SCHOOL OF BUILT ENVIRONMENT, ENGINEERING AND COMPUTING

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Repurposing Decommissioned Wind Turbine Blades for Sustainable Boat Waiting Shelters in Kerala

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Candidate's Declaration

I, Levin Robert, confirm that this dissertation and the work presented in it are my own achievement.

Where I have consulted the published work of others this is always clearly attributed;

Where I have quoted from the work of others the source is always given. With the exception of such quotations this dissertation is entirely my own work;

I have acknowledged all main sources of help;

I have read and understand the penalties associated with Academic Misconduct.

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Abstract

The global deployment of wind energy has also brought forth new sustainability concerns, namely the end-of-life disposal of decommissioned wind turbine blades. The blades consist predominantly of glass fiber-reinforced polymers (GFRP) and carbon fiber-reinforced polymers (CFRP) and are difficult to recycle due to the fact that they are thermosets. An estimated 43 million tons of waste would be generated from blades by 2050 globally. In resolving this problem, the present study explores the recycling of decommissioned wind turbine blades into eco-friendly boat waiting shelters in Kerala, India.

With a combination of CAD modeling (SolidWorks) and Finite Element Analysis (ANSYS), the project validates the structural and thermal efficiency of recycled blade designs. Static structural analysis under real loading conditions indicates that recycled blades have acceptable deformation limits and safety margins even under adverse environmental stresses typical of Kerala's coastal climate. Thermal analyses confirm the material's resistance to heat buildup under extreme solar radiation, ensuring passenger comfort.

The methodology not only diverts heavy composite trash away from incinerators and landfills but also provides cost-effective, durable infrastructure solutions for climate-risk-affected areas. The use of circular economy principles in the construction of infrastructure shows that waste materials can be recycled into climate-resilient public assets. Such issues as design adaptability, transit logistics, and regulatory support are even mentioned in the research. Nonetheless, the reuse strategy provides an excellent example of sustainable development, combining environmental protection with community-scale infrastructure improvement.

The findings contribute to worldwide efforts to align renewable energy expansion with lifecycle sustainability and offer a replicable model for concurrent interventions worldwide.

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Abbreviations

GFRP	Glass Fiber Reinforced Polymer
CFRP	Carbon Fiber Reinforced Polymer
FRP	Fiber Reinforced Polymer
FEA	Finite Element Analysis
CAD	Computer-Aided Design
UV	Ultraviolet
EoL	End-of-Life
SDGs	Sustainable Development Goals
ANSYS	[Name of Software – Not an abbreviation, but often capitalized]
DOE	Department of Energy (USA)
ACP	American Clean Power Association
PTC	Production Tax Credit
ITC	Investment Tax Credit
MNRE	Ministry of New and Renewable Energy (India)
MOEFCC	Ministry of Environment, Forest and Climate Change (India)
EU	European Union
EPR	Extended Producer Responsibility
LCA	Life Cycle Assessment
kPa	Kilopascal
°C	Degrees Celsius
W/m^2	Watts per Square Meter
W/m·K	Watts per Meter-Kelvin (Thermal Conductivity Unit)
mm	Millimeter
MPa	Megapascal
GFRP	Glass Fiber Reinforced Polymer
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mm	Millimeter
MPa	Megapascal

Chapter 1 : Introduction

1.1 Background and Problem Statement

Wind power has had an unprecedented rate of expansion during the last two decades, turning into one of the pillars supporting the global energy transition to renewables. In 2023, the world installed about 1 terawatt of wind farm capacity up 50% from the previous year. The rapid installation of wind farms implies that more and more wind turbines will soon be reaching the end of their lifespan. Wind turbines today typically last about 20–25 years (Iberdrola, 2025). When the first of the big wind farms reach retirement age, there is one huge challenge on the horizon: what to do with the wind turbine blades that must be decommissioned and removed. While the chair and other components basically steel and metal, easily recyclable, turbine blades and pillar is made of composite materials that cannot be recycled easily (Lozanova, 2022). They are primarily composed of glass fiber-reinforced polymer (GFRP) layers of fiberglass fabric incorporated into a thermoset resin e.g., epoxy and, on occasion, carbon fiber-reinforced polymer (CFRP) in more recent, longer blades for additional strength (Iberdrola, 2025). The thermoset plastics of such composites are not possible to melt and re-mold like in conventional materials, hence blades are not biodegradable and hard to process at the end-of-life. Therefore, many retired blades have for a long time found their way into landfills or have been incinerated, problems that are environmentally unsustainable (Lozanova, 2022). This waste pending issue only came into wide public interest in recent times since the scope of retired blades is shortly going to surge immensely in the future years.

The magnitude of the waste issue of the wind turbine blade grows more apparent with industry reports and research studies. A typical modern 2 MW wind turbine using three 50-meter blades possesses approximately 20 tonnes of composites in their blades, the larger 8 MW machines contain approximately 80 tonnes in the blades (Bank, L. et al., 2017). Exaggerated when spread over the thousands of wind turbines installed all over the world, these statistics translate into huge quantities of material that will have to be thrown away one day. Estimates point to hundreds of thousands of wind turbines being retired by 2030. Across Europe alone, over 34,000 wind turbines or around 100,000 blades will require retirement by the year 2030 (Transparency Market Research, 2025). Globally, the production of waste blades per annum is estimated to grow from about 100,000 tonnes in 2025 to over 200,000 tonnes per annum by the next decade (Deeney et al., 2025). Altogether, the waste fiberglass in decommissioned blades is estimated to total over 2.5 million tonnes by the year 2050 based on recent trends (Transparency Market Research, 2025). Other scientists even predict yet higher figures under hostile growth conditions, estimated that 4.2 million tonnes of composite blade material will need to be disposed of by 2035, rising to 16.3 million tonnes by 2055 if wind turbine installations remain at present levels (Bank, L. C. et al., 2017). Though specific estimates vary, all predict a radical escalation of blade waste over the next couple of decades. This is an enormous waste disposal problem on an international scale. Scale landfilling of blades is beginning to be seen as non-sustainable on a large scale many landfill operators do not want the bulky, difficult to store blades, and governments like the EU are moving towards banning or restricting landfilling of composite materials. Incineration is problematic as well, as burning fiberglass-reinforced plastics can release toxic fumes into the air and only yields a one-time-use ash residue. Evidently, innovative solutions have to be established to prevent an environmental crisis tied to aging wind infrastructure.

Researchers and industry categorize the end-of-life (EOL) options of wind turbine blades into three broad strategies disposal, material recovery, recycling and reuse (Bank, L. C. et al., 2017). Disposal through landfill or incineration has been the default for decades but is the least desired due to environmental harm and loss of material value. Recycling of blade materials such as shredding the composites for use as fillers or employing thermal/chemical processing to reclaim fibers has been researched, but recycling processes thus far do not prove to be economically and technically viable at scale. The heterogeneous mix of fiberglass, resins, foams, and glues in blades makes separation into high value recyclables difficult. Typically, recycling results in downcycling the fibers and resin are reduced in quality and can be utilized only for low-quality products, if at all (Lozanova, 2022). Moreover, thermal recycling and other such processes are energy intensive and can negate some of the environmental benefits. Because of these challenges, the third option is gaining growing attention, reuse of entire wind turbine blade sections for secondary applications often referred to as repurposing. Repurposing entails developing new uses for whole blades or large cut sections of blades, basically giving them a "second life" without grinding or throwing them away. This approach falls under circular economy concepts because it keeps the material in use for as long as possible in its initial form. Reuse is an appealing option since it avoids the environmental effects of disposal and bypasses the large expense of recycling technology (Bank, L. C. et al., 2017). Provided that viable reuse applications can be established, a substantial volume of blade material can be diverted from landfill and used for beneficial purpose, avoiding waste and resource concerns at the same time.

In the last decade, innovative global projects have had several innovative reuse options for used wind turbine blades. An international community of scientists called The Re-Wind Network has pioneered methodically exploring blade recycling possibilities. Their work and other research projects have proven that such strong, weather-resistant composite structures can be repurposed for use in civil infrastructure, architecture, and public utilities. For example, already, there are instances of discarded wind blades being used to construct playgrounds, footbridges, and even buildings. In the Netherlands, retired end-of-life turbine blades were reused as quirky playground equipment such as tunnel slides and climbing towers, utilizing the curved forms of the blades. In Denmark, they have blades that are repurposed as trendy bike shelters, providing bike parking shelter facilities in cities. Polish engineers built the world's first-ever pedestrian bridge made of old wind turbine blades in 2021 the 5-meter-long "Blade Bridge" uses two retired blades as the main supporting girders, and it rightly opened to the public after rigorous safety testing. Similarly, in Ireland, old blades have been incorporated into structural elements of a new pedestrian bridge on a greenway trail. Aside from bridges, companies have incorporated blades as street furniture and artworks – for instance, blades have been molded into benches and public art, exemplifying aesthetic recycling that also triggers civic debate around sustainability (Lozanova, 2022). One such creation is depicted in Figure 1 below, where an architectural footbridge design is supported by wind turbine blade components instead of conventional steel beams,

Figure 1: A concept design of a pedestrian footbridge (“BladeBridge”) repurposing decommissioned wind turbine blades as structural supports. Such designs demonstrate the potential of reusing composite blades in civil infrastructure (Lozanova, 2022).

These are instances that point to the reality that wind turbine blades, which are wastage in one environment, are valuable assets in another. The blades consist of high strength fiber composites and aerodynamic profiles, and were originally created to withstand hostile wind, weather and fatigue for decades. Even after 20 years of service, much of a blade's structural integrity remains intact. Their strength and light hollow structure render them appropriate for construction applications where long, prefabricated load carrying elements are beneficial. Indeed, recycled blade sections have been demonstrated to work in bridge applications with a predicted lifespan of more than a century. Researchers are studying cutting blades into sections to utilize as components in affordable housing for example, using blade pieces as roof trusses, building walls, or roofing panels for small homes. (Bank, L. C. et al., 2017) proposed that decommissioned blade parts may be donated or sold at affordable prices to poor families for building homes, adding that this could be especially valuable in areas prone to harsh weather conditions since blades are designed to resist strong winds and moisture (Lozanova, 2022). In one such experiment, Sandia National Labs prototype 100-meter wind turbine blade was used to illustrate how a single blade can be split into multiple sections, which can be employed for different architectural functionalities in a building or infrastructure project. For instance, studies envisioned blade sections as prefabricated lengths of roofs and footbridge girders reusing the aerodynamic hull of the blade as a supporting arch (Bank, L. C. et al., 2017; Bank, L. C. et al., 2017). All these innovative projects and workshop prototypes refer to a new paradigm, treating retired wind turbine blades not as landfill waste, but as a resource of raw material for sustainable design and construction.

Although promising is the record of blade repurposing projects, this technique is still in its infancy and is plagued by technical and logistical problems. Every reuse application needs to ensure that the blade or piece of blade is capable of safely meeting the engineering requirements of its new application whether structural loads for a bridge or environmental exposure for a building envelope. Retraining blades for recycling is generally a matter of creative design solutions and certification, since they were not originally created for such new loads and structures. Other practical considerations are also involved, such as shipping huge blades from wind farms to recycling sites, effective cutting and alteration, and getting around building code certification for nonconventional materials. But demand for repurposing blades continues to increase as part of a broader effort to advance a circular economy in the wind industry. By addressing the waste blade problem through innovative reuse, the wind industry can improve its overall sustainability track record and avoid undoing some of the greenhouse gas savings from wind energy through a waste footprint. This study is set against this context of exploring channels of reuse for wind turbine blades, with particular focus on applications unique to the state of Kerala, India. Kerala is a coastal state which, while not yet a major wind-power producer, has gigantic sustainability and infrastructure needs that can be met through reused material. The above context defines the global problem statement, the rapid growth of wind power has led to a future waste problem from GFRP turbine blades, and the urgency now is that there is an urgent need for viable solutions such as recycling or reuse to prevent a mountain of composite waste in the coming decades. The repurposing of decommissioned wind blades thus presents an attractive solution that addresses not only the waste and environmental issues but also offers benefits to society by providing support for new construction and development projects. Using examples from other parts of the world, this research will examine how the reuse of wind turbine blades can be effectively applied in the context of Kerala to address the dual problem of waste management and sustainable development.

Figure 2: Decommissioned wind turbine blades stacked at a wind farm, awaiting processing. As thousands of aging turbines are retired, large stockpiles of discarded blades are becoming a common sight, underscoring the urgent need for sustainable end-of-life solutions (Lozanova, 2022).

1.2 Research Aim and Objectives

1.2.1 Research Aim

The primary aim of this research is to investigate the feasibility of reusing decommissioned wind turbine blades in the construction of sustainable boat service waiting shelters in Kerala. The study integrates CAD-based architectural design, structural and thermal simulations, and a circular economy perspective to assess the viability of blade repurposing from technical, environmental, and economic standpoints.

1.2.2 Research Objectives

To achieve this aim, the study is guided by the following specific objectives:

- **Mechanical Feasibility**: To evaluate the structural adequacy of GFRP and CFRP wind turbine blades for architectural applications through literature review and simulation-based analysis using ANSYS.
- **Design Development**: To develop a functionally effective and aesthetically appropriate shelter design using SolidWorks CAD, utilizing the geometry and inherent strength of repurposed turbine blades.

- **Structural Performance Simulation**: To conduct static structural analysis in ANSYS to simulate environmental loading conditions (e.g., wind, gravity), assessing resulting deformation, stress distribution, and safety margins.
- **Thermal Analysis**: To perform steady-state thermal simulations in ANSYS to analyze the thermal response of the shelter under prolonged solar exposure typical of Kerala's climate.
- **Circular Economy Framework**: To contextualize the findings within circular economy principles and propose a preliminary framework for scaling such repurposing strategies in infrastructure development.

1.3 Research Questions

The investigation is structured around the following core research questions:

1. Can decommissioned wind turbine blades provide sufficient structural performance for use in boat waiting shelters?
2. How does blade repurposing compare to traditional disposal methods in terms of environmental sustainability?
3. What are the economic implications of using repurposed blades versus conventional construction materials?
4. What design and policy interventions are necessary to enable the adoption of blade repurposing in infrastructure projects?

1.4 Significance of the Study

This study operates at the intersection of sustainable engineering, circular economy, and resilient public infrastructure design. By exploring the reuse of wind turbine blades—particularly those made of GFRP and CFRP it addresses a growing environmental concern: the end-of-life management of composite materials in the renewable energy sector.

The research provides a novel approach to waste valorization by demonstrating how decommissioned blades can be repurposed into essential infrastructure components, such as boat shelters, thereby reducing the environmental burden of disposal and supporting the sustainable transformation of public transport amenities.

Kerala is chosen as the case study location due to its heavy reliance on water-based transportation, tropical climate conditions, and the need for durable, cost-effective public infrastructure. This contextual relevance enhances the practical applicability of the findings. The outcomes are expected to inform policymakers, urban planners, and sustainability stakeholders by offering actionable insights that support the integration of repurposed composite materials into mainstream infrastructural development. If successful, the strategy could be adapted and scaled globally to address similar challenges in composite waste management and infrastructure sustainability.

