REUSING COMPOSITE MATERIALS FROM DECOMMISSIONED WIND TURBINE BLADES

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ABSTRACT

The very rapid growth in wind energy technology in the last 15 years has led to a rapid growth in the amount of non–biodegradable, thermosetting FRP composite materials used in wind turbine blades that will need to be managed of in the near future. A typical 2.0 MW turbine with three 50 m blades has approximately 20 tonnes of FRP material and an 8 MW turbine has approximately 80 tonnes of FRP material (1 MW ≈ 10 tonnes of FRP). Calculations show that 4.2 million tonnes will need to be managed globally by 2035 and 16.3 million tonnes by 2055 if wind turbine construction continues at current levels and with current technology. Three major categories of end-of-life (EOL) options are possible – disposal, recovery and reuse. Reuse options are the primary focus of this paper since landfilling and incineration are environmentally harmful and recovery recycling methods are not economical. The current work reports on different architectural and structural options for reusing parts of wind turbine blades in new or retrofitted housing projects. Large-sized FRP pieces that can be salvaged from the turbine blades and potentially useful in infrastructure projects where harsh environmental conditions (water and high humidity) exist. Their non-corrosive properties make them durable construction materials. The approach presented is to cut the decommissioned wind turbine blades into segments that can be repurposed for structural and architectural applications for affordable housing projects. The geographical focus of the designs presented in this paper is in the coastal region of the Yucatan on the Gulf of Mexico where low-quality masonry block informal housing is vulnerable to severe hurricanes and flooding. In what follows, a prototype 100m long wind blade model provided by Sandia National Laboratories is used as a demonstration to show how a wind blade can be broken down into parts, thus making it possible to envision architectural applications for the different wind blade segments.

KEYWORDS: Architecture, Composite Materials, FRP, Housing, Recycling, Reuse, Waste, Wind Turbines

1. INTRODUCTION

This paper presents a potential approach to tackling the looming issue of waste glass fiber reinforced polymer (GFRP) composite material to come from decommissioned wind turbine blades. The approach presented is to cut the decommissioned wind turbine blades into segments that can be repurposed for structural and architectural applications for affordable housing projects. The geographical focus of the designs presented in this paper is in the coastal region of the Yucatan on the Gulf of Mexico where low-quality masonry block informal housing is vulnerable to severe hurricanes and flooding (Bank, 2017). Global, U.S. and Mexico wind industry statistics are shown to give a sense of the large quantity of out-of-service wind blades that will need to be recycled in the near future. In what follows, a prototype 100 m long wind blade model provided by Sandia National Laboratories (Griffith, 2013) is used as a demonstration to show how a wind blade can be broken down into parts, thus making it possible to envision architectural applications for the different wind blade segments.

2. WIND INDUSTRY

The very rapid growth in wind energy technology in the last 15 years has led to a dramatic

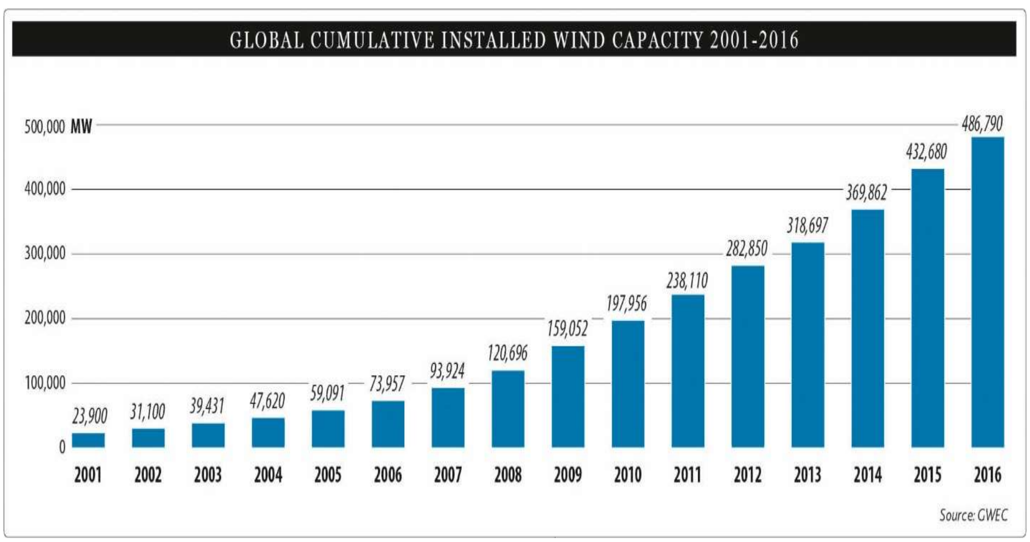

FIGURE 1. GLOBAL CUMULATIVE CAPACITY (GWEC, 2017)

increase in the amount of non–biodegradable, thermosetting FRP composite materials used in wind turbine blades that will need to be managed in the near future. A typical 2.0 MW turbine with three 50 m blades has approximately 20 tonnes of FRP material and an 8 MW turbine has approximately 80 tonnes of FRP material (1 MW ≈ 10 tonnes of FRP, see Arias (2016). Calculations show that a total of 4.2 million tonnes of wind blade FRP waste will need to be managed globally by 2035 and 16.3 million tonnes by 2055. As of December, 2016, the global cumulative installed wind capacity was 486,790 MegaWatts (MW) (Fig. 1). What is more striking in this figure is the fact that the global cumulative capacity has been increasing on a year-to-year basis over the last 5 years. However beneficial, this sharp growth in the wind industry also leads to substantial amounts of composite material to be dealt with in the future.

