LIFE CYCLE MANAGEMENT OF CONSTRUCTION FACILITIES
УПРАВЛЕНИЕ ЖИЗНЕННЫМ ЦИКЛОМ ОБЪЕКТОВ СТРОИТЕЛЬСТВА

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Sustainable Lifecycle Management: From Wind Turbine Blades to Modern Playground Complexes

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Abstract
Introduction. In modern conditions of the construction industry development, the concept of the life cycle of construction facilities encompasses not only the design and operation stages, but also the disposal of structural elements, particularly the components of wind turbines (hereinafter referred to as WT) with a service life of 20–25 years. Conventional methods of disposal of used elements of wind turbines display a low environmental efficiency. In the context of the circular economy, innovative solutions for integrating used WT components into construction practice are to be developed.
The aim of the study was to scientifically substantiate a possibility of using recycled wind turbine blades in the construction of children's playground complexes.
Materials and Methods. The study is based on a methodology for analyzing the life cycle of wind turbine blades, taking the specific features of their processing in the construction industry into consideration. The following methods were employed: a systematic analysis of the characteristics of wind turbine blades, a statistical assessment of their life cycle, a comparative analysis of recycling technologies and an assessment of the safety of structures made from recycled materials.
Research Results. As a result of the analysis and research conducted, a technology for processing blades into structural elements of a children's playground complex has been developed.
Discussion and Conclusion. The results confirm the fundamental possibility and practical expediency of employing recycled wind turbine blades as construction facilities in order to design safe and durable children's playground complexes. The developed technological solutions that take into consideration the full life cycle of materials – from operation as part of wind turbines to secondary use in building structures – enable transformation of the environmental problem of recycling into a resource for urban infrastructure development.

Keywords: life cycle, utilization of wind power plants, construction of playgrounds, secondary use, construction site

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Оригинальное эмпирическое исследование

Устойчивое управление жизненным циклом: от лопастей ветрогенераторов до современных игровых комплексов

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Аннотация
Введение. В современных условиях развития строительной отрасли концепция жизненного цикла строительных объектов охватывает не только этапы проектирования и эксплуатации, но и вопросы утилизации конструктивных элементов, в частности компонентов ветроэнергетических установок (далее — ВЭУ) со сроком службы

20–25 лет. Традиционные методы утилизации отработавших элементов ветрогенераторов демонстрируют низкую экологическую эффективность. В контексте циркулярной экономики возникает необходимость разработки инновационных решений для интеграции отработанных компонентов ВЭУ в строительную практику.
Целью исследования являлось научное обоснование возможности применения утилизированных лопастей ВЭУ в конструкциях детских игровых комплексов.
Материалы и методы. Исследование основано на методологии анализа жизненного цикла лопастей ветряных турбин с учетом специфики их обработки в строительной отрасли. В работе использовались следующие методы: систематический анализ характеристик лопастей ветряных турбин, статистическая оценка их жизненного цикла, сравнительный анализ технологий вторичной переработки и оценка безопасности конструкций, изготовленных из переработанных материалов.
Результаты исследования. В результате проведенного анализа и исследования разработана технология переработки лопастей в конструктивные элементы детского игрового комплекса.
Обсуждение и заключение. Полученные результаты подтверждают принципиальную возможность и практическую целесообразность использования утилизированных лопастей ВЭУ в качестве объектов строительства для создания безопасных и долговечных детских игровых комплексов. Разработанные технологические решения, учитывающие полный жизненный цикл материалов — от эксплуатации в составе ветроэнергетических установок до вторичного применения в строительных конструкциях, — позволяют трансформировать экологическую проблему утилизации в ресурс для развития городской инфраструктуры.

Ключевые слова: жизненный цикл, утилизация ветроэнергетических установок, строительство детских площадок, вторичное использование, строительный объект

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Introduction. In modern conditions of the construction industry development, there is a tendency towards the integrated implementation of the concept of the life cycle of construction facilities including not only the design and operation stages, but also the disposal of structural elements. The issue of life cycle management of the components of renewable energy sources, particularly wind turbines (hereinafter referred to as WT), with a physical service life of up to 20–25 years, is gaining particular relevance.

