head vertical orientation. The system instrumentation is presented in Figure 6.

The experiment took place in an immersive room equipped with a large rear-projected screen (2.4x1.92 m), 2 spatial sound speakers, a control computer and 2 video projectors (Figure 4). We decided to place the user 1.5 m far from the screen, which ensures a field of view of 77 degrees horizontally (1:1 scale). The virtual camera is positioned at 1.6m from the digital floor in order to match with a common cyclist's eyes position.

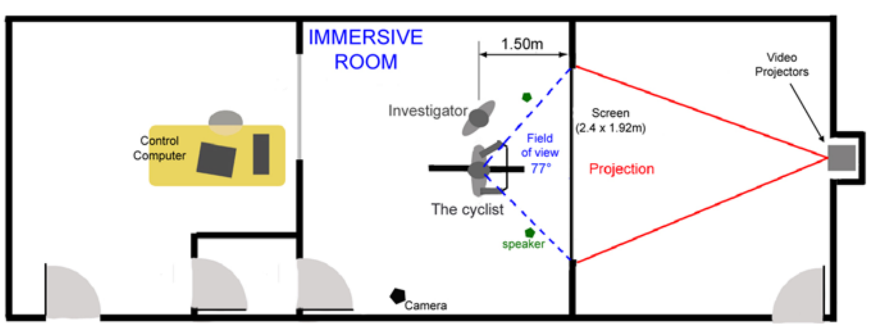

Figure4 Experimental room

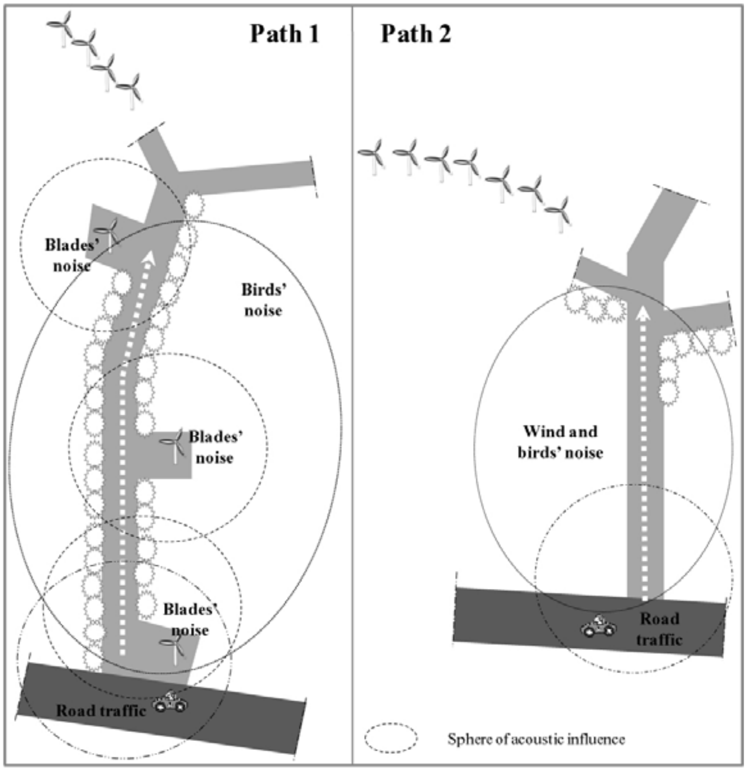

Figure 5 Sound setting up and spheres of acoustic influence in the digital world

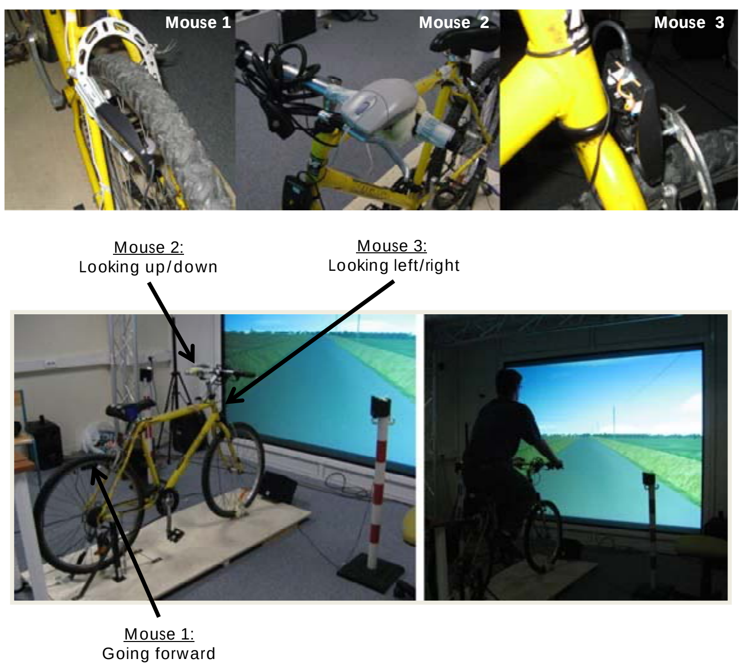

Figure 6 Instrumentation of the bicycle with mouses' sensors

4 Results and comparison

In situ, 9 participants participated in Path1 survey and 9 others in Path2 survey (*in vitro*: 10 participants – Path1; 9 participants – Path2).[37] The questionnaires' results are separated from the comments' ones because we want to show that on one hand, 'immediate' perception drew more information and results than 'remembered' perception; and on the other hand, the comparison between real and virtual worlds was more obvious through comments' analysis than in questionnaires' answers. But we think they complemented each other.

37 **Jallouli J.** & **Moreau G.** (2009). ibid

4.1 Questionnaires' analysis

The questionnaires enhanced 'remembered' perception of WT impacts, landscape features and path sequences. The VR system characteristics were discussed in the *in vitro* questionnaire.

WT impacts. The questionnaires confirmed that WT impacts are both visual and acoustic. 1/ *Visual impact*: in Path1, most of participants found out that the WT scale is the most important visual impact (60% *in vitro* and 88% *in situ*) and 50% of them considered that the WT has got a positive impact (variety, colour, focal point). In Path2, scale was also the most impressive feature in both worlds but only for 50% of participants and blades' rotation was the most important asset of WT (77% *in situ* vs. 33% *in vitro*) because from Path2, WT develop a rhythmic horizontal that is animated by blades' rotation. 2/ *Acoustic impact* was deduced from Path1because only one participant heard WT noise in real Path2 (wind direction was favourable). In virtual Path1, the WT noise was assessed as not disturbing (60%), annoying (20%) and annoying because of its repetition (40%). In real Path1, answers depended of wind speed; when it was strong (more than 35 km/h), the WT noise was impressive and very annoying.

