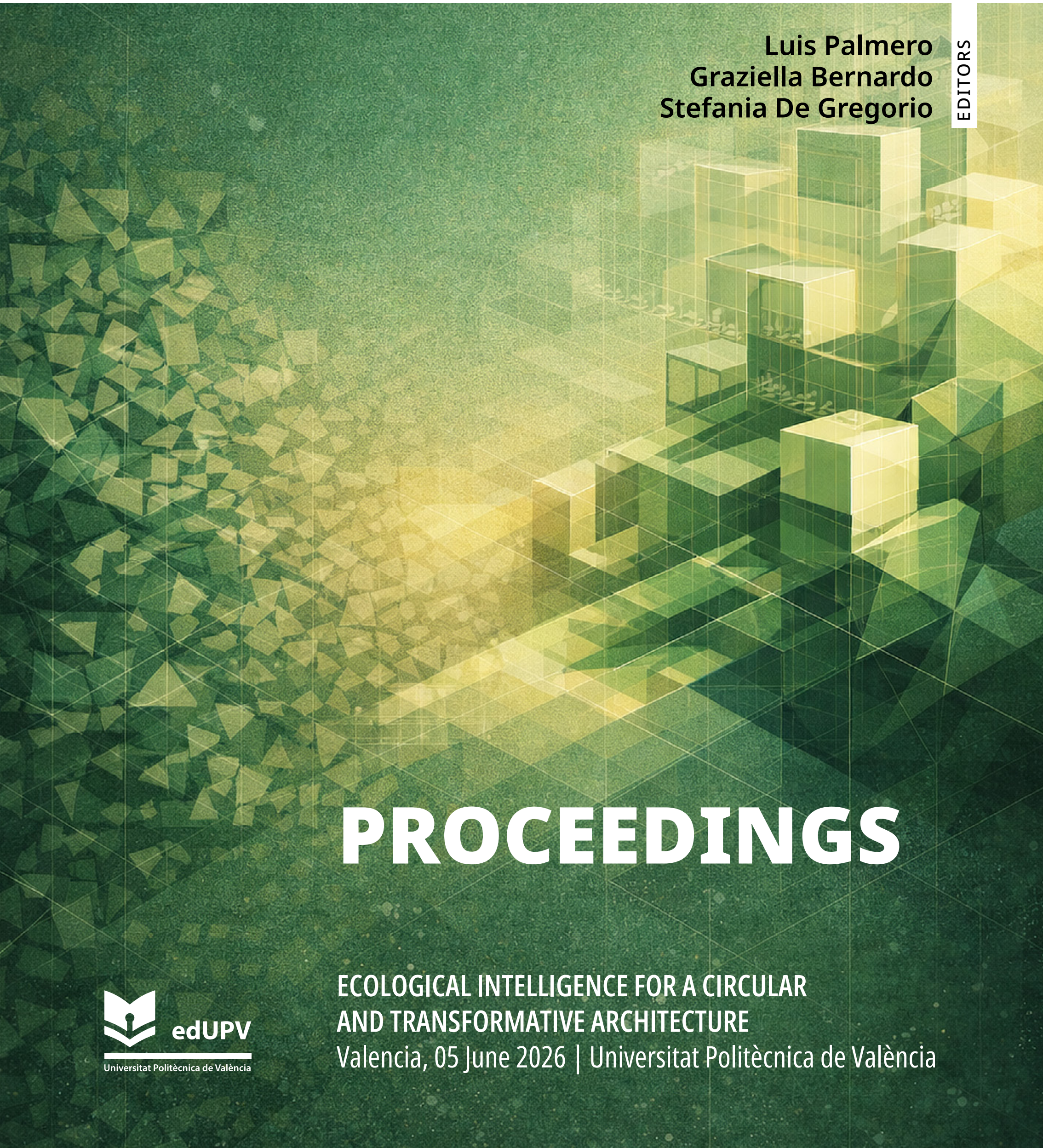
RE-CYCLING

VII INTERNATIONAL CONFERENCE

Luis Palmero
Graziella Bernardo
Stefania De Gregorio
EDITORS



PROCEEDINGS

ECOLOGICAL INTELLIGENCE FOR A CIRCULAR AND TRANSFORMATIVE ARCHITECTURE

Valencia, 05 June 2026 | Universitat Politècnica de València

edUPV
Universitat Politècnica de València

Proceedings of the

RE-CYCLING
VII INTERNATIONAL CONFERENCE

ECOLOGICAL INTELLIGENCE FOR A CIRCULAR AND TRANSFORMATIVE ARCHITECTURE

Luis Palmero
Graziella Bernardo
Stefania De Gregorio
(Eds.)