Conventional approaches to disposal of used elements of wind turbines, such as landfill disposal or heat treatment, display a low environmental efficiency and contradict the principles of sustainable development of the construction industry. In the context of the circular economy, innovative solutions that integrate used WT components into construction practice are to be developed.

The concept of a project life cycle (PLC) serves as a methodological foundation for forming effective strategies for construction waste management. Special attention is paid to searching for sustainable ways of recycling composite materials of wind turbine blades with high strength characteristics and resistance to external impacts.

The aim of the study is a comprehensive scientific substantiation of a possibility of using recycled WT elements, particularly blades, as structural elements of children's playground complexes. This research area corresponds to the current trends in the construction industry development and contributes to implementing the principles of cyclical economics in urban development. The foundation for developing the scientific idea was the architectural design of a playground in Rotterdam (Fig. 1).

Unlike individual architectural projects (Fig. 1), the work integrates a comprehensive management system for the entire life cycle – from the design and construction of a wind turbine to the criteria for selecting blades at the stage of dismantling WT and assessing the economic feasibility of a project for av secondary use of WT structural elements.

Attaining this goal entails addressing the following: analyzing the physical and mechanical characteristics of WT blade materials, examining the existing methods of their disposal, developing technological solutions for processing and modifying composite materials, as well as substantiating a possibility of using them in playground structures in view of the safety and durability requirements.

Fig. 1. Architectural solutions for a playground in Rotterdam designed by means of WT blades

Materials and Methods. The study is based on an integrated approach to analyzing the life cycle of WT blades. The methodological foundation of the research is the concept of life cycle management of construction facilities adjusted to specific features of WT processing components. To this end, the following research methods were applied:

– a comprehensive analysis of design features and physical and mechanical characteristics of WT blades;
– a statistical analysis of data on the service life and utilization volumes of WT blades;
– a comparative analysis of the existing technologies for processing composite materials;
– expert evaluations of the safety and durability of structures made from recycled materials.

Research Results. The analysis of data from numerous studies of composite materials employed in the production of WT blades (E-glass fiberglass and EPIKOTE™ epoxy resins) has enabled us to conclude that they have stellar performance characteristics [1, 2]. According to a study conducted by a team of authors [3], the bending strength of these materials is 350–500 MPa, which is actually comparable with the characteristics of individual grades of structural steel.

The data on the resistance of materials to atmospheric influences are of particular interest. As shown by the climatic tests described in a study by Ermakov B.S., et al. [4], following 1000 cycles of accelerated testing, a decrease in strength characteristics was not over 5–7%. These results have been confirmed by more recent studies [5].

The conclusions drawn by a group of researchers [6] regarding the preservation of up to 80% of the original mechanical properties of blades following 25 years of operation are critical. This lays a science-based foundation for their secondary use as load-bearing structures.

As regards the processing parameters of materials, the optimal cutting temperature mode to prevents delamination of a composite structure was 60–80°C, as found through the course of the experiments described in [7]. The requirements for edge grinding (rounding radius ≥ 3 mm), ensuring safety for children, are justified in by a team of authors in [8] based on a series of mechanical tests.

The data on the physical and mechanical characteristics of composite materials of wind turbine blades are paramount for choosing the optimal methods of their disposal. [3, 5] show that preserving 80% of the original properties following 25 years of operation considerably expands capacities of recycling structural elements. However, the efficiency of different processing methods varies greatly depending on the safety of a material and the required quality of an end product.

Based on the systematization of the latest research [6, 7, 9], a classification of wind turbine blade processing methods has been developed including three major technological directions (Fig. 2).

