Public Participation to Support Wind Energy Development: The Role of 3D GIS and Virtual Reality

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ABSTRACT

Wind energy is identified as having a significant contribution to reducing greenhouse gas emission, and Scottish Government targets for the generation of energy from renewable sources. Public policy emphasises the importance of using an ecosystem approach, and the role of public engagement in decisions about future uses of land and sea. A prototype 3D model was developed to present a loch with hypothetical wind turbines on the west coast of Scotland. The model was used to identify issues arising between the growing interest marine renewables, land use changes in line with changing policy and the potential effects on existing seascapes and marine industries and activities. An interface has been developed to provide interactive movement of features in models, including hotkeys to: (i) Switching between images (e.g. 1:50,000 map and aerial images) and GIS Data layers (e.g. Scottish Natural Heritage (SNH) designations); (ii) Introducing new features (e.g. houses, wind turbines, trees); (iii) 'drag and drop' features, guided by the audience.

The virtual reality model was tested with a range of different audience types at events in Oban, on the west coast of Scotland, and Aberdeen on the east coast through Virtual Landscape Theatre (VLT) and Oculus Rift. Factors identified for detailed testing included the significance of lighting conditions on the east and west coast, sea state on perceptions of seascape and wind energy generation, and people's activities at different times of the day.

Keywords

3D GIS, Public engagement, Virtual reality, Wind energy, Virtual Landscape Theatre.

1. INTRODUCTION

In response to development proposals, such as for wind turbines, computer visualisations form part of the materials used in assessing visual impacts. Guidance on standards for such materials, such as the visual representation of wind farms [1], set out requirements and settings for the preparation of visualisations. However, these are restricted to the use of photomontages, and wireframe representations for use in the illustration of the location and nature of a proposed wind farm and predicted visual effects of developments. 3D GIS, VR and associated tools, may have benefits which could support delivery of the types of aspirations or regulatory requirements in public policies which relate to planning and development.

ICT tools and visualisation in particular, have been used increasingly as part of information, consultation, and collaboration in relation to issues of global significance. For example, the representation of landscapes of the future including 3D imagery [18][19], sketches, or imagery [20] enables the interpretation of change in relation to landscapes. Visualisation tools have been used for helping communities to plan for adaptation against impacts and effects of climate change as demonstrated by the research team at the Collaborative for Advanced Landscape Planning, at University British Columbia, Canada [21]. They have developed the use of virtual and augmented reality and Geographic Information Systems, with tools such as Community Viz [22], and provide a video game which they describe as empowering lifelong learners to creatively construct their own futures.

Public participation is another issue regarding people engagement in decision making and stakeholder's planning and feedback. The impact on the planning process depends on the level of stakeholder involvement. This involvement can be divided into three aspects as shown by Miller et al [2]:

1) Dissemination, where information is almost exclusively communicated to the public by the 'experts';

2) Consultation, where public opinions are sought and considered in expert or managerial decision-making;

3) Collaboration, where representatives of the public are involved actively in developing solutions and

directly influencing decisions to a greater or lesser degree.

Recently, there is a trend to create methods and tools for investigating landscape and seascape time-depth and historical scenarios through the use of 3D modelling tools and virtual reality engines [11][12], further encouraged by new technological developments that enhance performance and interactivity. For example, virtual reality head-mounted display such as Oculus Rift [14] and PlayStation VR [13] provide a 90 degrees horizontal and 110 degrees vertical stereoscopic 3D perspective. The result is the sensation that you are looking around a very realistic 3D world.

2. BACKGROUND

The 2020 Renewable Routemap for Scotland – Update [3] sets out ambitious targets of the equivalent of 100% of Scottish demand for electricity and 11% of heat capacity to be generated from renewable sources by the end of 2020. This is to be achieved in the context of international agreements for reductions in greenhouse gas emissions alongside those relating to environmental, economic and social considerations. Planning Scotland's Seas [4] notes the importance of considering the onshore implications of offshore developments, and recognises that renewable energy developments offshore have associated infrastructure onshore. In particular, Planning Scotland's Seas identifies links between the marine and terrestrial planning systems, and the requirement for inputs from local stakeholders and knowledge in the development of spatially more detailed Marine Region Plans. It proposes the use of the Ecosystem Approach to better integrate management of seas and coastal areas, the same approach as advocated in the Scottish Land Use Strategy [5].

