Greenway pedestrian and cycle bridges from repurposed wind turbine blades

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Abstract

Greenways are long-distance walking and cycling routes, often developed along the routes of disused railways. Greenways therefore are a means of repurposing underused infrastructure to provide sustainable transport. They also offer benefits for leisure activities, rural development and tourism.

The network of greenways in the Republic of Ireland is projected to grow to 240 km by 2022, and a further 800 km of long-distance pathways has been proposed. The Irish government announced €64m in funding for greenway projects in 2020, with further commitments to sustainable transport spending in the 2020 Programme for Government. In Northern Ireland there is 1,000 km of abandoned former transport routes with the potential for development as greenways. Many of the proposed greenway routes will need extensive works. In many cases, bridges and overpasses are in poor condition and will require complete reconstruction.

Alongside the repurposing of disused railways as sustainable transport routes, there is an opportunity to reuse another type of repurposed infrastructure to create functional and attractive new bridges on greenways: end-of-life decommissioned wind turbine blades. Wind turbine blades are made of durable, lightweight and strong fibre-reinforced polymer (FRP) materials. They are difficult to recycle by conventional methods, but are ideally suited to repurposing. A US-Ireland-Northern Ireland initiative, the Re-Wind network, has created designs for several new artefacts from repurposed wind turbine blades, including a pedestrian bridge.

In this paper we will show the advantages of the blade bridge design for deployment on greenways, show details of the testing and design of the world's first repurposed greenway blade bridge, scheduled for installation on the Midleton-Youghal Greenway in Co. Cork in 2021, and outline the environmental and social advantages of using repurposed FRP blades in new infrastructure such as bridges. The paper also discusses the future expected flow of end-of-life blades from decommissioned wind turbines in Ireland and how this can be aligned with repurposing opportunities.

Keywords: Circular Economy; Repurposed Infrastructure; Sustainable Transport; Composite Materials.

Introduction

The Greenway Network

A century ago there were 5,540 km of railways on the island of Ireland. Today, 2,300 km of railways remain in use, leaving over 3,000 km of former routes no longer in operation [1]. In recent years, there has been a movement to repurpose disused railways and other disused or under-used transport infrastructure as long-distance amenity walkways and cycleways, or Greenways. Greenways offer multiple opportunities for social and economic development to local communities. Firstly, during the construction phase, there are employment opportunities for local people. Secondly, there is the considerable benefit to health and well-being of having a local high-quality recreational amenity. In a 2017 survey of users of the newly-opened Waterford Greenway, 64% gave their place of residence as Co. Waterford [2]. Greenways are also attractive to tourists and can potentially support sustainable tourism in rural areas. For example, in a survey of tourists to Ireland, Deenihan et al. [3] found that almost two-thirds would choose to stay in a hotel that was near a dedicated cycling route over one that was not. In the survey of the Waterford greenway users, 68% of non-local users gave the greenway as the main reason they visited Waterford [2]. Another project, the 42 km Great Western Greenway has been estimated to attract €1.1m in tourist expenditure per year [4].

The total length of the greenway network in the Republic of Ireland is predicted to reach 240 km by 2022, and a further 800 km of long-distance pathways has been proposed. The Irish government announced €64m in funding for greenway projects in 2020, and there is a commitment of almost €1m per day of sustainable transport spending in the 2020 Programme for Government[1]. In Northern Ireland, there are 1,000 km of abandoned former transport routes with the potential for redevelopment as greenways[2] .

Wind Energy in Ireland

The wind energy industry in Ireland has expanded hugely in the past two decades. The installed capacity of wind turbines on the island has increased from 153 MW in 2001 to 5,576 MW by 2020 [5]. During this time, the average power rating of wind turbines has also grown. In the early 2000s, many installed wind turbines were in the 1 MW range. Nowadays, onshore machines of 3 MW or greater capacity are typical. As the power capture of wind turbines is dependent on the area of the disk swept out by the blades as they rotate, blade lengths have expanded as the turbine power has increased. Typical blade lengths in the early 2000s were in the range 20-35 m, whereas in the early 2020s, blade lengths of 50 m are not unusual. The growth in turbine size and power ratings has been even greater offshore. The governments of the UK and Ireland have set ambitious targets for the decarbonisation of the electricity sector. A large increase in the installed wind energy capacity will be required in order to meet the targets. It is envisaged that by 2030, up to 8.2 GW of onshore wind capacity and a further 3.5 GW of new offshore capacity will be installed in the Republic of Ireland in order to meet the target of 70% of electricity generation from renewables [6].