2.1 Wind Industry – Mexico

The Mexican wind industry has been installing wind turbines over the past nine years. Wind industry giants such as Gamesa, Acciona and Vestas have played a crucial role in this development. Fig. 2 shows a forecast of the installed capacity (12,823 MW total) for each of Mexico's provinces in 2020. It is worth noting that the two provinces with the largest anticipated wind energy capacities in 2020 are Oaxaca and Yucatan. Large amounts of wind turbine blades facing inevitable decommissioning close to vulnerable communities on the Gulf of Mexico coast would make it feasible to transport blade segments to these communities for reuse.

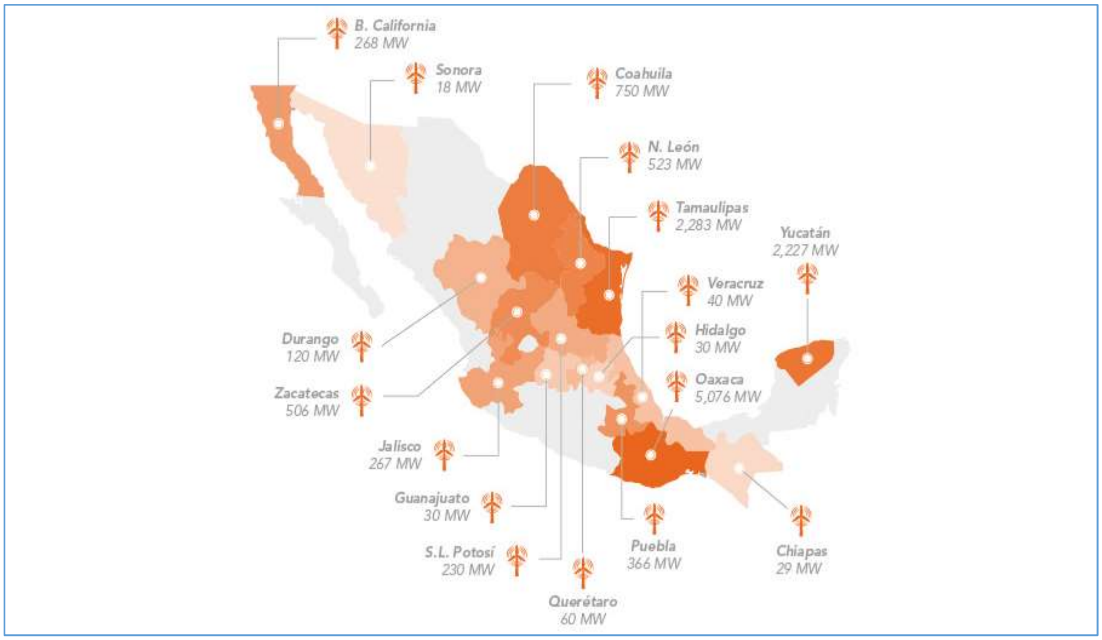

FIGURE 2. MEXICO 2020 FORECAST (MWEA, 2017)

3. END-OF-LIFE OPTIONS

Three end-of-life (EOL) options for FRP wind blades are currently possible – disposal, recovery and reuse. The two options to dispose of FRP composites at the present involve landfilling or incineration (with or without energy recovery and/or silica ash recovery). Recovery options consist of reclamation of the constituent fibers or the resins by thermo–chemical methods or recovering of small pieces of granular FRP material for use as filler material in concrete or other composites by cutting, shredding or grinding. Reuse options consist of reusing the entire FRP blade or large parts of it in new structural applications. Reuse options are the primary focus of this paper since landfilling and incineration are environmentally harmful and recovery methods are not currently economical for GFRP, of which the vast majority of current blades are made.

4. THE 100-METER LONG SNL-100-01 PROTOTYPE WIND BLADE

SNL-100-01 is a publically-available 100 meters long prototype wind turbine blade model that was designed by Sandia National Laboratories (Griffith, 2013). It has GFRP in most of the shell structure, and a smaller amount of carbon fiber reinforced polymer (CFRP) composite material in the shear web and spar caps. The geometry is defined by 25 different airfoil shapes. A total of 393 solid and sandwich composite material lay-ups are used in the blade. The software tool NuMAD (2015) was used build three-dimensional models of the wind blade. Model parameters are airfoil type, station parameters, division points, material models, composite materials, and shear web division points. Fig. 3 shows a finalized version of the SNL-100-m blade. The different colors in the figure represent the 393different material lay-ups in the blade. Most current blades in the 40-50 meter length range are exclusively made of GFRP. Future longer blades (80 m and above) will also use CFRP. This study used the glass and carbon blade model as an example. Rhino 3D (2017) was used to render the blade. Rendering the blade with its actual material thicknesses is required to extract realistic segments for architectural applications. Fig. 4 shows an isometric view of the SNL-100-01 blade.