Currently, 3D based approach plays an important role and makes a real contribution to support wind energy development [23][24]. However, the system developed have lacked direct connection to spatial data, it is a major task to integrate with GIS seamlessly.

In this study visualisation tools were used to present topographic contexts of land and sea use and the introduction of potentially new features and their planning developments such as renewable energy. This takes advantage of the ongoing development of software tools for use in representing 3D environments, such as Maya, 3D Max, Vega Prime, Octaga or specialized landscape visualisation tools such as Visual Nature Studio. These provide a high degree of visual realism for landscape and seascape, enabling the rendering of images or animations [6][7][8][9][10].

3. METHODOLOGY

The main steps involved can be summarised as follows (Figure 1):

(i) Compilation of spatial datasets comprising land sea floor, and surrounding terrain to represent the present-day sea loch;

(ii) Creation of 3D models using existing GIS data, with representation of alternative layouts and designs of offshore wind turbines; 3D models interaction and usability of the interface.

(iii) Development of wind farm preferences using visualisations of each scenario from different viewpoints;

(iv) Elicitation of public opinions on future wind farm planning using VR facilities including VLT and Oculus rift.

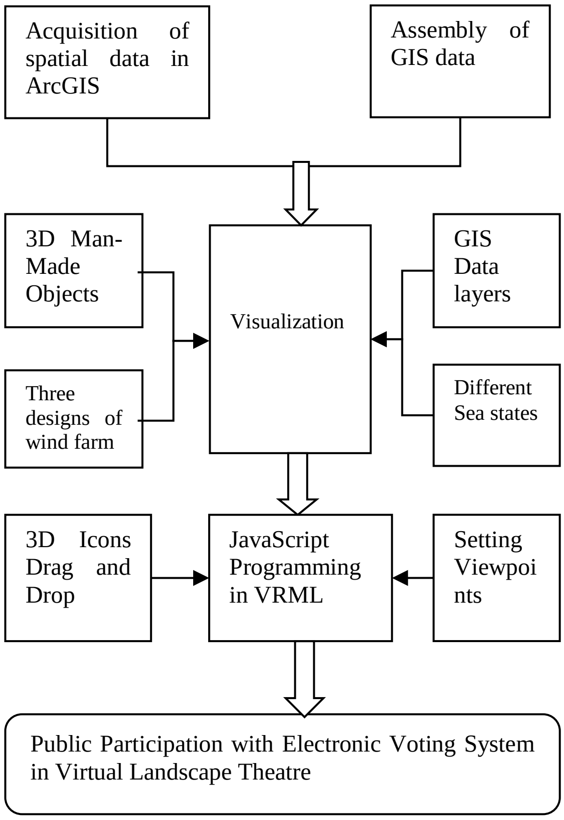

Figure 1 Framework for 3D visualization and simulation of offshore wind farm

The prototype model was used in events designed to elicit public aspirations and concerns regarding future land and sea uses, and to develop scenarios driven by local input. Sessions comprised:

- Introducing drivers of land and sea use change (e.g. movement of features) and electronic voting system;
- Audiences recording preferences for wind farm layout from different viewpoints;
- Audiences voting to prioritise wind farm topics

for in-depth discussions;

- Discussion and voting on sea loch issues (e.g. fish farm location/ size; woodland location/type, building location/type).

3.1 STUDY AREA

The study area was Loch Linnhe, a sea loch on Scotland's west coast, approximately 50 km long, running from Fort William to Oban, at the south end of the Great Glen fault. Land use is dominated by agriculture, particularly crofting on the islands and western shores, forestry, and tourism. Uses of the loch include inshore fishing and fish farming, sailing, and diving, with increasing interest in marine renewable energy.

The topographic context of Loch Linnhe is of glaciated valleys, with terrain rising steeply away from the loch, bare rock and scree, and land on the eastern shore which includes a raised beach. During past ice ages, the loch was a major outlet for glaciers from the Rannoch Moor area, where ice built up in the initial stages of development [15].

3.2 3D Model Creation

A basic model was created of the sea floor and surrounding land of Loch Linnhe in Figure 2.