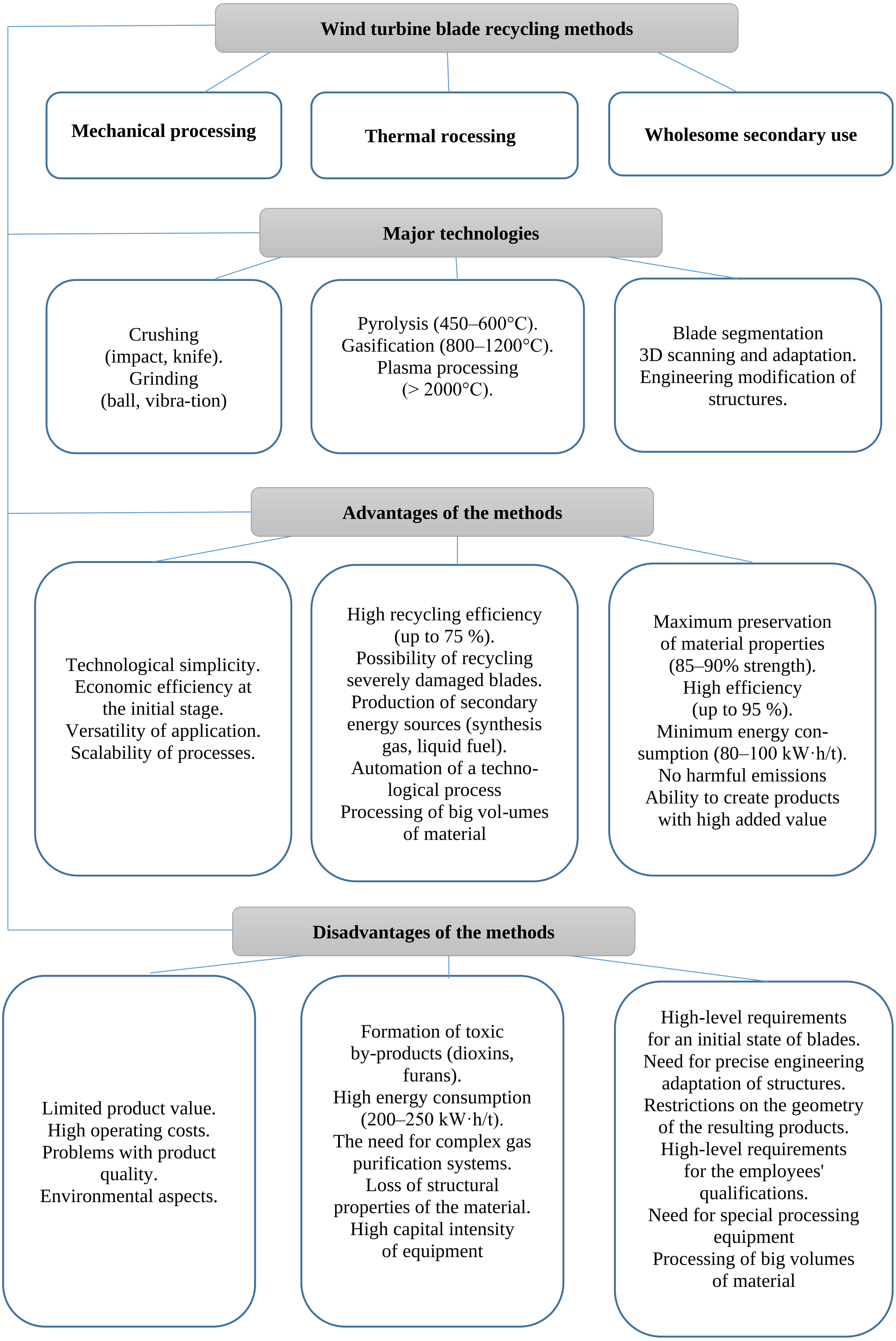

Fig. 2. Classification of the recycling methods of wind turbine blades

The economic and environmental analysis performed (Table 1) has identified significant benefits of wholesome processing.

Table 1

Comparative indicators of the disposal methods

Criterion	Mechanical crushing	Pyrolysis	Wholesome processing
Unit costs, roubles/t	9600–12000	16000–20000	6400–8000
Carbon footprint, kg CO_2-e/t	180–220	350–400	70–90
Payback period, years	5–7	8–10	3–4
Toxicity level	Low	High	No

Calculations show that wholesome processing provides:

– a 60% reduction in carbon footprint compared to pyrolysis;
– a reduction of energy consumption by 35–40% compared to mechanical crushing;
– a possibility of obtaining value-added products.

The major technological advantages of integral reuse have been confirmed by [10, 11]:

– preserving the anisotropic properties of a material;
– minimum technological waste (< 5%);
– a possibility of creating a closed cycle of composite use.