Landscape. The most remembered landscape features were also visual and acoustic. 1/ *Visual features*: in both real and virtual Path1, 90% of participants were mostly attracted by WT and moving blades but in virtual Path1, 40% of participants brought back flat vegetation. In real and virtual Path2, WT were visually the most attractive (66%) then fields, houses and cows. 2/ *Acoustic features*: in Path1, WT noise was the most significant acoustic feature (100%) then the birds' one (60%). In Path2, participants mentioned birds' noise first then road traffic.

Path sequences. By moving, the participant evolves in space, changes his point of view and discovers new sequences, motion constructs the space mental representation. This question shows participant's understanding of the world where he was (especially in the virtual world) and which elements structure his space. In both worlds, most of participants sketched straight paths with main visual elements (Figure 7). We notice that WT structured the sketched Path1 while in Path2, others landscape elements such as fields, cows and houses also participated in the path mental image.

VR conditions. Remarks deal with modelling, immersion (visual and acoustic) and interactive devices. 1/ *Modelling*: in Path1, 40% of participants were not satisfied about flat and unreal vegetation that borders the country road. 2/ *Visual device*: 20% of participants thought that the screen limited their field of view especially in Path2 where they cannot move forward and look to all WT on the left. 3/ *Acoustic device*: 30% of participants regret the wind absence (sound and breeze). 4/ *Interactive device*: first, 10 % of participants in Path1 vs. 66% in Path2 thought that they were limited by the bicycle speed. The important amount in Path2 is justified by spread landscape (all elements are concentrated in the end of the path) that encourages participants to accelerate. Second, the VR device to look up (use the scroll wheel of the mouse) was not ergonomic for 40% of participants in Path1 (participants do not need to look up in Path2). Third, the VR device to look around (stop and turn the handlebar) was not ergonomic for 22% of participants in Path2 and many participants even forgot to use it.