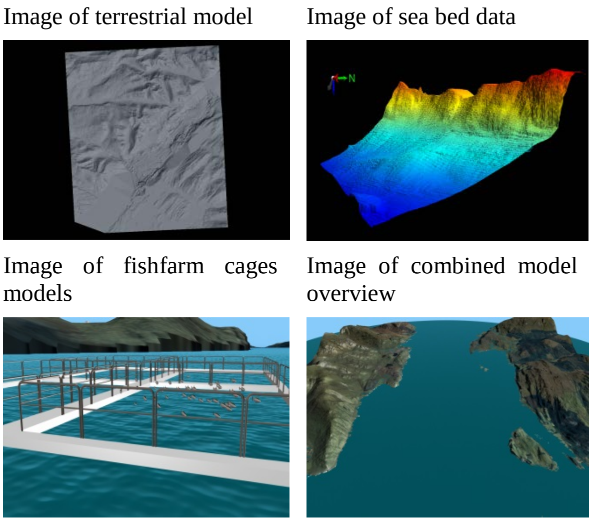

Figure 2 Basic Loch Linnhe Model

This used data of above and below the water line, and the addition of 3D model features, for use in a virtual reality environment:

1) Ordnance Survey (10m resolution) Digital Terrain Model extracted for the land around Loch Linnhe.
2) Multibeam sonar data (1m resolution), surveyed by the UK Marine Environmental Mapping programme (MAREMAP) of British Geological Survey, Scottish Association of Marine Sciences (SAMS) and National Oceanography Centre (NOC), combined with Admiralty seabed data.
3) Autodesk Infraworks used to render a 3D model combining the seafloor and terrestrial areas (221km2; 2.5m resolution), with true scale above sea level and a 2 times vertical exaggeration below sea level.
4) High-resolution aerial imagery used for background landscape textures.
5) Extruded buildings were derived from Ordnance Survey MasterMap.

Further elements added to the model were:

(i) Features associated with coastal environments, developed in Autodesk Maya, including fishfarm cages, leisure craft and renewable energy structures.
(ii) GIS Data layers representing designations (e.g. National Scenic Areas, shell fishing zones).
(iii) Water, using colour to distinguish between above and below water surface.
(iv) Different sea states [16].

A 3D geo-referenced model was created of the island and surrounding sea, with representation of alternative layouts and designs of offshore wind turbines. The spatial data were compiled in ArcGIS, in a single coordinate reference system. The software tools used for the 3D models were Google Sketch-up, Infraworks and Maya.

The spatial data were converted for use in the Octaga virtual reality software in the Virtual Landscape Theatre [11]. The theatre is a mobile curved screen projection facility in which people can be 'immersed' in computer models of their environment to explore landscapes and seascapes.

3.3 Three designs of a wind farm

The model of the windfarm comprises 20 wind turbines, approximately 1.5 km apart, with three different heights of wind turbine: 128m, 165m and 215m. Each turbine is set up with a different location and rotate speed (cut-in wind speed: 3-5 m/s; cut-out wind speed: 25 m/s) [25] in the Loch Linnhe virtual environment which shows a potential area for renewable energy development.

The model includes three different representations of sea state (based on the World Meteorological Organization sea state code; [16]), each with a unique texture and tide height. Wind speed and wind direction have also been considered and corresponding parameters such as cloud cover and wind turbine start-up speed have been added into the

3D Loch Linnhe model, with a dominant wave direction applied to the sea surface, each of which can be switched between. The modelling of illumination conditions is used to enable the inclusion of shadows from the wind turbines in appropriate sunlit conditions and reflections off the sea surface.