edUPV
Universitat Politècnica de València

UPV Conference
RE-CYCLING. VII International Conference. Ecological Intelligence for a Circular and Transformative Architecture

ISBN: 978-84-1396-440-9

DOI: https://doi.org/10.4995/9788413964409edUPV

Scientific committee

Rossano Albatici - *Università degli Studi di Trento*
Paola Altamura - *Sapienza Università di Roma*
Pablo Altaba - *Universitat Politècnica de València*
Jacopo Andreotti - *Politecnico di Torino*
Giuseppe Andrisani - *Università degli Studi della Basilicata*
Adolfo F. L. Baratta - *Università degli Studi Roma Tre*
Francisco Palomino Bernal - *Instituto Tecnológico de Ciudad Guzmán*
Edoardo Bocci - *Università Telematica eCampus*
Laura Calcagnini - *Università degli Studi Roma Tre*
Eliana Cangelli - *Sapienza Università di Roma*
Agostino Catalano - *Università degli Studi Telematica eCampus*
Fabrizio Comodini - *Università Telematica eCampus*
Fernando Cos Gayón - *Universitat Politècnica de València*
Luis Cortés - *Universitat Politècnica de València*
Giuseppe Cultrone - *Universidad de Granada*
Mariangela De Vita - *CNR Roma*
Carlos Alberto Duica Cuervo - *Universidad El Bosque*
Michela Dalprà - *Università degli Studi di Trento*
Ornella Fiandaca - *Università degli Studi di Messina*
Francesco Focacci - *Università Telematica eCampus*
Fabiola Colmenero Fonseca - *Universidad Autónoma de Coahuila*
Juan Antonio García Esparza - *Universitat Jaume I*
Ilaria Giannetti - *Università degli Studi di Roma Tor Vergata*
Francesca Giglio - *Università degli Studi Mediterranea di Reggio Calabria*
Roberto Giordano - *Politecnico di Torino*
Antonella Guida - *Università degli Studi della Basilicata*
Martino Hutz - *Technische Universität Wien*
Jaime Llinares - *Universitat Politècnica de València*
Maria Teresa Lucarelli - *Università Mediterranea di Reggio Calabria*
Raffaella Lione - *Università degli Studi di Messina*
Antonio Magarò - *Università degli Studi Roma Tre*
Luigi Marino - *Università di Firenze*
José Miguel Molinés - *Universitat Politècnica de València*

Luigi Mollo - *Università degli Studi della Campania "L. Vanvitelli"*
Antonello Monsù Scolaro - *Università degli Studi di Sassari*
Stefania Mornati - *Università degli Studi di Roma Tor Vergata*
Andrés Salas Montoya - *Universidad Nacional de Colombia*
Matteo Ocone - *Università Telematica eCampus*
Ramiro Rodriguez Perez - *Instituto Tecnológico de Ciudad Guzmán*
Claudio Piferi - *Università degli Studi di Firenze*
Camilo Alberto Forero Pineda - *Universidad de Boyacá Tunja*
Vito Porcari - *Università degli Studi della Basilicata*
Annette Rudolf-*Cleff - Technische Universität Darmstadt*
Hector Saul Quintana Ramirez - *Universidad de Boyacá Sogamoso*
Andreas Schwarting - *HTWG Konstanz*
Enzo Siviero - *Università Telematica eCampus*
Donatella Radogna – *Università degli Studi "G. D'Annunzio" Chieti-Pescara*
Alessandro Rogora - *Politecnico di Milano*
Monica Rossi Schwarzenback – HTWK Leipzig
Camilla Sansone - *Università degli Studi del Molise*
Fabio Enrique Forero Suarez - *Universidad El Bosque*
Antonella Violano - *Università degli Studi della Campania "L. Vanvitelli"*

The Scientific Committee selected the contributions by a double-blind peer review procedure

Founding committee

Adolfo F. L. Baratta - *Università degli Studi Roma Tre*
Agostino Catalano - *Università degli Studi Telematica eCampus*