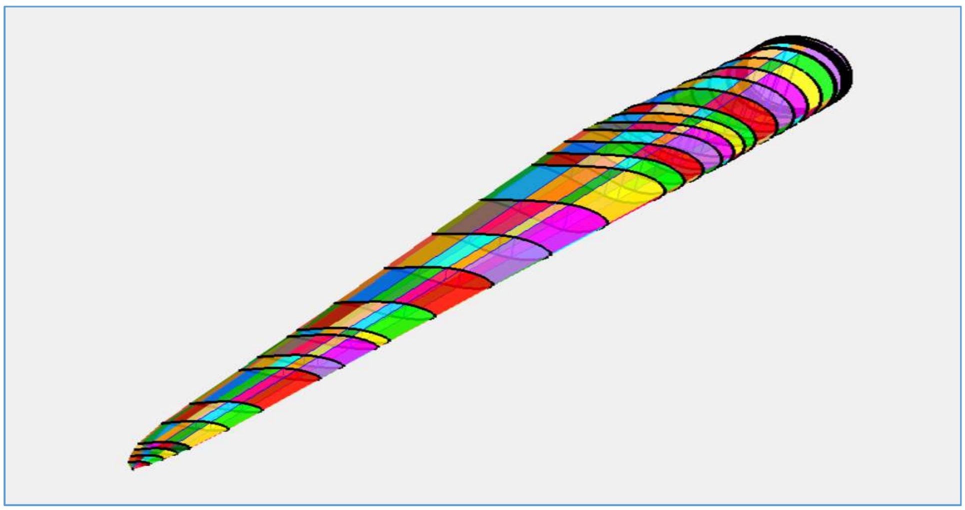

FIGURE 3. THE SNL-100-01 NUMAD BLADE MODEL (NUMAD, 2015)

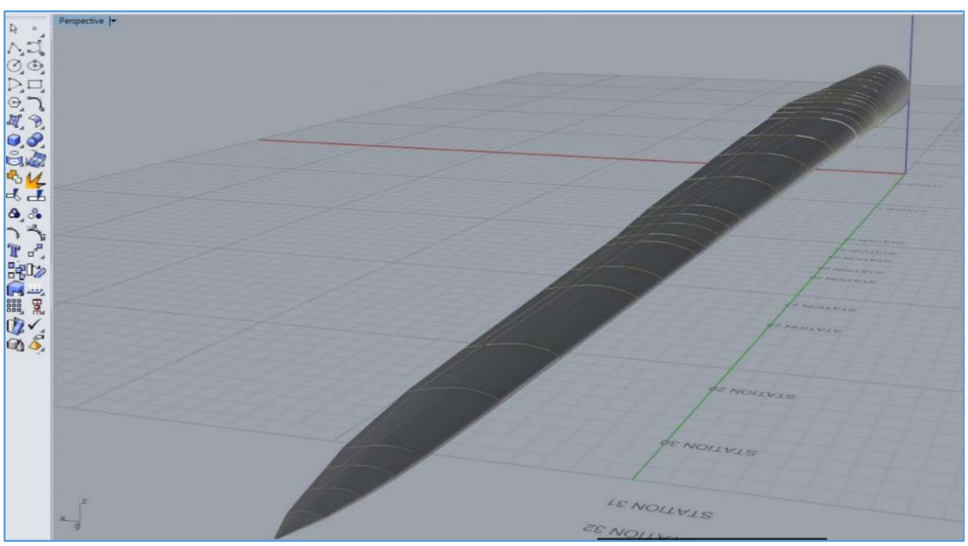

FIGURE 4. THE SNL-100-01 BLADE RENDERED IN RHINO 3D

5. ARCHITECTURAL CONCEPTS FOR DECOMMISSIONED 100 m LONG WIND BLADE SEGMENTS

5.1 Root-Foundation System

The root segment of the SNL-100 blade has circular and elliptical cross sections. The top and bottom halves of the blade shell consist of a variety of FRP materials arranged in different layers: gelcoat, resin, triaxial fiber fabrics, and unidirectional fiber (Griffith, 2013). At its thickest point, the root has an FRP thickness of 110.6 mm. The starting chord length for the root is 5.7 meters; it eventually reaches a maximum of 7.5 meters. A typical 2 MW 2000s-era wind blade of about 50-60 m in length would have a root chord ranges from 3 to 4 m in length.

Based on Yucatan 2014 surveys (Matta, 2016)**,** flooding is the second most damaging environmental occurrence to informal houses (wind and rain being the first). Elevating homes is proposed to avoid flooding damage. By cutting the wind blade root section (closest to the turbine hub) into short segments, platforms suitable for home elevations can be obtained. The resulting platforms have cylindrical or elliptical cross sections. One meter high platforms of different root sections are shown alongside a rendering of a typical rectangular masonry house with dimensions of 7 m long, 5 m wide and 2.7 m high are shown in Fig. 5. The platforms would have to be driven into the ground. If a higher elevation for a house is desired, larger segmented platforms can be extracted from the root to provide adequate embedment. Additionally, the inside of the platform may be filled with an aggregate. Fig. 6 shows houses being elevated off the ground by such platforms (scaled down for the 100 m blade to fit the size of the house).