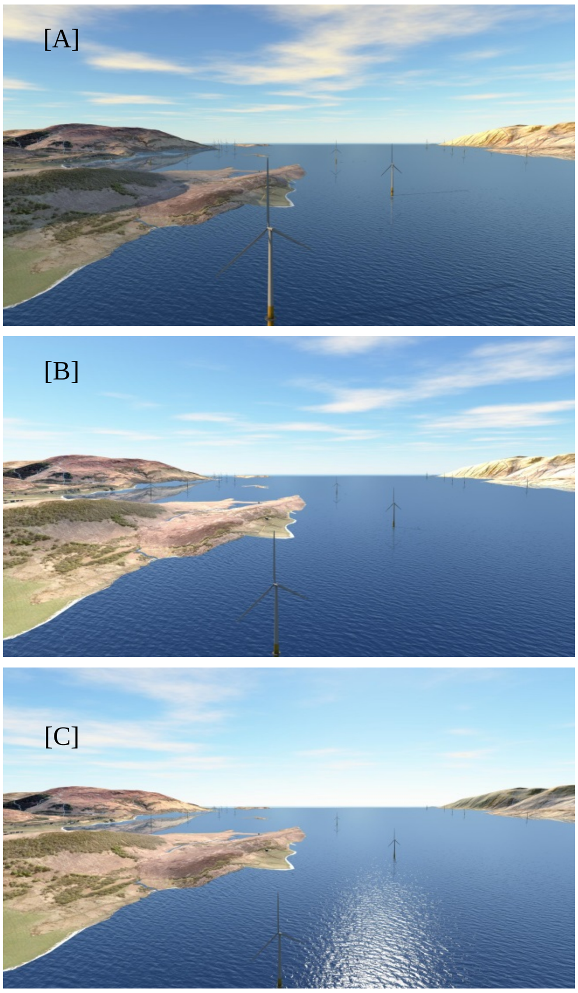

Figure 3 Hypothetical wind farm layouts in 3D virtual Environments of Loch Linnhe: [A] wind turbines 215m to the tip of the blade at sunrise; [B] wind turbines 165m to the tip of the blade at midday; [C] wind turbines 128m to the tip of the blade in the afternoon.

3.4 Interactive functionality and interface for Loch Linnhe model

An interface has been developed to fit with the output of 3D model and the model content with respect to purpose of use. This part of the experiment focused on the interaction and usability of the interface, and the recognizability of the type of visualization. A 'drag-and-drop' feature that allows participants to choose where they would like to position elements (wind turbines, trees, houses, etc.) was added based upon a series of 3D icons (Figure 4). The icons are coded in JavaScript to allow participants to select locations of the forest, housing development, access to the town, car parking, renewable energy, playgrounds and conservation area. It also provides functions for pointing out those areas where audiences definitely do not want such a feature. Icons were 'dragged and dropped' to audience selected positions, with VRML code 'ground clamping' them to the terrain surface (i.e. the icons were automatically located at a vertical elevation consistent with the ground surface).

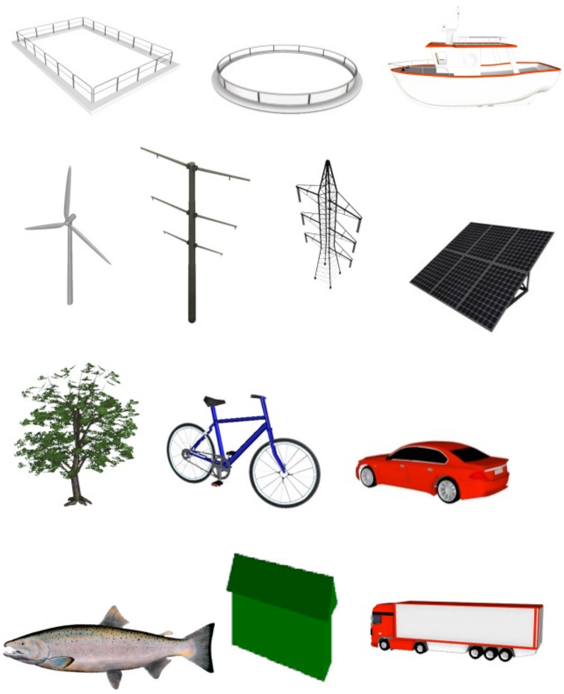

Figure 4 3D icons of land and sea use features

Landscape and seascape could be future modified according to participant's preferences. For example, wind turbines are normally located upon the hill, trees are usually distributed with reference to existing woodland areas, and buildings are mostly situated adjacent to existing settlements. In Figure 5 the infrastructure of an onshore wind farm can be seen. In addition to the wind turbines, the associated power lines for connection to the electricity grid are visible together with features in the vicinity of the development, such as field boundaries and trees. For effective stakeholder engagement it is important to provide sufficient detail of features to enable participants to be able to relate to the site, and locate themselves with respect to a planned development. The level of detail (e.g. number of features, and the visual detail with which they are presented) is tested in a workshop with key stakeholders, so informing the design and implementation of the 3D model.