Scientific Direction

Luis Palmero Iglesias - *Universitat Politècnica de València*
Graziella Bernardo - *Università degli Studi della Basilicata*
Stefania De Gregorio - *Università degli "G. D'Annunzio" Chieti-Pescara*

Organizing Committee

Pablo Ariel Escudero - *Universitat Politècnica de València*
Carla De Juan - *Universitat Politècnica de València*
Ester Martínez - *Universitat Politècnica de València*
Pablo Palmero - *Universitat Politècnica de València*
Pilar Rodrigo - *Universitat Politècnica de València*
Lucía Tordera - *Universitat Politècnica de València*

TABLE OF CONTENTS

Introduction

Closing the loop: circular materials, recycling and upcycling strategies

Living territory: adaptive reuse and circular urban transformations

Increasing circularity of small-scale wind turbines: the PANORAMA vertical axis prototype

Massimiliano Condotta

Associate Professor, Università Iuav di Venezia – Department of Architecture and arts, Italy. *condotta@iuav.it*

Tommaso Morbiato

Independent researcher, Windcity S.r.l., Italy. *tommaso@windcity.it*

Chiara Scanagatta

Researcher, Università Iuav di Venezia – Department of Architecture and arts, Italy. *cscanagatta@iuav.it*

Elisa Zatta*

Researcher, Università Iuav di Venezia – Department of Architecture and arts, Italy. *ezatta@iuav.it*

Abstract: despite the extensive research to optimise the performance of large- and small-scale wind turbines, little research has been conducted on design choices to improve the circularity of their components. Considering the relatively short life expectancy of these systems and, above all, their prospected contribution in increasing the sustainability of built and natural environments through diffused networks, this matter crucially shifts their impacts from the energy dimension to the material resources one.

Starting from this premise, the Interreg project PANORAMA tackled the issue by designing and producing a prototype of a vertical axis micro-wind turbine which implements recyclable, renewable and reused materials in a fully reversible assembly system. The exploration of alternative materials and reversible connections also allowed expanding the investigation to another domain of the project: the landscape integration of renewable energy production systems, including site restoration. The investigation resulted in improving the material efficiency of a renewable energy production system in a life-cycle perspective while preserving its performance, that will soon be field-tested.

The article frames the research by presenting the state of the art on large- and small-scale wind turbines, illustrating their difficult circular management despite current technological improvements. It then introduces the prototype and the theoretical framework behind its design, describing its technical features and the design choices on materials and assembly systems. The potential of implementing

* Corresponding author

reversibility, recyclable content, material substitution, and upcycling in these systems will then be described, in light of both their ecological relevance and the prospected diffused integration within urban and landscape contexts.

Keywords: micro-wind turbines, reversible installation, recyclable materials, renewable materials, upcycling.

1. Introduction

Renewables play a central role in the European strategy supporting a sustainable and just transition, a position recently upheld by the 2023 revision of the Renewable Energy Directive, raising the EU's binding target for the share of renewable energy to a minimum of 42.5 % by 2030 (European Parliament, 2023). Besides large-scale production plants, this framework also relies on prosumers and Renewable Energy Communities (RECs) to support small-scale green energy systems – photovoltaic (PV), wind and hydropower ones (Corasaniti et al., 2025). Intended as distributed and community-based, these elements could become widespread in future European urban and natural contexts. Nevertheless, the devices most used in these installations currently fail to comply with circular principles due to technological, financial and environmental challenges (Condotta et al., 2023). As in the coming decades these systems will be increasingly produced – and discarded, addressing their impacts across the entire life cycle is therefore essential. This will enable their full contribution to sustainable consumption and production patterns in the built environment.

Focusing on wind turbines (WTs), technological advancements further intensify this trend (Liu & Barlow, 2017) by shortening their average lifespan through increased repowering opportunities (Jadali et al., 2021) and the replacement of old components and models with more efficient ones (Jensen and Skelton, 2018). At the end of their life, even components that fall outside the scope of the Waste Electrical and Electronic Equipment Directive (WEEE) are difficult to manage through circular patterns due to complex assembly systems and used materials.