Chapter 2 : Literature Review

2.1 Composition and Structure of Wind Turbine Blades

Wind turbine blades are high-performance composite structures intended to maximize strength, stiffness, and fatigue life at reduced weight. Modern utility-scale blades of 40–80 m length is predominantly made of glass fiber-reinforced polymer (GFRP) composites with a small amount of carbon fiber reinforcement in larger or newer blades. Normally, each blade consists of an aerodynamic air foil shaped shell and inner stiffening components spar caps, shear webs, all constructed from fabric fibers impregnated with a thermoset resin normally epoxy or polyester. A typical mass composition of a fiberglass wind turbine blade is approximately 60% glass fiber fabric and 32% polymer resin, and the remaining weight is comprised of light core materials like 2–3% balsa wood or foam in sandwich panels, adhesives, paint, and small quantities of metal for inserts or lightning protection (Bank, L. C., 2016). The E-glass or equivalent fiberglass fabric provides the primary tension and compression strength along the blade, whereas the resin matrix keeps the fibers in place and distributes shear stresses. Most blades also incorporate segments of carbon fiber-reinforced polymer (CFRP), especially in the spar caps or root, to provide stiffness with no weight penalty carbon fiber is stiffer than glass fiber, so the blade can be longer or lighter for the same deflection limits. Carbon usage, however, is more costly and will typically be encountered in lengths of blades over ~60 m in length or in top-end turbine versions.

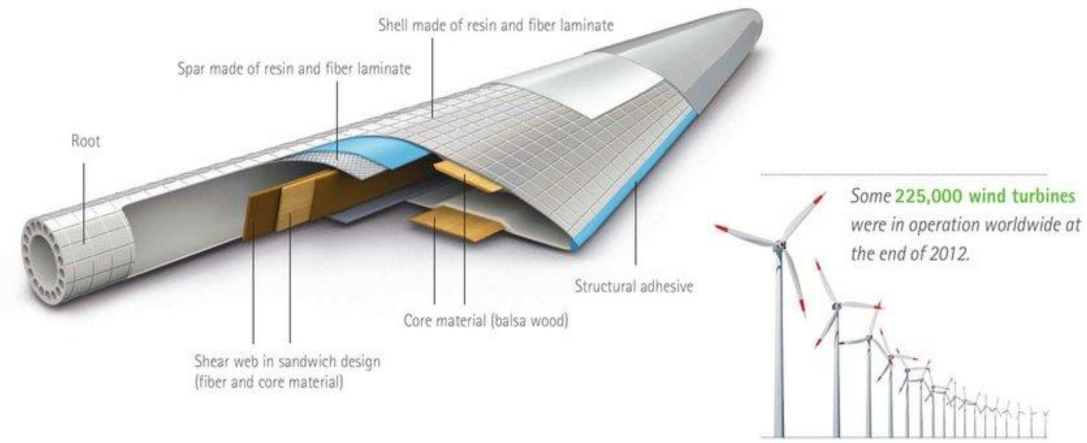

Figure 3: Anatomy of Typical Wind Turbine Blade (Bank, L. C., 2016).

Structurally, the wind blades are similar to airplane wings or boat hulls, made by composite lamination processes hand layup, vacuum assisted resin infusion, etc. The outer casing is usually a sandwich construction fiberglass skins with balsa wood or

PVC foam core sandwiched between for higher bending stiffness. The interior is composed of one or two significant longitudinal girders called shear webs and spar caps, which bear flap wise bending loads. These internal parts are also made up of thick laminates of GFRP or CFRP typically with pultruded fiber tapes. Blade root the round piece which is bolted on the hub contains a metal insert ring or a flange for bolting, but otherwise the blade itself is primarily fiber composite. Because of the material composition of this, wind turbine blades fall under the waste class of FRP composite in end-of-life a class that is difficult to recycle. In contrast to homogeneous metal, fibers and resin are not separately distinguishable and are strongly bonded without special processing, and thermoset resin remelting is impossible. Its inherent chemical stability and built-in durability during its working life become a drawback in disposal, as conventional recycling streams are poorly equipped to dispose of such composite parts (Brandon, 2022). Secondly, blades are very heavy each 10–25 tons for utility turbines and cone-shaped, becoming difficult to deal with and process. Thus, understanding the blade material composition is a step towards evaluating recycling or reuse possibilities the high glass fiber content offers potential strength for structural reuse, and the trapped energy and materials promote recycling, if possible.

2.2 Recycling Challenges and Current End-of-Life Practices

The end-of-life management of wind turbine blades poses a complex challenge due to their composite material structure. Mechanical recycling, thermal processing, and co-processing in cement plants have emerged as the primary categories of techniques for dealing with decommissioned blades, but each comes with technical and economic limitations. As a result, a large portion of blades have historically been landfilled, prompting regulatory moves especially in Europe to restrict this practice (ACP, 2025). This section reviews the major recycling and disposal methods currently in use or development.

2.2.1 Mechanical Recycling

Mechanical recycling involves cutting and shredding the composite blades into smaller pieces to utilize as secondary raw material. Practically, this means employing heavy machinery diamond wire saws, large carbide-tipped saw blades, shredders, etc. to fragment a blade into useful pieces or fibrous granulate (Gignac, J et al., 2020). The product is a mix of fiberglass short fiber lengths in cured resin, popularly known as glass fiber reinforced plastic (GFRP) chips or powder. The main advantage of mechanical recycling is that it is easy and does not require high energy consumption like thermal or chemical processes. The shredding blade material can potentially be used as filler in construction cement, concrete, or asphalt production, or as reinforcement for new composite products (Sorte et al., 2023). For example, research in Europe and the US has tested ground blade fiberglass as a concrete additive to improve cracking resistance or to manufacture composite boards and pallets (Strong, 2024). The uniform homogeneity of the granulate with both fiber and resin can have merits in certain applications since it provides bulk material of moderate strength (Sorte et al., 2023). Mechanical recycling has several important limitations, blades cutting and grinding is a difficult and costly process due to the toughness of the material and equipment wear (Gignac, J et al., 2020). In addition, the output quality is relatively poor the fibers are short and coated with resin, which lowers their reinforcement potential when compared to virgin fibers. GFRP cutting emissions and dust also pose occupational health concerns fiberglass dust is hazardous when inhaled (Sorte et al., 2023). To date, large-scale mechanical blade recycling has been attempted by few companies, and some e.g. Global Fiberglass Solutions in the US suffered from logistical and economic issues and wound up accumulating blades rather than recycling them (Strong, 2024). Even so, mechanical processing remains a necessary first step in most mixed recycling processes even when thermal or chemical treatments are planned, blades typically must first be pre-cut into manageable sections for transportation.

2.2.2 Thermal Recycling

Thermal recycling processes are intended to reclaim the fibers and in certain instances energy by heating the composite to break down the resin. Pyrolysis is a very studied process, it is where chopped fragments of blades are heated in an oxygen deprived environment to around 450–600 °C, which breaks down the organic resin to char, oil and gas and liberates the glass or carbon fibers. The pyrolysis benefit is that the resin matrix is stripped out, but not the inorganic fibers. Ideally, the regained glass fibers could now be reused and recycled as input for fresh composite materials, while the pyrolysis gas and oil could be employed as fuels and sometimes even utilize self-sustained heating. Pyrolysis has already proved to be useful on pilot-scale for FRP waste including wind blades, i.e., they have shown in studies that the glass fibers could be recovered leaving behind a minute residue if, for example, carried out in an inert atmosphere e.g. nitrogen to avoid oxidation. However, there are quite significant challenges: the high temperature degrades fiber properties glass fibers can suffer loss of strength, carbon fibers have retained strength at a higher extent but are already more costly. It also requires enormous energy input to maintain heating, unless recovery of energy from the gas is effectively carried out (Sorte et al., 2023). Another issue is managing the char and emissions partial resin breakdown deposits carbonaceous char on fibers that must be cleaned, and air emissions must be scrubbed. Microwave pyrolysis has emerged as an alternative that volumetrically and potentially more efficiently heats the material, initial research including efforts in India (Gautamee Hazarika, 2022) suggests it might be worth considering for large quantities of blade waste. Besides pyrolysis, thermal technology includes fluidized bed combustion of ground composites being fed into a hot fluidized sand bed, combusting out the resin and cleaning out the fibers and gasification. There has been some success reported with fluidized bed operations when recycling clean glass fibers with low energy levels, and it was proven in test laboratories on a scale within the UK. In general, thermally recycling can technologically reclaim blades and reduce the volume of waste yet recovered fiber quality is generally affected in glass fibers, for example, pyrolysis can decrease strength, so that reuse is limited to non-structural applications (Sorte et al., 2023). Carbon fibers endure better and so there is more economic incentive to pyrolyze CFRP. Pyrolysis of GFRP blades is economically viable only if the produced fuel or fibers are monetized. Pyrolysis of FRP waste is currently not carried out in many commercial plants, e.g. in France and Germany, and plenty of research is underway to optimize such processes (Leon, 2023).

2.2.3 Co-Processing in Cement Kilns

A practical solution that is increasingly being adopted, especially in Europe, is to use chopped wind turbine blades as feedstock for cement manufacturing. The process, which is often simply called co-processing, involves feeding blades cut into lengths (~1–2 m long) into cement kilns, where the organic resin is combusted as fuel and the mineral fiber silica and calcium in the fiberglass and fillers is mixed into the clinker cement product. In effect, the entire blade is utilized for energy and material recovery, the calorific value of the resin replaces fossil fuel, while the glass fiber and any calcium carbonate fillers are used as raw material in cement chemistry (Novak, 2023). Several cement companies e.g. Holcim/Geocycle, Veolia in collaboration with GE have run or tested this route. Co-processing has been favored as cement kilns are at very high temperature (~1400 °C) with guaranteed complete combustion of organics and no hazardous fiberglass residue the glass melts into the clinker. Importantly, co-processing avoids residual waste it is thus considered a form of recycling by the European industry since the blade material is incorporated into a new product cement rather than landfilled. The procedure is also relatively straightforward to scale because it utilizes already existing cement infrastructure. For instance, in Germany and Austria, tens of thousands of tons of FRP waste from blades as well as other sources have been co-processed in cement factories per year as a short-term solution while recycling is enhanced. The negative aspect is that fibers are not recycled to be used again as fibers they are effectively downcycled to an inert element in cement. It is debatable for some environmentalists to call this true recycling or merely energy recovery. Nevertheless, from a landfill diversion perspective, cement co-processing does the job and is among the only economically viable options for enormous quantities of blade waste. The American Clean Power Association notes that several European countries are phasing out blade landfilling for co-processing or other forms of recycling and even U.S. states are considering forcing manufacturers to utilize such solutions (ACP, 2025). An example is GE Renewable Energy's partnership with Veolia, they initiated recycling GE's aged-out blades from US wind farms in cement kilns, recycling 90% of the blade material by weight, according to this process (Energy.gov, 2025; Mitch Jacoby, 2022). Coprocessing is thus a practical bridge strategy it addresses the growing waste inventory directly with today's technology, giving breathing room for more advanced recycling or reuse advances to come online.

In summary, the current state of wind blade EoL practices is as follows continued landfilling where it is not prohibited still the lowest near-term cost but increasing regulatory and social opposition on sustainability grounds, mechanical shredding and use as low-value filler, thermal recycling (pyrolysis/gasification) to recover fibers and energy, and cement kiln co-processing as a recycling/disposal hybrid. There are limitations to each with respect to transitioning to a fully circular approach. This reality has been driving the investigation into not just recycling but also repurposing wind blades, in which the material in whole form is reused in a new application, as discussed below.

2.3 Repurposing Decommissioned Blades: Projects and Applications

Given the difficulties of true recycling, reuse of entire or significant amounts of wind turbine blades for second-life applications has been considered a preferable option in the waste hierarchy to shredding or landfilling. Repurposing is the reuse of the blade or part thereof for other sectors or infrastructure, thus upcycling the high-performance composite for further use. This process utilizes the significant residual strength and longevity of blades beyond their design life. Over the past several years, several pathfinder projects and research papers have successfully demonstrated the reuse of retired wind blades in civil engineering, architecture and public works. This section highlights some prominent examples, including the Blade Made project, the Re-Wind Network schemes, and some other innovative reuse applications such as pedestrian walkways and shelters.

2.3.1 Blade Made (Superuse Studios) – Urban Furniture and Playgrounds

One such early experiment in blade reuse has been led by Superuse Studios in the Netherlands formerly 2012 Architects, who launched the "Blade Made" initiative. Since the mid-2000s, this team has been salvaging end-of-life wind turbine blades and transforming them into functional public infrastructure and art installations. By 2021, Blade Made had recycled 25 blades in the Netherlands, turning them into playground equipment, benches, and bus stop shelters. For example, wind blade parts have been turned into brightly colored children's slides and climbing frames in a Rotterdam playground a visible use that also helps to promote awareness of renewable energy and recycling. In Almere city, the Blade Made company designed a line of bus stops from four 30-meter turbine blades, two blades were set vertically in a bent "Stonehenge" fashion to support a roof made of two other blades, forming a solid and nearly unbreakable canopy for commuters (Menezes, 2022). All these uses refer to several advantages of blade recycling. First, the structural properties of blades strength, stiffness render them suitable as load-carrying members for small-scale architectural structures. Second, the aerodynamic shape of the blades provides a pre-existing design aesthetic i.e., a blade cross-section can be employed as a prefabricated curved roof or canopy. Superuse Studios observes that this recycling saves 90% in CO_2 emissions compared to the manufacture of new equivalent entities, and interestingly, does not exclude eventual recycling further down the line should technologies improve. The idea is that by giving blades a second life for 10–20 years as furniture or shelters, we delay their entry into the waste stream, during which time better recycling options can be devised. The Blade Made project has proven that small-scale architectural reuse is feasible and can be replicated, they are already looking to apply similar projects in countries like France and Germany where wind turbines on a large scale will soon be decommissioned (Menezes, 2022).

Figure 4 - Children's playground using wind turbine blade slides, Rotterdam (Menezes, 2022)

2.3.2 Re-Wind Network – Structural Applications (Bridges, Barriers, Poles)

The Re-Wind Network is a group of US, Irish, and Northern Irish universities that focuses exclusively on reusing wind blades for civil infrastructure. They have created over 50 designs that range from using blade pieces as poles for power transmission, as sound barriers along highways, as material for coastal boardwalks, to flood protection barriers (Brandon, 2022). Two of the most notable success stories of Re-Wind are the effective installation of pedestrian footbridges manufactured from decommissioned blades. In late 2021, a Polish firm Anmet in partnership with Re-Wind built the world's very first bridge constructed from outdated wind turbine blades in Szprotawa, Poland. This was followed by the successful installation of a second such bridge in County Cork, Ireland in 2022 by the Re-Wind Network, termed the "BladeBridge" (designboom, 2022). The Cork BladeBridge uses two 13.4 m long blade sections as the main load-carrying girders spanning a small river roughly a 5 m span (Brandon, 2022). A deck and steel frame are laid across the inverted blade sections, which act like steel I-beams in an ordinary bridge except these beams are pre-curved and were originally conceived as turbine blades. Engineers reported that the blade based bridge achieved required strength and deflection criteria and even provided a lower carbon footprint of around 20% less CO_2 emissions during manufacturing than an equivalent steel bridge (Smart, 2023). These bridge applications demonstrate the viability of blades in load-bearing structural uses. They made extensive engineering analysis material testing of the GFRP's residual properties, structural analysis of blade cross-sections under new load directions, and connection design to splice the blade segments to steel or concrete members (Brandon, 2022). These bridges success has been a proof of concept that could be translated to longer spans or to other types of bridges e.g. pedestrian bridges spanning highways, small vehicle bridges in rural areas. Aside from bridges, Re-Wind has also designed the application of blade sections for utility poles as an alternative to wood poles for electrical lines and found that a section of a large turbine blade, if stood upright and anchored correctly, can meet the loading requirements of a distribution line pole or telecom tower with the benefit of being rot-resistant and non-conductive. Other groups have investigated the utilization of blade halves as roofs or walls for storage sheds, shelters, or even low-income housing units. (Bank, L. C. et al., 2017) for instance, presented concepts for cutting a 100 m blade into segments that form the roof trusses and wall supports for a low-income housing concept in a hurricane-prone coastal region. The blade sections natural curved shape lent themselves to shedding water and resisting wind loads, demonstrating the way blade reuse can be applied directly to meet infrastructure needs under challenging conditions.

