AKADÉMIAI KIADÓ

Pollack Periodica • An International Journal for Engineering and Information Sciences

17 (2022) 2, 127–132

DOI:
10.1556/606.2022.00554

ORIGINAL RESEARCH PAPER

Spatial narrative and sustainable design with retired wind turbine components

Xue Kang[1,3*], Gabriella Medvegy[2] and Yufang Zhou[3]

[1] Marcel Breuer Doctoral School, Faculty of Engineering and Information Technology, University of Pécs, Boszorkány Str. 2, H-7624 Pécs, Hungary

[2] Faculty of Engineering and Information Technology, University of Pécs, Boszorkány Str. 2, H-7624 Pécs, Hungary

[3] School of Architecture, China Central Academy of Fine Arts, Huajiadinan Str. 8, Chaoyang, Beijing, China

Received: December 28, 2021 • Revised manuscript received: January 24, 2022 • Accepted: February 5, 2022
Published online: May 16, 2022

ABSTRACT

Wind generation is regarded by many as the future of renewable energy source, but the difficulty of recycling end-of-life wind turbine components could create another kind of environmental pollution. Either landfill or incineration of end-of-life wind turbine components will cause environmental hazards. However, the current recycling technology is immature and economical. Make clean energy 'cleaner'! The recycling of end-of-life wind turbine rotor hub and blades has become a new goal and task for architects and designers. This article uses a real project reconstructed by end-of-life wind turbine components to demonstrate the positive role of spatial narrative in achieving low-carbon and sustainable design.

KEYWORDS

spatial narrative, reusing, recycling, sustainable design

1. INTRODUCTION

Reducing coal-fired power generation and promoting renewable energy has been an important guideline for energy transition in many countries around the world. Wind power is regarded as one of the important sources of green energy. But as more wind turbine components come to the end of their service lives, the world is facing the challenge of how to recycle them.

Wind turbine is designed to have a service life of about 20–25 years. After wind turbine is retired, most unit components (foundation, tower, gear box and generator) can be recycled, but rotor hub, especially blades, are difficult to recycle due to their material composition. Existing methods of disposing of end-of-life wind rotor blades include: landfill, incineration or recycling. Although this fiber-reinforced resin composite material is lightweight and high-strength, its characteristic is that the chemical process of the material is irreversible, and it cannot return to the original material matrix properties after curing and forming. More importantly, if it cannot be degraded without processing, incineration will also produce pollutants and exhaust gases [1]. Obviously, this treatment does not meet the original intention of wind power as a clean energy source [2]. Recycling is a relatively environmentally friendly treatment method. However, there are few ways to recycle wind rotor blades at present, most of which are broken and mixed into cement for reuse. According to the analysis, adding blade fragments to cement can not only achieve reuse, but also reduce the total amount of carbon dioxide emitted during cement manufacturing [3]. However, the relatively low recycling value makes it difficult for this treatment model to be widely promoted.

*Corresponding author.
E-mail: 250659063@qq.com

The harmless treatment of end-of-life wind rotor hub and blades is a common problem for countries all over the world. Over the past few years, industry experts and research institutions around the world have conducted number of exploratory experiments on this question, mainly focusing on the development of new materials. However, there is no shortage of creative transformations and product-level design cases in the low-cost recycling and reuse of End-of-Life (EoL) wind rotor blades. For example, Superuse Studios in the Netherlands uses EoL wind rotor blades to create playground, public furniture and landscape sculptures [4]. The rotor blade furniture "bladesign" designed by a team of students from the University of St. Gallen and Karlsruhe Institute of Technology, was showcased at Milan Design Week 2019 in collaboration with German design studio Tarantik & Egger [5], among other cases.

Architects and designers also play a decisive role in the transition to a circular economy, and the design of innovative space products can also "turn waste into treasure", finding suitable application scenarios for EoL wind rotor hubs and blades.

2. METHODOLOGY

2.1. Cognitive narratology: spatial narrative

Cognitive narratology was first proposed by The German scholar Manfred Jahn [6] in 1977. Simply put, cognitive narratology is the research of how narrative audiences reconstruct the world of a story in their minds. But earlier, in the field of architecture, French philosopher Guy Debord's in his books [7, 8, pp. 40–141] and Kevin Lynch's [9] and other creations and research have shown the cognitive narrative of space. The development from cognitive maps to spatial narratives is the translation of architecture into another possible language system, which in turn effectively constructs the socio-cultural meaning of space. In other words, cognitive narrative can help architects express spatial connotations in a perceptive way.