Although modular, WTs are generally not designed for disassembly. This also applies to small-scale devices implemented in RECs (micro- and mini-WTs), which differ from large-scale units in configuration: the former ones employ a vertical axis system (VAWTs) rather than a horizontal one (HAWTs) (Table 1). Concerning materials, two modules in both HAWTs and VAWTs involve downcycling or even less suited processes once decommissioned: the foundations or base, realised in reinforced concrete, and the wind turbine blades (WTBs), usually made of glass fiber-reinforced plastics composites (GFRP), which are difficult to dispose of and often landfilled (Firoozi et al., 2024). To mitigate this drawback, current research explores the repurposing of decommissioned durable GFRP blades as structural components, promoting circularity within the construction industry (André et al., 2024) (Ramaswamy et al., 2025). On the other hand, the tower module is typically made from steel or aluminium alloys, ensuring higher recyclability rates.

Table 1. Different modules composing HAWTs and VAWTs. [source: authors].

HAWTs: main modules	
Module	**Function**
Tower	Elevates rotor to stronger winds, carries loads to the foundation
Nacelle	Houses gearbox, generator, brake and turbine control systems
Rotor	Converts wind energy into rotational mechanical torque
Blades (WTBs)	Capture wind and produce lift to spin the rotor
Foundations	Anchors the tower, transfers loads to the ground
VAWTs: main modules	
Module	**Function**
Structure	Holds rotor and shaft while resisting wind loads
Generator	Converts shaft rotation into electrical power
Central shaft	Vertical axis transmitting torque from blades to generator
Blades (WTBs)	Extract energy from wind flows
Bearings/base	Support shaft rotation, transfers loads to ground/structure

While issues related to assembly systems and materials concern both large- and small-scale WTs, the latter appears a more dynamic field of study as the scale factor encourages experimentation. Nonetheless, current research primarily focuses on efficiency improvements, such as aerodynamic optimization in the blades design (Yossri et al., 2021) or modular features easing WTs adaptation and resizing (Muñoz-Palomeque et al., 2025). Few studies address circular design, either by proposing material substitution strategies (Firoozi et al., 2024) or design for reuse (Gast et al., 2024); none suggest alternatives to their perceived permanent nature – a circumstance hindering WT's social acceptance, whereas a careful landscape integration should be fostered (Bianchini et al., 2022).

2. Aim and methods

This contribution illustrates a specific experimental study carried out as part of the Interreg project PANORAMA.[1] The project's aim is to support decision-making processes for the development of RECs through the installation of photovoltaic and wind systems, based on (i) local climate conditions, (ii) technical-economic feasibility, and (iii) landscape or urban integration. Within the research, a micro-VAWT prototype was designed and developed considering these three points and two key criteria: full reversibility and a low material footprint compared to current practice.

The paper presents the design of the prototype, detailing its technical features. It then examines strategies informed by circular principles and reduced material footprint across three modules of the WT: the base (reversibility), the structure (renewable material), and the blades (recyclable material, upcycling).

1 The Interreg VI-A Italy-Austria 2021-2027 project PANORAMA "PiANificazione di cOmunità eneRgetiche AMbientalmente e pAesaggisticamente sostenibili - PlANung von umweltschOnenden und landschaftlich gerechten eRneuerbAren" (2023-2026) involves 7 partners: Università degli Studi di Udine, Research Studios Austria mbH, Università Iuav di Venezia, Consorzio BIM Piave, CML S.r.l., Consorzio NIP, Ökostrombörse Salzburg.

3. The prototype

3.1. General features and components

The prototype is an innovative small-scale H-rotor vertical axis wind turbine based on a Passive Variable-Geometry (PVG) technology, designed by the project partner CML srl.[2] Its dynamic functioning relies on an automatic wind-driven adjustment mechanism (passive) that regulates the blades configuration (variable geometry) in both radius (850 to 1050 mm) and pitch (max +/-20°), with no electronic input required. This allows to optimize the efficiency of the WT also in small-scale installations, leveraging the changing wind conditions at different elevations within urban and natural environments, and allowing an optimal efficiency also in case of turbulence. The prototype was designed to be readily integrated with PV systems and to operate entirely off grid.

Table 2 specifies the features of the prototype, while Figure 1 shows a digital mock-up which studies the proper WT integration in a natural context consistent with the project pilot areas (pre-alpine sites in the Italian and Austrian territory).

Table 2. Features of the prototype.