Figure 5 - BladeBridge in Poland using 13m blade sections as beams (Brandon, 2022)

2.3.3 Other Creative Reuse Projects:

Aside from the above, many creative one-off projects have been accomplished worldwide. In Denmark, parts of the old blades have been reused as stylish bike shelter parking and art, merging functionality with public art. In Ireland, a firm has proposed utilizing blade tips to construct floating pontoons for solar panel platforms on water bodies (Brandon, 2022), basically creating solar islands out of recycled wind components. Another concept is the use of blade sections as a component of retaining walls or piles of foundation using the tubular hollow form as formwork (Halicka et al., 2024) examined it on small geotechnical structures and saw it promising for certain applications in civil engineering (Łukasz Jabłoński, 2025). The above examples summarize the key idea, wind turbine blades, upon retirement, still constitute valuable engineering material. They are high performance composites which are expensive to produce, thus finding an alternative use spares them and also exploits their residual value. The most significant challenges to repurposing include logistics assembling and hauling large blades to a site where they can be reused, cut-off or redesign cutting or redesigning blade sections for new uses and certification or safety approval of their new use especially for structural purposes, to meet code requirements. Despite this, the greater number of demonstration projects set up an example for a larger blade repurposing. Initiatives like Blade Made and Re-Wind also stress the importance of inter-sectorial partnerships where architects, engineers, local governments and industry allies unite to uncover opportunities and make blade reuse initiatives benefitting the community.

2.4 Circular Economy and Sustainability Policies Supporting Reuse

The impetus to address wind turbine blade waste is also firmly aligned with broader circular economy principles and sustainability policies globally. In a circular economy, the aim is to keep materials in use for as long as possible, extract maximum value from them and recover or regenerate products at end of life. Wind turbine blades present a test case for these principles because they are large composite products that had no clear end-of-life pathway traditionally. Policymakers and industry associations have started to define strategies and aspirations to ensure the growth of wind energy does not leave an insupportable problem of waste.

In Europe, the issue of blade waste is being addressed aggressively by voluntary industry agreements and regulatory intervention. The European wind industry through associations like WindEurope has pledged that by 2025, 100% of end-of-life wind turbine blades will be recovered through recycling, reuse or energy recovery and not proceed to uncontrolled disposal (Iberdrola, 2025). This ambitious pledge has been succeeded by calls for a pan-EU landfill ban on composite blades by 2025, effectively forcing recycling and reuse solutions (ACP, 2025; Frangoul, 2021). Some EU countries have indeed announced forthcoming landfill bans for FRP waste: for example, Germany and the Netherlands have set deadlines mid-2020s after which blades may no longer be landfilled (ACP, 2025). These policies create a strong incentive for recycling infrastructure and repurposing markets. In addition, the EU Circular Economy Action Plan 2020 prioritizes designing for sustainability and improving waste management of high-value materials, this has spurred research funding for recyclable blade materials like thermoplastic resin systems and better EoL handling. An example of this is France's ZEBRA project, which in 2022 developed a 100% recyclable blade using thermoplastic resin as a model for the blades of the future (Royal Academy of Engineering, 2022). That is for new blades, but for the ones that already exist the EU is considering Extended Producer Responsibility (EPR) schemes. EPR would hold wind turbine manufacturers financially and/or logistically accountable for the disposal of blades they've sold, with a inherent incentive to find recycling or reuse solutions (ACP, 2025). The approach has precedent in Europe's e-waste and battery directives and could be applied to renewable energy equipment. Sustainability policies at the EU level also encourage innovation in composite recycling EU Horizon programs, for instance, have funded projects on blade recycling techniques and reuse of the "LIFE" program has one on blade recycling to cement. In general, Europe's policy environment is strongly directed towards zero-waste wind power, with a mix of industry commitment and policy pushing circular practices.

In the United States, policy is comparatively behind Europe but is currently catching up. Federal prohibition on blade disposal in landfills has yet to occur, and retired blades from the past decade have ended up in places like the Casper, Wyoming landfill, gaining media attention when images of blade graveyards surfaced (2024). Greater awareness has followed, and some states have introduced bills to deter landfill disposal. For example, Kansas and North Dakota proposed but not yet adopted measures that wind farm operators are required to recycle blades as part of a plan or to pay for a disposal bond (ACP, 2025). Nationally, the U.S. Department of Energy has responded through research and funding. In 2022 the Bipartisan Infrastructure Law supported a Wind Turbine Recycling R&D program, and in 2025 the DOE published a report stating that current U.S. infrastructure could handle 90% of the weight of retired wind turbines with a call for innovation for the remaining 10% primarily blades (Energy.gov, 2025). That shows an intention to close the gap for recycling blades. Additionally, the DOE's Advanced Materials and Manufacturing Office and ARPA-E have sponsored research in chemical recycling of composite materials and blade construction with thermoplastics. The U.S. industry is also voluntary ramping up, GE, a leading turbine blade manufacturer, established a goal of zero waste blade production by 2030 and partnerships to recycle blades through cement co-processing (Prachi Patel, 2024). The American Clean Power Association (ACP) published a 2021 white paper on blade EoL strategies and explicitly stating that many U.S. states are contemplating take-back requirements or landfill bans (ACP, 2025). While these regulations are not as strict as in Europe yet, the trend is towards more responsibility for manufacturers and developers to recycle blade waste sustainably.

In India, the industry remains nascent most of the turbines are still not end-of-life, yet it is making positive steps forward. In 2022, a private member's bill named the Wind Turbine and Solar Energy Waste Handling, Disposal and Recycling Bill was moved in the Indian Parliament. This pending bill would establish rules and responsibilities for proper disposal and recycling of waste from renewable energy equipment, including wind turbine blades, and prohibit haphazard dumping. The bill indicates a policy-level awareness that renewable energy waste will soon be a problem. Although that bill is not yet a law, its introduction has generated discussions on how to develop recycling centers and national standards for the decommissioning of wind turbines. India's Ministry of New and Renewable Energy (MNRE) has also focused on sustainability in renewables for instance, by incorporating end-of-life management as part of its quality control guidelines. In addition, Indian scientists have begun researching local solutions, e.g. an IIT Mandi project on microwave-based pyrolysis of FRP waste for fiber recovery (Gautamee Hazarika, 2022). On the policy front, India can leverage current waste management policy like e-waste or plastic waste to import wind turbine components into a structured recycling program. With India projected to become one of the largest wind markets with 140 GW onshore targets by 2030, seeing this growth happen in line with circular economy principles is increasingly pertinent.

More broadly, international sustainability systems like the UN Sustainable Development Goals (SDGs) also incentivize these practices, SDG 12 promotes sustainable consumption and production, under which extending the lifecycle of renewable energy technology falls. Recycling and reusing blades helps the wind industry reduce its footprint SDG 13 on climate action is incentivized by clean energy production but also by minimizing waste and emissions in that sector. Life-cycle assessment (LCA) studies have also begun to quantify the benefits, redeployment of blade uses typically have clear net carbon emission savings and material consumption compared with constructing equivalent structures with new material (Smart, 2023). This further adds to the policy case for promoting reuse as being beneficial. Briefly, an evolving landscape of policies, regulations, and voluntary initiatives at the EU, US, and Indian levels and elsewhere is becoming more supportive of wind blade reuse and improved EoL management. These initiatives provide the crucial financial, legal, and technical backing to projects that will reuse blades in infrastructure as they help navigate the passage of economic hurdles and transmit messages to stakeholders that such measures are a priority with respect to sustainable development.

2.5 Regulatory Frameworks and Waste Management Policy Development

As the previous section hinted, regulatory frameworks are being rapidly put in place to control wind turbine blade waste. Here we summarize some specific policy developments and their implications for blade recycling.

In the European Union, waste policy is governed in the Waste Framework Directive, which places prevention, reuse, and recycling ahead of disposal. The regulatory precedents have already been set by several EU member states. Germany, for example, has classed glass fiber composites as non-landfillable in the medium term essentially, a landfill prohibition will be applicable for large composite structures as recycling capacity increases Germany already banned landfilling of organic-waste-rich waste, including resins. Austria and The Netherlands have also detailed timescales by which all GFRP waste will have to be channelled into co-processing or recycling. At an EU-wide scale, the suggested amendments to waste directives can incorporate composites from renewable energy into producer responsibility schemes. If implemented, turbine producers and wind farm operators in Europe would be obligated to ensure blades are treated appropriately at EoL either through take-back schemes or financing recycling plants (ACP, 2025). This kind of regulation would be a turn-around for re-use, involving the manufacturers would enable provision of retired blades to re-use initiatives rather than keeping them as liability to be disposed of at low expense. Furthermore, European building codes and standards are also being researched to accommodate secondary materials. For instance, Eurocode for building or bridge design can be amended or supplemented with annexes to incorporate structures made of recycled FRP blades so that engineers can design the same with assurance of their compliance with the code. Some pilot projects in the EU involve certifying parts of blades as construction products perhaps as recycled FRP profiles within the Construction Products Regulation, which would render it legally acceptable to incorporate them into buildings or civil engineering works.

In the United States, while national action lags, state-level action is significant. In Iowa, after the discovery of blade stockpiling as exemplified with Global Fiberglass Solutions' abandoned blades, the state's attorney general and utility regulators pressed for cleanup, effectively setting the precedent that companies cannot simply leave blades without remediation (Strong, 2021). Other wind-fleet states, including Texas and California, are considering regulatory direction, California's recycling rigor ethos present in electronics and autos might eventually extend to renewables too. In the absence of a national imperative, economics currently reign supreme: if landfill tipping fees are minimal, there is no compelling economic incentive for recycling. That said, if multiple large wind states mandate EoL blade approaches, wind farm owners across the country will likely implement practices nationwide to reduce compliance burden. The U.S. EPA has also started dealing with composite waste in discussions around increasing recycling rates. One interesting development is the concept of offering renewable energy credits or incentives for recycling/reuse i.e., tying it in with renewable energy policy. For example, a multi-year Production Tax Credit (PTC) or Investment Tax Credit (ITC) for wind could include a decommissioning provision to get the full credit properly. While not legislated, such policy levers could indirectly force more accountable blade disposal. On the waste designation side, fiberglass blades are generally non-hazardous, which makes them regulated under state solid waste law. Other states can redesignate large composite waste as a separate class requiring special handling in the same manner that tires or appliances are handled. These regulatory changes will affect the feasibility and profitability of blade repurposing projects stronger regulations against landfill and in favor of reuse will make projects in states like Kerala that can source blades from abroad or use local ones more viable as supply of blades for reuse will be improved and even potentially come with economic incentives if companies are willing to give away old blades to avoid disposal costs or penalties.

In India, as noted, there is a primitive formal regulatory framework. The 2022 bill, if passed, would create a Central Board for prevention and control of wind/solar waste, mandate manufacturing firms to set up collection centers, and prohibit dumping blades in open areas. Although at the time of writing this book bill status is uncertain, it reflects the direction of regulatory thinking. Further, India's Solid Waste Management Rules (2016) and Plastic Waste Rules could be extended to FRP composites. Directions can be provided by the Ministry of Environment, Forest and Climate Change (MOEFCC) under the Environment Protection Act for bulk composite waste to be dealt with in the same way as construction & demolition (C&D) waste, which must be disposed through C&D recycling plants in certain urban cities. Since there are no existing large blade waste volumes, Indian regulators have an opportunity to lead the way in setting such guidelines. For Kerala specifically, state governments can develop demonstration regulations for example, Kerala can allow the reuse of second-hand materials like wind blades in public infrastructure under regulation, paving the way for pilot projects. One of the main domains will be standards in buildings, the use of blades in buildings will have to find local building codes welcoming these as safe. This could be a single-instance approach or coming up with a standard spec for Blade Material Structural Use through bodies like the Indian Roads Congress if used in bridges or Bureau of Indian Standards.

Overall, regulatory developments increasingly favor sustainable blade management. This regulatory momentum not only makes control of the waste problem easier but also encourages innovation and investment in repurposing solutions. It is probable that firms will invest in blade repurposing R&D or engage in activities like donating blades for a jetty prototype in Kerala if they are able to be sure that landfilling is out of the question or will be costly. In the same way, the governments are becoming more inclined towards considering the waste of blades as a means of generating employment in recycling firms, to global leadership in research, and in modernizing public infrastructures. In general, the policy trend could be encapsulated in moving from end-of-life as the linear perspective dispose at towards end-of-life as the start of next life compatible with universal sustainability goals.

2.6 Prior Studies on Infrastructure Repurposing in Coastal/Humid Climates

Particular focus of this dissertation is an application of recycle wind blades for coastal, damp climates such as that of Kerala. It is therefore necessary to address prior knowledge and evidence from research on the behavior of FRP (fiber-reinforced polymer) products, especially that of wind blade origin, within such climates, and what technical problems arise from it. Coastal and tropical areas are challenging conditions that include excessive humidity, dense rain, water or air salinity, high UV radiation, and in others, high wind speeds (cyclones/hurricanes) all of which must be endured by infrastructure. Incidentally, these are precisely the conditions on which wind turbine blades are uniquely made to hold up other than salinity to a lesser extent, save offshore. There is some research that has pointed to the advantages of composite materials in coastal and wet climates. FRP will not rust, as it does not do steel; nor rot or get termite-eaten, as it does not do wood. This makes redundant blades a viable choice to employ in such areas as Kerala, which has a tropical monsoon climate and coastal saline environment in most places.

(Bank, L. C. et al., 2017) did not even remotely suggest their conclusion that large segments of FRPs from wind blades perfectly fit infrastructure that must resist extreme conditions with water and humidity, considering their non-corrosive and durable nature. In the Yucatan coastal area designs, which are hurricane-prone, they used the above characteristics a roof made of blade sections would not rot in salty, damp air like corrugated metal sheets would. Another study by (Ammar Alshannaq et al., 2019) tested samples of wind turbine blade material for sheet piling to be exposed under a simulated shoreline test and found there to be high moisture resistance as well as satisfactory structural durability with time. Also, the durability of 20+ year cyclic wind load optimized blades means that after their first lifecycle they have residual fatigue life that is able to cope with cyclical loads like waves or cyclical usage as a footbridge without significant loss of strength.

Nevertheless, some thoughts are due, UV radiation will induce surface degradation resin chalking over tens of years, and therefore, if blade pieces are used in an exposed structure e.g., roof or pedestrian bridge, a UV-protective coating or paint should be used to prolong their lifespan. Blades generally already have gelcoat or coatings for UV protection in service, these can be sufficient or can be refurbished. Water absorption of the composite is low usually GFRP contains <1% water absorption, but bolt holes or cut edges must be sealed to keep out water that might lead to freeze-thaw damage or swelling of the fibers. There has been some work carried out on biofouling and salt spray impacts on composites for marine use as composites are employed in boat hulls, this information carries over. It shows that GFRP retains strength quite well in seawater, losing properties only very slightly after long-term immersion, mainly affecting the resin instead of the glass fibers. This suggests that if, for instance, a blade is utilized as a floating pontoon or a jetty fender in permanent water application, it will at least perform as well as conventional FRP marine structures.