The International Renewable Energy Agency has estimated that 13 tonnes of polymers and 7.4 tonnes of fibreglass are required for every 1 MW of installed offshore wind capacity [7]. The typical design life of a wind turbine is 20 years, and a recent study of end-of-life blades in Ireland predicted 53,000 t of decommissioned blade material from onshore wind turbines by 2040, based on an estimate of 10.33 t of blade material per installed megawatt of wind power capacity [8]. The greatest concentration of blade material will be in the west and southwest of the island, where large numbers of wind farms were developed in the first decade of

[1] Over €64m for 15 greenway projects , https://www.rte.ie/news/ireland/2020/1115/1178289-greenways/

[2] Northern Ireland Greenways, http://nigreenways.com/about/

the current century [8]. As the volume of decommissioned blades increases, and as available landfill capacity decreases in the coming years, new end-of-life solutions will have to be found for decommissioned wind turbine blades. For the past three decades, glass fibre reinforced polymer (GFRP) has been the material of choice for construction of wind turbine blades. Unfortunately, as a composite material, GFRP is not easily or economically recyclable using current technologies, and the typical end-of-life treatments are landfill, incineration, or co-processing in cement kilns [9].

The Re-Wind network[3] is looking at environmentally, socially and economically sustainable end-of-life options for wind turbine blades, with an emphasis on repurposing blades to create new artefacts. Repurposing, rather than material or energy recovery, preserves more of the original engineered value of the blades and also is a more-favoured option on the EU's waste hierarchy [10]. The Re-Wind network has identified many potential applications for end-of-life blades and has developed several concepts into detailed designs including roofs for small buildings [11], [12], and bridges [13].

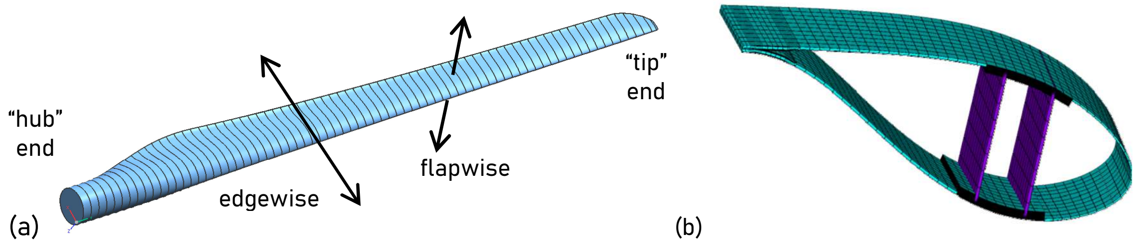

Figure 1. (a) Typical geometry of a wind turbine blade; (b) Section of a wind turbine blade showing exterior aerofoil geometry and internal shear webs (in purple) and spar caps (indicated by black edges). Images modified from [14].

Wind turbine blades have complex three-dimensional geometry (Figure 1). The blades usually have a circular cross-section at the "root" section which attaches to the rotor hub, which then transitions to an aerofoil cross-section (Figure 1b) in the mid-section and the tip. Blades usually have a twist from hub to tip, whereby the orientation of the aerofoil gradually changes along the length of the blade. Flapwise loads arise from the wind force, whereas edgewise loads are influenced by the blade's own weight and its rotation (Figure 1a). The internal shear webs (purple) and spar caps (black edges; Figure 1b) form a box beam which runs along most of the length of the blade along its longest dimension, from hub to tip. The spar caps provide the blade's stiffness in the flapwise direction, while the outer shell (green in Figure 1b) provides most of the edgewise stiffness [15].