Module	Features
Structure	Three GL24h glulam beams of variable length, approx. 300 cm (consistent with the shaft positioning, 235 cm from the base)
Generator	IV Class, IEC 61400-2
Central shaft	Aluminium alloy extrusion EN AW-6063 T5, additive manufacturing PA12
Blades	Three elements, 1900 x 250 x 50 mm each
Bearings/base	External radius of the three beams at the base up to 90 cm
Foundation	Steel screw piles supporting a prefab concrete base

[2] CML co-founded Windcity srl, startup that develops small-scale wind turbines designed for urban and suburburban environments.

Figure 1. Render of the prototype. [Source: authors, courtesy of Ivan Del Ponte].

Geographical and climate features of the pilot areas influenced the prototype dimensions, as its design was based on the local pattern of wind flows. Landscape integration was addressed minimising the base plinth and choosing finishings suited with the specific environment.

3.2. Materials and assembly systems

In terms of circularity, the modules were devised to be completely disassembled thanks to the use of mechanical connections, up to the reversible foundations.

Besides strictly mechanical and electric components, research maximised the use of recyclable, renewable, or upcycled content in the modules to enhance sustainability compared to current practice:

- The WT base must ensure the transfer of wind and shaft rotation loads to the ground; therefore, the foundation reversibility must be carefully balanced with the need of a device safely performing. The research group opted for a system of small steel helical anchors that can be screwed/unscrewed to the ground (Figure 2), linked by steel rods to a prefabricated concrete block providing the structure footing.

Figure 2. Reversible foundation system (screw piles). [Source: Tommaso Morbiato].

- The support structure consists of four glulam beams. All connections are reversible: flat and T-shaped steel plates are inserted in the beams' width to ensure the connection with the rotor and the concrete base respectively. While the steel plates are welded to the shaft, beams-plates fastening is achieved by through-hole bolts (Figure 3); the connection to the concrete base uses steel rods (Figure 4).

Figure 3. Connection of the glulam structure to the shaft.
[Source: authors, courtesy of Ivan Del Ponte].

Figure 4. Connection of the glulam structure to the prefabricated concrete base [source: authors, courtesy of Ivan Del Ponte].

- The blades design is the most complex part of a micro-VAWT: they must be lightweight while ensuring high resistance. Since the recycled content in GFRP blades is limited to 10 % to ensure the necessary mechanical strength, a material substitution strategy was adopted. The innovative design features a thin aluminium 'hull' structure, defining the geometric shape of the blade, enclosed by PVC sheets reclaimed from lorry tarpaulins (Figures 5 and 6).

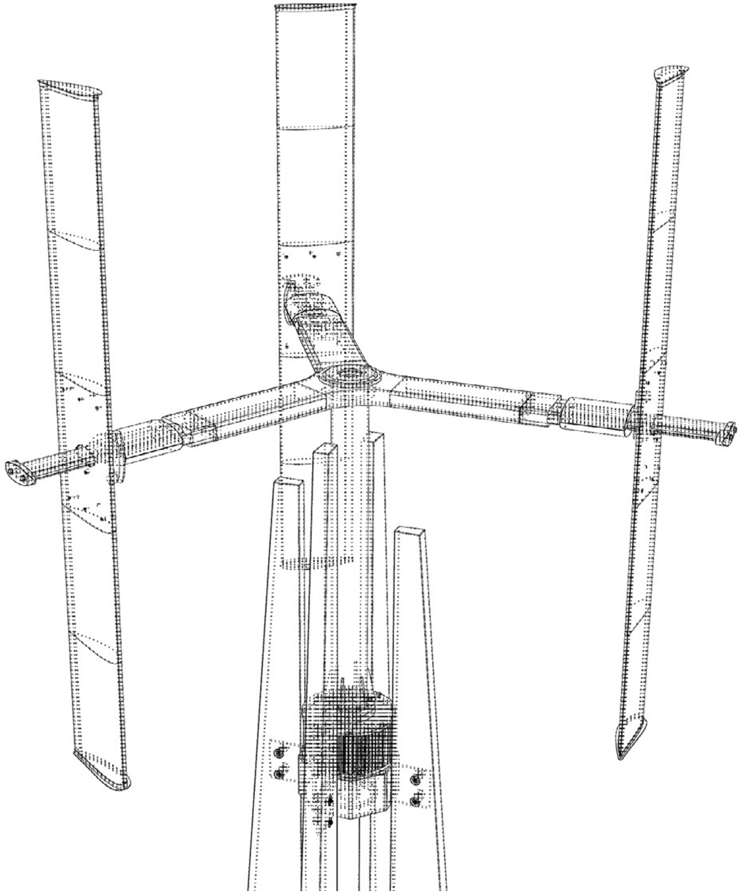


Figure 5. Micro-VAWT blades’ technical drawing: detail.
[Source: authors, courtesy of Ivan Del Ponte].