Figure 6 shows a still from a model of the aquaculture feature, in which the animation version shows the water under different conditions of illumination, levels of variability in waves and the movement of salmon in the cages. Viewing can be from above or below the waterline. When tested with stakeholders (e.g. public, fisherman) at the World Marine Biodiversity Congress, Aberdeen, September 2012, the interactive capabilities were very well received, as was the functionality and appropriateness of the levels of detail.

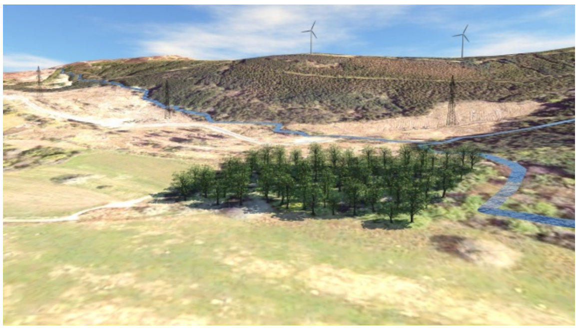

Figure 5 3D drag and drop of icons showing proposed location of new features adjacent to Loch Linnhe.

Figure 6 Planning the siting and support of aquaculture in Loch Linnhe

3.5 Eliciting audience opinions

A prototype of the virtual reality model was tested with a range of different audience types at events in Oban, on the west coast of Scotland, and Aberdeen on the east coast. The Virtual Landscape Theatre and Oculus Rift were used as the medium with invited groups or individual drawn from schools and youth groups, universities, natural heritage managers, planners, and the general public.

The James Hutton Institute's Virtual Landscape Theatre (VLT) is a mobile curved screen projection facility measuring 5.5 metres x 2.25 metres. The screen curvature of 160 degrees provides immersive viewing for up to 20 people. The VLT 'frame' is similar to that used in music concerts, consisting of aluminium trusses which are bolted together to form the walls and roof of the facility. A projection screen is attached to the rear curved wall to form the projection surface. Parallel processing of the 3D models is undertaken by a cluster of three high-end PCs, each consisting of dual quad core processors, RAID Hard Drives and Nvidia FX4800 Quadro graphics cards. The images from each PC is registered and seamlessly joined by 3D Perception UTM before being transmitted to three 3D Perception SX+ projectors. The projectors are mounted overhead and in-front of the screen (front projection). Software models are prepared in either in VRML or OpenFlight formats, and displayed by Octaga Panorama or Vega Prime applications respectively. The portability of the VLT allows it to be used in community venues across Scotland, thereby bringing planning and public participation to planners and the general public. The VLT facilitates visualisation of landscape changes such as woodlands, vegetation, farm management practices, wind farm developments, design and layout of parks, urban expansion and climate change; as well as marine planning such as offshore renewables and aquaculture.

The Oculus rift is one of the low cost HMDs which allow a user to immerse into the virtual environment and look in any direction. It provides an effective resolution of 960 x 1080 pixels per eye with 100° nominal field of view.

Figure 7 Virtual Landscape Theatre: stakeholder dialogue and opinion sharing

Figure 8 Oculus rift: single user exploration of seascapes

Figure 7 and 8 show the use of visualisation tools for eliciting stakeholder opinions, explore scenarios and discussing options. Mobile virtual reality tools for groups (VLT) or individuals (Oculus Rift) are used for selected case study areas.

Table 1 summarises an example of the factors used to assess ‘success’, and the issues identified by stakeholders as key elements to assess the state of progress of 3D visualisation tools for the purposes of their business needs.

Factors for success	**Issues identified by participant**
Impact	1.Improve efficiency 2.Higher quality decisions 3.Improved communications
Information delivery	1.Multiple modes of information (use of mixed media) 2.Multiple methods of delivery (abstraction, perspectives, interactivity) 3.Multiple interface capabilities (delivery platforms)
Information quality	1.Accuracy 2.Completeness 3.Reliability 4.Unbiased 5.Understandable 6.Relevance
Functionality	1.Trend analysis (prediction) 2.Access to data
Ease of use	1.Easy to use 2.Fast response time (rendering speed)

Table 1 Summary of factors for assessing suitability of VR tools for use by stakeholders.

