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Construction Assessment Framework of Electrical Transmission Structures from Decommissioned Wind Turbine Blades

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ABSTRACT

Wind energy is widely deployed and plays a key role in reducing the world's dependency on fossil fuels. The first generation of wind turbines is now coming to the end of their service lives, and there are limited options for the reuse or recycling of the composite materials in the wind turbine blades. Wind turbine blades are composed of glass or glass and carbon fibers in a thermosetting polymer matrix, along with core materials including polymer foams and balsa. The nature of the composite materials and the monocoque construction of wind blades make it highly energy intensive to separate the materials and the parts for reuse. Most decommissioned wind blades are either landfilled or incinerated, due to the low cost of these processes. This paper reports on a novel case study to remanufacture decommissioned wind turbine blades and redeploy the blades as the primary load-carrying elements for high-voltage electrical transmission line structures. This research focuses on the development of an information framework for the material, environmental, and cost analyses for the successful repurposing of decommissioned construction elements. The framework utilizes material flow analysis to assess the amount of material used at each stage of the process and its environmental and cost implications.

INTRODUCTION

Wind turbines have been powering renewable energy for a few decades now, and for the first time in U.S. history, renewable energy of all types surpassed coal energy production in 2020 (BCSE 2021). While on one hand this is promising for the renewable energy industry, on the other hand it has also increased the amount of non-biodegradable blade waste. Cooperman et al. (2021) estimated in their sensitivity analysis that the projected decommissioned wind turbine blades total weight by 2050 will range from 1.53 to 2.75 million tonnes. Work by our team indicates the potential for even larger amounts of waste due to current trends in repowering of wind turbines (Bank et al. 2021). Therefore, it is imperative that current research focuses on finding the most cost effective and environmentally friendly way of providing solutions for current and future wind turbine blades coming out of service.

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Currently, wind turbines are not designed to follow the fundamental tenants of the circular economy, whereby materials from decommissioned wind turbines are used in the creation of new structures or products. Rather, like most products in civil engineering construction, wind turbines still follow a linear economy paradigm from production to operation to disposal without a sustainable end-of-life reuse solution. Wind turbine blades are made of glass (or glass and carbon) fiber reinforced polymer (FRP), balsa wood, polyethylene, and copper wiring and separating these materials at the end-of-life is an extremely high energy intensive and polluting process (Cooperman et al. 2021). In a linear economy, end-of-life solutions focus on disposing of the material in incineration facilities or landfills (Cooperman et al. 2021). Some potential solutions for recycling FRP composites that have been studied to-date include cement coprocessing, mechanical recycling, high-voltage fragmentation, thermal recycling, chemical recycling (hydrolysis and solvolysis) (Cooperman et al. 2021). However, these processes often reduce the overall value of the recycled materials produced.

Repurposing the material in the wind turbine blades is needed to preserve the highest possible value. When a structural element reaches its end-of-life, we assert that there are three scales for reuse: element scale, aggregate scale, and molecular scale (Gentry et al. 2020). At the element scale, the wind blade is reused in its entirety or in large sections, and the nature of the continuous fiber-reinforced composites and the structure are preserved. At the aggregate scale, the composite materials are separated into centimeter size pieces or ground to milli- to micrometer sized particles and used as reinforcements or fillers in concrete or in other products (Yazdanbakhsh et al. 2018). At the molecular scale, the resins revert to monomers for use in new polymers, and the fibers are recovered in short strands. In general, energy inputs to recycle materials goes up as the scale decreases. The case of cement production from co-processing is a special case of the molecular scale, as the hydrocarbon-based resins are burned as fuel and the oxides of silicon, calcium and iron in the glass fibers are used in the production clinker for Portland cement.

This paper focuses on reuse at the element scale. If full material repurposing measures were set in place, we could divert over 1 million tonnes of global blade material waste annually (Bank et al. 2021). However, reuse and repurposing research is still in its initial stages of design and implementation. This paper will focus on wind turbine blades because they present a more challenging recycling problem. The remainder of the turbine is composed primarily of concrete, steel and copper, and there are well-known processes for reusing and recycling these materials. The product that will be evaluated in this study is wind turbine blades repurposed as high voltage transmission power poles (Alshannaq et al. 2021), which will be called the BladePole (Al-Haddad et al. 2021). This paper focuses on providing the material, cost, and ecological framework for decommissioned civil engineering construction elements with the BladePole application as a test use case.