The prospects of the area are made particularly obvious while analyzing the life cycle of processed products where solid structures display a 2.5–3 times better environmental performance compared to the alternative recycling methods [12].

Based on a comprehensive analysis of the existing recycling methods, an innovative three-stage technological chain for preparing blades for reuse in children's playground complexes has been developed including 4 main stages: dismantling, preparation, processing and quality control.

The specialized technology for dismantling wind turbine blades involves the following processes:

– laser scanning of the structure to identify the optimal cutting points;
– use of water-cooled diamond rope saws;
– use of vacuum lifts with a lifting capacity of up to 20 tons;
– transportation in shock-absorbing containers fitted with a climate control system, vibration sensors, GPS monitoring.

At the same time, it is critical to minimize mechanical damage to dismantled structures and comply with the safety standards while working with large-sized objects. In order to assess a possibility of reuse of wind turbine blades in playgrounds and other facilities, a system of 12 major criteria grouped into 4 categories (Table 2) is set forth.

The next preparation stage is a multi-stage system of technological processes and includes:

– mechanical cleansing: abrasive blasting (pressure 2–3 atm);
– chemical treatment: biodegradable detergents (*pH* 7.5–8.5), neutral solvents;
– antiseptic treatment.

Cleansing quality control can be performed by means of electron microscopy, infrared spectroscopy, and contact angulometry.

The stage of mechanical preparation of the elements of the dismantled blades is a critical stage of the suggested technology to be used in construction of a children's playground complex. The geometry is adapted to new tasks by means of precision cutting that removes damaged areas, optimizes dimensions for target structures, and creates mounting joints.

Also, the stage of mechanical treatment makes it possible to ensure the safety of a future structure. This typically involves treatment of the edges (rounding, polishing, applying protective chamfers) and creating technological holes for fastening systems. E.g., for a children's slide, a central segment (6 m long) must be cut out of a blade, there must be side stops up to 30 cm high as well as a controlled sliding surface with a roughness of 3.2–6.3 microns for a safe descent, and attachment zones to the foundation must be treated.

Table 2

Criteria for the suitability of wind turbine blades for secondary use

Category	**Parameter**	**Requirements**	**Assessment method**
1. Structural and mechanical characteristics	Residual flexural strength	≥ 60 % of the original one (~ 300 MPa)	Three-point bending tests by ASTM D790
	No critical damage	Cracks > 5 mm, delaminations > 10 % of the area	Ultrasonic flaw detection
	State of a composite matrix	Humidity < 1 %, no resin degradation	Thermogravimetric analysis (TGA)
2.Geometric and operational parameters	Preserved segment length	≥ 3 m for load- bearing elements	Visual inspection
	Curvature radius	1–5 m for arch structures	Geometric measurements
	Wall thickness	Homogeneity ± 15 % of the original	Measurement tools
3.Environmental and chemical safety	No toxic emissions	Volatile organic compounds < 0.1 mg/m³	Gas chromatography
	UV resistance	Strength loss < 5 % after 1000 h of a test	UV-testing
	Corrosion resistance of metal inclusions	No corrosion is allowed	Visual inspection, corrosion tests
4. Economic and technological criteria	Recycling energy costs	< 100 kW·h/t	Energy analysis
	Compatibility with the joining methods	Adhesive / mechanical fasteners	Technological assessment
	Damage localization	≤ 30 % of the area is in need of repair	Visual inspection, measurements

Hence the developed technological chain allows one:

– to ensure a full cycle of wind turbine blades recycling;
– to preserve up to 95% of the original material properties;
– to create safe and durable gaming complexes;
– to reduce recycling costs by 40–45%.

Discussion and Conclusion. The study has confirmed that the recycled blades of wind turbines can be successfully employed in construction of children's playground complexes providing an appropriate degree of safety and durability. The resulting technological solutions take a full life cycle of materials into consideration: from their operation as part of wind turbines to the secondary use in building structures. This approach allows not only to solve the environmental problem of composite waste disposal, but also to create an additional resource for urban infrastructure development.