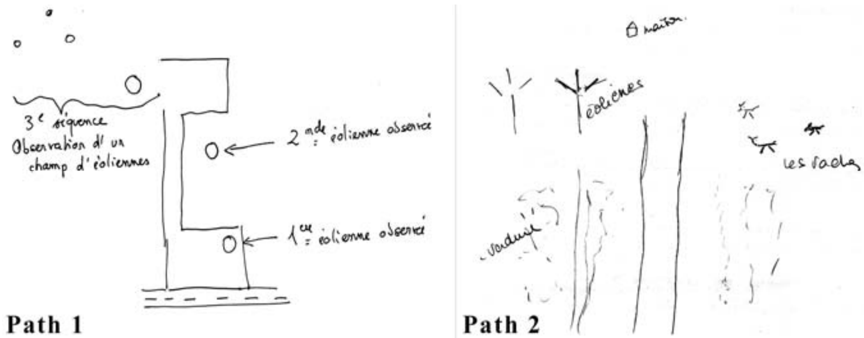

Figure 7 Example of participants' sketches

4.2 Comments' analysis

We show in Table 1 an example of comments' classification. Participants addressed three main subjects: WT, landscape and VR system biases. The following results tally with this classification.

Table 1 Example of comment's classification

WT			Landscape		VR system biases
Visual impact	*Acoustic impact*	*Others*	*Visual features*	*Acoustic features*	*Modelling, immersion, interaction*
So now, I go to the WT foot... but like this, while I am moving forward to it, I do not see that it is a WT... I look up and I am impressed, I told myself that it is high...	The noise impresses me... I did not think that it has got this intensity... it is especially periodic and continuous.	*Souvenirs:* I remember the WT of Boin in front of the ocean... they are often in open spaces... *Renewable energy*: it produces energy without consuming, just with air! Electricity is expansive!	I like country spaces with fields and cows... I see wheat fields, a forest in the back, sky and clouds... it is a lovely day...	What I hear is the road traffic behind? It is nice to hear birds... The WT noise impresses me much more than the scale.	I do not feel the wind... I am wondering what kind of wind sensation we have here on the foot of the WT. The vegetation is too flat here...

WT. They activated visual and acoustic perception in Path1, visual perception in Path2 and many ecological thoughts. They were a central subject in the comments' particularly in Path1 because WT fulfil space more than in Path2. 1/ *Visual perception*: it differs between both paths. In real Path1, scale and moving blades impressed and were the focus point of vision for all participants while *in vitro*, they impressed less; but in both worlds, participants gave rather positive WT description (modern, elegant). In real and virtual Path2, the scale was less impressive than in Path1. But while *in situ*, Path2 generated a horizontal pleasant reading thanks to repetition and to moving blades; *in vitro* the limited screen stopped to 1 or 2 WT and participants seldom think about looking to the left: the reading is vertical and the rhythm of moving blades was then not seen (Figure 8). 2/ *Acoustic perception*: the integrated sounds improved immersion sensation. In Path1, 70% of participants classified the noise as mechanical (airplane, washing machine), which means that the WT is not assimilated to a countryside object. Otherwise, it was negatively perceived because of its cyclic repetition in both worlds. 3/ *Others*: Many participants appreciate WT because it is a renewable energy thus it must produce electricity all the time. A WT that do not turn is not only aesthetically ugly but it is principally not producing green electricity.

