Use of the metaverse to advance wind power generation projects

Norio Harada[1*], *Chikako* Takei[2], and *Ichiro* Kimurai[3]

[1]Mitsui Consultants Co., Ltd., 2-1-2 Benten, Osaka city, Japan
[2]FORUM8 Co., Ltd, 2-15-1 Minatoku Tokyo, Japan
[3]University of Toyama, 3190 Gofuku Toyoma pref., Japan

Abstract. In recent years, considering global efforts to use renewable energy to combat climate change, the promotion of wind power generation in Japan has become crucial. Due to the limited land area available for wind power deployment, it is imperative to enter into consensus with stakeholders and local communities when such endeavors are planned. However, the prediction and management of environmental changes associated with this type of project represent substantial technical challenges. In this study, we developed a visualization technique utilizing virtual spaces, one of the recent metaverse technologies, and a shadow prediction technology for wind power generation facilities. To understand the effectiveness of these visualization materials, we constructed a model that dynamically visualizes the timeline of the construction process for floating offshore wind power generation. The effectiveness of the model's visualization platform was evaluated through a questionnaire survey conducted with 15 business operators. The survey results indicated a 3.5-fold improvement in understanding of the construction details and project impact using our visualization method.

1 Introduction

In Japan, the maximum introduction of renewable energy is required to achieve carbon neutrality by 2050; offshore floating wind power is one of the key components of this effort, given the limited availability of land and the high introduction potential of wind technology [1, 2]. However, the prediction and visualization of environmental changes with project implementation are critical technical challenges; the public and stakeholders (e.g., those involved in its construction and power generation) must be well informed so that a consensus can be reached as to how to proceed [3-7].

To this end, detailed three-dimensional (3D) renderings of Japan's building structures and terrain are readily available for creating virtual spaces using metaverse technology. Moreover, the data can be added and updated to provide users with visualization feedback in real-time. This type of visualization greatly aids in the environmental assessment and planning of renewable energy projects. In recent years, large amounts of virtual space data that include landscape resources and key visual landscapes from still image photomontages have been collected and used as evaluation items in prediction methods for project

---

*Corresponding author: harada@mccnet.co.jp development visualization. However, there is a lack of detailed knowledge regarding the examination and evaluation methods. For example, the dynamic impact of wind turbine blades, which are generally considered to have a significant effect in wind power generation, has not been taken into account in previous visualization models, thus necessitating further discussion.

The term “metaverse” (a synonym of “another world” from the 1992 Neal Stephenson novel “Snow Crash”) [8] is now commonly used to describe the virtual reality (VR) worlds of many networks [9]. Considering the ongoing technological innovations and the associated diverse classifications of metaverse spaces [10], further advances are anticipated, particularly in Japan, based on the proliferation of detailed 3D models of buildings and terrain (PLATEAU, [11]). Here, we present a novel method by which planned projects may be explained to those with concerns about using visualizations based on virtual space technology; these are useful applications of the metaverse.

2 Technological development for the use of multiple metaverses in the cloud

2.1 Overview

The construction of metaverse environments where users experience phenomena that are difficult to reproduce in real space (e.g., prediction of the visual impacts of large-scale wind power generation facilities before such facilities are built) has become possible using virtual spaces [12]. Efforts have been made to facilitate information-sharing, both remotely and non-intrusively, using 3D data [13]. The global impact of the coronavirus disease 2019 (COVID-19) pandemic emphasized the need for information-sharing through efficient web conferences and remote stakeholder meetings. Thus, it was imperative to develop smooth sharing systems that adequately cope with the challenges involved in high-level information processing over the Internet.

In this context, metaverses that enable smooth information-sharing by many users effectively manage technological challenges. We suggest that metaverse visualization techniques explaining planned wind power generation projects and focusing on system construction enable seamless information-sharing across multiple users.

2.2 System development

An overview of the configuration of our virtual space information system, which facilitates mutual sharing of 3D information, is depicted in Figure 1. We use synchronized servers connected to databases that host virtual space information. Multiple clients engage in mutual communication via networks such as the Internet. Each client is connected to information-processing terminals utilized by all users. Such terminals include personal computers, mobile devices (e.g., smartphones), displays that render virtual spaces, and inputs that aid interactions (i.e., “standalone VR devices”; Figure 2). Using all of these components, users acquire detailed spatial data in displayed virtual spaces, create new information, update existing data, and delete information. For example, user avatars navigate within virtual spaces while engaging in smooth communications with other users via chat or video conferences.