LITERATURE REVIEW

Circular economy implementation in construction in the US is still in its infancy. According to Hossain et al (2020), most of the research on the circular economy in construction has been conducted in Europe and Asia; very little has been conducted in North America. Therefore, more research on the circular economy and more specifically infrastructure material recirculation and feasible material repurposing methodologies is necessary in North America (Joensuu et al. 2020). Current research focuses on deconstruction as reverse construction to salvage infrastructure material. For example, Berg et al. (2021) demonstrated the importance of analyzing existing

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conditions, labelling elements, and applying deconstruction demolition for the recovery of infrastructure waste material.

Contemporary research has focused on circular economy solutions for recycling construction and demolition waste (Zhao et al. 2010) and less on the reuse of infrastructure demolition waste based on minimum material modification. Several environmental consequences have been directly related to the current recycling solutions (Ramirez-Tejeda et al. 2017) including release of methane, other volatile organic compounds (VOCs), pollutants, and the use of hazardous chemicals for reprocessing. In addition, in many cases the overall value of the recycled product has been significantly reduced from the initial value.

Additionally, collaboration between stakeholders in the building and construction industry is inefficient due to their personal interests and lack of personnel training/education related to integrated collaboration (Volk et al. 2014). Information exchange between stakeholders is one of the biggest challenges to successful deconstruction and repurposing process for infrastructure waste (Jayasinghe et al. 2019). Moreover, because there is no consolidated platform for stakeholders to interchange information, stakeholder collaboration has the potential to remain ineffective. Volk et al. (2014) determined in their literature review that deconstruction procedures and frameworks are not implemented due to time and cost constraints.

Previous research has focused on economic analysis of recycling or disposing construction waste that often reduces the initial value of the product. To address these concerns, recently-completed research focuses on the design of a framework for construction, building operations and maintenance (McArthur 2015), information processing model for building end-of-life coordination (van den Berg et al. 2020), the post end-of-life building (PEoLB) concept with reverse supply chain (Jayasinghe et al. 2019), and energy flow for closed-loop recycling of construction and demolition waste (Yuan et al. 2011). These frameworks inform our goal to develop a generalizable workflow for decommissioned construction elements, which will require the analysis of detailed operational processes to characterize material flows and the subsequent tabulation of costs and ecological impacts.

Frameworks for decommissioned construction elements have been developed in previous research for applications with similar reuse purposes (Hradil et al. 2014) and as an indirect/direct matching between deconstructed building elements and a potential future uses (Ali 2017). The building elements in these studies have well-known physical properties and cross sections. Zhao et al. (2010) describes a methodology that focuses on estimating the generation of waste and the subsequent market analysis, estimated costs, and investments required for the recycling of construction and demolition waste. Zhao focuses on recycling construction materials instead of reusing or repurposing them. Therefore, this paper expands these frameworks to develop an end-of-life framework for repurposing decommissioned construction elements. EPRI (2020) developed a techno-economic analysis (TEA) model for the recycling of thermoset composite materials, including: thermal methods, mechanical methods, cement co-processing, landfilling, and incineration. We adopt their framework is the point of departure for the analysis of electrical transmission structures from decommissioned wind turbine blades. Our research goes beyond EPRI (2020) by moving past recycling and disposal alternatives and implementing assessment of reuse options through a material, cost, and ecological process model.

METHODOLOGY

Case-Study: The BladePole is a concept that focuses on using decommissioned wind turbine blades as energy transmission power poles (Alshannaq et al. 2021). Wind turbine blades are targets

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for reuse due to their high first cost and high-quality material that they are constructed from, and from our material and structural investigations that have shown that the blades have significant residual strength and stiffness when they are decommissioned. Furthermore, because of their large size, disposing of the materials entails a great cost and complexity (Cotrell et al. 2014). Also, given the demonstrated need for improvements to the U.S. energy grid, high voltage power structures have a high potential for implementation in large quantities.