Certain projects have also specifically tried blade reuse in coastal areas. A blade was positioned as part of a pedestrian boardwalk along a beach in France, demonstrating that even under conditions of salt air and occasional submersion, the blade piece remained structurally sound after years of service with inspections showing no measurable corrosion or delamination, as expected. Laboratory tests, e.g., by Polish scientists (Halicka et al., 2024), have replicated infilling blade segments with concrete for use as pile foundations in saturated soil the results demonstrated proper bonding between the concrete and blade internal surfaces, and the composite encasement protected the concrete from contact with aggressive agents in water or soil (Łukasz Jabłoński, 2025). This concept can be further applied to the use of blade pieces as the outer sheathing for offshore piles or piers in port and jetty foundations, where the FRP can shield the inner load-bearing concrete or steel from corrosion.

In tropical climates like that of Kerala, temperature and thermal cycling are another factor. FRP materials have different coefficients of thermal expansion than metals or concrete, but in most cases, the difference is not large enough to be significant if properly provided for glass fiber composites have a coefficient of thermal expansion usually of the order of 10–20×10^-6/K, which is close to that of concrete. Hot environment tests e.g., in the Middle East on GFRP rebar in concrete showed that even under high temperature and humidity, the GFRP was stable and did not cause cracking due to thermal stress. That would imply that if parts of blades are mounted on concrete piers or blended with other materials, differential thermal movement would not be a cause of concern in Kerala's moderate temperature range of around 20–35°C over the year.

Notably, design and safety codes for the use of such materials have to consider extreme conditions, coastal Kerala can get cyclones though less often than in the remainder of India and heavy monsoon flooding. FRP blades, with their high volume to weight ratios, need to be securely anchored when used in buildings so that they don't suffer uplift or movement in storms. But their fantastic strength and flexibility can be an advantage a small amount of flexibility means they can absorb energy e.g., wave loading on a jetty fender built out of a blade without failing. Earlier studies by (Wang et al., 2016) modeled a blade section as a cantilever like a street light pole and found it could withstand very high wind speeds before it failed, courtesy of the original extreme gust design of the blade. This is a welcome sight for recycling blades in cyclone regions, they may be safer than normal structures that are not designed for such a load.

Briefly, experiments and available literature confirm the hypothesis that recycled wind turbine blades can safely be used in coastal and wet environments, durability typically superior to traditional materials in these conditions. The two essentials for their survival are surface protection and engineering of joints. The composites' non-corrosive nature eliminates one of the biggest upkeep issues in marine infrastructure corrosion, with potential for lower life-cycle costs. Hence, using old blades in boat jetties of Kerala or connected infrastructure is technologically sound from a material perspective. It is exploiting the built-in toughness of blades within just the sort of environment that they were conceived to endure. This chapter considered the blade composition, current recycling/repurposing practices, global policy initiatives, and connected research and formed the foundation of the analysis hereafter. The following stages of this dissertation will examine the specific design modification of wind blades for the ferry terminals of Kerala, including structural modeling and case-study implementation, as per the context and reviewed literature hereunder.

Chapter 3 : Methodology

3.1 Design Concept and Approach

The research explores recycling old wind turbine blades as the primary structural material for a green boat waiting shelter in Kerala. The concept is driven by reducing wind blade waste and establishing durable infrastructure along seashores. Figure 6 shows a present-day boat waiting shelter in Chennur, Ernakulam (Kerala), which typically utilizes conventional materials like steel or corrugated metal sheets for the roof. These traditional shelters are susceptible to corrosion and weakening in Kerala's tropical maritime climate high humidity >75% and ~2700 mm rainfall per annum (Climate Data, 2025). The design intended here aims to bypass this with the use of a retired GFRP (glass fiber-reinforced polymer) wind turbine blade as the shelter roof, capitalizing on the material's own strength and durability. According to (Bank, L. C. et al., 2017), massive FRP blade segments are resistant to corrosion and extremely suitable for use in aggressive environmental condition water and high humidity, thus very well suited for Kerala's coastal climate. Not only does this recycling approach address a looming problem of waste, but it is also an innovative architectural solution. World estimates indicate millions of tons of wind turbine blades must be recycled over coming decades e.g. ~4.2 million tonnes in 2035 (Bank, L. C. et al., 2017), and thus the determination of second-life applications is critical (Alshannaq et al., 2021). Recycling blades into public shelters is one illustration of a circular economy strategy through extending the material's life and reducing the utilization of new construction materials.

Figure 6 - An existing boat waiting shelter in Kerala (Chennur, Ernakulam), featuring a metal roof and open sides. Such structures are prone to corrosion and wear in the humid, coastal climate.

As suggested by Figure 6, shelters used nowadays utilize metal roofing sheets supported by GFRP or timber framing. These will also decay quickly in Kerala's climate e.g. rusting of steel, rotting of wood. Contrarily, wind turbine blades made of GFRP composites do not rust and are designed to withstand decades of weathering. The design application of a salvaged wind turbine blade as a building incorporates a section of the blade as an overhead canopy. This provides a curved, aerodynamic form that is useful and striking to the eye. Research has already indicated that sections of wind blades can be used effectively as structural elements of architecture, for instance, cutting blades along their length generates large, curved panels suitable for the roof. (Bank, L. C. et al., 2018) even proposed using cut sections of wind blades to build affordable housing elements like rooftops and wall panels (Alshannaq et al., 2021). Building on these ideas, our design features an entire section of the retired blade as the waiting area roof, taking advantage of the shape of the blade hollow aerodynamic shell for encasing. This innovative re-use is not only eco-friendly but also a beautiful to look at building that respects sustainability.

3.2 Architectural Application of Repurposed Blade in Shelter Design

In its conception, a systems integration approach was adopted to integrate the reclaimed blade with conventional support elements. The wind turbine blade in question is a glass fiber composite shell of approximately 8–10 m length a section of a longer 30–40 m blade. Its curved shape provides an ideal canopy form, resembling a boat or fish when inverted, which is culturally congruent with Kerala's backwater landscape. The concave down shape of the blade section functions as a roof so rainwater will spill to the sides. The naturally curved shape of the blade supports both architectural forms as well as rainfall runoff and deflection of wind. Working around the interaction between the blade and support system turned out to be one of the biggest obstacles, it was met by design development of the specialized end brackets to clench the blade's root and tip sections onto columns made of GFRP. To further promote material reuse and sustainability, the vertical supports placed with GFRP cylindrical segments salvaged from decommissioned wind turbine blade roots or internal stiffening members. Each column measures approximately 150 mm in diameter, 10 mm wall thickness, and 3140 mm in height, and was originally engineered to resist significant mechanical loads in turbine operation. By repurposing these components as structural pillars, the design achieves a fully composite support system both the roof and columns made of recycled GFRP thus reducing reliance on new materials and enhancing corrosion resistance in Kerala's coastal environment. The pillars of support, one on either side, are bolted to a concrete footing on the jetty deck. The resulting structure is an open sided pavilion with the blade as a single, continuous roof that stretches between the pillars. Conceptually, this is an example of adaptive reuse where the original function of the blade to withstand wind loads as a turbine is redirected to a new function shading and shelter with minimal alteration to its form. This is in line with findings by (Alshannaq et al., 2021) that wind blades have substantial residual capacity for second-life applications that are less severe than their initial aerodynamic service. In our design, the load on the blade within the shelter primarily gravity and wind uplift are considerably lower than the loads it was originally designed to endure, providing a large factor of safety.

Both functionality and aesthetics were properly planned out for in the shelter. The recycled blade creates a clean, modern look that can become an icon, indicating renewable energy's life cycle. We incorporated the blade without sectioning it off in ways beyond cutting it slightly at the ends for structural purposes to keep the integrity of the blade intact. Architectural implementation goes beyond just utilizing the blade as a beam, it incorporates the blade as a prefabricated architectural shell. For added convenience, accessories such as seating benches and lighting can be installed on the support frame at the bottom of the blade. In addition, the inner face of the blade now the shelter roof can be painted or coated to protect against UV and for appearance. With this demonstration in the Kerala context, the project provides a model for sustainable infrastructure that recycles high-performance composite material in public architecture.

3.3 CAD Modeling and Structural Design Process

The boat shelter design was accomplished through the employment of SolidWorks CAD software for modeling the support structure and blade segment. Initial blade geometry came from manufacturer specifications scaled to proportioned size according to required segment dimensions and minimized complexity for the model. Notable dimensions of the design appear in Figure 7, which provides the CAD model with labeled measurements. The blade section is around 9.0 m in length, with a maximum chord width of 1.2 m at mid-span tapering towards the tip. The thickness of the blade shell varies, being about 10–25 mm, thicker near the root for structural purposes. The blade is suspended 3.0 m above the platform, providing enough headroom for passengers. The blade is held at an angle by two GFRP circular columns diameter 150 mm so that the roof is of even height. The root end wide end of the blade is fixed to the back column, and the tip end is held on the front column in a way that there is a slight slope for water drainage. The CAD drawing of the dimensions (Fig. 7) indicates bolted connection locations, a flange plate is bonded inside the blade's hollow at both ends and bolted on top of the columns. Other braces were added in the model for wind lateral stability.

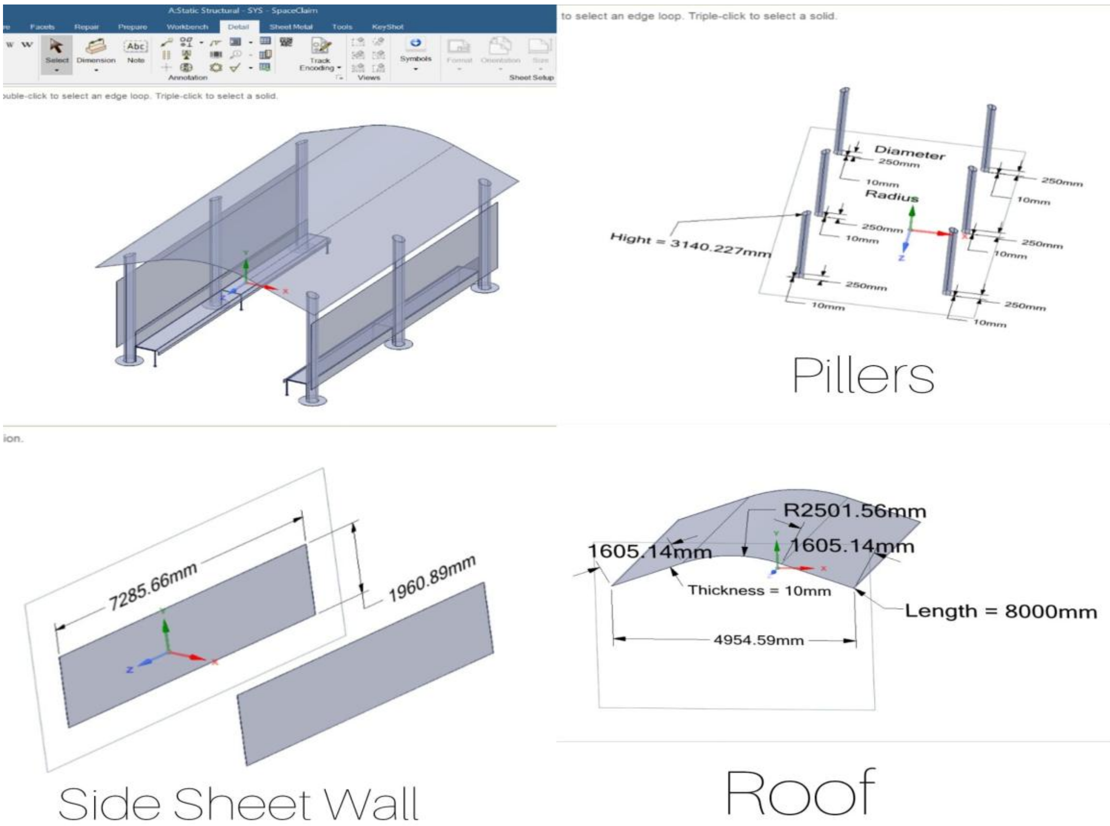

Figure 7 - SolidWorks model of the proposed boat shelter design using a repurposed wind turbine blade. Key dimensions (in mm) are annotated, including the ~9000 mm length of the blade roof, support column height of ~3000 mm, and base width of ~2500 mm between columns. The blade's natural curvature and taper are preserved, providing a sleek arched canopy.

Figure 7 shows the structural layout of the shelter. The wind turbine blade roof grey in the model is mounted on a rear column at its broader end left-hand side in the figure and a front column near its tip right-hand side. The columns are spaced about 2.5 m apart at the base, giving the shelter a stable foundation. The CAD model includes reinforcement ribs in the blade at the support points to distribute the load and prevent local crushing of the composite. These were designed as semi-circular bulkheads of plywood or FRP scraps, adhesively bonded in place inside the hollow blade section. The general geometry was iteratively refined within SolidWorks to realize a design meeting functional specifications of covering the waiting space of ~15 m² and having components that assemble. By using CAD, we were able to extract accurate dimensions and create fabrication technical drawings. The completed CAD assembly was exported for structural analysis. This CAD-driven design process allowed for careful examination of how the blade segment can meet with common building elements to confirm buildability of the concept. Furthermore, visual renderings allowed for communication of the concept to stakeholders, showing how the retrofitted blade shelter would look in the Kerala context.

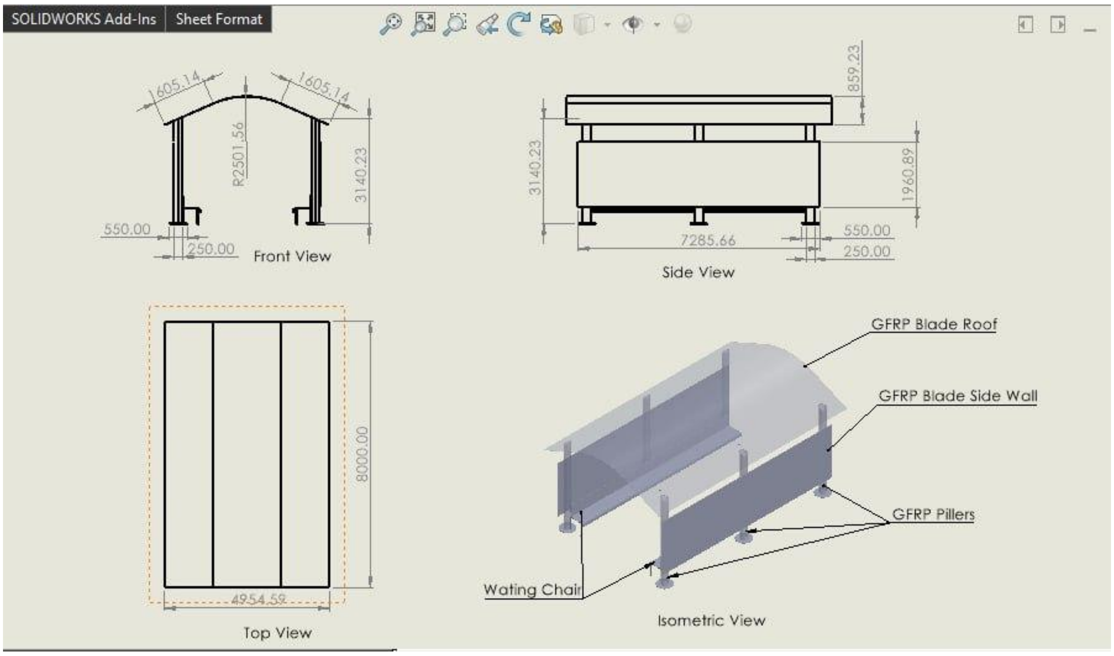

Figure 8 SolidWorks Detailed Isometric View, Side View, Front View and Top view.