Each client retrieves virtual space information from the database (Table 1) and immediately delivers these data to user terminals. Clients are required to process virtual space information in response to user terminal requests. Accordingly, modularized programs within the main memory devices must be able to engage in direct processing. A synchronized server receives requests from all clients, delivers database material in response to such requests, and receives client demands, to update the virtual space information in the database. Thus, it is possible to achieve real-time visualization of content that is modified in response to feedback when projects are explained to residents. Furthermore, when receiving information from each client, the system is developed to execute one of the corresponding processing methods smoothly by selecting it according to the first, second, or third data classifications (Figure 3).

Using this system, multiple cloud users can mutually share information and update vast amounts of virtual space ("metaverse") information in real time. Data are immediately delivered to the information-processing terminals of all users via the Internet. In such an environment, stakeholder consultations and information-sharing using the digital-twin technologies of the metaverse will increasingly become possible.

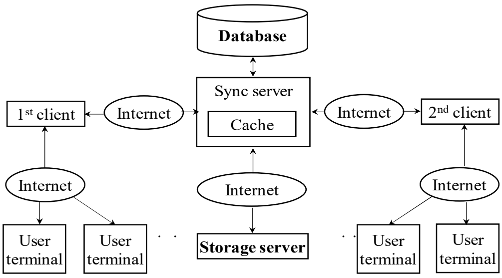

Fig. 1. Overview of the metaverse environmental system

Fig. 2. Visualization tools in use.

Table 1. Client processing information (database)

Data classification	Example
1	Building location information
2	Weather information, large trees, temperature, atmospheric pressure
	Video conference shared data
3	Communication by chat function
	Video and audio web conferencing
	Location of the mobile avatar

3 Development of visualization technology utilizing the metaverse

When planning wind power generation projects, it is essential to provide very clear explanations to stakeholders and residents. The following section discusses the characteristics and advantages of metaverse-based visualization materials in this context.

3.1 Development of shadow prediction and visualization technology for wind power generation facilities

In recent years, the social impacts of wind turbines, including noise and shadow flicker (when sunlight is intermittently blocked by turbine blades, triggering flickering ground shadows), have received increasing attention. However, the conditions in which such impacts occur are poorly understood; better environmental impact assessment methods are essential [6]. Earlier field surveys have suggested that shadow flicker, particularly in coastal areas, enhances the perception of discomfort [7].

Detailed 3D urban models (the PLATEAU urban models) have been developed for Japan [11]. Outdated building models imparted limited information [14]; however, the new models manage building heights (Figure 4) and internal building information, facilitating more detailed impact analyses.

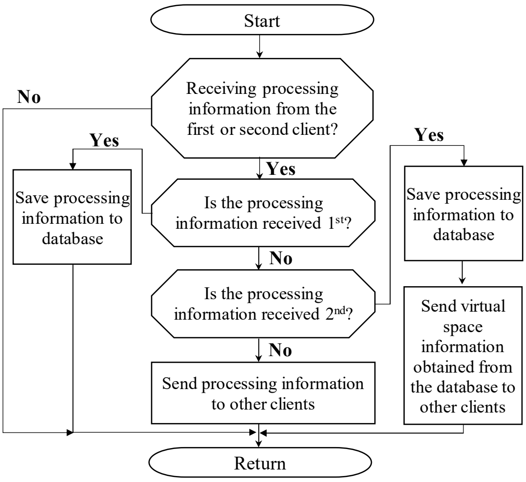

Fig. 3. Overview of the processing routine.

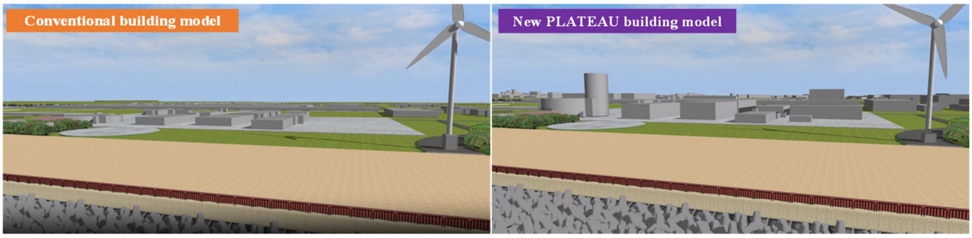

Fig. 4. Two building models (left: a conventional building model [14]; right: a PLATEAU model [11]).

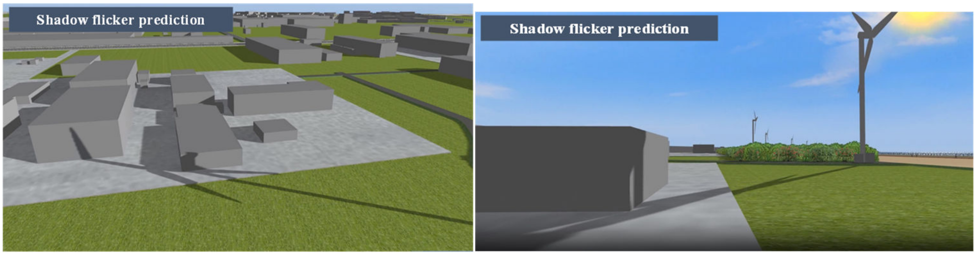

Fig. 5. Shadow flicker impact predictions (left: aerial view, right: ground-level view).