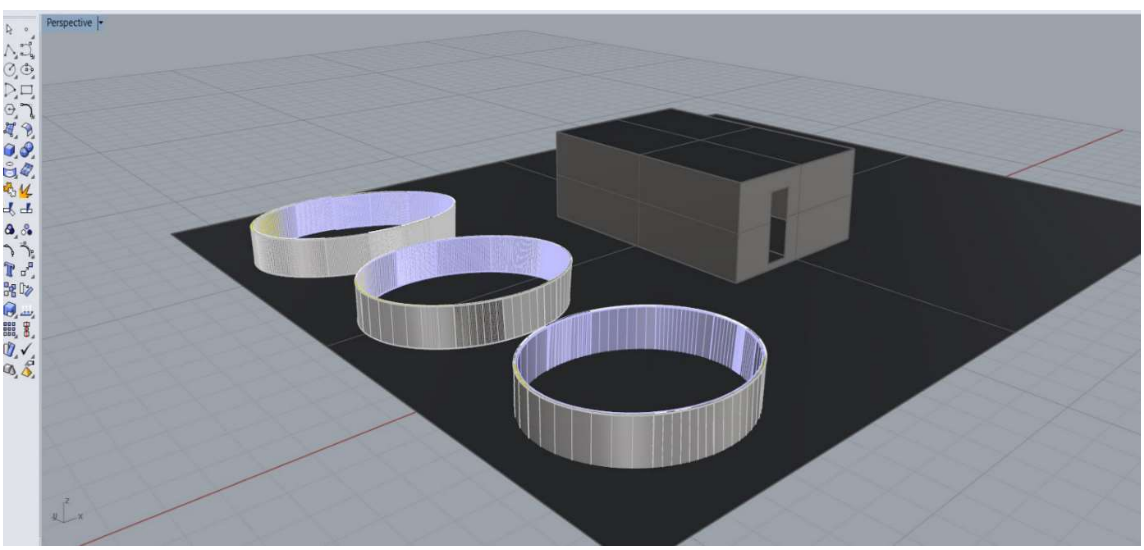

FIGURE 5. ROOT SECTIONS ALONGSIDE HOUSE MODEL

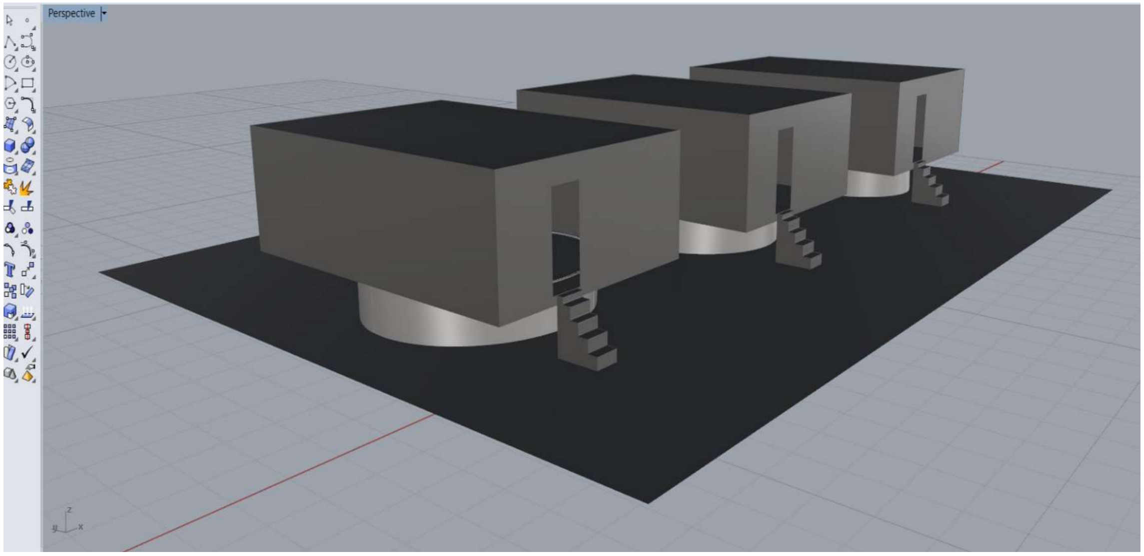

FIGURE 6. ELEVATED HOUSES

5.2 Door/Window Applications

Three shear webs connect the top and bottom halves of the blade shell and run along the length of the blade. The shear webs are made of a sandwich composite that has a 60-millimeter-thick foam core (shown in yellow in Fig. 7) in the center and 3-millimeter carbon fiber skins (show in black) on either side of the core. Two of the shear webs are 80 m long and are connected to the carbon fiber spar caps (which are solid carbon fiber and provide the flexural stiffness to the blade). The third shear web is 40 m long at the end of the blade and provides rigidity to the trailing edge (the flatter edge) near the tip of the wind blade. These straight, slender pieces of FRP material are excellent for applications involving doors, window shutters, flooding barriers, structural insulated panels (SIPs) and facades.