2.2. Phenomenology in architecture: genius loci

Norwegian architectural theorist Christian Norberg-Schulz [10, pp. 31–45] believes that place is the "generator" of events. Many times, the purpose of human narratives is to resist forgetting. People, events, and places are related existences. When people experience events in places, it is "narrative" to describe the events in a definite order and form; and the reappearance of the occurrence of events through certain structural organization of the place is "space design". That is to use spatial media to express time and transcend time.

2.3. Sustainable design

Sustainable design is a strategic design activity for building and developing sustainable solutions. Sustainable design requires the harmonious development of people and the environment, and designs products, services and systems that can meet the needs of the current generation and guarantee the sustainable development of future generations [11]. The design mainly involves the establishment of sustainable consumption mode, the establishment of sustainable communities, and the development of sustainable energy and other technical projects.

2.4. Low carbon design

Low-carbon design is to take design as the starting point to reduce the material and energy consumption of product manufacturing, storage, transportation, circulation, consumption and recycling, as well as construction and other fields, so as to effectively reduce greenhouse gas emissions [12]. It is based on low energy consumption, low pollution and low emissions. In the architectural design, it is mainly reflected in adapting to local conditions and respecting the local natural and human environment; use local materials and techniques; appropriate development, protecting the local ecological environment and native landscape; cost control, avoid blindly pursuing low carbon and putting the cart before the horse.

3. A REUSE CASE OF SPATIAL NARRATIVE

The project is located in Desheng Village, Zhangbei County, Hebei Province. It was still a poor village a few years ago, but with the leadership of the government to give full play to the regional and resource advantages to develop the comprehensive utilization project of "photovoltaic + agriculture", the village was well-off. Desheng village's next development goal is to build a national renewable energy core demonstration zone, continue to promote the diversified development of new energy industry and multi-energy complementary and other forms of comprehensive utilization of new energy.

In the design process of the project, the concept of sustainability and low carbon runs through. The spatial narrative design becomes the characteristic of this project, constructing the narrative scene, situational and emotional needs from various aspects such as location, environment, material, structure, and function.

3.1. Location conditions of scene construction

Desheng Village located in Zhangbei County of Zhangjiakou, more than 180 km from Beijing (Fig. 1). In addition to Zhangjiakou and Beijing being the host sites of the 2022 Winter Olympic Games, Zhangbei flexible Direct Current (DC) power grid test and demonstration project is the world's first DC power grid project to realize the complementarity of wind, light and energy storage. After the project goes into operation in 2020, it will help 26 Venues of the Winter Olympic Games to achieve 100% clean energy supply [13].

Zhangbei has an average altitude of 1,400–1,600 m and is rich in wind and solar resources. It is a 10 million kilowatt-class

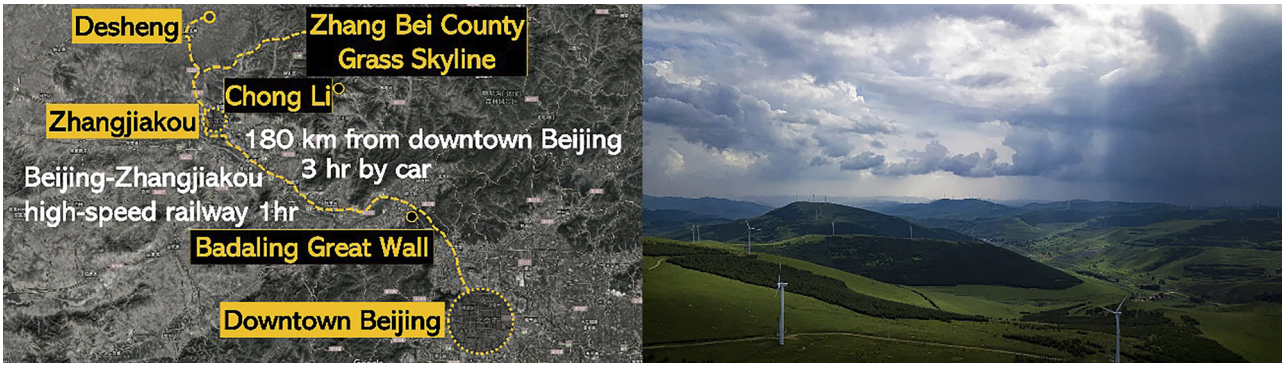

Fig. 1. Location analysis and ecological environment of Desheng Village (by X. Kang)

wind power base in China's renewable clean energy development plan. According to the measurement, the annual effective wind energy reserves in Bashang area of Zhangbei can reach 1,436 kWh m^{-2} and the annual effective wind speed hours can reach 5,200–7,000 h. At the same time, Zhangbei County is also very good sunshine conditions, the annual average sunshine of 2,897.8 h [14]. The cultural and local spirit together paints an overall impression and scene, which becomes the foundation of the project.