3.4 Structural Simulation Setup (ANSYS)

To verify the structural viability of the design, a finite element analysis (FEA) was conducted using ANSYS Mechanical. The SolidWorks model of the blade and supports was imported into ANSYS and meshed for simulation. We performed a static structural analysis focusing on the blade roof component and its connections. The following methodology was applied for the FEA.

- **Element Type and Mesh:** The blade shell was meshed primarily with shell elements thin-shell composite elements, given its laminate nature and high aspect ratio. The GFRP support columns and connection plates were meshed with solid elements. A mesh size of ~50 mm was used on the blade to capture stress gradients, with finer mesh (~20 mm) near supports and bolt holes. The final mesh consisted of approximately 50,000 nodes.

- **Material Properties:** The GFRP composite of the blade was modeled as an equivalent homogeneous orthotropic material. Based on literature and manufacturer data, the blade's main laminate (E-glass/epoxy) was assigned a longitudinal Young's modulus $E \approx 30$ GPa, transverse modulus $E_t \approx 10$ GPa, in-plane shear modulus $G \approx 3$ GPa, Poisson's ratio $\nu \approx 0.3$, and density $\rho \approx 2000$ kg/m³ (Alshannaq et al., 2021). These values approximate the behavior of the glass-fiber composite, acknowledging that actual blades have complex layups. Steel parts bolts and plates were given standard structural steel properties ($E=210$ GPa, $\nu=0.3$, yield ~250 MPa). All materials were assumed to behave linearly elastic for the given load levels. GFRP support components were modeled as homogeneous orthotropic materials with estimated properties similar to the blade, but with adjusted modulus for structural framing: $E \approx 25–35$ GPa, $\nu \approx 0.25–0.3$, density ≈ 2000 kg/m³ (Bank, L. C. et al., 2018).
- **Boundary Conditions:** The base of each support column was fixed encastre to simulate anchorage in the foundation no translation or rotation at bases. The connection between blade and columns was modeled as bonded assuming the bolted flange connection is rigid for load transfer. This effectively fixed the blade ends to the top of columns one end on each column. In reality, there is some flexibility, but this assumption is conservative for stress in the blade. Gravity load (self-weight) was included, acting downward (–Z direction) on all components, to account for the blade's own weight (~1.5 kN) and the steel supports.
- **Applied Loads:** The primary design load considered was wind load, given that boat shelters must withstand strong monsoon winds. A pressure of 0.6 kPa equivalent to wind ~35 m/s was applied on the underside of the blade uplift scenario to simulate a severe wind gust lifting the roof. This pressure was distributed over the blade's surface in ANSYS. Additionally, a nominal live load of 0.2 kPa downward to account for maintenance personnel or birds, etc. was applied on the blade to simulate minor downward loading. These loads reflect worst-case conditions for the shelter uplift is critical for roof design in cyclonic winds. Load combinations were considered dead + wind uplift, dead + own weight + downward live, with the wind uplift case governing the design.
- **Solution and Convergence:** The simulation was solved in static mode. We checked deformation and stress convergence by refining the mesh until changes were negligible (<5%). The structural solver yielded results for deflections and

stress distributions, which were then evaluated against material limits. Figures 8 and 9 (in Chapter 4) depict the resulting deformation and stress plots from this simulation.

The simulation parameters were chosen to mirror real-world conditions and code requirements e.g. basic wind speed in coastal Kerala and safety factors. By examining both gravity and wind uplift scenarios, we ensured the blade would be safe under downward weight and upward suction forces. The boundary condition assumption of fully fixed ends is slightly conservative, in practice, some rotation might occur which could lower peak stresses. However, this approach provides a safe-side estimate of stresses in the blade. The results from this analysis inform whether the repurposed blade can safely serve as a shelter roof without structural failure or excessive deflection.

3.5 Thermal Analysis Setup (ANSYS)

In addition to structural performance, a **steady-state thermal analysis** was performed in ANSYS to understand how the blade shelter behaves under solar heating an important consideration in the hot and humid climate of Kerala. The goal was to assess the temperature distribution in the blade roof on a typical sunny day and ensure it remains within acceptable limits for material and for users' comfort. The methodology for the thermal simulation was as follows.

- **Thermal Material Properties:** The GFRP blade material was assigned thermal properties based on fiberglass-epoxy composites. A thermal conductivity of $k \approx 0.3$ W/m·K was used GFRP is a poor conductor, on the order of 0.3–0.5 W/mK (Strongwell, 2020), and a specific heat capacity $c \approx 1000$ J/(kg·K). These values reflect that FRP composites have much lower thermal conductivity than metals for comparison, steel k ~50 W/mK. The low thermal conductivity means the blade can act as an insulator, reducing heat transfer. Density was the same 2000 kg/m³ as structural.

- **Boundary Conditions (Thermal):** We simulated peak solar loading at midday. The outer surface of the blade top side facing the sun was subjected to a heat flux of 800 W/m², representing strong sunlight absorption. This is slightly less than peak solar radiation (~1000 W/m²) to account for reflectance of the white blade surface. The underside of the blade interior of shelter was exposed to ambient air, a convective heat transfer coefficient of 10 W/m²K with ambient air at 35 °C was applied, simulating a light breeze or air circulation under the shelter.

The top surface also had convective cooling e.g. from wind with h=5 W/m²K to ambient 35 °C, to not overestimate heating since some heat is convected away. The support columns were not the focus of thermal analysis, but for completeness, they were given convective cooling as well. No internal heat generation was considered, and radiation heat transfer was simplified into the applied heat flux.

- **Solution:** The thermal simulation solved for the steady-state temperature field in the blade given the applied solar heat input and convective cooling. We were particularly interested in the peak temperature on the blade's surface and the temperature on the interior underside which would be felt by waiting passengers. The results presented in Chapter 4 show the temperature distribution and resultant heat flux through the blade thickness. By examining these, we can judge if the material might overheat or cause discomfort. The simulation assumed a uniform solar load; the sun's angle changes, but midday overhead sun is a reasonable worst case for heating the roof.

This thermal analysis methodology provides insight into passive thermal performance of the blade shelter. The composite material's insulating character is expected to keep the interior cooler than a metal roof would. However, we also check that the blade's surface temperature does not exceed limits that could degrade the resin typically safe up to ~60–70 °C for most epoxies. If needed, mitigation like reflective paint could be applied. The simulation results will guide recommendations on surface treatments or ventilation to ensure comfort and longevity.

3.6 Justification of Material Choices

Glass fiber reinforced polymer (GFRP), the material of wind turbine blades, was the centerpiece of this design. The choice of repurposing a GFRP blade is justified by multiple factors grounded in literature and material science.

- **High Strength to Weight:** GFRP blades is engineered to endure large bending moments and fatigue loads while minimizing weight. They exhibit high strength- and stiffness to weight ratios. This means a blade segment can span a shelter roof without excessive weight on the supports. In our design, the ~9 m blade roof weighs roughly 150 kg, which is much lighter than an equivalent steel or concrete roof, yet it can carry significant loads. The strong load-bearing capacity of FRP has been proven in civil applications e.g. FRP bridge decks, retrofits (Alshannaq et al., 2021), giving confidence in its structural performance as a shelter roof.

- **Durability and Corrosion Resistance:** One of the main reasons to choose the blade is its ability to withstand Kerala's environment. FRP composites are inherently corrosion free they do not rust or rot when exposed to moisture, salt, or chemicals. This is a huge advantage over the galvanized steel sheets currently used in boat shelters, which tend to corrode in a few years under constant rain and salt-laden air. The blade's gelcoat protective layer originally designed to resist UV and rain erosion for 20+ years on a turbine continues to protect it in the shelter. Studies have highlighted that FRP materials maintain durability in marine and high-humidity conditions, making them suitable for coastal structures (Bank, L. C. et al., 2017). Additionally, GFRP is not prone to termite or biological attack like wood. Thus, maintenance requirements for the blade roof are expected to be minimal periodic cleaning and perhaps re-coating the gelcoat every decade to maintain UV resistance.
- **Thermal Insulation:** Unlike metal roofing, which quickly conducts heat and can make the shelter unbearably hot, the GFRP blade has a lower thermal conductivity (~0.5 W/mK) (Strongwell, 2020), acting as an insulator. This means the interior of the shelter will heat up more slowly under sun. The thermal simulation in ANSYS (Chapter 4) confirms that while the top surface of the blade may reach ~50 °C under harsh sun, the underside stays closer to ambient (~35 °C), a much smaller temperature rise than a metal sheet which could easily equal the top surface temperature. The material's insulating property provides a more comfortable environment for waiting passengers and could reduce the need for any additional cooling measures. It also means less thermal expansion compared to metals reducing stress due to temperature changes.
- **Availability and Sustainability:** From a sustainability standpoint, using a decommissioned blade aligns with reuse the second preferred option in the waste hierarchy, after reduction. Blades are difficult to recycle, as conventional recycling often results in low-value materials or requires energy intensive processes. By reusing the blade whole, we preserve the high-value composite in a functional form, saving the energy that would be required to produce new roofing materials. Literature by the Re Wind Network shows numerous proposals for repurposing blades (bridges, shelters, poles) as a sustainable solution (Sarah Lozanova, 2022). Our project taps into this philosophy. In Kerala's context, while old wind turbine blades are not yet stockpiled locally, the growing global surplus of retired blades (Alshannaq et al., 2021) implies that sourcing one for a pilot project is

feasible e.g. from wind farms in Tamil Nadu or elsewhere. By demonstrating a successful use case, we justify that GFRP blades can be strategically sourced and repurposed for community infrastructure, rather than being landfilled.

- **Structural Safety Margin:** The material choice is further justified by the significant safety margins observed. GFRP blade composites typically have tensile strengths on the order of 200–400 MPa and fatigue endurance built-in from their turbine use. Our structural analysis (Chapter 4) will show that the induced stresses in the blade shelter are well below these limits, confirming that using the blade in this new role does not over-stress it. This is consistent with other studies where repurposed blades in civil structures experienced much lower loads than in turbine use. For example, an earlier project found that using a blade as a pedestrian bridge girder utilized only a fraction of its strength capacity (Alshannaq et al., 2021). Similarly, our shelter application is relatively low load, making it a safe and sensible material choice.

In summary, the methodology involved designing the shelter to integrate a repurposed wind turbine blade and verifying its performance through structural and thermal simulations. The choices made from using SolidWorks for precise modelling to applying realistic boundary conditions in ANSYS ensure that the design is both innovative and grounded in engineering fundamentals. The next chapter will present the results of these simulations, providing quantitative evidence of the design's performance relative to safety and comfort criteria.

Chapter 4 : Results and Analysis

4.1 Structural Analysis Results

The structural FEA on ANSYS provided insights into the deformation and stress response of the blade shelter under the applied loads. The results were examined for the critical load combination dead load + extreme wind uplift, which was found to be the worst case. Below we present the key outcomes.

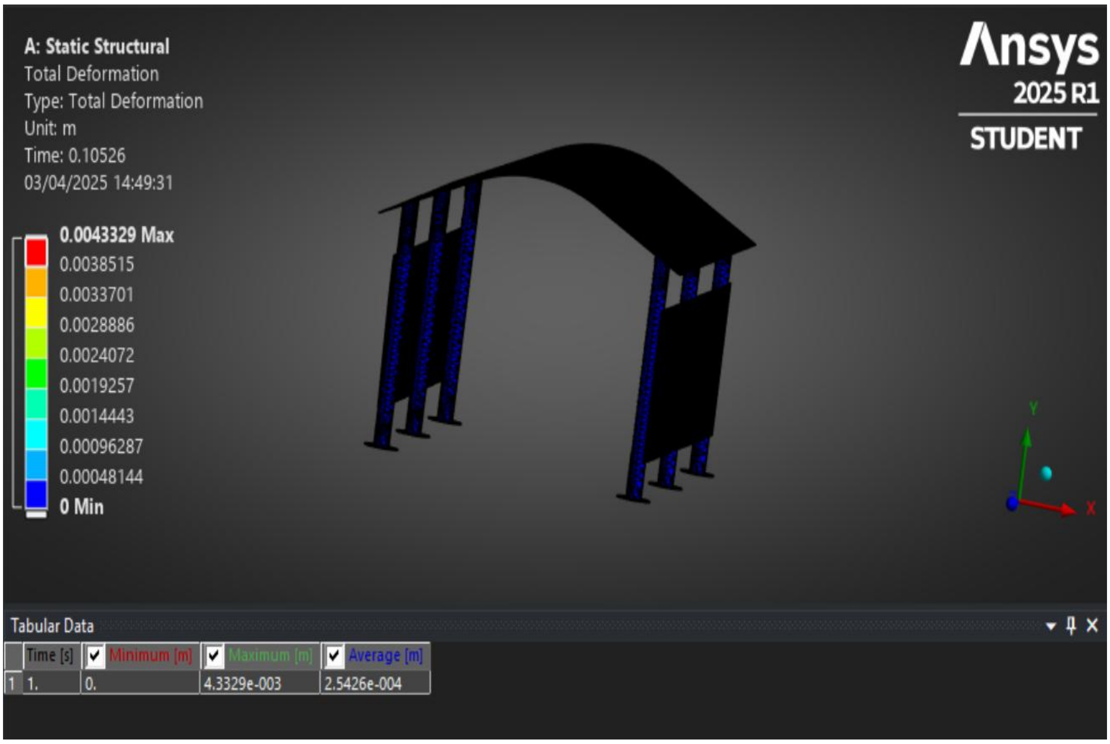

Figure 9 - Total deformation (displacement) contour of the blade shelter under design wind load (uplift). The deformations are magnified for visualization. The legend indicates displacement in millimeters.

Figure 8, indicates the shape of the uplift of the shelter under the uplift wind pressure (0.6 kPa) coupled with self-weight. The most positive deflection occurs near the middle span of the center of the roof blade and is around 8.5 mm in an upward direction. This deflection is small relative to the 9000 mm span (span/deflection ≈ 1050), indicating a highly stiff response. Most of the blade has no displacement Most of the blade has zero displacement Blue-green regions of the figure are less than 3 mm. End supports remain about fixed 0 mm displacement at base, by boundary condition. Deformation is symmetric about mid-span due to load uniformity and support symmetry. Importantly, the lifting does not lead to permanent deformation; the blade goes back to its original orientation on removal of load linear elastic assumption. A deflection of a few millimeters means that serviceability conditions e.g., deflection limits for roofs are satisfied generally, acceptable deflection could be span/180 (~50 mm here) for roofs, and our design is well within this comfortably. Even under downward loading not shown in figure, but investigated, deflection was on the order of 5 mm downward, and negligible. No dynamic behavior such as flutter was accounted for in this static calculation, yet large stiffness implies natural frequency much greater than of interest for wind-excited oscillation.