Case Study: Roxborough Bridge on Midleton-Youghal Greenway, Co. Cork

The Midleton to Youghal Greenway is a project under development by Cork County Council and funded by the Irish Government's Department of Transport under the Project Ireland 2040 initiative. It is expected that the greenway will be completed in 2022, but sections will open before the final completion date. The greenway will run for 23 km between the towns of Midleton and Youghal in East Cork along the path of a former railway (Figure 2). The scope of the greenway project includes localised repair or replacement of bridges or culverts. The guideline width for the greenway is 3-4 m [16]. The Re-Wind project team visited existing bridges along the route early in 2020 to identify locations where a blade bridge could be constructed. Cork County Council subsequently identified a suitable site, where a replacement bridge at Roxborough, near Midleton at the Western end of the greenway, was specified as part of the works for the greenway project (Figure 3). The required bridge span is 5 m. The bridge is intended for foot passenger and cycle use only, however it also has to support an emergency vehicle of up to 10 t in case of accidents on the greenway.

[3] Re-Wind project website, https://www.re-wind.info/

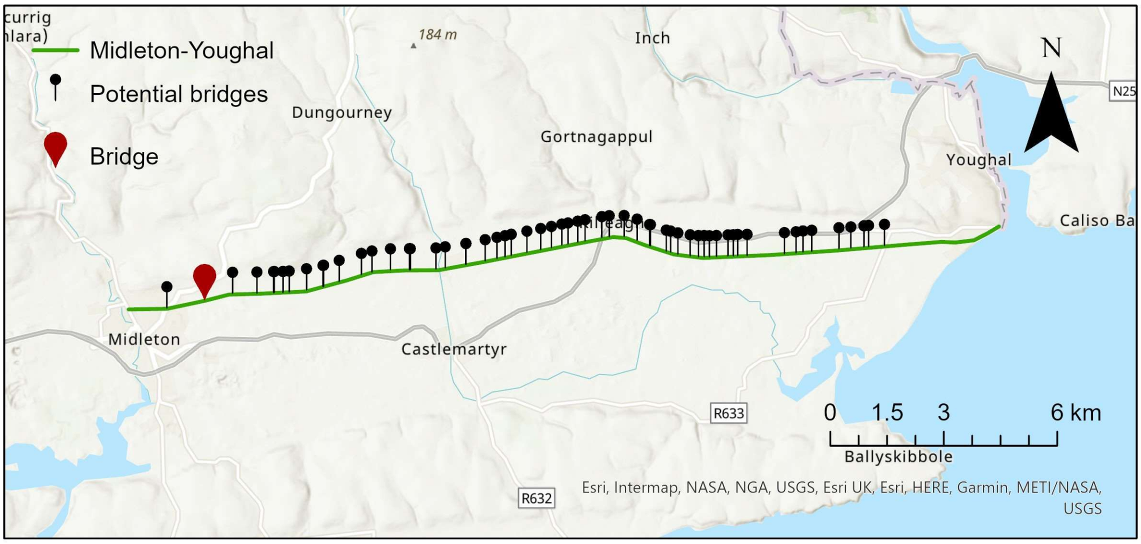

Figure 2. Map showing locations of bridges and crossings along greenway route in Co. Cork

Figure 3. Existing structure on greenway route at Roxborough, showing steel girders and masonry abutments

Results: Bridge Design and Testing

Three blades from decommissioned Nordex N29 turbines were obtained from Everun Ltd, Belfast. The Nordex N29 is a 250 kW, three-bladed, 29m rotor diameter wind turbine, first installed in 1994. The blades are 14 m long.

Two cut sections of the N29 blades will be used as the main load-bearing elements for the blade bridge (Figure 4). The blades are oriented with trailing edges pointing upwards, and the blades will rest on pre-cast concrete forms atop of the existing masonry abutments (Figure 5). Cross-members will be attached to the blades and a surface of textured concrete will be applied. The handrail will be attached directly to the blades.

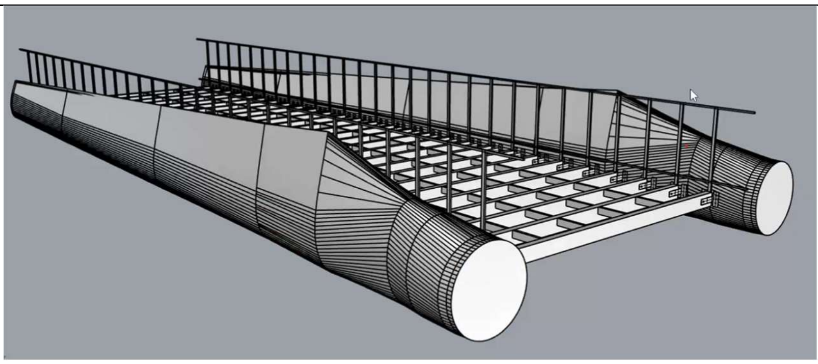

Figure 4. Preliminary render of blade bridge design showing Nordex N29 blade sections as primary load bearing members