3.2. Environmental conditions of situational construction

Desheng Village has the fantastic scenery of the Grass Skyline and comfortable climate, as well as large number of excellent cultural, ecological, geological and tourism resources, which has become a recognized summer resort and the heart of many people. The average altitude of Grass Skyline is 1,400 m. Driving on the highway, people can see the blue sky connecting with it, and the white clouds echoing it, just like walking in the clouds. The large number of wind turbines are scattered across the grasslands, vast as white forests beneath a sea of violent clouds. The land is vast and sparsely populated, with occasional herders and flocks of cattle and sheep, as well as farmers working the fields. The regional environment has a natural narrative of situation construction, which becomes an important factor of project function positioning.

3.3. Resource conditions for low-carbon design

The principle of low-carbon design is low energy consumption, low pollution, low emissions, requirements of local conditions, local materials. In Zhangbei, which is one of the eight famous wind power generation sites in China, wind power generation is very popular, over wind turbines. The more wind turbines are built, the more decommissioned wind turbines need to be dealt with after the production cycle. The most economical and low-carbon way of harmless treatment of end-of-life wind turbine rotor hub and blades is to reuse it in the workplace where it works (Fig. 2). This is the most suitable way to design and construct the project.

Fig. 2. Dismantled and cut end-of-life wind turbine rotor hub and blades, with large number of working wind turbines in the background (Photo by M. Wang)

3.4. Ecological conditions for sustainable design

The first is the ecological integrity and the realization of human aspirations, so that the living environment of human beings can be sustained. It is emphasized that the protection of native natural resources and regional humanities in the Zhangbei is the most important. Second, it is to maximize economic value on the basis of sustainable development. The unique natural landscape and regional customs are the characteristic resources and cultural advantages for Desheng to develop health care, vacation, research and other industries for poverty alleviation and rural revitalization. Third, combine with local green technology to reduce the consumption of energy and other resources.

This determines that the construction of this project cannot destroy the original soil and landform, minimal intervention in the natural environment. This is also the reason for the design of wooden platforms and trestle with a height of more than 1 m, the construction of buildings on the platform, and the arrangement and connection of equipment pipelines under the trestle and on the ground.

3.5. Design of narrative themes and genres

The theme and genre of the narrative should be tailored to fit the historical and cultural context and be in harmony with the natural environment. It can arouse people's interest and emotional resonance, but also in line with people's cognition and expectations. Combined with the analysis of the natural and cultural landscapes of Desheng Village's

location, environment, resources, etc., the theme of the narrative is selected to highlight the natural landscape of Grass Skyline, wind power new energy technology and recycling energy building materials as the core. The key words of the design include but are not limited to rustic luxury, immersion, novelty, healing and so on. The genre of design combined with narrative themes can be developed into homestays, camping areas and playgrounds for leisure vacations.

3.6. The procedural mechanism of spatial narration

The action of the design is actually, direct and simple. The goal of the project is to directly build space with waste materials and make it become reused products. This product can be room, stage, furniture, landscape, sculpture, etc., (Fig. 3). The program is designed to dismantling, cutting, combine and renovation this series of actions.

3.6.1. Living space and playground. The renovation is based on the structural and dimensional study of rotor hub and blades in end-of-life wind turbine. Consider the rotor hub as a basic unit that constitutes a space, and research the combination of multiple basic units and how they are connected. Throughout the process, connection methods and materials have become the key to the design. In order to adhere to the design concept of using waste recycling, the design team proposed three connection methods (Fig. 4).