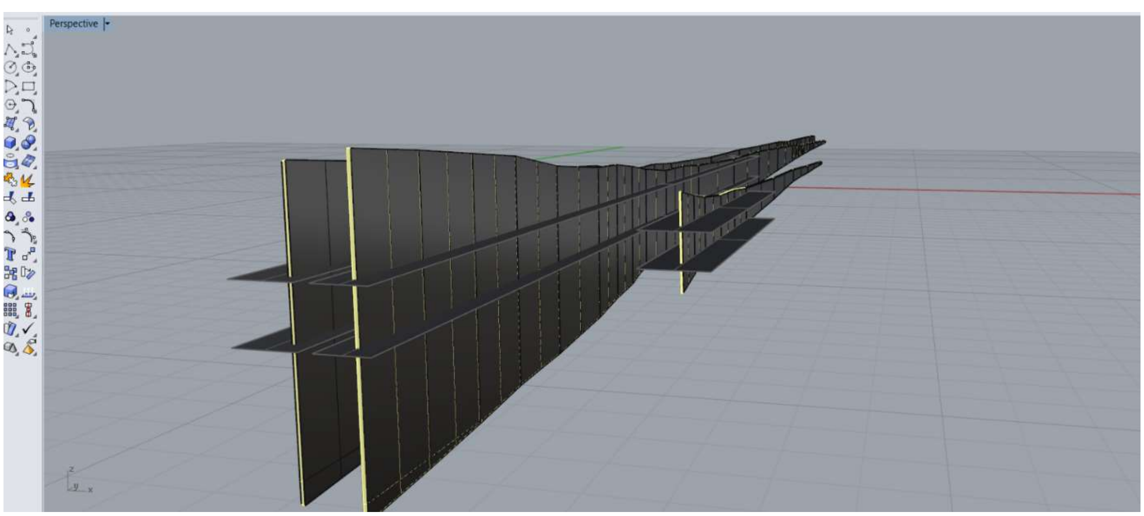

FIGURE 7. SHEAR WEBS

Fig. 7 shows the three shear webs extracted from the SNL-100-01 wind blade model. Two rectangular virtual cutting planes, one meter apart, are superimposed onto the shear webs. These two planes show the longitudinal cuts that would be needed to produce solid straight one meter high sandwich panels. Fig. 8 and Fig. 9 show cut-out segments of the shear webs being used as doors and windows covers for the model house, respectively.

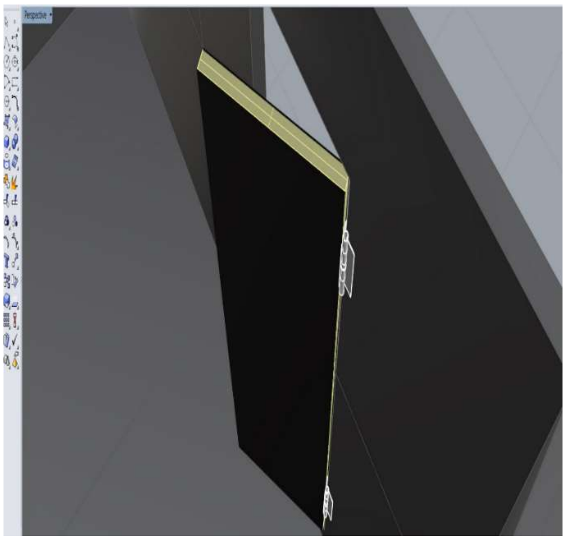

FIGURE 8. SHEAR WEB – DOOR

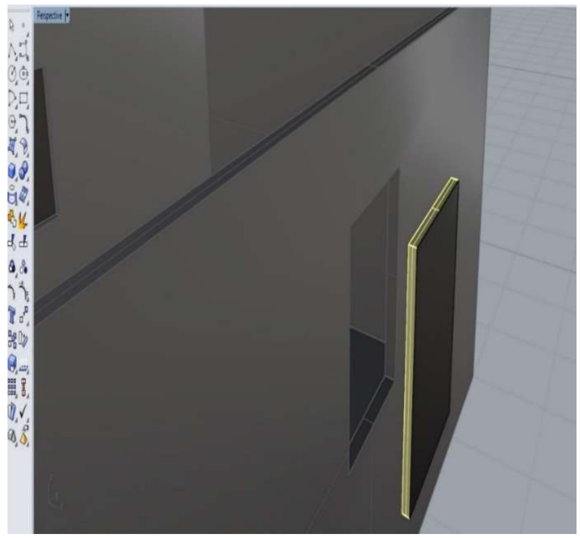

FIGURE 9. SHEAR WEB – WINDOW COVER

5.3 Roof Frames

In Fig. 10, the leading-edge (the rounded panels at the front of the blade shell) has been removed from a blade segment to leave the three shear webs and the trailing-edge panels. The leading top and bottom panels have then been separated to make two roof frames. The shear webs (discussed above) run up to 80 m down the blade length, are over 2 m high at their highest point, most importantly, they are straight, making them easy to line up geometrically with other