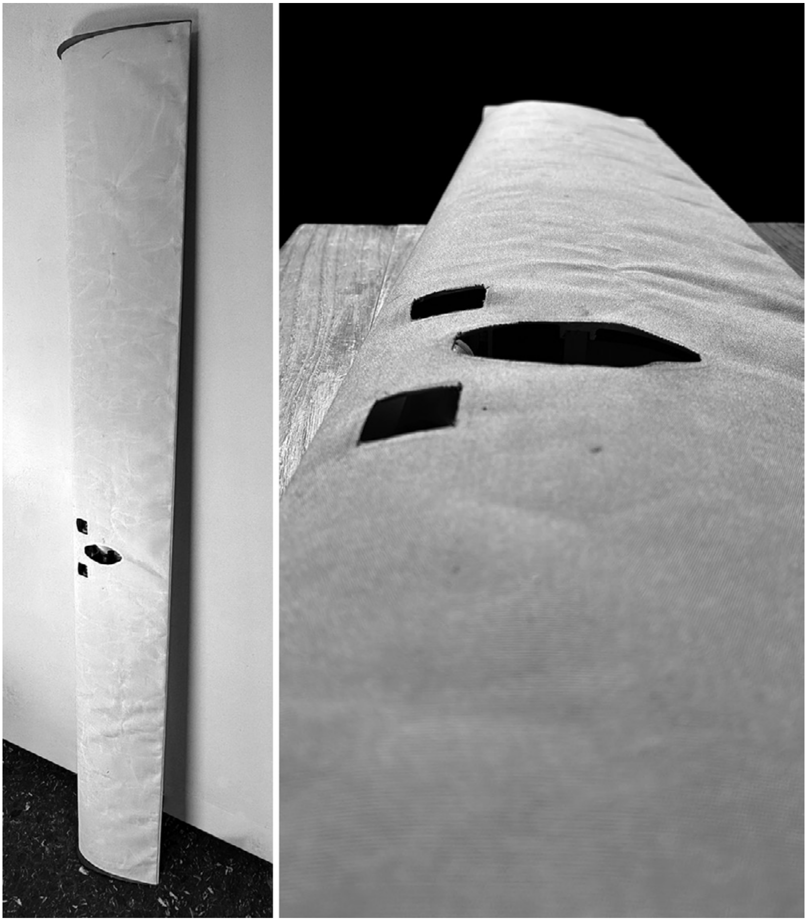


Figure 6. First prototype of the upcycled PVC blade envelope. [Source: CML srl].

The system assembly of the prototype is fully reversible, ensuring operational stability. Structural needs also informed the selection of the concrete base: although not an inherently circular material, the reversible connections to the screw piles enable full disassembly and reuse, in addition to site restoration. The structure design employs a renewable and less energy-intensive material compared to common alternatives: glulam. Albeit less durable and generally downcycled, the research group opted for it to comply with the landscape integration criteria. While material choices for the base and structure remain subject to further investigation, the fully recyclable aluminium blades, also integrating upcycled PVC elements, represent the most innovative feature of the micro-WT design in terms of circularity.

The prototype was realised and it is expected to be installed in the pilot area in summer 2026, to validate the aluminium and PVC efficiency for the blades and the overall turbine aerodynamic performance, as well as the glulam durability.

4. Conclusion: circular strategies for micro-wind turbines

The research investigated circular improvements in the assembly systems and material footprint for micro-wind turbines, supported by the design and production of a prototype. Reversible connections were implemented in the whole WT, including a removable and reusable foundation system enabling full disassembly and site restoration. The devised blades, engineered using recyclable materials and upcycled elements, provide valuable insight into alternatives to the environmentally critical GFRP composites. The wood-based structure, designed to enhance integration within natural contexts, will be tested for durability and functionality once the prototype is installed.