A regional model was used to introduce the events, providing a context for discussion of issues around the development of offshore windfarms. The Loch Linnhe model was then used to elicit opinions on the issues associated with developing a windfarm in this area of the west coast of Scotland. A preset flythrough route was used to introduce the island, its geography, and the uses of the land and surrounding seas. This was followed by views of the different options for wind farms from specific view points, including at the coast, from specific properties. Audience opinions regarding the views were recorded using electronic handsets.

4. Results

The 3D model and simulation of visual impacts of hypothetical wind farm were used both at events on the west and east coast of Scotland. In total, six formal sessions (108 participants) were arranged for invited groups that consisted of land managers, natural heritage managers, planners, schools and youth groups, university students and the general public.

The medium-scale wind farm was identified as having the strongest preference amongst audience groups (Table 2).

Hypothetical wind farm	Small-scale wind farm	Medium-scale wind farm	Large-scale wind farm
Voting Results (108 participants)	30(27.8%)	58(53.7%)	20(18.5%)

Table 2 Participant preference ratings for hypothetical wind farm in 3D virtual environment.

Audience feedback suggested that the virtual environment was very effective in providing an impression of the different layouts and characteristics of the offshore wind farm, and enabled comparisons to be made of the differences in the visual impacts of the alternative heights of wind turbines (Figure 9).

Figure 9 Audience discussion over the different options for windfarm offshore of Loch Linnhe

Comparing the feedback on presentations in venues on the west and east coast of Scotland, with models of windfarms on each coast, the issues arising included the different impacts in the morning and evenings of developments on the east and west coast relating to lighting conditions and the patterns of people’s daily activities. In particular, differences were identified between visual impacts at sunrise and sunset in an east and west coast environment, and the effects of horizontal views (i.e. with sky backdrops) compared to those downwards towards the development (i.e. with sea backdrops).

Findings from use of the prototype are being used to develop tests to consider the potential significance of sea state with respect to view characteristics, and the significance of different lighting conditions and turbine layouts on people’s landscape and seascape preferences [17].

5. Discussion and Conclusions

The nature of audience interaction with the models appears to have been appropriate to satisfy the aims of the participation. Based on voting results from feature recognition (e.g. lochs, islands, mountain, villages, woodlands) and hypothetical wind farm layouts, the virtual environment provided materials with levels of familiarity suitable for credible suggestions for consideration of existing and new features. Audience surveys suggest that the package (i.e. the evidence of recording views, relevant models, the facility and its interactivity) supported material participation, beyond that of information dissemination. The level of influence on final decisions remains to be assessed after completion of the process of plan development.

Exploring and interpreting the offshore environment was reported by teachers, and professionals, as providing a better understanding of the potential impacts of a proposed windfarm. Some of the issues raised were identified as being of specific relevance to the school curriculum for follow-up discussions in class. Feedback from professionals in natural heritage management and planning reported the value of being able to see representations of different options in heights and siting of turbines, and from locations selected by members of the audience.

Engaging with stakeholders and the public has enabled discussion, explanations and opinions to be exchanged, and feedback on renewable energy use, now and in the future. The results are being used to inform improvements in the design of tools for eliciting public responses to prospective changes in offshore wind farms interpretation, and demonstration of one aspect of an ecosystem approach to the planning of change at sea.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] SNH 2014. Visual representation of wind farms. Scottish Natural Heritage. http://www.snh.gov.uk/publications-data-and-research/publications/seitarch-the catalogue/publication-detail/?id=846

[2] Miller, D. R., Morrice, J., Horne, P. and Ball, J, “Integrating programmes of awareness and education for professionals and the Public”, proceedings of Environment 2007, Abu Dhabi, 27 January – 2 February, 2007.

[3] Scottish Government 2012,2020 Renewable Routemap for Scotland – Update www.scotland.gov.uk/Resource/0040/00406958.pdf

[4] Scottish Government (consultation documents) 2013, Planning Scotland's Sea: Scotland’s National Marine Plan (including offshore renewables) www.scotland.gov.uk/Topics/marine/marine-consultation

[5] Scottish Government 2011, Land Use Strategy, Scottish Government. www.scotland.gov.uk/Resource/Doc/345946/0115155.pdf

[6] Ball, J., Capanni, N. and Watt, S. 2007, Virtual reality for mutual understanding in landscape planning. International Journal of Social Sciences 27(2) pp78-88.