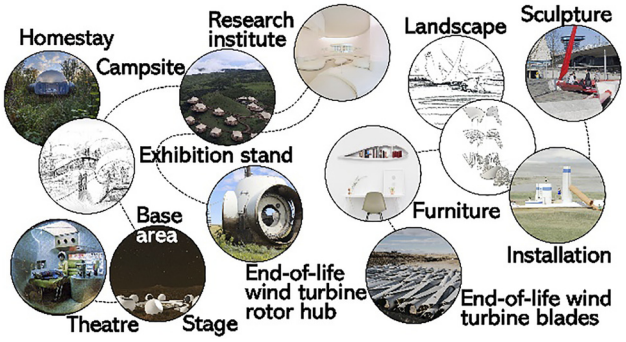

Fig. 3. Narrative themes diagrams (by X. Kang)

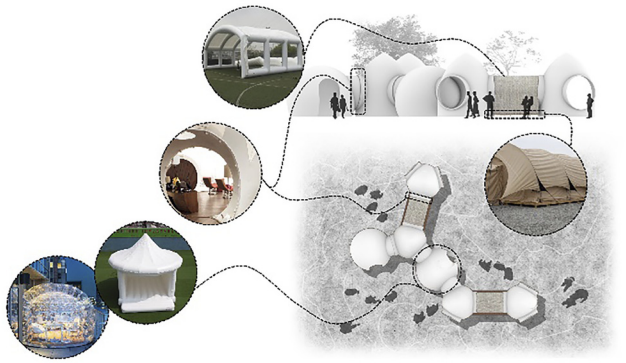

Fig. 4. Design three connection modes of Rotor hub (by X. Kang)

The first is a customized inflatable mold, the material of the gas mold is recycled using PVC waste (The PVC is processed into a keel shape by using a heat-sealing machine sewing machine and other equipment, and the tension force blown by a centrifugal fan and the air pressure difference between the inside and outside of the film are formed). The edge of the gas mold is inserted into the corner rope and fixed with the rotor hub inset lock.

The second type is a tent supported by a custom inflatable keel. The tent materials are recycled textile materials by parachute, and the tent's corner ropes extend into the rotor hub and are fixed with locks. The keel is also recycled using PVC waste.

The third type of connection is inspired by articulated buses. Of course, the materials are still recycled. In addition, the design team proposed to use nets to form various spatial forms within the rotor hub, or to form a playground together with the rotor blades (Fig. 5). The rotor hub can also be rotated 90° and connected in pairs to form a room or swimming pool with a good view (Fig. 6).

3.6.2. Landscape and furniture. The partial segment cutting of end-of-life wind turbine blades can be used to make outdoor seats and landscape installations, which is simple. Even rotor hub's spinners could become landscape installations. The dimensions and shapes of rotor blades are precisely designed and manufactured industrial products, which are cut according to the calculation and then modularized to combine various amusement facilities, even skateboard park (Fig. 7).

In addition, many designers have tried to make furniture with rotor blades. Compared with the way of chemical treatment of EoL wind turbine blades, the physical way of reuse is more efficient, economic and environmental.

Fig. 5. EoL wind turbine rotor hub and blades to build the playground scheme (by X. Kang)

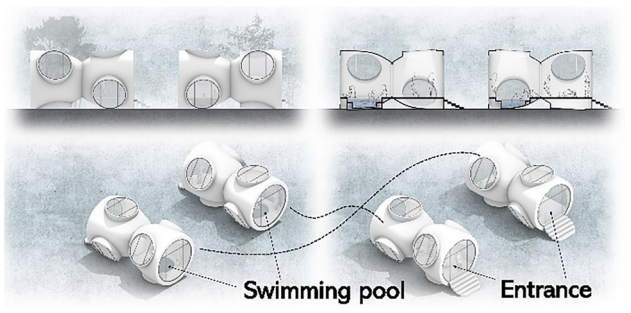

Fig. 6. Rotor hub's various combinations: swimming pools (by X. Kang)