The research is a first step in filling the state-of-the-art gaps in the circular design of wind turbines. By addressing both the necessary increase in renewable energy production and the lack of circularity of related devices, it supports the significant role of diffused small-scale installations in future sustainable built environments. The illustrated approach implements four strategies – reversibility, recyclable content, material substitution and upcycling, to reduce both material footprint and the degradation of natural or anthropogenic landscapes, also supporting increased acceptance of these technologies.

Bibliographic references

André, A., Bru, T., Abbasi, A. G., Sinha, S., Nunes, S., Juntikka, M., Kazmierczak, K., Egilsson, N. Ó., Frid, G., Sobczyk, M., & Haghani, R. (2024). A Holistic and Circular Approach for Managing End-of-Service Wind Turbine Blades. *Sustainability*, *16*(17), 7858. https://doi.org/10.3390/su16177858

Bianchini, A., Bangga, G., Baring-Gould, I., Croce, A., Cruz, J. I., Damiani, R., Erfort, G., Simao Ferreira, C., Infield, D., Nayeri, C. N., Pechlivanoglou, G., Runacres, M., Schepers, G., Summerville, B., Wood, D. and Orrell, A. (2022). Current status and grand challenges for small wind turbine technology, Wind Energy Science, *7*(5), 2003-2037, https://doi.org/10.5194/wes-7-2003-2022

Condotta, M., Scanagatta, C., Zatta, E. (2023). Lost in transition: The burden of material resources for renewable energy sources, in Baratta A., Calcagnini L., Magarò A. (eds.), *Recycling: Il valore della materia nella transizione ecologica del settore delle costruzioni. Atti del V Convegno Internazionale, 26 maggio 2023, Università degli studi di Roma Tre – Dipartimento di architettura*, pp. 68-79. Conegliano: Anteferma.

Corasaniti, S., Coppa, P., Atzori, D., & Rehman, A. U. (2025). Renewable Energy Communities (RECs): European and Worldwide Distribution, Different Technologies, Management, and Modeling, *Energies*, *18*(15), 3961, https://doi.org/10.3390/en18153961

Liu, P., & Barlow, C.Y. (2017). Wind turbine blade waste in 2050. *Waste Management, 62*, 229-240, https://doi.org/10.1016/j.wasman.2017.02.007

European Parliament (2023). Directive (EU) 2023/2413 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652.

Firoozi, A. A., Firoozi, A. A., & Hejazi, F. (2024). Innovations in Wind Turbine Blade Engineering: Exploring Materials, Sustainability, and Market Dynamics. *Sustainability, 16*(19), 8564. https://doi.org/10.3390/su16198564

Gast, L., Meng, F., Morgan, D. (2024). Assessing the circularity of onshore wind turbines: Using material flow analysis for improving end-of-life resource management, *Resources, Conservation and Recycling, 204*, https://doi.org/10.1016/j.resconrec.2024.107468

Jadali, A.M., Ioannou, A., Salonitis, K. et al. (2021). Decommissioning vs. repowering of offshore wind farms—a techno-economic assessment. *Int J Adv Manuf Technol, 112*, 2519-2532, https://doi.org/10.1007/s00170-020-06349-9

Jensen, J.P., Skelton, K. (2018). Wind turbine blade recycling: Experiences, challenges and possibilities in a circular economy, *Renewable and Sustainable Energy Reviews*, *97*, 165-176, https://doi.org/10.1016/j.rser.2018.08.041

Muñoz-Palomeque, E., Esteban, S., & Santos, M. (2025). Mechanical Design and Experimental Study of a Small-Scale Wind Turbine Model. *Machines, 13*(10), 929. https://doi.org/10.3390/machines13100929

Ramaswamy, N., Joshi, B., Song, G., Mo, Y.L. (2025). Repurposing decommissioned wind turbine blades: A circular economy approach to sustainable resource management and infrastructure innovation. *Renewable and Sustainable Energy Reviews, 215*, https://doi.org/10.1016/j.rser.2025.115629

Yossri, W., Samah B.A., Abdessattar A. (2021). Airfoil type and blade size effects on the aerodynamic performance of small-scale wind turbines: Computational fluid dynamics investigation, *Energy 229*, 120739, https://doi.org/10.1016/j.energy.2021.120739