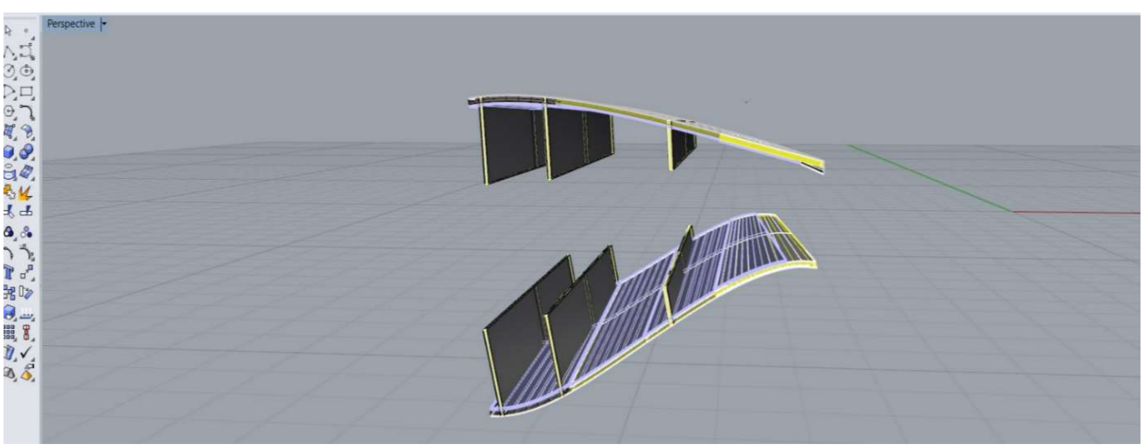

FIGURE 10. BLADE SEGMENT CUT

structural elements found in housing construction. To extract the roof frames, the panels must be sliced at an angle so that the cut bisects the shear webs and passes through the joint at the tip of the trailing-edge as seen in Fig. 10. Bisecting the blade segment in this manner results in one roof frame from the bottom of the blade and another from the top. These two roof frames are similar, but not identical. Both have the same cross-sectional length, height, and material construction. However, the top roof frame has a concave-down roof curvature, while the bottom roof frame has an inflection point midway along its roof curvature. This geometric difference can be observed in Fig. 11, where both half-trusses are displayed next to one another.

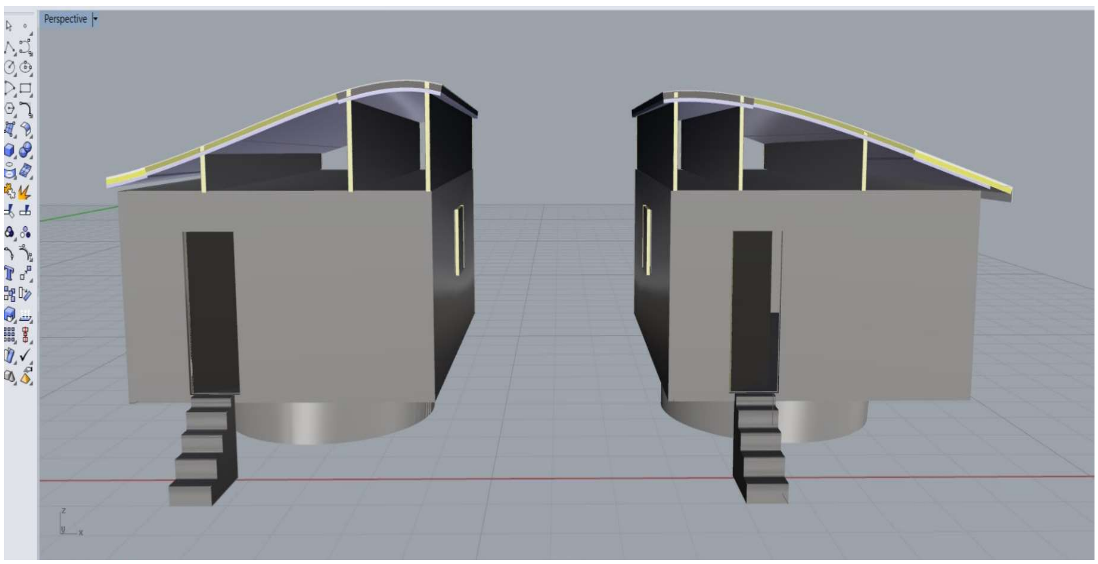

FIGURE 11. ROOF FRAMES

5.4 Interlocking Roof System

The FRP material found in the panels of the leading-edge of the blade comprises up to a third of the entire wind blade structure. A substantial amount of the FRP material can be salvaged from the leading-edge (rounded front) portion of a decommissioned blade. It is important to understand the geometric arrangement and material composition of the panels if large-sized FRP blade segment are to be extracted and used for architectural/structural applications. Fig. 12 shows two blade segments extracted from 30 and 47 meters from the root of the blade. Also in Fig. 12, the leading edge FRP panels are cut and extracted from the rest of the blade segments. These panels are the reduced down into smaller shells, as shown in Fig. 13, where the virtual cuts are represented by the black planes.

Arranging the cut-out segments in a configuration as seen in Fig. 14 yields a possible roofing system for affordable housing.