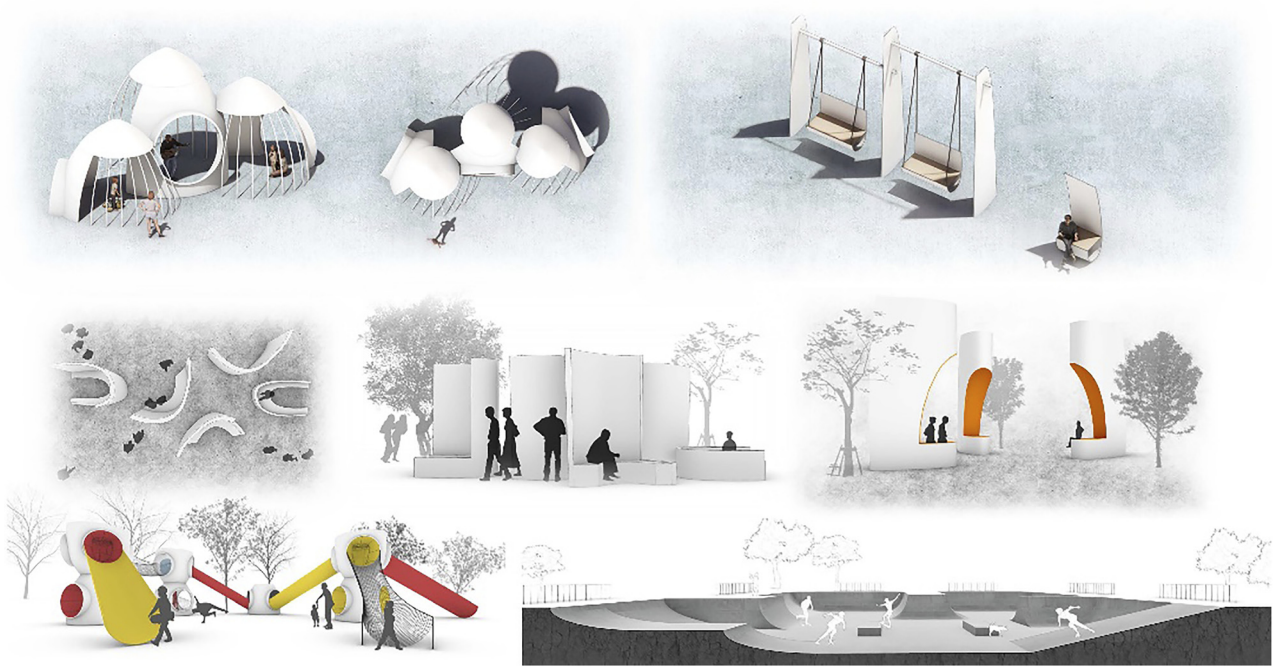

Fig. 7. Landscape, public furniture, playground and other installation schemes (by X. Kang)

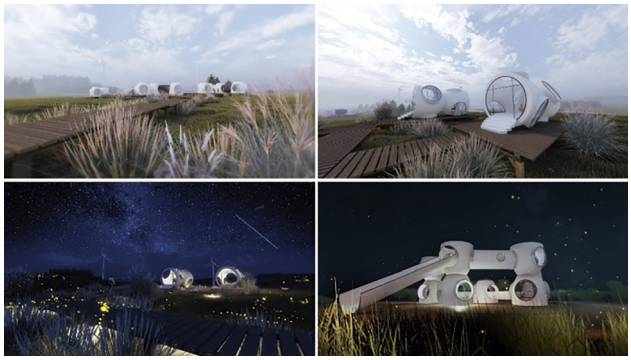

Fig. 8. Renderings of rotor hub's various combinations (by X. Kang)

3.7. Summary

Exploring sustainable production and construction is the original intention of this project. Space narration is a medium that makes the construction method more compatible with the regional environment and human emotions. In fact, the main research of the project is focused on structure, materials and construction methods (Fig. 8). Spatial narration is a natural narrative endowed by natural environment, history and humanities and recycled materials. But spatial narrative is as important to the project as low-carbon and sustainable design, because without the spirit of the place, there is nothing here.

4. CONCLUSION

Based on the concept of low carbon and sustainability, the project developed a new use and scenario for the end-of-life wind rotor hub and blades through a spatial narrative design method. It shows how architects use professional knowledge and skills to rebuild the harmonious relationship between man and nature through recycling design.

Another effective shortcut to continue production facilities is to construct service facilities and landscape products. Architects and designers can play an important role in transforming societies, re-architecting and connecting existing materials, resources and systems. The spatial narrative design method is used in the reuse of end-of-life wind rotor hub and blades. It is committed to developing a sustainable production based on “waste utilization” and an ecological construction design system of “make the best use of everything”.

In the context of global new energy transformation, wind power and other new energy construction will also develop on a large scale, and there will be more problems to be dealt with. In the future, the architect’s work should prioritize the use of the current underutilized potential of various resources, and identify and link the input, ratio, waste and output of these resources, and use the concept of circular design to reduce the use of original materials and new resources and promote the sustainable development of social resources and ecological environment.

ACKNOWLEDGMENTS

Thanks to B. W. Pan, W. Z. Chen and J. Y. Lu, graduate students from Studio 9, School of Architecture, Central Academy of Fine Arts, for participating in the author’s research. A large part of the performance of the project results comes from their help. In addition, special thanks to

M. Wang and other energy experts for their professional suggestions on the project.

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