Figure 8 Extended field of view in situ vs. limited field of view in vitro

Landscape. Landscape features that were deduced from comments' were principally visual and acoustic. But obviously, vision dominated perception (60% of comments are about visual features and 20% are about acoustic features). 1/ *Visual features*: surrounding shapes and objects influenced perception. In Path1, the field of view was rather narrow and only opened on vertical and noisy WT (feeling of being overwhelmed); while in Path2, the field of view was widely open with an attractive straight road, which encourages participants to accelerate. 2/ *Acoustic features*: *in situ*, acoustic perception varies a lot depending on wind speed and direction, which is not the case *in vitro* (wind is an ambiance sound). Otherwise, the integrated sounds were assessed positively (like in real world) and they enhanced immersion especially the countryside sounds that were compulsory for the presence feeling.

VR biases. The VR system limitations are the same with those cited in the questionnaires' answers for modelling, immersion devices and interaction devices but with a bigger amount of participants because many participants were not conscious of their remarks and do not remember them afterwards (e.g. '*the vegetation angle is 90 degrees… but apart from that, the world seems very realistic…*').

5 Discussion

Results show that the restitution of multisensory and dynamic perception in virtual world is of great importance in order to tally with real landscape experience. This restitution is conditioned by immersion and interaction devices because they influence each other and they influence perception.

Immersion. The immersive experience was visual and acoustic. On one hand, visual immersion was conditioned by 1:1 scale, modelling, visual device (screen) and ‘user-screen’ distance. 1/ 1:1 scale restituted some landscape and WT characteristics (open/closed space, WT scale). 2/ Modelling realism helped the user mental implication in the virtual world except 2D vegetation (Path 1) that accentuates road perspective; when the observer is nearby, 3D vegetation must be used. 3/ The screen used in the experiments do not tally with real field of view, it was vertically limited (Path 1) and horizontally limited (Path 2). The use of a mouse to look up (Path 1) and the handlebars to look left and right (Path 2) was neither ‘natural’ nor ‘ergonomic’ for users; that is why a CAVE-based solution might be more appropriate to restitute extended and spread rural landscape. 4/ The screen proximity (1.5m) made the ‘rotor-observer’ distance unreal: at the real WT foot, when a participant looks above to see the blades, this distance is more than 50m. Consequently, even with 1:1 scale, the WT is less impressive in the VR experience than in a real park. On the other hand, acoustic immersion was successful because the WT noise was described in the same way in both worlds and because inter-sensory perception made the VR world more realistic: the WT noise in Path 1 reinforced the landscape ‘production’ identity and the birds’ sounds in Path 2 confirmed the space countryside reading. The only limitation affected the wind sound that was missed for some users.

Interaction. Two devices must be discussed: visual movement and self-motion displacement. On one hand, visual movement devices manage head horizontal orientation (handlebars) and head vertical orientation (mouse wheel). In Path 1, horizontal orientation was natural thanks to path direction (user looks and goes forward in the same direction) while vertical orientation cuts user’s immersion because he must use an unnatural way (turn the mouse wheel). In Path 2, vertical orientation was not needed and horizontal orientation forced the user to stop and to turn the handlebars in order to see all WT without going out of the road. These divergent results show some limits of our system and how landscape influences the devices’ choice and vice versa. On the other hand, displacement devices allowed a natural motion (tiredness, stop, acceleration, etc.) thanks to the use of a cheap bike; consequently, it improved user’s implication and immersion. The bike is a good solution for extended rural spaces (hundred meters to cover).

A comparative chart between in situ and in vitro results is presented in Table 2.

In general, the developed VR system is faithful to the landscape complex because it restores the ‘perception/action’ couple, in other words the ‘user-environment’ relationship. Immersion, inter-sensory perception and motion determine the individual entity that interacts with the world and that must be restored in the representation and discussion tool in order to tally with user’s reality and assessment.

6 Conclusion: VR as a landscape decision-making tool

WT landscape is singular because of WT height, moving blades or acoustic impact. The developed VR system was first built to answer to those unique object characteristics but it also restored general landscape features: aesthetic and acoustic qualities of space, movement, motion, human point of view and scale, and principally interaction of all those features together. A VR decision-making tool must integrate all those criteria in a restrictive space where human dimension and scale can be of paramount importance.