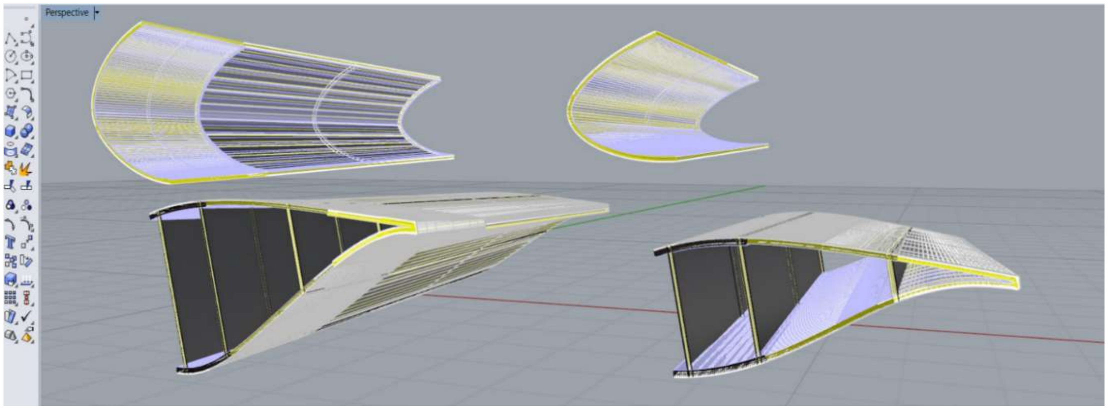

FIGURE 12. SEPARATED LEADING EDGE SEGMENTS (TOP)

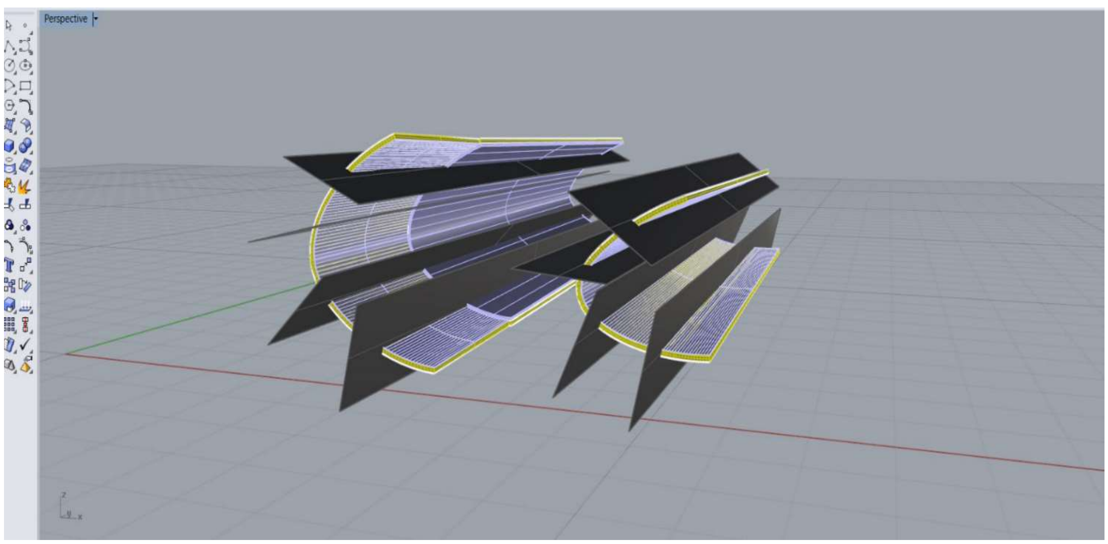

FIGURE 13. LEADING EDGE VIRTUAL CUTTING PLANES

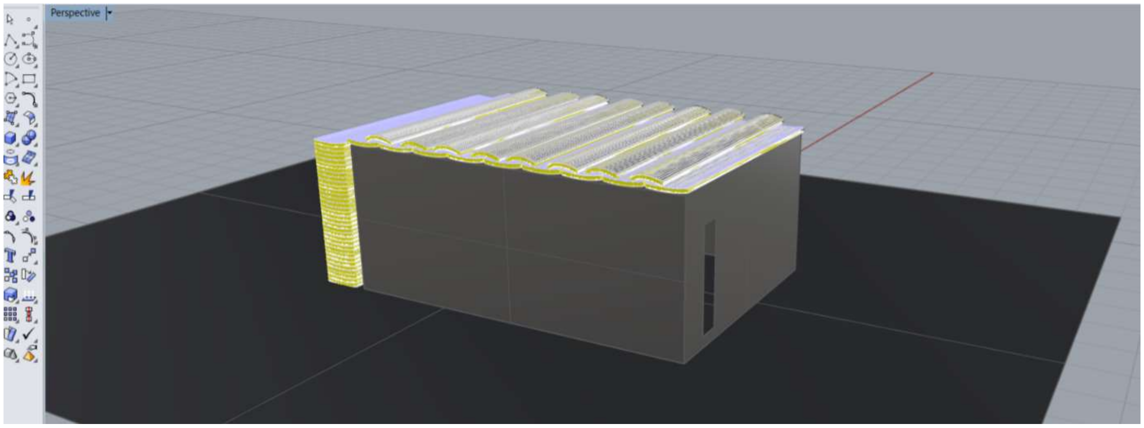

FIGURE 14. INTERLOCKING ROOF PANEL CONFIGURATION

There are two important issues to consider when extracting the leading edge panels and repurposing them for use in a roofing system. First, there is a slight warping in blade geometry that is due to the twist along the length of the wind blade. The most noticeable effect of this can be observed at the transition between the root and wing segment of the blade. As the blade tapers off, the angle of twist decreases and the warping is less significant. Nonetheless, the extracted leading edge shells will not be perfectly straight, making the interlocking roof configuration difficult to arrange. The gaps formed in between the shell segments may prove to be an issue when providing a leak-proof roofing system. This may be addressed by cutting a small amount of materials off to produce tapered edges (in thickness direction) to make them perfectly fit. An alternative is to seal the gaps due to misfit with other materials.