The wind turbine blade used for this study is the GE37 (37 m/125 ft long) glass fiber composite material made in 2009 and decommissioned from the Langford wind farm in Texas, USA. Materials from this blade were procured by our team starting in 2020 for testing and prototyping due to this type of blades coming out of service in the near future. Previous research by the Re-Wind team includes design of end-of life alternatives (Bank et al., 2018; Delaney et al. 2021) structural analysis (Alshannaq et al. 2021; Gentry et al. 2020) and life cycle assessment (Nagle et al. 2020) of wind turbine blades. This case study advances the work by analyzing the material flow, costs, environmental impacts, and construction processes required for the successful implementation of the BladePole. In the text that follows the stakeholders in the case study are presented, followed by an introduction to material flow analysis and a detailed process model for creation of the BladePole.

Table 1. Information flow requirements by stakeholder

	BladePole Designer	**Blade Supplier**	**Transport. Provider**	**Hardware Supplier**	**Power Company**	**Foundation Subcontractor**	**Installation Subcontrac.**
Inputs	Material specifications BladePole design requirements	BladePole demand	Location Blade quantity Size	Quantity Length Hardware configuration	Energy transmission requirement	Geotechnical report Location Foundation loads	Blade weight and height Site accessibility
Outputs	Conceptual idea BladePole A/E design	Blade location Blade quantity	Transport. cost Pick-up and delivery date	Hardware specifications Hardware delivery dates	Power pole demand Project location	Construction schedule Labor required	Crane size Labor required Work schedule

Stakeholders: Based on the limitations of previous research about recycling construction waste, this study aims to develop a comprehensive framework that integrates communication between stakeholders. To achieve this, this paper focuses on studying the interrelations between material, cost and ecological data associated with different economic activities that are crucial for the BladePole development: decommissioning, transportation, hardware procurement, product design, product modifications, and installation.

We start this process by evaluating the stakeholders (Table 1) that directly affect the completion of the project and provide relevant data to the process. The stakeholders are the people, companies or organizations that are directly involved in the processes of sourcing, designing, remanufacturing, transporting, and installing the reuse elements. The framework depends on describing each stakeholder and acquiring the data about the costs and time required for each activity to take place as well as the requirements involved in the successful completion of the activity. The stakeholders are characterized by their inputs and outputs, where the inputs represent the information and materials required for their processes, and the outputs represent the updated information and/or revised materials produced by each process step. Some stakeholders, such as designers, consume and produce information, whereas other stakeholders consume raw materials

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and produce value-added materials and waste as part of their process steps. It is critical to track both information and material flows, as both of these flows add cost to the reuse product.

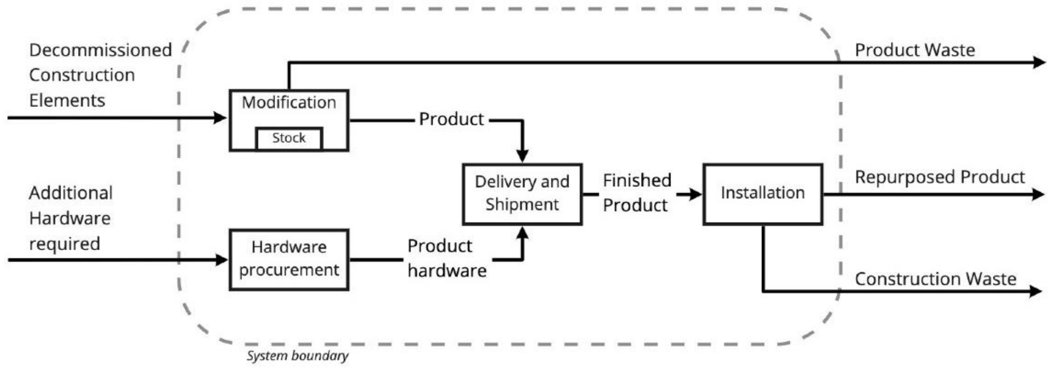

Figure 1 Material Flow Analysis illustrating inputs, outputs, processes, and the creation of value-added goods. Source referenced for diagram: (Brunner & Rechberger 2017)