Table 2 Summary and comparison in situ /in vitro

		In situ	***In vitro***
Path 1	*Comments*	WT	WT
	Landscape character	'industrial'	'industrial'
	WT impacts	*Visual* : 1/ scale (strong) 2/ moving blades *Acoustic*: repetitive	*Visual* : 1/ scale (strong) 2/ moving blades *Acoustic*: repetitive
	Acoustic perception	WT, wind	WT, birds
	Perception in motion	3 sequences (WT structure space)	5 sequences (WT structure space)
	Mental chart	WT structure space	WT structure space
	Physical factors	Influence	-
	Modelling		Realistic model except 2D vegetation (accentuate perspective)
	Immersion limits		– Screen vertical limits – WT top visual details
	Interaction limits		*Visual* : natural movement horizontally but not vertically
Path 2	*Comments*	1/ WT 2/ immediate environment	1/ WT 2/ immediate environment (including road perspective)
	Landscape character	Countryside	Countryside
	WT impacts	*Visual*: 1/ moving blades 2/ scale (strong)	*Visual*: 1/ moving blades 2/ scale (important)
	Acoustic perception	Birds (countryside character)	Birds (countryside character)
	Perception in motion	2/3 sequences	2/3 sequences
	Mental chart	WT and road structure space	road structures space
	Physical factors	Influence	-
	Modelling		Realistic model
	Immersion limits		– Screen horizontal limits – Object position in space
	Interaction limits		*Visual* : unnatural movement horizontally

A landscape project includes 2 steps: conception and decision-making. Generally, project discussion is the final step and users and designers can barely review it. That is why we think that the discussion process must be integrated at different stages of conception. Like this, 1/ users would progressively 'get used' to the project before construction (minimizing impact); 2/ project review would be easier and more debatable for users because their ideas would be taken into account from the beginning of the project; and 3/ a progressive detailed approach of the representation tool (from static representation tools to VR tool) would help WT actors (designers, local authority and users) to 'build' a dialogue, an idea, a project together. In the following paragraphs, we identify some criteria and steps to build a VR tool for landscape decision-making:

Paths and points of view. In order to choose the area to study, the designer must answer to 2 questions: which user is concerned by the space (visitor, inhabitants, other)? 2/ which places are attended by those users?

Modelling. It depends of conception's steps: in sketches, static representations could be used, and in advanced steps, VR system could be evolutive in realism (2D vegetation, 3D shapes), and immersion and interaction protocol: visual immersion then coupled senses, no interaction (walkthrough) then interaction.

Multi-sensory landscape. First of all, the designer must identify the aims of the multi-sensory restitution: to evaluate and qualify sensory perception? Or: to improve the user's immersion? In the first case, restitution must be precise which is more difficult. In second case, the location of acoustic sources, volume, etc. are important. Which senses are important to restore? Generally, vision and hearing are the most used senses in landscape; their restitution is the easiest in comparison with touch or the smell.

Immersion and interaction interfaces. *Immersion*: every restored sense needs an immersive interface. Visual interface is the most important to provide. In rural landscape, extended scale (horizontally and vertically) is important to question. *Interaction*: here it shall not be forgotten that movement cues are not only visual: though joysticks (like the Wiimote) are today frequently used, they cannot render non-visual motion cues. Head-tracking systems help the user understand the word he is in, but cannot be enough because of their limited range with respect to the size of the virtual environment. The cheap-instrumented bicycle appears as a trade-off with respect to motion non-visual cues, motion speed and instrumentation costs (compared with a 2D treadmill for example).

Survey method. The *commented walk* consists of a free dialogue between 2 persons (for example, user and designer) and it is an interesting way to characterize and to contextualize immediate perception. In the virtual world, we are investigating the solution of introducing a virtual guide who will question the user (in the real world); this solution may improve user's immersion in the virtual world. Otherwise, questionnaires enhance memorized perception and are an interesting complement to the commented walks.

In this work, we validate VR potentialities as a discussion tool. That is why, next step will be the impact of VR use in conception and decision-making of a landscape project. We also plan to study the impact of using a virtual investigator on immersion and interaction protocol, and to substitute VR by augmented reality because real world might increase user's immersion and implication. This raises new difficult challenges for AR: outdoor tracking is under active research in urban environments, very few researchers are yet working on non-urban environments with flat non-textured landscapes.

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