[7] Wang C., Wan T.R and Palmer I. 2010, Urban Flood Risk Analysis for Determining Optimal Flood Protection Levels Based on Digital Terrain Model and Flood Spreading Model, The Visual Computer, Springer, 26 (11): 1369-1381.

[8] Wang. C, Miller. D, Jiang Y and Donaldson-Selby. G, Use of 3D Visualisation Tools for Representing Urban Greenspace Spatial Planning, 2015 IEEE International Conference on Information Science and Control Engineering (ICISCE 2015), 24-26 April, pp 528-532, 2015.

[9] Resch. B, Wohlfahrt. R and Wosniok. C, Web-Based 4D Visualization of Marine Geo-Data Using WebGL, International Journal of Cartography and Geographic Information Science, 41:3, 235-247, 2015.

[10] Wang. C, Wan, T.R. and Palmer, I.J. 2012. Automatic reconstruction of 3D environment using real terrain data and satellite images. Intelligent Automation and Soft Computing, TSI, 18(1), 49-63.

[11] Vasáros, Z. 2008. Authenticity and accuracy of virtual reconstructions – a critical approach. In: CAA2008 Session – On the Road to Reconstructing the Past, Programs and Abstracts, Budapest, Hungary, April 2–6, pp. 249. ISBN: 978-963-8046-95-6.

[12] Verhagen, P. 2008. Dealing with uncertainty in archaeology. In: CAA2008 Session – On the Road to Reconstructing the Past, Programs and Abstracts, Budapest, Hungary, April 2–6, pp. 99. ISBN: 978-963-8046-95-6.

[13] https://en.wikipedia.org/wiki/PlayStation_VR

[14] https://en.wikipedia.org/wiki/Oculus_Rift

[15] http://planetearth.nerc.ac.uk/features/story.aspx?id=749

[16] WMO 2008, Guide to Meteorological Instruments and Methods of Observation) - part II, Chapter 4 (Marine Observations), publication No. 8.
[17] Bishop, I.D. and Miller, D.R. 2007, Visual assessment of off-shore wind turbines: the influence of distance, contrast, movement and social variables *Renewable Energy* **32** pp 814–831.
[18] DOCKERTY, T., LOVETT, A., APPLETON, K., BONE, A., SUNNENBERG, G. 2006. Developing scenarios and visualisations to illustrate potential policy and climatic influences on future agricultural landscapes. Agriculture, Ecosystems and Environment, 114, 18.
[19] Donaldson-Selby, G.; Wang, C.; Miller, D.R.; Horne, P.; Castellazzi, M.; Brown, I.; Morrice, J.; Ode-Sang, A., Testing public preferences for future land uses and landscapes (2012) GIS Research UK Conference 2012, University of Lancaster, April 2012.
[20] Palomo, I., Martín-López, Berta., López-Santiago, Cesar., Montes, Carlos.,2011. Participatory scenario planning for protected areas management under the ecosystem services framework: the Don˜ana socialecological system in Southwestern Spain. Ecology and Society, 16.
[21] SHEPPARD, S. R. J., SHAW, A., FLANDERS, D., BURCH, S. & SCHROTH, O. 2013. Bringing climate change science to the landscape level: Canadian experiences in using landscape visualisation within participatory processes for community planning. . In: FU, B. & JONES, K. B. (eds.) Landscape ecology for sustainable environment and culture. Dordrecht: Springer Netherlands.
[22] PLACEWAYS. 2013. Community Viz [Online]. Available: http://placeways.com/communityviz/.
[23] Bishop, I. and Miller, D.R. 2007. Visual influence of off-shore wind turbines: the influence of distance, contrast, movement and social variables. Renewable Energy 32**,** 814-831.
[24] Manyoky, M., Wissen Hayek, U., Heutschi, K., Pieren, R. and Grêt Regamey, A. (2014) Developing a GIS-Based Visual-Acoustic 3D Simulation for Wind Farm Assessment. ISPRS International Journal of Geo-Information, 3, 29-48. http://dx.doi.org/10.3390/ijgi3010029
[25] Siemens Wind Power Platform , http://www.energy.siemens.com/hq/en/renewable-energy/wind-power/