Material Flow Analysis: To capture the changes of material as it moves through the economic system, our research is focused on material flow analysis (Brunner & Rechberger 2017). The analysis starts from the input of decommissioned wind turbine blades (the stock or "reservoir" of wind turbine blades), the necessary modifications to be performed, the power pole hardware added for the electrical utility, and the installation of the product at the site. At the end of the analysis (outputs in Figure 1), we present the "sinks" as waste products from the modification process, repurposed products, and construction waste from the installation process. Because the goal of this research is to predict the amount of decommissioned construction elements that can be diverted through this repurposing process, material flow analysis (MFA) separates material and processes to calculate the quantities at each process step boundary. Mass conservation is a pillar of MFA and supports our assessment of "circularity" by ensuring that inputs must equal the outputs and that all materials are accounted for at each step of the process. The MFA flowchart presented in Figure 1 describes the building blocks for the MFA analysis and identifies the key, inputs, outputs, processes, and products.

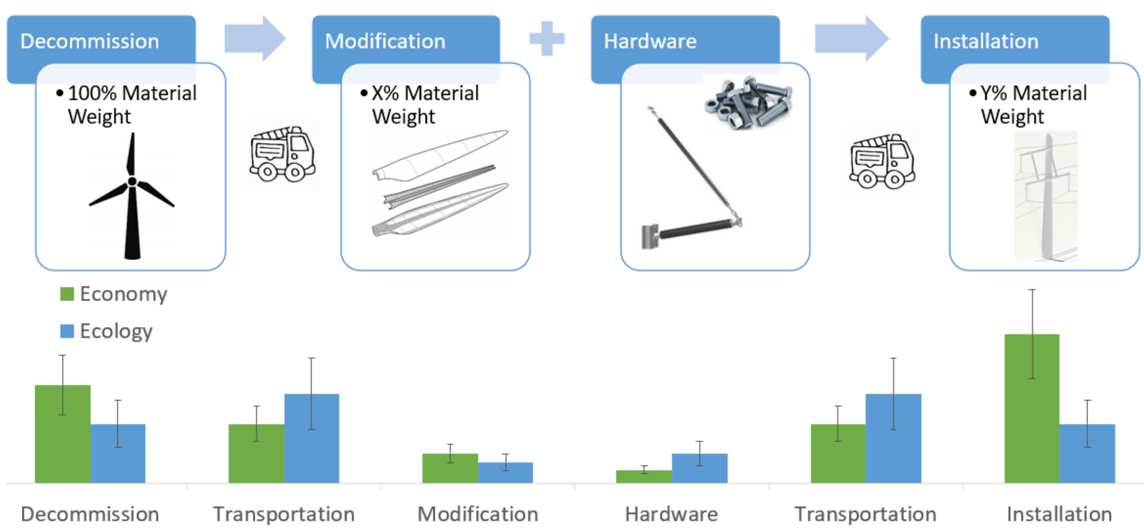

Figure 2 Data Collection: High Level Material Process.

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After establishing the data requirements and the sourcing the data created by each stakeholder, we introduce a high-level process from the moment the material (wind turbine blade) is decommissioned until the BladePole is installed (Figure 2). The environmental efficacy of the proposition is determined by the percentage weight of the blade that is retained in the value-added product at each stage (Nagle et al. 2020). The weight fractions that are not used for the end product must be evaluated and based on the end-of-life mechanism for this residual fraction, e.g., recycling at the aggregate or molecular scale or disposal via landfill/incineration.

Additionally, cost and ecological data are collected at each stage of the process and are key elements of the framework. Similar to Cooperman et al (2021) and James (2014), we intend to obtain the cost information from experts in the decommissioning, transportation, hardware, and installation industry. This work is ongoing as of this writing. Once the data is collected, the variances in total cost can be determined by the standard deviation between the cost data collection of several stakeholders and is represented by a confidence interval of cost variation—as implied by the standard deviation bars in Figure 2. The total cost results for each stage will help pinpoint what stages are significant when performing a sensitivity analysis in our future research. And the economic viability of the BladePole will come from our analysis of total mean cost (and consideration of variance) as compared to the cost of current steel and concrete structures used for high voltage transmission structures. The current work focuses on economic analyses however the framework will allow us to extend it into an ecological feasibility analysis (Nagle et al. 2020).