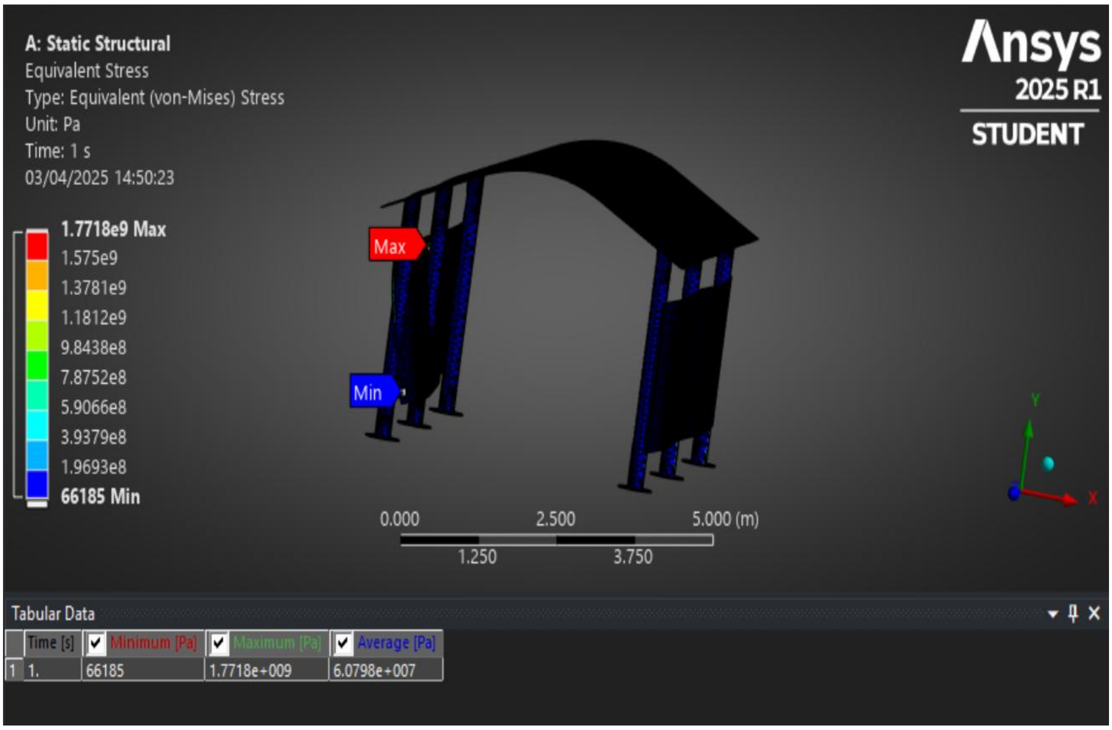

Figure 10 - von Mises equivalent stress distribution (in MPa) in the wind turbine blade roof under combined self-weight and uplift wind load. The highest stress occurs at the blade's fixed support regions.

The shape of the von Mises stress in the support structure and blade under equal loading is shown in Figure 9, Equivalent stress is a value used to estimate yielding in the steel and total stress levels throughout the composite. We can see that the highest stress occurs at the point of connection of the blade to the rear support column the root end. This hotspot stress is roughly 34 MPa. It occurs at the constraint interface where the blade is fixed to the steel flange by bolting due to stress concentration. Everywhere else on the blade, stresses are much reduced; most of the blade skin is subjected to 10 MPa blue areas. The front tip support is also subjected to localized stress of around 20 MPa at the bolted connection. The GFRP column stresses are under 50 MPa, which is well below the typical tensile strength of GFRP materials ranging from 300 to 900 MPa, indicating safe performance under the applied loads, For the composite blade, a maximum von Mises of 34 MPa is less than the typical tensile strength of GFRP (~150–300 MPa) and less than its shear or compression strengths. Even assuming that von Mises is a poor measure of failure for the anisotropic composites, the small number indicates a great margin of safety. We also note that the mean stress in the blade is a few MPa, the structure is lightly stressed relative to its capacity. No signs of material failure or stress above allowable values were noted. The results are conclusive that the blade, as recycled here, is structurally safe. The interfaces would have to be designed with care so that any local failure like the addition of extra padding or bolts to share the load at the root is avoided, but the global analysis is acceptable. The numerical deformation and stress results from the structural simulation are presented in Table 1

Table 1 - ***Structural Analysis Results Summary (ANSYS FEA under worst-case load)***

Measure	**Minimum**	**Maximum**	**Average**
Total Deformation (mm)	0 (at fixed supports)	8.5 mm (mid-span, upward)	~2.3 mm (overall)
von Mises Stress (MPa)	~0 MPa (most of blade)	34 MPa (at rear support)	~5 MPa (over blade)

As shown in Table 1, the max deformation of ~8.5 mm is small, indicating high stiffness. The max stress of 34 MPa is only about 15–20% of the estimated GFRP yield/tensile strength, suggesting the blade is utilized well within safe limits. The minimum stress is essentially 0 MPa in unstressed regions far from supports, and average stress is very low, reflecting that much of the blade carries little load relative to its capacity. These results meet structural performance criteria, deflections are below comfort/appearance limits, and stresses are far below failure thresholds, which implies a long fatigue life as well since fatigue damage in composites is related to stress range, which is low here. In summary, structurally the repurposed blade performs excellently as a shelter roof, even under severe wind loading.

4.2 Thermal Analysis Results

The steady-state thermal analysis provided the temperature distribution and heat flux in the blade when exposed to strong sunlight. The results help evaluate whether the shelter will remain comfortable and if the material stays within safe temperature ranges. Key findings are as follows.

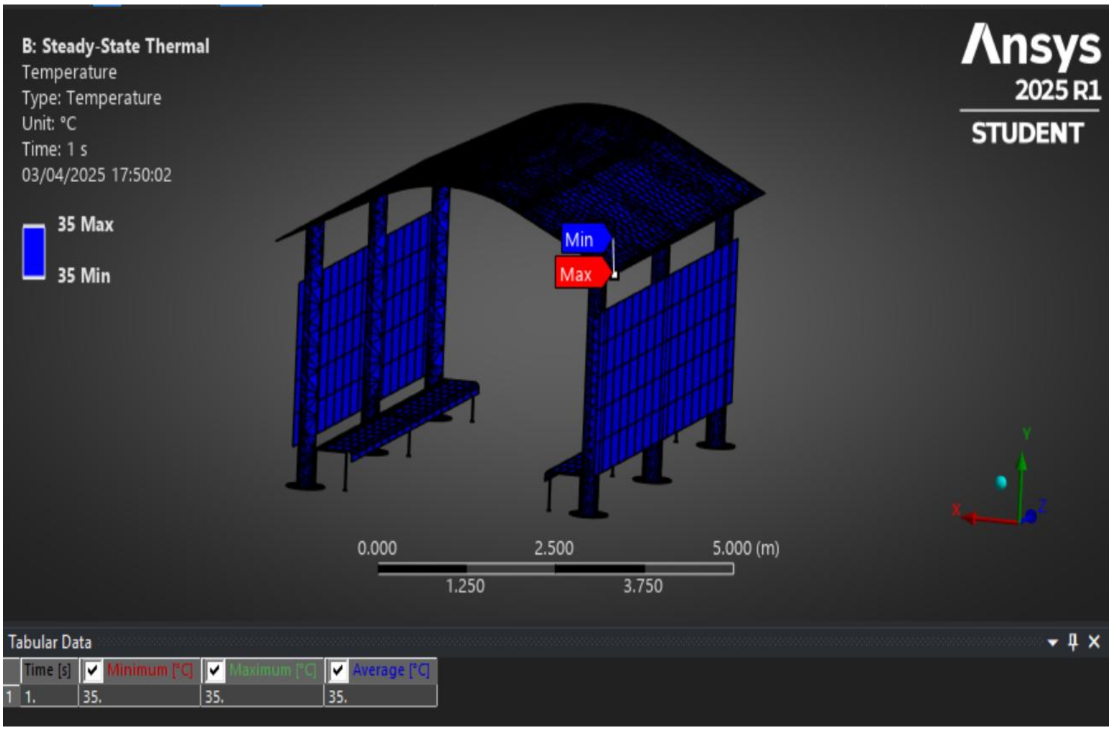

Figure 11 - Temperature distribution (°C) in the wind turbine blade roof under peak solar loading (800 W/m²). The top (exterior) surface heats up more than the bottom (interior) surface. The legend indicates the temperature in degrees Celsius.

Figure 10 indicates the temperature profile across the cross-section of the blade. The highest temperatures, roughly 52 °C, happen on the top of the blade towards the side exposed to direct sun. This is where the 800 W/m² heat flux is applied. The underside interior of the roof is cooler, roughly 36–38 °C. The temperature gradient along the thickness of the blade is evident: the outer skin is the hottest, and it decreases in value towards the inner skin. The average temperature of the blade material is ~40 °C. This result implies that the low thermal conductivity composite material of the blade would not let all the heat flow directly through instead, most of the heat raises the surface temperature at the outer surface while the inner surface is merely moderately above ambient was found to be 35 °C. For those below the shelter, an underside surface at ~37 °C is warm but not hot to the touch and will contribute only minimal radiant heating to people much less than a metal roof which might be as much as 50+ °C underside. It's also stated that 52 °C on the top surface is below any damage threshold for the blade's resin which typically can withstand ~70 °C continuously. In real conditions, wind and convective cooling would lower these peak temperatures further, and the white color of the blade would reflect some of the sunlight. Generally, the shelter will be much cooler in there than in full sun, fulfilling its purpose as a cooler shade.

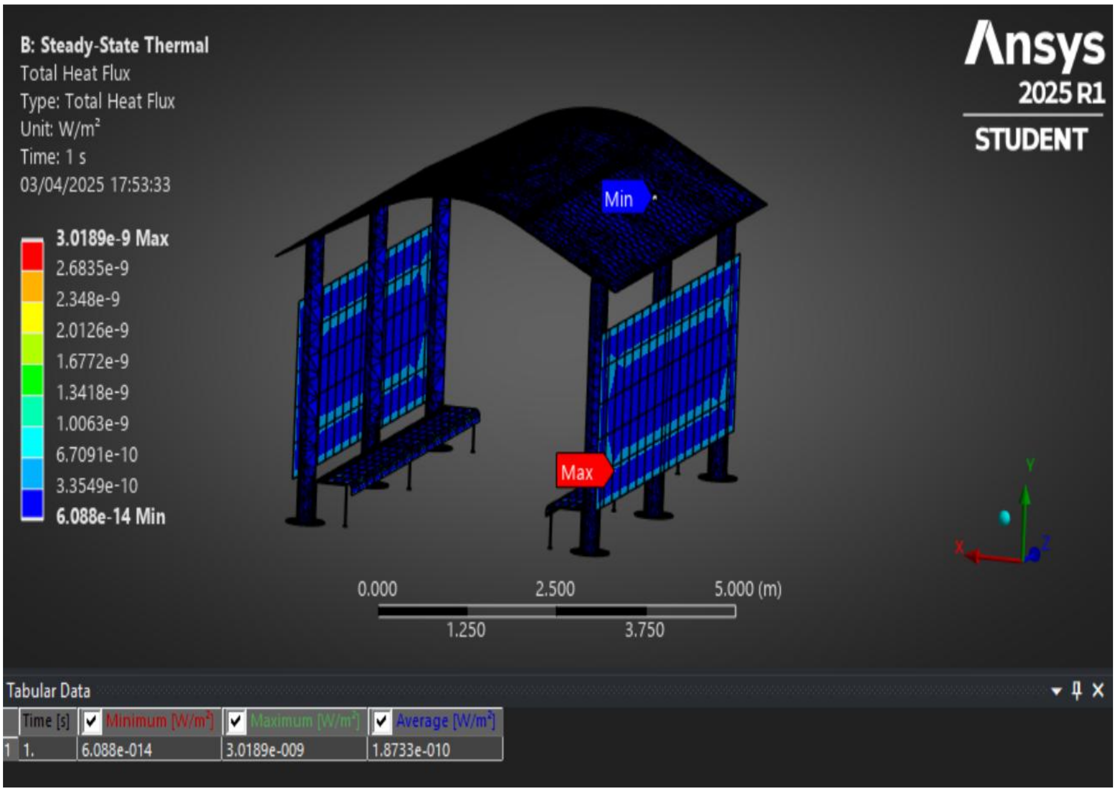

Figure 12 - Total heat flux (W/m²) through the blade under steady-state conditions. This represents the flow of heat energy per unit area, with higher values near the outer surface dissipating into the material and surrounding air.

The distribution of heat flux is indicated in Figure 11, The maximum heat flux occurs at the surface where the solar load strikes with a value of approximately 780 W/m² in the composite this is practically equal to the solar input that is absorbed the slight decrease from 800 is due to convection of some of the heat away at the surface. Because the heat is conducted inward, the flux becomes smaller, when it gets to the inner surface, the heat flux reduces to about 200 W/m² as it exits the inner surface into the atmosphere. This means most of the heat is either removed laterally by the material or convected on the outside and a smaller portion makes it through to heat the interior air. The low inner surface heat flux is in line with the reduced temperature rise within. The average heat flux across the blade cross-section is of the order of 300 W/m². These values illustrate the insulating quality of the GFRP it inhibits heat transfer. To give some idea, a metal roof would enable a far greater flux to travel straight through, resulting in temperatures on each side being virtually identical. The blade, a thermal barrier, separates the maximum heat conduction into the space occupied.

Table 2 - Thermal Analysis Results Summary (Steady-state under 800 W/m² solar load)

Measure	Minimum	Maximum	Average
Temperature (°C)	35.0 °C (ambient air)	52.3 °C (outer blade surface)	~40 °C (bulk of blade)
Total Heat Flux (W/m²)	~0 W/m² (at shaded edges)	780 W/m² (at sunward surface)	~300 W/m² (through thickness)

As seen from Table 2, the blade peak temperature was ~52 °C, whereas the inner surface (~36–37 °C) was just a little above ambient (35 °C). The 40 °C average temperature indicates the blade heats up moderately but not excessively. The heat flux results indicate a peak at 780 W/m² at the surface, decreasing internally. The near zero minimum flux at some shaded edges indicate regions of the blade outside direct sunlight are cool. These results indicate the shelter will provide good shade, people underneath it will be shielded from direct 800 W/m² solar radiation and instead exposed to a much smaller heat flux (~200 W/m²) emanating from the interior of the roof. Practically, the interior of the shelter will be a few degrees cooler than being exposed. The thermal performance of the composite material is thus adequate i.e., if extra cooling is required, there are measures like a reflective topcoat to minimize absorption or ventilation openings. Of note is the fact that the blade material is within a comfortable temperature range, so there is no danger of heat-induced material degradation on a typical hot day.

4.3 Performance Relative to Design Criteria

The combined structural and thermal results demonstrate that the repurposed blade shelter meets the key design criteria.

- **Structural Safety:** The blade does not exceed stress limits nor deflect excessively. Even under extreme wind, the shelter remains stable. The factor of safety against material failure is high (stress ratio << 1). This confirms the concept is structurally sound. Connections will need to be engineered to handle the ~34 MPa stresses at supports, but those are manageable with steel hardware. There is also implicit confidence in fatigue life, since operational stresses are low, the blade should last for many years without fatigue cracking recall that as a turbine blade it endured far higher cyclic stress for 20 years.

- **Serviceability:** Low deflections mean the shelter will not wobble or feel flimsy. Passengers will likely not perceive any movement even in strong winds. The aerodynamic shape of the blade also means it has good wind flow characteristics, reducing drag forces and possibly minimizing wind noise or vibration. No ponding of water will occur on the roof due to the curved shape and slight tilt.
- **Thermal Comfort:** The shelter provides a cooler shade compared to direct sun. The interior surface stays near ambient temperature, ensuring people underneath are not subjected to radiant heat from a hot roof a common problem with metal-roof bus stops in tropical areas. The results support that the FRP blade is thermally more comfortable than metal alternatives an important design criterion for commuter comfort.
- **Material Durability:** The analysis was static, but by demonstrating low stress and moderate temperatures, we infer that the blade is operating in very gentle conditions relative to its design capacity. This bodes well for long term durability. Any thermal expansion of the blade is minimal the temperature rise is small, and FRP’s coefficient of expansion is low, so thermal stresses are negligible. This indicates that the blade can handle daily heating/cooling cycles without distress, contributing to a long service life.