Second, as the wind blade tapers off after reaching its maximum chord length, the material thickness for the foam decreases. This means that at some points along the blade closer to the root the FRP pieces will be thicker than the pieces found further down the blade. This will raise some concerns when selecting curved segments for the interlocking-roof system. Having segments that are too thin or thick with respect to their adjacent segments will create additional gaps that need filling. However, this would not be an issue if all the concave segments are tapered in one direction and all the convex segments are tapered in the opposite direction.

6. A POSSIBLE VISION

Building or retrofitting an affordable housing community with salvaged wind blade parts might resemble something like that depicted in Fig. 15. In this representation the root-foundation system has been used in all the houses, elevating them off the ground. All doors and windows have been modelled using the shear webs panels. Lastly, the roof frame and the interlocking roof configuration are shown in different scenarios.

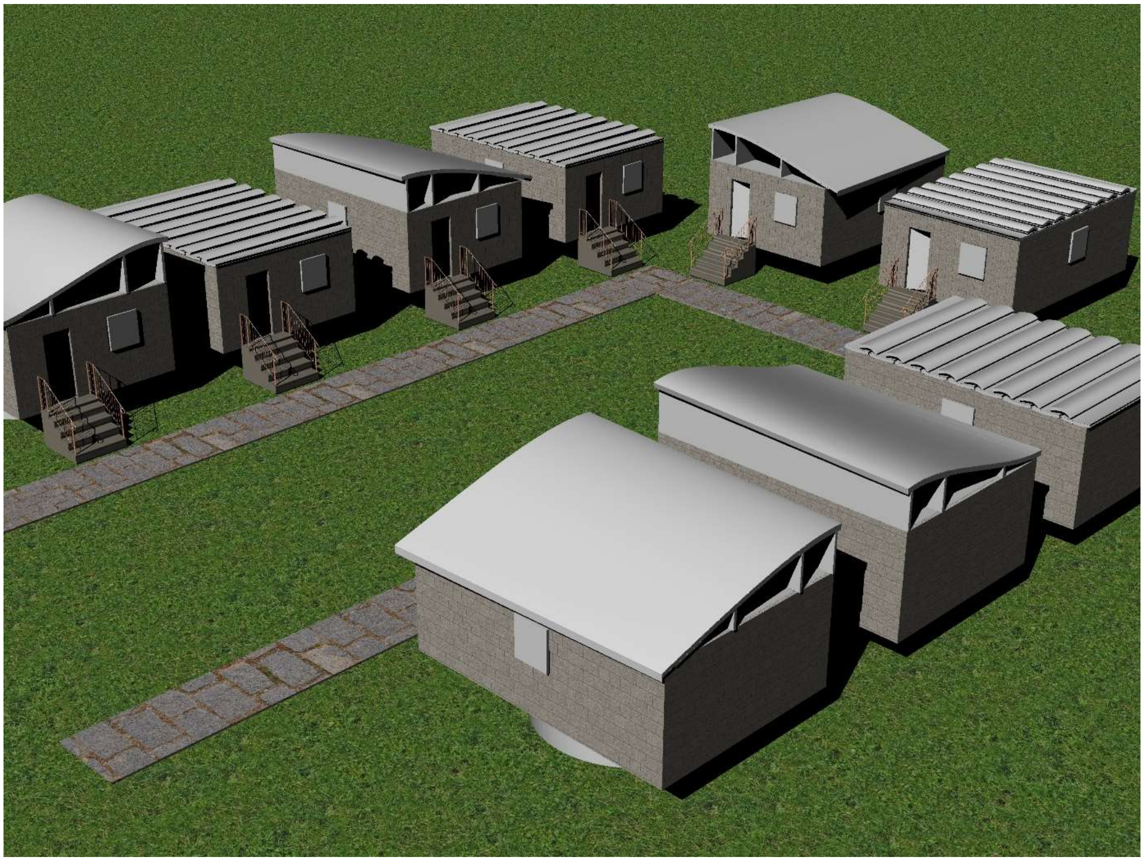

FIGURE 15. RETROFITTED AFFORDABLE HOUSING CONCEPT

CONCLUSIONS

The purpose of this paper was to present a feasible solution to the impending issue of recycling decommissioned wind turbine blades. As discussed, a wind turbine blade, in this case, the SNL-100-01, can be presented as a wireframe model. From this rudimentary wireframe model, a blade can be reassembled as a 3D model for better architectural/mechanical analysis. Computer software like NuMAD and Rhino 3D made it possible to extract segments from a decommissioned SNL-100-01 wind blade and find real-life structural applications for affordable housing communities. However, this paper is a first step towards making the disposal of wind blades efficient and environmentally friendly. In time, this process of repurposing decommissioned wind blade parts must be further researched with regards to mechanical systems (MEP), structural analysis, logistics, and detailing, other architectural and infrastructural applications; cost and ease of dis- and reassembly; social accessibility and acceptability.

AKNOWLEDGEMENTS

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