DETAILS OF CASE STUDY:

The stakeholders (Table 1), their activities, and the data exchanges between stakeholders are presented in Business Process Model Notation (BPMN) as a detailed process model that presents the information and material flow between stakeholders and the required activities (Figure 3). The data exchanges contain key model and non-model data. Model data is defined as that information that can be shared through modeling software such as Revit, AutoCAD, etc, while non-model data are generally less well-structured data such as load tables, cost estimates, specifications. We are specific in this regard as other aspects of this research focus on the structuring and automation of information flows as a means of reducing costs and risks with the design and engineering tasks associated with structural reuse of infrastructure elements (Tasistro-Hart et al. 2019).

We present the decommission, modification, transportation, and installation phases (Figure 3 and 4) with detailed information required so that experts can provide detailed data estimates for each process step. This can help improve the information communication process between stakeholders. The blue horizontal swim lanes represent data exchanges, and the yellow lanes represents process steps by stakeholder. Data exchanges swim lanes provide material, cost, and ecology data exchanged between stakeholders. The process model is structured based on our preliminary interviews with transportation providers, electric utility designers and installers, wind farm owners, and wind turbine OEMs and maintenance experts.

The early stage processes (Figure 3) show that the case for structural reuse of construction elements differs from traditional design and construction processes as "design" is performed after the construction element is decommissioned and assessed, and these two processes are directly dependent on each other due to the non-traditional materials (glass fiber composites) and variable geometry of the wind turbine blades. The BladePole designer and the material supplier (wind farm owner) exchange non-model data related to material requirements and specifications; this information is key for successful material assessment and its BladePole implementation. In

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addition, the power company and the BladePole designer exchange information about the requirements and specifications for a successful design of the final product. Therefore, the framework presented ensures that the BladePole complies with transmission pole requirements such as required height and clearances, electricity conductivity, transmission hardware requirements, and structural integrity of the material.