Figure 5. Render of blade bridge at Roxborough, Midleton, Cork (Image Courtesy: Asha E. McDonald & Alexander D. Poff, Georgia Tech)

Challenges encountered in the design of the blade bridge included dealing with the unknown geometry of the N29 blade. Blade manufacturers treat blade geometry as proprietary information and generally do not release it. Therefore, the blades were scanned with 3D LiDAR, and the "blade machine" software developed by the Re-Wind team was used to generate a smooth exterior geometry shapefile for the blades [17]. The internal structure of the blade was also unknown, therefore the internal structure was determined by making a series of cuts through the blade, and by extracting cores and measuring the internal dimensions. Sections of the GFRP were extracted and subjected to "burn-out" tests which removed the polymer component of the material, allowing the layers of fibre mat to be studied in detail.

Further challenges were posed by the curved shape of the blades and the necessity for a continuous handrail and deck to be attached to the curved and twisted blades. Making attachments to GFRP requires specialised techniques in order to avoid damage to the composite material when the attachment points are subjected to loads, for example pedestrian, cycle or vehicle loads carried on the bridge deck and transferred via attachments to the blades.

The residual strength of blades after an indeterminate number of lifetime load cycles in service on the turbines was also unknown. Hand calculations and prior work (see [18]) indicated that the residual strength of the blades would be more than sufficient for the expected loading of a greenway bridge. However, in order to provide direct experimental evidence, one of the N29 blades was subjected to a series of non-destructive and destructive tests in the Structures Laboratory of Munster Technological University. Blades were cut to the lengths required for the bridge and were placed in a structural load cell where they were subjected to a three-point load test in the edgewise direction (Figure 6). The test protocol and results will be reported in a separate communication, but all test results were sufficient to satisfy the design requirements for the greenway bridge.

Figure 6. Load testing cell at the Structures Laboratory, MTU, showing N29 blade section under test.

Discussion

Using repurposed materials displaces highly energy-intensive and/or carbon-intensive virgin raw materials such as steel or concrete. As blades are a local resource in many cases, there are also opportunities for local enterprises to carry out the fabrication work close to the point of installation [19]. This also has the advantage of reducing the CO_2 emissions from transportation of materials. Finally, as bridges are long-lived structures which can be reasonably expected to last for 60 years or longer, the carbon-containing polymers are locked in for duration of bridge's lifetime and do not enter the atmosphere as CO_2 which would be the case if the blades were disposed of by incineration, waste-to-energy, or relatively short-lived repurposing applications. In this way, blade repurposing delivers immediate climate change mitigation benefits.

The Roxborough bridge design described in this paper is actually a reduced span version of the original Re-Wind blade bridge which has a 8.5 m span and was designed using sections of 14.3m blades from a modified aftermarket version of a Vestas V27 turbine blade [18]. Experienced gained in the design, testing and construction of the Roxborough blade bridge project will be useful to streamline the design and testing process for longer span bridges to be deployed on greenways or in other locations. The blade bridge concept has the potential to be developed as a kit bridge which can be mostly prefabricated off-site, delivered in sections, and assembled *in situ*, which would deliver cost reductions for customers.

Conclusions

This paper has demonstrated the feasibility of repurposing end-of-life wind turbine blades as structural elements. There is will be a considerable supply of blades from wind farms reaching the end of their service lives in the next decade. This increase in the supply of blades coincides with an unprecedented expansion of long-distance walking and cycle pathways in the form of the greenway programmes in Northern Ireland and the Republic of Ireland. The sustainability of greenways can be enhanced by incorporating repurposed wind turbine blades in reconstructed bridges, and potentially in ancillary structures such as outdoor furniture and bicycle shelters. Environmental, social and economic benefits of greenway blade bridges accrue from diverting GFRP material from landfill, incineration or other undesirable disposal options, substituting virgin structural materials such as steel, encouraging sustainable transport and eco-tourism, and potentially stimulating local enterprise in blade remanufacturing for transportation applications.

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