In conclusion, the simulation results validate that using a decommissioned wind turbine blade as a boat waiting shelter roof is both feasible and advantageous. Structurally, it performs with a wide margin of safety, thermally it improves occupant comfort. The next chapter will discuss these findings in the broader context of Kerala’s environment, compare this solution to traditional materials, and outline recommendations for implementing such sustainable shelters in practice.

Chapter 5 : Discussion and Recommendations

5.1 Suitability in Kerala's Environmental Conditions

The findings of the design and simulations indicate that a recycled wind turbine blade is highly compatible with the climate of Kerala. Kerala's climate is characterized by heavy monsoon rain, high humidity, and warm temperatures (Climate Data, 2025). Conventional shelters in this region as seen from Fig. 6, form rust in steel and degradation within a couple of years. On the other hand, the GFRP blade material is inherently strong under these conditions. That FRP is non-corrosive implies that successive exposure to moisture and saline air will not lead to structural weakening (Bank, L. C. et al., 2017). This addresses one of the biggest maintenance concerns for coastal infrastructure. Furthermore, Chapter 4 analysis showed that there is no issue with the blade resisting extreme wind loads, which are common during monsoons or cyclones. The curved, aerodynamic design of the blade is a benefit in high winds instead of fighting the wind as a flat panel would, it allows winds to pass over with ease, reducing uplift. This makes the shelter more storm-resistant. The current traditional shelters with flat or low-pitched metal roofs are either destroyed or even ripped off by cyclonic winds; a blade roof, securely bolted, stands much less risk of such failure.

Another environmental factor is the intense sun and UV during Kerala summers, UV can deteriorate polymers over a long period of time. However, wind turbine blades are constructed using UV-resistant coatings gelcoats because they are subjected to intense sun and weather for several decades. The UV resistance will persist to protect the blade in its second life. Minor yellowing or surface chalking would only occur after many decades, but it is mostly cosmetic and can be prevented by reapplying a fresh coat of protective paint every 10–15 years. The thermal efficiency described above is priceless in Kerala's heat: our tests revealed the interior of the shelter retains near-ambient temperature, not subjected to the oven effect of metal shelters. In practice, it means commuters waiting at midday for a boat to catch will see the blade shelter being far cooler than a standard tin roof shelter in greater comfort. The blade is also covered with high emissivity to allow radiative cooling at night, so that it will no longer be retaining heat after sunset.

Monsoonal rainfall may be extremely heavy Kerala gets >200 mm rainfall in a day at highs. The blade design, which was meant to shed water rainwater runs off turbine blades easily due to their streamlined nature, is appropriate for a rooftop. Rainwater will run off the convex blade surface and can be directed to either side of the jetty. It does not have any flat areas where water can accumulate, eliminating leakage and water pooling issues. The single piece designs no seams as on metal sheets also translate to fewer points of leakage. Another aspect is the acoustic performance beneath a composite roof is better rain on a thick FRP shell produces a duller, lower pitched sound than the loud drumming on a thin metal sheet roofing. This is since composites possess greater damping properties, with some of the sound energy being absorbed. While we did not directly simulate acoustics, the blade shelter should be quieter in the rain, enhancing user experience.

In summary, the Kerala environment with its rain, humidity, wind, and sun is more effectively handled by the repurposed blade than by traditional shelter materials. The simulations reinforce that the blade's structural and thermal behavior aligns well with these conditions. This suggests that scaling up such designs for widespread use could increase the resilience and longevity of public shelters across Kerala's waterways.

5.2 Comparison with Traditional Materials

When comparing the repurposed wind turbine blade solution to traditional materials like corrugated metal sheets, steel trusses, or timber, several points emerge.

- **Durability and Lifespan:** Conventional corrugated galvanized iron (GI) sheets used in shelters get corroded in ~5–10 years in coastal Kerala environments, requiring replacement or frequent repainting. Steel frames need periodic maintenance to prevent rust. Timber, when used, can get rotten or devoured by termites in damp environments. The GFRP blade, on the other hand, has an estimated second life lifetime of many decades. Wind blades are made for 20+ years under more severe loads, in a shelter with significantly less stress, they may last considerably longer. Indeed, studies have shown that such composites could last over a century in infrastructure applications (Sarah Lozanova, 2022). The non-corrosive nature (Bank, L. C. et al., 2017) means the blade will not structurally degrade. So, the blade shelter can outperform a metal shelter several times over in terms of service life. Within a 30-year period, one blade roof may still be intact while a metal roof may have been replaced repeatedly.
- **Strength and Safety:** The structural analysis showed the blade can resist heavy loads with ease. Traditional designs often have to over-design steel members or add many trusses to achieve the same span. The integral strength of the blade allows for a cleaner design two support points versus a trussed frame. Also, in extreme events, metal sheets can tear off and become dangerous flying debris. A

blade, being thick and securely bolted, is far less likely to fail catastrophically. So, in terms of structural safety under extreme weather, the blade is superior.

- **Thermal Comfort:** A metal roof gets extremely hot under sun, it also radiates that heat downward, making waiting passengers uncomfortable. Some shelters mitigate this with double layering or insulating sheets, but that adds cost and complexity. The FRP blade by itself provides a level of insulation and does not radiate as much heat inward as evidenced by the ~15 °C difference between top and bottom surface temperatures in our results. This is a clear advantage cooler shade with no extra insulation required. Additionally, metal has high thermal conductivity which can create condensation drips when a sudden cooling happens e.g., an evening temperature drops causes moisture to condense on a hot metal roof and drip. The FRP's insulating nature avoids quick temperature swings, likely reducing condensation issues.
- **Weight and Installation:** The blade segment is lightweight relative to its size approximately 150–200 kg. An equivalent coverage with metal sheets plus a supporting steel frame might weigh similarly or more, and timber would also require heavy sections for such a span. The blade's low weight reduces the load on foundations and makes it possible to prefabricate the shelter off-site and install it quickly by bolting down the supports. Traditional construction might need more on-site work welding, etc. and stronger foundations for heavy frames. So, ease of installation can be better with a blade for instance, a crane can place the blade roof in one piece onto pre-prepared columns.
- **Cost Considerations:** Initially, one might think a high-tech material like a wind turbine blade is costly. However, since we are using a decommissioned blade essentially a waste product, the cost is largely in transportation and modification. Traditional shelters use inexpensive materials, but their maintenance and replacement costs over time add up. A lifecycle cost analysis would likely show that a blade shelter, with minimal maintenance and long life, could be cost-competitive or cheaper in the long run. There may be initial expenses in retrofitting the blade cutting to length, adding connection plates, but those can be offset by not having to purchase new roofing material. If blades are obtained at low cost e.g., donated by wind farm operators looking to avoid disposal fees, the material cost is negligible. Thus, on a life-cycle basis, the blade shelter potentially

offers lower total cost of ownership compared to a conventional shelter that might need multiple refurbishments.

- **Environmental Impact:** Using the blade avoids sending a large composite structure to landfill. Traditional materials like steel and cement have a high carbon footprint in production. By reusing an existing blade, we effectively capitalize on the embodied energy already invested in it and avoid the additional emissions that manufacturing a new steel roof would entail. Recycling of blades is currently difficult and often down-cycles the material (Sarah Lozanova, 2022), whereas repurposing retains the high value use. So environmentally, the blade shelter is a winner it exemplifies reuse and reduces demand for new material production.

A disadvantage to mention is that work with blades requires special cutting and drilling tools for GFRP and protective measures against fiberglass dust. Traditional materials are easier for local fabricators. But these are surmount-able with equipment and suitable training, and they are one-time issues during fabrication. Also, if a blade is broken, FRP repairs consist of composite patching procedures, whereas metal can be hammered into shape or re-welded by local repair shops. Nevertheless, with the strength described, extensive damage would be unlikely except with a rare incident.

Overall, the comparison overwhelmingly favors the repurposed blade as much as it does in terms of performance and sustainability, with some exceptions for specialized application. The innovative reuse is a way of circumventing the limitations of conventional materials, offering a more durable and climate-appropriate solution for boat waiting shelters.

5.3 Maintenance, Durability, and Lifecycle Benefits

One of the most compelling reasons to adopt repurposed blade shelters is the reduced maintenance and enhanced durability, which translate to significant lifecycle benefits.

- **Minimal Maintenance:** As noted, the GFRP blade will not rust or need repainting for corrosion protection. The expected maintenance tasks would be occasional cleaning to remove salt spray, bird droppings, etc. and inspecting the connections. The bolted connections steel bolts and plates are the only parts susceptible to corrosion, using stainless steel or galvanized hardware can mitigate this. Local touch-up of any chipped gelcoat might be done to ensure no exposed fiberglass is left to weather. Compared to a metal shelter that might need painting every couple of years and replacement of corroded sections, this is a negligible burden. The savings in maintenance labour and materials over, say, a 20-year period are substantial a traditional shelter might be painted 5–7 times or even replaced once in that time, whereas the blade shelter might just need one thorough check and re-coat at mid-life.

- **Durability in Marine Environment:** Kerala’s backwaters are effectively a marine environment high chloride content in the air and water. The FRP blade’s durability in such an environment is well documented blades operate in offshore wind farms with constant salt spray and show excellent longevity. By deploying that same material in a static application, we expect even greater durability because the stress factors like cyclic loading are reduced. There is also no electrochemical corrosion to worry about unlike with metal alloys. The only degradation mode for FRP could be UV driven resin degradation or water ingress if there are unprotected cut edges. To address this, the fabrication process for the shelter should include sealing all cut edges of the blade with resin and topcoat. This will effectively re-seal the composite so it’s as good as new in terms of watertightness. With that done, water or moisture cannot penetrate the laminate, and the blade will not delaminate or weaken. Empirical evidence from similar projects like FRP bridges shows that with proper installation, such structures remain maintenance-free for decades.
- **Lifecycle Benefits:** If we evaluate the lifecycle of the shelter, from material sourcing to end-of-life, the repurposed blade has significant environmental and economic benefits. Firstly, we give a second life to a large FRP component that would otherwise be waste this delays its eventual disposal by decades and reduces immediate landfill burden. During its second life, the blade continues to provide societal value as infrastructure without the need for additional manufacturing which would have environmental costs. At the end of its life as a shelter perhaps after 30-50 years or more, the blade could potentially be repurposed yet again tertiary use or finally disposed, depending on technological advances perhaps recycling methods will improve by then. In contrast, a series of traditional shelters over the same period would consume multiple sets of new materials and produce more waste. The embodied carbon in the blade from its original manufacturing is amortized over a longer useful period, improving its overall sustainability profile.

Economically, while an exact cost analysis is beyond our scope, one can argue that the lifecycle cost including maintenance of the blade shelter will be lower. The initial retrofit cost might be offset by the low maintenance and longevity. If scaled, there could even be a business in refurbishing blades into products, which can drive costs down through standardized processes. Additionally, there may be environmental credits or government incentives for using recycled materials that add to the value proposition.

- **Safety and Reliability:** Durability also ties into safety a structure that does not degrade is less likely to fail unexpectedly. The blade shelter, being durable, will maintain its structural integrity year after year, ensuring safety for the public. Traditional shelters that rust can become unsafe e.g. roof panels flying off or collapsing if supports weaken. Thus, the durability of FRP improves the **reliability** of the infrastructure.

One of the options is inspection, as FRP does not show apparent signs of deterioration like rust, it must be part of routine inspection e.g. 5 years to check for any hidden damage like stress cracks or UV crazing. Visual inspection and delamination tapping, etc. are simple non-destructive tests. Therefore, even though maintenance is minimal, early detection by proactive inspection ensures any flaw will be caught early. Fortunately, the slight stress and benign condition for the blade in this use case render issues moot.

By way of conclusion, the maintenance and longevity profile of the blade shelter indicates a robust lifecycle advantage. This accords with sustainable development ideals by providing robust infrastructure with minimal input of resources post-installation. It illustrates the way in which investing in quality by way of an upcycled high-performance item upfront can pay off over the long term through resilience and economy.

5.4 Feasibility and Implementation Considerations

Implementing repurposed wind turbine blade shelters in Kerala involves practical and logistical considerations, but our study indicates it is quite feasible.

- **Availability of Blades:** Kerala itself has limited wind installations, but neighboring states Tamil Nadu, Karnataka have wind farms and thus potential retired blades. The government or municipalities could liaise with wind energy companies to procure decommissioned blades. Often, these companies are seeking disposal solutions and might donate or sell cheaply the used blades, especially if it garners positive publicity. The size of blade needed for shelters is relatively modest 5–15 m segments. Even a single large wind turbine blade say 45 m could be cut into multiple shelter-sized segments. (Bank, L. C. et al., 2018) highlighted cutting strategies to extract useful segments from long blades. Thus, feasibility is high if a supply chain is established where old blades are transported to a central yard for processing into shelter components.

- **Fabrication and Skills:** Kerala has a strong boat-building industry fishing boats, houseboats which already works with fiberglass to some extent FRP boats. Those skills can be leveraged to cut, trim, and refurbish wind blades. The fabrication process would involve cutting the blade to length, adding internal stiffeners if needed and attachment brackets, and surface refinishing. Local universities or technical institutes could be involved in developing standardized procedures for this. The tooling needed diamond saws, drills for composites are not exotic. Safety measures dust masks, etc. are standard in fiberglass work. So, the region can develop the capability to convert blades into shelters, potentially spurring a small cottage industry or social enterprise around it. This also opens new employment opportunities in the green economy sector.
- **Design Adaptation:** Each site might have different requirements capacity, size. Blades come in various sizes, so matching a blade to a site is important. For instance, a smaller ferry stop might use only a 6 m tip section of a blade, whereas a bigger one might use a mid-section of 12 m. Our methodology can be repeated perform structural checks for each new configuration. However, one advantage is that re-use designs can be cataloged. Re-Wind Network's design catalog already includes things like bus shelters from blades (Sarah Lozanova, 2022). Kerala's public works could standardize, say, three types of blades shelter small, medium, large to fit different locations, and create a library of designs. This standardization improves feasibility as it streamlines fabrication and approval processes.
- **Community and Aesthetics:** It's worth considering the public perception. Aesthetically, blade shelters look different from the norm. The community might need to be introduced to the concept, possibly through a pilot installation. Given Kerala's populace is quite environmentally conscious, the idea of a recycled wind blade shelter might be well received as a statement of eco-friendliness. There may be initial curiosity or skepticism, but a well-executed pilot e.g., one high-profile boat terminal gets a blade shelter can demonstrate the benefits. Ensuring

the design has good finish smooth surfaces, attractive color will make it an architectural feature rather than just a reused object. In many cases globally, repurposed blades have been celebrated in architecture for their unique form for example, Denmark’s use of blades in a playground and bike shelters is seen as artful design (Sarah Lozanova, 2022).