An example of shadow flicker impact prediction using a new 3D building model [11] is presented in Figure 5. The predicted impact of shadow flicker is visualized in detail. The model predicts seasonal and time variations (Figure 6(a)) according to solar altitude at a target location (defined by latitude and longitude), enabling detailed impact assessment. Further improvements in terms of evaluating indoor impacts (e.g., how indoor spaces differ in terms of window positions) are expected. Figure 6(b) illustrates the results obtained using detailed indoor 3D models. Differences in the features of buildings (e.g., presence and positioning of windows) substantially affect indoor shadow flicker when the external impacts of the outer walls of buildings are sources of concern (Figure 5).

Fig. 6. (a) Overview of shadow flicker prediction (b) Assessment of indoor shadow flicker impact.

Thus, detailed predictions using 3D building models are essential when assessing the impacts of shadow flicker on living environments and other factors.

3.2 Construction of visualization materials (models) for the installation of offshore wind power facilities

Currently, most offshore wind power generation platforms are located in Europe; they are cost-effective in that geographical context. Such platforms are also planned for Japan [1]. The construction of such facilities involves many challenges that are absent during onshore construction [15]. Floating offshore wind power facilities are associated with minimal landscape and noise concerns; they exploit stable and strong winds. Few such facilities have been built in Japanese waters. We believe that visualization-based information-sharing by stakeholders who coordinate construction activities would be valuable. There are few Japanese precedents, and offshore construction in Japan involves unique challenges.

To address these challenges, we propose a visualization method that presents the construction details in a four-dimensional (4D) manner (Figure 7). Although the visualizations are presented as stills (Figure 7), the method dynamically reveals the fabrication/activation process of floating offshore wind power facilities [10]. Furthermore, using the tools shown in Figures 1 and 2, visualizations from various perspectives are possible, enabling detailed examination and verification of the construction steps. Additionally, the crane operation simulations during blade installation at sea (Figure 7) predict the need for dedicated training and the environmental parameters that must be monitored (e.g., wave height and wind), thereby facilitating advanced construction planning.

3.3 Efficacy of the proposed visualization materials

To assess the efficacy of metaverse visualization materials that use recent building and terrain models to aid implementation of wind power generation projects, we used a questionnaire survey administered to selected stakeholders in power generation companies (specifically, 15 individuals who lacked experience in floating offshore wind power generation projects). The survey gauged the level of understanding of the methods and equipment used during construction of floating offshore wind power facilities, as well as the construction flow. Changes in understanding before and after examination of the video material (Figure 7) were evaluated (Figure 8).

Before the survey, respondents were given an overview of floating offshore wind power generation projects, including the structural and construction methods (explained using still image montages). After visualization, the level of understanding increased significantly to approximately 95%; in other words, visualization improved understanding by ~3.5-fold.

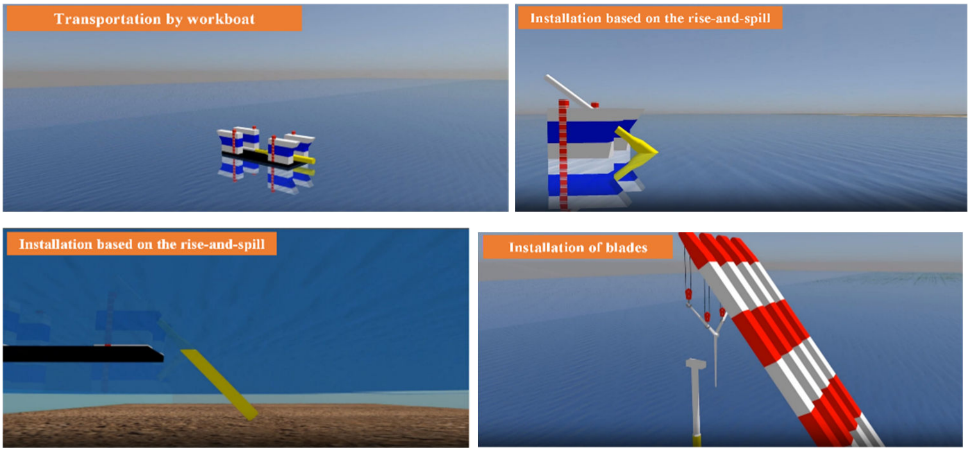

Fig. 7. Videos showing the construction status of floating offshore wind power facilities.