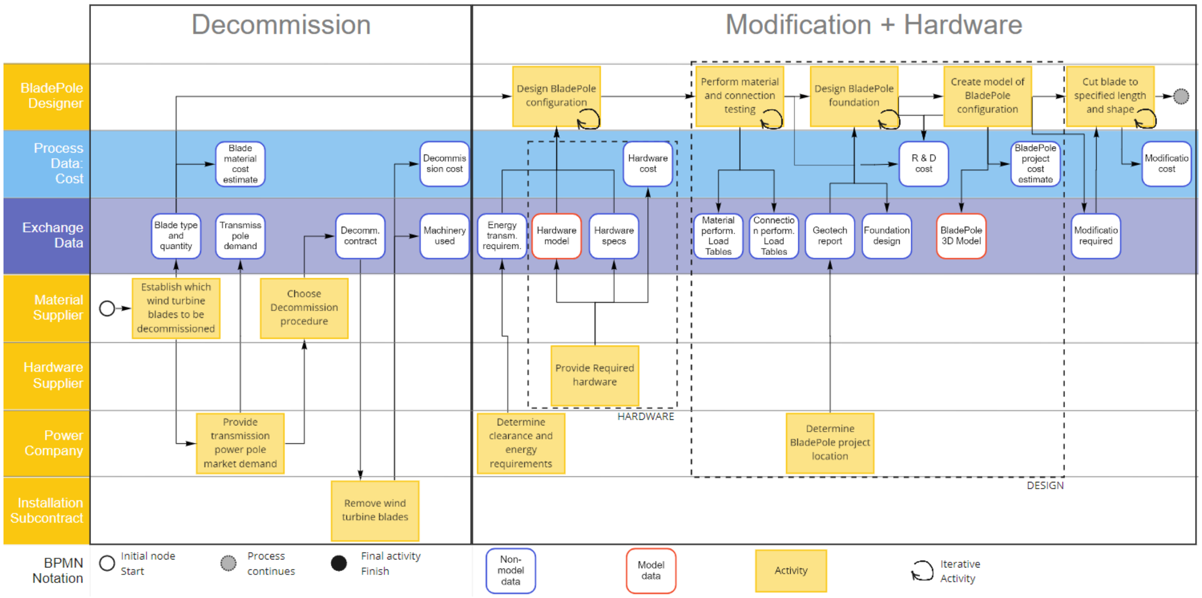

Figure 3 Business Process Model Notation of decommission and modification processes from wind turbine blade to energy transmission tower.

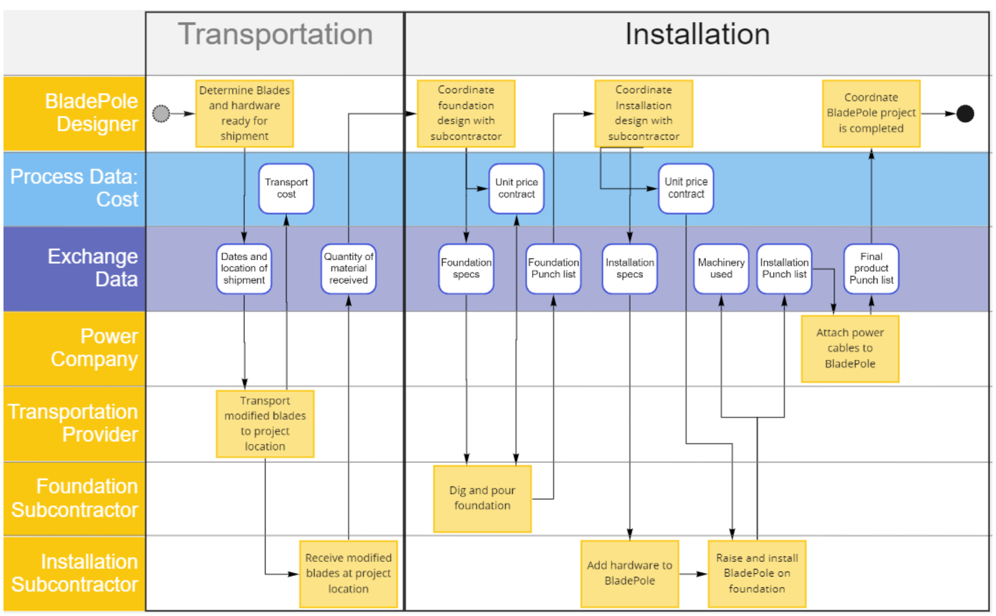

Figure 4. Business Process Model Notation of transportation and installation processes from wind turbine blade to energy transmission tower.

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The information exchange between the power company and the designer about the product demand and project location directly affect the project cost while the data exchange between the BladePole designer and the transportation provider (Figure 4) refers to material quantity and material location, which are key for cost estimation and supply chain analysis. A more detailed selection of key exchanges of information and materials, the costs embodied, the informational and constructional risks, and how the process model identifies and quantifies them is presented in Table 2.

Table 2 Key information, material, cost, and risks associated with the framework

	Decommission	Modification	Hardware	Transport.	Installation
Key information exchange	Blade type and quantity vs. transmission pole demand	BladePole 3D model: modification required	Hardware specifications	Blade location: origin and destination	BladePole model: installation
Key material exchange	Blades from wind farm to BladePole designer	Change in blade length or volume	Hardware exchanged	Blade quantity to be transported	Total blade installed compared to initial
Costs embodied	Cost per blade decommissioned	Cost per blade cut	Cost per hardware required	Cost per mile of blade transported	Cost per blade installed
Informational risks (Example)	Blade condition and quality and BladePole demand accuracy	Power pole requirements not met by wind blades	Hardware that may not work for all scenarios	Blades ready to be shipped coordination	Coordination between foundation and installation
Constructiona l risks (Example)	Decommissioned blades handled with care	Material soundness after modifications	Potential special hardware development	Transportation safety	Potential special equipment requirement
How the process model identifies risks	By identifying the sequencing between process' activities, information (material, cost, ecology) required, and stakeholder involvement, the process model presented in Figure 3 can identify issues ahead of time and fast track what needs to be done, who is responsible, and what are the affected activities.				