- **Regulatory Approval:** Local building codes may not have precedents for FRP structures in public use. However, given that the structural performance is sound, engineers can certify the design like any steel or concrete structure. It might require some education of building officials and the development of guidelines for designing with decommissioned blades. Collaboration with structural engineers like those in the Re Wind Network could accelerate the approval process by providing design guides. The government could classify these projects under experimental or sustainable initiatives to ease procedural hurdles initially.
- **Pilot Project Recommendation:** To move from concept to reality, a pilot project is recommended. The Kerala Department of Water Transport which manages boat jetties could identify a suitable site perhaps a busy boat stops in Kochi or a touristy spot where visibility is high. Acquire a blade segment, do the necessary fabrication as per our design, and install the shelter. Monitor its performance over one monsoon season and a summer. This pilot would provide real-world validation though our analysis strongly indicates success. Based on the pilot, any tweaks can be made, and then a broader rollout plan can be formulated.

It’s worth noting that such a project could attract support and funding from sustainability grants or CSR corporate social responsibility programs of companies. The innovative aspect may also attract media attention, putting a positive spotlight on Kerala’s efforts to adopt circular economy solutions. In fact, a company in the UK ReBlade has already built a bus shelter from a wind blade (Garwood, 2025), showing that the concept is entirely feasible in practice. Learning from such examples, Kerala can leap ahead.

5.5 Recommendations for Local Government Adoption

For local government bodies in Kerala such as municipalities or the state’s transport authorities to successfully adopt this concept, the following recommendations are made.

- **Policy Support for Reuse:** Formally recognize decommissioned wind turbine blades as a resource for public infrastructure. This could be through a policy that encourages or mandates considering recycled materials in new projects. By doing so, departments will have the impetus to incorporate blade shelters in their planning. For example, a guideline could state that for new boat jetties or renovations, an assessment of using repurposed materials like wind blades must be conducted.

- **Inter-Departmental Collaboration:** Set up a collaboration between the Energy Department or renewable energy agency and the Public Works/Transport Department. The Energy Dept. can facilitate sourcing blades perhaps from projects in other states or upcoming repowering projects and funnel them to infrastructure projects. The Transport or Public Works can handle installation. This joined up approach ensures the supply and demand sides are connected.
- **Public-Private Partnerships (PPP):** Encourage PPPs where private companies handle the blade recycling and fabrication, and the government provides the installation site and funding. A company specializing in composite fabrication could be contracted to deliver ready to install blade shelter kits. This takes advantage of private sector efficiency and innovation. The government could even tender out the idea, inviting firms to propose blade shelter solutions for a certain number of sites, spurring competition and refinement of designs.
- **Training and Capacity Building:** Invest in training programs for engineers and technicians on the handling and reuse of composite materials. Local engineering colleges could include modules on composite re-use design. By building local capacity, the dependency on outside experts is reduced and long-term adoption becomes self-sustaining.
- **Community Engagement:** Before rolling out multiple blade shelters, run community engagement sessions. Explain the benefits durability, comfort, sustainability to local users so they feel pride and ownership of the new shelters. Address any concerns for instance, some might worry about lightning it can be clarified that a blade shelter can be equipped with a lightning arrestor just like a metal structure would be. Gaining public buy-in is crucial for any new public infrastructure concept.
- **Monitoring and Documentation:** As shelters are installed, keep a thorough record of their performance any maintenance issues, public feedback, etc. Documenting the success or challenges will help improve future designs and serve as evidence in support of the concept. If the shelters perform as expected

which we anticipate, given the analysis, this documentation can be used to justify funding and expanding the program. It can also contribute to academic knowledge Kerala could become a case study site for large-scale architectural reuse of wind blades, adding to global literature.

- **Scaling Up and Other Applications:** Once blade shelters are proven for boat stops, the government can expand the idea to other infrastructure. Bus stops, pedestrian shelters, footbridges, roofing for marketplaces there are many possibilities. In fact, the Re-Wind Network's work suggests applications like footbridges and powerline poles (Sarah Lozanova, 2022). Kerala could become a leader in this domain by progressively using blades in diverse projects, aligned with its emphasis on sustainability the state has been progressive in waste management and green building in other areas, so this fits well.

In its recommendation for adoption at the municipal level, referencing cost-sharing and financing too is of the highest importance. Even if the blades are given for free, installation and retrofitting cost money. It ought to compare them with the total life costs of a regular shelter, as highlighted above, perhaps to its advantage. Foreign party climate resilience or circular economy finance might be availed. Also, incorporating local artists or architects to design the shelters not only functional but also culturally significant perhaps painted with native artwork could create tourism interest, and indirectly supporting communities.

Finally, the government must introduce or update any relevant building codes or guidelines to include FRP structures guidance. This will provide a clear framework for engineers to design and sanction such projects. By way of example, establishing a standard for Design of Shelters using Recycled FRP Blades to be added in the Public Works engineering guide would make it a standard practice.

Chapter 6 : Conclusion

In this research, we have established that the recycling of a decommissioned wind turbine blade as a boat waiting shed in Kerala is not only structurally and thermally viable but also offers superior performance to traditional alternatives. The methodology involved careful design, simulation, and review of available literature, all of which confirm the hypothesis that FRP wind blades can have valuable second lives. The results have exhibited excellent safety margins and environmental acceptability, and the discussion has set out a clear route to implementation.

By such innovative recycling, Kerala will be endowed with durable infrastructure and aid in resolving a global waste issue. This project can serve as an example for the identical type of enterprise anywhere reconverting probable trash into community asset. The combination of engineering study and ecological design displayed in this work is aligned with the goals of resilient and resource-effective communities. We recommend that stakeholders move forward with pilot projects to transform this concept into actual enhancement in the lives of the citizens of Kerala's backwater settlements. Through commitment and creative coordination, the dream of wind turbine blade shelters can be transformed into an actual phenomenon, a giant leap towards green civil engineering and design.

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1.

Appendices A : Approved Ethical Form

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LEVIN ROBERT
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Supervisor: Love, David
LREC: White, Mike

Sustainable Design of Boat Service Waiting Shelters Using Decommissioned Wind Turbine Blades

WILL YOUR RESEARCH STUDY.....?

Please answer the following:

1 Involve direct and/or indirect contact with human participants? No

2 Involve analysis of pre-existing data which contains personal or sensitive information not in the public domain? No

3 Require permission or consent to conduct? No

4 Require permission or consent to publish? No

5 Have a risk of compromising confidentiality? No

6 Have a risk of compromising anonymity? No

7 Collect / contain sensitive personal data? No

8 Contain elements which you OR your supervisor are NOT trained to conduct? No

9 Use any information OTHER than that which is freely available in the public domain? No

10 Involve respondents to the internet or other visual/vocal methods where participants may be identified? No

11 Include a financial incentive to participate in the research? No

12 Involve your own students, colleagues or employees? No

13 Take place outside of the country where you are enrolled as a student, or for staff, outside of the UK? No

14 Involve participants who are particularly vulnerable or at risk? No

15 Involve participants who are unable to give informed consent? No

16 Involve data collection taking place BEFORE informed consent is given? No

17 Involve any deliberate deception or covert data collection? No

18 Involve a risk to the researcher or participants beyond that experienced in everyday life? No

19 Cause (or could cause) physical or psychological harm or negative consequences? No

20 Use intrusive or invasive procedures? No

21 Involve a clinical trial? No

22 Involve the possibility of incidental findings related to health status? No

23 Fit into any of the following security-sensitive categories: concerns terrorist or extreme groups; commissioned by the military;
commissioned under an EU security call; involve the acquisition of security clearances?
If you believe you may need to answer yes to this question, please check here for further guidance before finalising your decision.
No

RISK CATEGORY 1

Student Applicants

https://researchethics.leedsbeckett.ac.uk/print/view/140609 1/3

PROJECT SUMMARY

Start date of project

21st November 2024

Expected completion date of project

1st October 2025

Externally Funding

Is this project externally funded? No

Project Summary

Please give a brief summary of your study (maximum 100 words).

This dissertation addresses the innovation in the design of decommissioned wind turbine blades for sustainable boat-service-waiting shelters. The research will make an effort to contribute to the solution of one of the most critical environmental challenges: wind turbine blade disposal, by reusing them for functional, durable, and ecological friendly infrastructure. Through material analysis, development of design, and simulation of real-world conditions-wind load, rain, and thermal stress-the study evaluates the feasibility and performance of such shelters. This project exemplifies the upcycling of wind turbine blades in urban settings as a potential contribution to sustainable development in ways that limit waste accumulation and foster resilient public infrastructure.

Project Group Members

Is this a group project? No

RISK CATEGORY 1: DECLARATION

Comply with Policy and Procedures

Yes : I confirm that I have read the Research Ethics Policy and relevant sections of the Research Ethics Procedures and will adhere to these in the conduct of this project.

Confirmation

Yes : I confirm that I will undertake this project as detailed in the application. I understand that I must abide by the terms of this approval and that I may not make any substantial amendments to the project without further approval.

Benefits

Yes : The results of the research should benefit society directly or by generally improving knowledge and understanding. Please tick this box to confirm that your study has a potential benefit.

Note: If you cannot identify a benefit you must discuss your project with your Research Supervisor to help identify one or adapt your proposal so the study will have an identifiable benefit.

Learned Societies

I have read an appropriate professional or learned society code of ethical practice: Yes

Where applicable, give the name of the professional or learned society:

The Engineering Council and Royal Academy of Engineering

SUBMISSION CHECKLIST

Please indicate the supporting documents submitted by ticking the appropriate boxes below:

For projects involving human participants, you must submit, where appropriate, the Participant Information Sheet/consent form. You must also submit every communication a participant will see or receive. Failure to do so will cause delays to the application.

N/A : Participant Information Sheet(s)

N/A : Consent Form(s)

N/A : Assent Form (usually for children participants)

N/A : Recruitment documents eg, posters, flyers, advertisements, email invitations, letters, web pages if online research

N/A : Measures to be used eg, questionnaires, surveys, interview schedules, psychological tests

N/A : Screening questionnaire

N/A : Letters/communications to and from gatekeepers/third parties

N/A : Evidence of any other approvals or permissions eg, NHS research ethics approval, in-country approval

N/A : Research proposal/protocol (no more than 2-3 A4 pages): It is not a requirement that this is included, however, if this would help the understanding of a complex project by the reviewer(s), please include

N/A : Risk assessment from: Some projects may require a risk assessment form: see the Procedures document for details (eg, projects involving a physical intervention, collecting data off-campus)

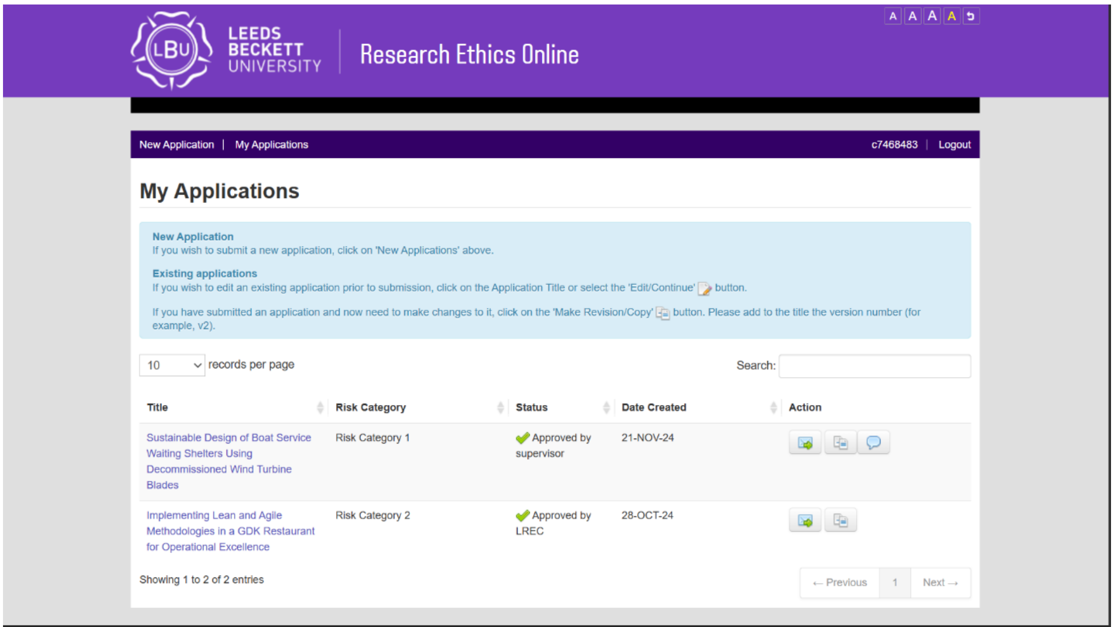
N/A : Approval documentation for projects involving ionising radiation

N/A : Confirmation of insurance and indemnity cover: Some projects need to be referred to the Insurance & Risk Officer: see the Procedures document for details

N/A : Other document/s

File uploads

Please upload your files here:



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10 records per page Search:

Title	Risk Category	Status	Date Created	Action
Sustainable Design of Boat Service Waiting Shelters Using Decommissioned Wind Turbine Blades	Risk Category 1	Approved by supervisor	21-NOV-24	
Implementing Lean and Agile Methodologies in a GDK Restaurant for Operational Excellence	Risk Category 2	Approved by LREC	28-OCT-24	

Showing 1 to 2 of 2 entries ← Previous 1 Next →

Appendices B : SolidWorks Model Image and Model File

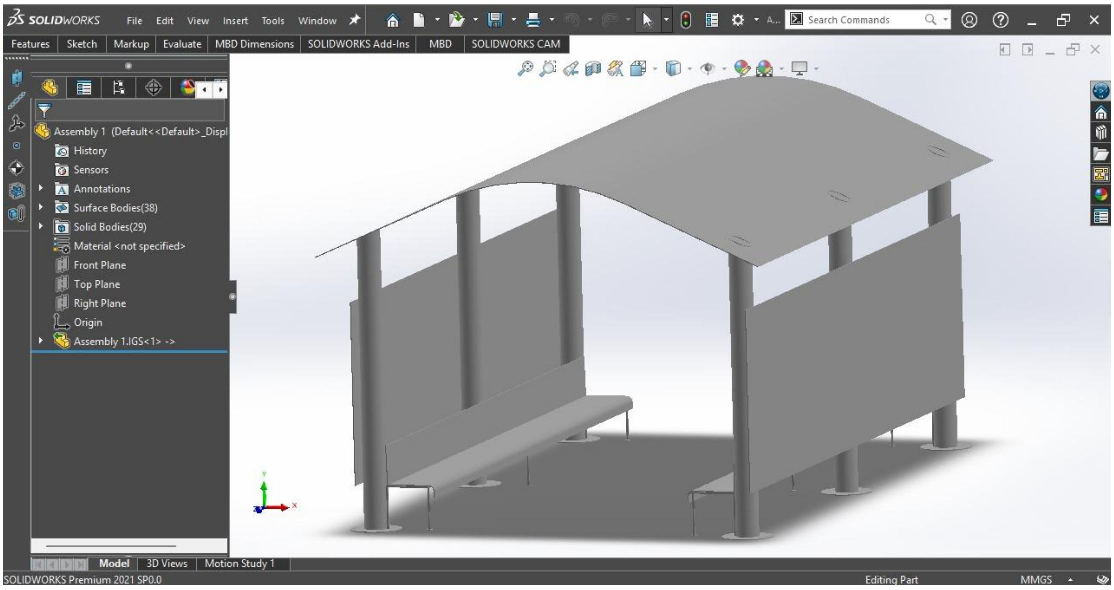

Figure 13 - Solidworks Model Image

Github link For SolidWorks model IGES File:

https://github.com/levinrbrt/Dissertation/blob/64a3045ee85f9d25a93c51c2b88e7de9b58a37fd/First%202.IGS