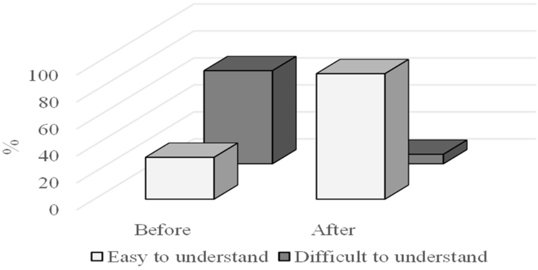

Fig. 8. Results of the survey that explored understanding of how floating offshore wind power facilities were constructed (a comparison before and after visualization; valid responses from 15 participants).

The results suggest that dynamic visualizations involving consideration of timelines more effectively explain the construction of floating offshore wind power facilities compared with still image montages. Further interviews were conducted with respondents who initially found the material difficult to understand (approximately 5% of respondents). They expressed a desire for simpler explanations of equipment delivery before construction and the environmental impacts of future floating offshore wind power facilities on the surrounding areas.

4 Conclusion

To promote wind power generation projects aimed at transitioning to a decarbonized society in Japan, we propose using recent digital data for visualization materials to explain projects and prediction methods. First, we developed a system to visualize 3D building and terrain data smoothly in a virtual space via the cloud over the Internet. Next, prediction and visualization methods were created as effective means for addressing shadow flicker and bird strikes, which are issues in wind power generation projects. Further, we constructed visualization materials that considered the timeline of the construction process for floating offshore wind facilities, which have few precedents in Japan, and conducted interviews with project stakeholders. Questionnaire survey results obtained from 15 stakeholders suggested that the visualization materials significantly improved their understanding of both the construction process and impact of offshore wind power generation facilities by approximately 3.5-fold.

References

1. S. Nishikizawa, Major issues on community acceptance of wind power. Planning and Public Management, **42-2**, 21-26 (2019). https://doi.org/10.20714/jsia.17.1_52
2. R. James and M.C. Ros, Floating offshore wind market and technology review. Prepared for the Scottish Government (2015). https://doi.org/10.1016/j.heliyon.2024.e33948
3. J.B. Grahama, J.R. Stephenson, and I.J. Smith, Public perceptions of wind energy developments: Case studies from New Zealand. Energy Policy, **37**, 3348–3357 (2009). https://doi.org/10.1016/j.enpol.2008.12.035
4. H. Bailey, K.L. Brookes, and P.M. Thompson, Assessing landscape impacts of wind turbines: Lessons learned from more than 50 years of wind power development worldwide. Aquatic Biosystems, **10-1**, 8 (2014). https://doi.org/10.1016/j.rser.2018.07.022
5. J. Abromas, P. Grecevicius, and N. Piekiene, Visual impact assessment of wind farms: A review of the potential influence of turbine rotational speed on their visual impact. In Proceedings of the 7th International Scientific Conference Rural Development (2015). https://doi.org/10.1016/j.landurbplan.2022.104423
6. M. Kobayashi, Stakeholder analysis for offshore wind power generation and challenges to consensus building. Papers on Environmental Information Science, **35**, 268-273 (2021). https://doi.org/10.11492/ceispapers.ceis35.0_268
7. T. Handa, S. Nishikawa, and T. Murayama, Factors of social impacts due to coastal wind farms in the hilly area. Papers on Environmental Information Science, **28**, 43-48 (2014). https://doi.org/10.11492/ceispapers.ceis28.0_43
8. N. Stephenson, Snow Crash (1992).
9. G. Lohmann, Volumetric image analysis. Born digital (2009).
10. Acceleration Studies Foundation, Metaverse road map. http://metaverseroadmap.org/
11. Y. Uchiyama, Efforts by the Ministry of Land, Infrastructure, Transport and Tourism on project PLATEAU: development, utilization, and open data of 3D urban models. Monthly magazine, Land readjustment, **64-5**, 14-20 (2021).
12. K. Husamae, Utilization of metaverse and digital twins in the construction industry. Construction Management, **529,** 51-55 (2022).
13. Y. Tanaka, Infrastructure DX promoted by the Ministry of Land, Infrastructure, Transport and Tourism. Construction Management, 529, 8-11 (2022).
14. Geospatial Information Authority of Japan: GSI Maps. https://www.gsi.go.jp/
15. M. Shimatani, D. Rikiishi, S. Sasaki, T. Nakai, and Y. Yamaguchi, Construction management for offshore wind power facilities. Journal of Japan Society of Civil Engineers, **69-2**, I114-I119 (2013). https://doi.org/10.2208/jscejoe.69.I_114
16. N. Harada, Examples of Utilizing DX (Digital Transformation) Technologies on YouTube. https://www.youtube.com/watch?v=5Oxn6BkjlZ8