In general, one of the highest expenses when it comes to large asymmetrical elements like wind turbine blades is installation, especially, when repurposing solutions include the use of most or the entire blade. Additionally, there are several transportation and logistics challenges (Cotrell et al. 2014): the longer the length, the higher the price of transportation. Therefore, it is key to compare the use of the entire length of the blade or the modified blade before transporting and installing it.

CONCLUSIONS AND FUTURE RESEARCH:

This paper develops a framework for information, material, cost, and ecological analysis for reuse of decommissioned civil engineering construction elements, through the specific case of conversion of de-commissioned wind blade into power transmission structures. This framework acknowledges the complexity of redesign and the need for enhanced information requirements in redesigned scenarios (Ali 2017). The framework presented formalizes the non-standard processes required to realize new products from civil engineering decommissioned elements. Through the fusion of information process modeling with material flow analysis, our research considers both soft processes (design and engineering) and the cost of hard processes (remanufacturing, transportation, and installation). The combined information and material flow analysis is presented as in BPMN notation considering all design, remanufacturing, and installation processes. In Figure 2 we postulate ecological impact and economic costs of each of the process steps of creating the

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BladePole and future work with experts will validate the cost model and assess the risks and cost variances in each of the major process steps.

Contemporary research must focus on the economic feasibility analysis of circular economy solutions beyond the evaluation on recycling facilities for construction and demolition waste (Zhao et al. 2010) and evolve to the reuse of structural elements with minimum material modification. In the future, this framework will underpin an extensive data-gathering process to quantify the economic and ecological implications at each of the process steps demonstrated in this paper. While this study presents the process framework for material, cost, and ecological data collection and analyses for decommissioned construction elements, future research will implement this framework in a stakeholder integrated process that collects expert opinions and validates the proposed process model. This future research will focus on quantifying the cost of each activity in the process and the associated inherent informational and constructional risks.

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REFERENCES

Al-Haddad, T., Gentry, R., Bank, L., Alshannaq, A., Pye, J., and Bermek, M. (2021). Systems and Methods for Repurposing Retired Wind Turbines as Electric Utility Line Poles (Patent No. WO/2021/026198). https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2021026198&_cid=P20-KPML4H-00697-2.

Ali, A. K. (2017). Architecture within a circular economy: Process mapping a resource-based design-bid-build project delivery system. *Enquiry The ARCC Journal for Architectural Research*, 14(1), 48–61.

Alshannaq, A. A., Bank, L. C., Scott, D. W., and Gentry, T. R. (2021). Structural Analysis of a Wind Turbine Blade Repurposed as an Electrical Transmission Pole. *Journal of Composites for Construction*, 25(4), 04021023.

Bank, L. C., Arias, F. R., Yazdanbakhsh, A., Gentry, T. R., Al-Haddad, T., Chen, J.-F., and Morrow, R. (2018). Concepts for Reusing Composite Materials from Decommissioned Wind Turbine Blades in Affordable Housing. *Recycling*, 3(1), 3.

Bank, L. C., Delaney, E. L., McKinley, J., Gentry, R., and Leahy, P. G. (2021). Defining the landscape for wind blades at the end of service life. Composites World. https://www.compositesworld.com/articles/defining-the-landscape-for-wind-blades-at-the-end-of-service-life.

BCSE. (2021). 2021 Sustainable Energy in America Factbook. BCSE. https://bcse.org/factbook/.

van den Berg, M., Voordijk, H., and Adriaanse, A. (2021). BIM uses for deconstruction: An activity-theoretical perspective on reorganising end-of-life practices. *Construction Management and Economics*, 39(4), 323–339.