The major aspect is analyzing a life cycle of such structures, which displays their economic and environmental efficiency at all of the stages: from design and installation to operation and possible recycling. Introducing this technology into playground construction contributes to a sustainable urban environment that adheres to the principles of the circular economy.

For further improvement of the method of recycling wind turbine blades, the following areas should be addressed:

– automation of dismantling processes — introduction of modern technologies for disassembling and sorting blades in order to reduce labour costs and increase efficiency;

– robotic processing complexes — use of automated systems for cutting, grinding and preparing composite segments in order to increase the operating accuracy and safety;

– development of "smart" coatings — designing multi-functional materials with a capacity to self-diagnose damage, which will increase the service life of structures and reduce maintenance costs.

Implementing these measures would not only expand the application scope of recycled wind turbine blades, but also boost the economic attractiveness of the technology contributing to its large-scale adoption in the construction industry.

References

1. Animasaun AB, Adeniran AO, Udorah FN, Oluyemi IA Optimization of Wind Turbine Performance through Advanced Materials and Design. *Optimality*. 2025; 2(1),1–15. https://doi.org/10.22105/opt.v2i1.69

2. Lagos F, et al. Recent Advances in the Analysis of Functional and Structural Polymer Composites for Wind Turbines. *Polymers 17.17*. 2025: 2339. https://doi.org/10.3390/polym17172339

3. Satchilembe VL, et al. Simulation Modeling of Parallel Operation of Wind Power Plants. *Vestnik of Ivanovo State Power Engineering University*. 2025;4:66–75 (In Russ.) https://doi.org/10.17588/2072-2672.2025.4.066-075

4. Ermakov BS, et al. The Influence of Water-Repellent Coating on the Performance of Structures Made of Polymer Composite Materials in Conditions of Extremely Low Temperatures. *Russian Mining Industry*. 2024;5S:198–203. (In Russ.) https://doi.org/10.30686/1609-9192-2024-5S-198-203

5. Cherkashina NI, Pavlenko ZV, Domarev SN, Ruchiy AYu, Solgalov VV Creation of a Composite Material Based on Plant-Based Components. *Nanotechnologies in Construction*. 2024;16(1):67–76. https://doi.org/10.15828/2075-8545-2024-16-1-67-76 .

6. Li L, et al. Collaborative Disposal of Exhaust Gas and Waste Wind Turbine Blades: Mechanical Properties of Recycled Glass Fibres and Economic Analysis. *Journal of Cleaner Production*. 2024;471:143351. https://doi.org/10.1016/j.jclepro.2024.143351

7. Chen Jie, et al. Transition of material removal mechanism in cutting of unidirectional SiCf/SiC composites. *The International Journal of Advanced Manufacturing Technology* 2024;133:391–408. https://doi.org/10.1007/s00170-024-13761-y

8. Zhang Y, et al. Environmental and Economic Assessment of Mechanical Recycling of End-of-Life Wind Turbine Blades into Rebars and Comparison with Conventional Disposal Routes. *Composites Part A: Applied Science and Manufacturing*. 2025;190:108711. https://doi.org/10.1016/j.compositesa.2025.108711

9.Samarskaya NS, Paramonova ON, Lysova EP, Chistyakova VD Development of a Life Cycle Model for a Wind Turbine. *ModernTrends in Construction, Urban and Territorial Planning*. 2022;4:25–31. (In Russ.) https://doi.org/10.23947/2949-1835-2022-1-4-25-31

10. Oh Eunyoung, et al. Sustainable green composite materials in the next-generation mobility industry: review and prospective. *Advanced Composite Materials* 2024;33:1368–1419. https://doi.org/10.1080/09243046.2024.2348237

11. Türker, Yasemin Sümeyye, Fahrettin Öztürk, and Yahya Öz. Review of recycling methods of thermoplastic composite materials. *Polymer-Plastics Technology and Materials* 2024;63.12:1693–1713. https://doi.org/10.1080/25740881.2024.2352148

12. Riuttala Mari, et al. How building component reuse creates economic value–Identifying value capture determinants from a case study. Journal of Cleaner Production 2024;443:141112. https://doi.org/10.1016/j.jclepro.2024.141112

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