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Brunner, P. H., and Rechberger, H. (2017). *Handbook of material flow analysis: For environmental, resource, and waste engineers* (Second Edition). CRC Press, Taylor & Francis Group.
Cooperman, A., Eberle, A., and Lantz, E. (2021). Wind turbine blade material in the United States: Quantities, costs, and end-of-life options. *Resources, Conservation and Recycling*, 168, 105439.
Cotrell, J., Stehly, T., Johnson, J., Roberts, J. O., Parker, Z., Scott, G., and Heimiller, D. (2014). Analysis of Transportation and Logistics Challenges Affecting the Deployment of Larger Wind Turbines: Summary of Results (NREL/TP--5000-61063, 1123207; p. NREL/TP--5000-61063, 1123207).
Delaney, E. L., McKinley, J. M., Megarry, W., Graham, C., Leahy, P. G., Bank, L. C., and Gentry, R. (2021). An integrated geospatial approach for repurposing wind turbine blades. *Resources, Conservation and Recycling*, 170, 105601.
EPRI. (2020). Wind Turbine Blade Recycling: Preliminary Assessment. https://www.epri.com/research/products/000000003002017711.
Gentry, T. R., Al-Haddad, T., Bank, L. C., Arias, F. R., Nagle, A., and Leahy, P. (2020). Structural Analysis of a Roof Extracted from a Wind Turbine Blade. *Journal of Architectural Engineering*, 26(4), 04020040.
Hossain, M. U., Ng, S. T., Antwi-Afari, P., and Amor, B. (2020). Circular economy and the construction industry: Existing trends, challenges and prospective framework for sustainable construction. *Renewable and Sustainable Energy Reviews*, 130, 109948.
Hradil, P., Talja, A., Wahlström, M., Huuhka, S., Lahdensivu, J., and Pikkuvirta, J. (2014). *Re-use of structural elements: Environmental efficient recovery of building components* (p. 74).
James, T., and Goodrich, A. (2014). "Supply Chain and Blade Manufacturing Considerations in the Global Wind Industry." NREL/PR-6A20-60063. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy14osti/60063.pdf.
Jayasinghe, R. S., Rameezdeen, R., and Chileshe, N. (2019). Exploring sustainable post-end-of-life of building operations: A systematic literature review. *Engineering, Construction and Architectural Management*, 26(4), 689–722.
Joensuu, T., Edelman, H., and Saari, A. (2020). Circular economy practices in the built environment. *Journal of Cleaner Production*, 276, 124215.
Nagle, A. J., Delaney, E. L., Bank, L. C., and Leahy, P. G. (2020). A Comparative Life Cycle Assessment between landfilling and Co-Processing of waste from decommissioned Irish wind turbine blades. *Journal of Cleaner Production*, 277, 123321.
Ramirez-Tejeda, K., Turcotte, D. A., and Pike, S. (2017). Unsustainable Wind Turbine Blade Disposal Practices in the United States: A Case for Policy Intervention and Technological Innovation. *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy*, 26(4), 581–598.
Tasistro-Hart, B., Al-Haddad, T., Bank, L. C., and Gentry, R. (2019). *Reconstruction of Wind Turbine Blade Geometry and Internal Structure from Point Cloud Data*. 130–137.
van den Berg, M., Voordijk, H., and Adriaanse, A. (2020). Information processing for end-of-life coordination: A multiple-case study. *Construction Innovation*, 20(4), 647–671.
Volk, R., Stengel, J., and Schultmann, F. (2014). Building Information Modeling (BIM) for existing buildings—Literature review and future needs. *Automation in Construction*, 38, 109–127.

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Yazdanbakhsh, A., Bank, L., and Tian, Y. (2018). Mechanical Processing of GFRP Waste into Large-Sized Pieces for Use in Concrete. *Recycling*, 3, 8.
Yuan, F., Shen, L., and Li, Q. (2011). Emergy analysis of the recycling options for construction and demolition waste. *Waste Management*, 31(12), 2503–2511.
Zhao, W., Leeftink, R. B., and Rotter, V. S. (2010). Evaluation of the economic feasibility for the recycling of construction and demolition waste in China—The case of Chongqing. *Resources, Conservation and Recycling*, 54(6), 377–389.

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