

## Digital Twin modelling for Offshore Wind Farms

\***M. Bhati**<sup>1</sup>, **F. Goerlandt**<sup>1</sup>, **R. Pelot**<sup>1</sup> and **S. Scholtysik**<sup>2</sup>

<sup>1</sup>Department of Industrial Engineering, Dalhousie University, Halifax, Canada

[madhulika.bhati@dal.ca](mailto:madhulika.bhati@dal.ca), [floris.goerlandt@dal.ca](mailto:floris.goerlandt@dal.ca), [ronald.pelot@dal.ca](mailto:ronald.pelot@dal.ca)

<sup>2</sup>Net Zero Atlantic, The Pier, Halifax, Canada

[sscholtysik@netzeroatlantic.ca](mailto:sscholtysik@netzeroatlantic.ca)

### Background

Digital Twins (DTs) are real-time virtual models that replicate physical systems by integrating data, advanced modelling, and simulations. In offshore wind farms (OWFs), DTs can represent individual turbines, components, or entire farms, helping to improve OWFs’ efficiency.

Traditional approaches often assess OWF efficiency and ecosystem health separately, such as monitoring turbine performance through operational data, while environmental assessments track species distribution or habitat quality independently. This isolation can miss the crucial interactions between the two systems. A DT helps overcome this gap by establishing a two-way link. It integrates operational data from OWFs (such as noise, vibrations, or seabed disturbance) with ecological data (such as fish migration, biofouling, or biodiversity changes). By doing so, it creates feedback loops that demonstrate how changes in OWF operations directly impact marine ecosystems and how these ecosystem dynamics, in turn, influence OWF performance, risks, and maintenance. A DT acts as an integrating hub, moving beyond isolated measurement to provide a holistic view of the co-dependency between renewable energy infrastructure and marine environments.

In Nova Scotia, where the OWF industry is still emerging, there is a limited understanding of stakeholder perspectives on the value and design of DTs for OWFs in managing environmental risks.

### Goals and Objectives

#### Goals

This project, led by Dalhousie University in collaboration with Net Zero Atlantic (NZA), seeks to explore stakeholder views on the potential use of DTs in Nova Scotia’s offshore wind sector, with a focus on monitoring, predicting, and managing trade-offs in environmental impacts.

#### Objectives

- ❖ Engage diverse stakeholders (industry, government, academia, NGOs, indigenous communities, and the public) to capture perspectives on DT applications in OWFs.
- ❖ Identify key requirements for DT development tailored to Nova Scotia’s local, regulatory, and policy context.

### Conceptual Framework of OWFs’ DT

The physical asset consists of sensors and IoT devices. The DT platform consists of three main fronts: Big data and analytics, simulation & property modelling, and visualization. Data are provided from the physical assets to the DT platform, whereas information and processes are sent to the physical assets from the DT platform

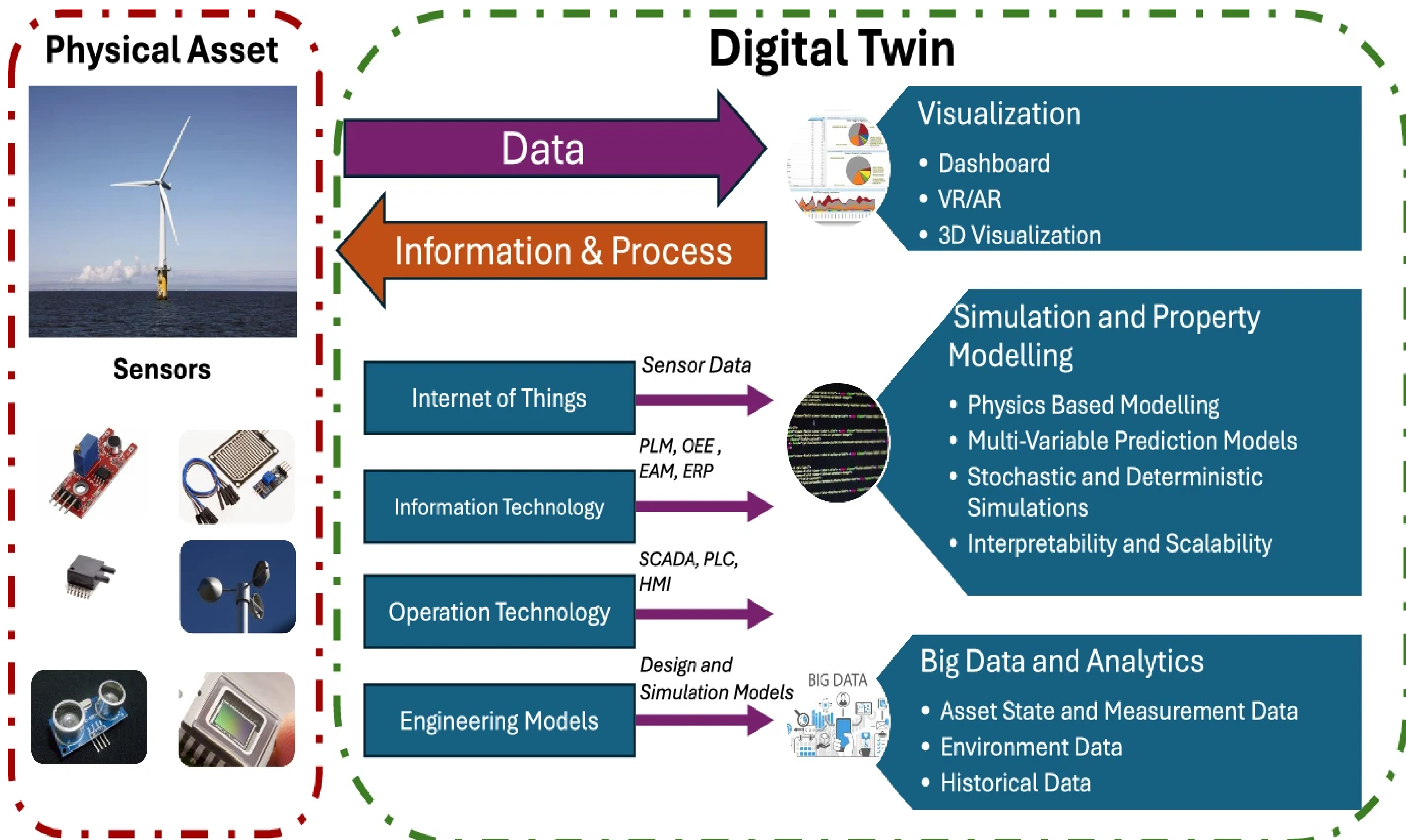


Figure 1: Conceptual Framework of Wind Turbine’s DT

Source: Kandemir, E., Hasan, A., Kvamsdal, T. et al. Predictive digital twin for wind energy systems: a literature review. *Energy Inform* 7, 68 (2024). <https://doi.org/10.1186/s42162-024-00373-9>

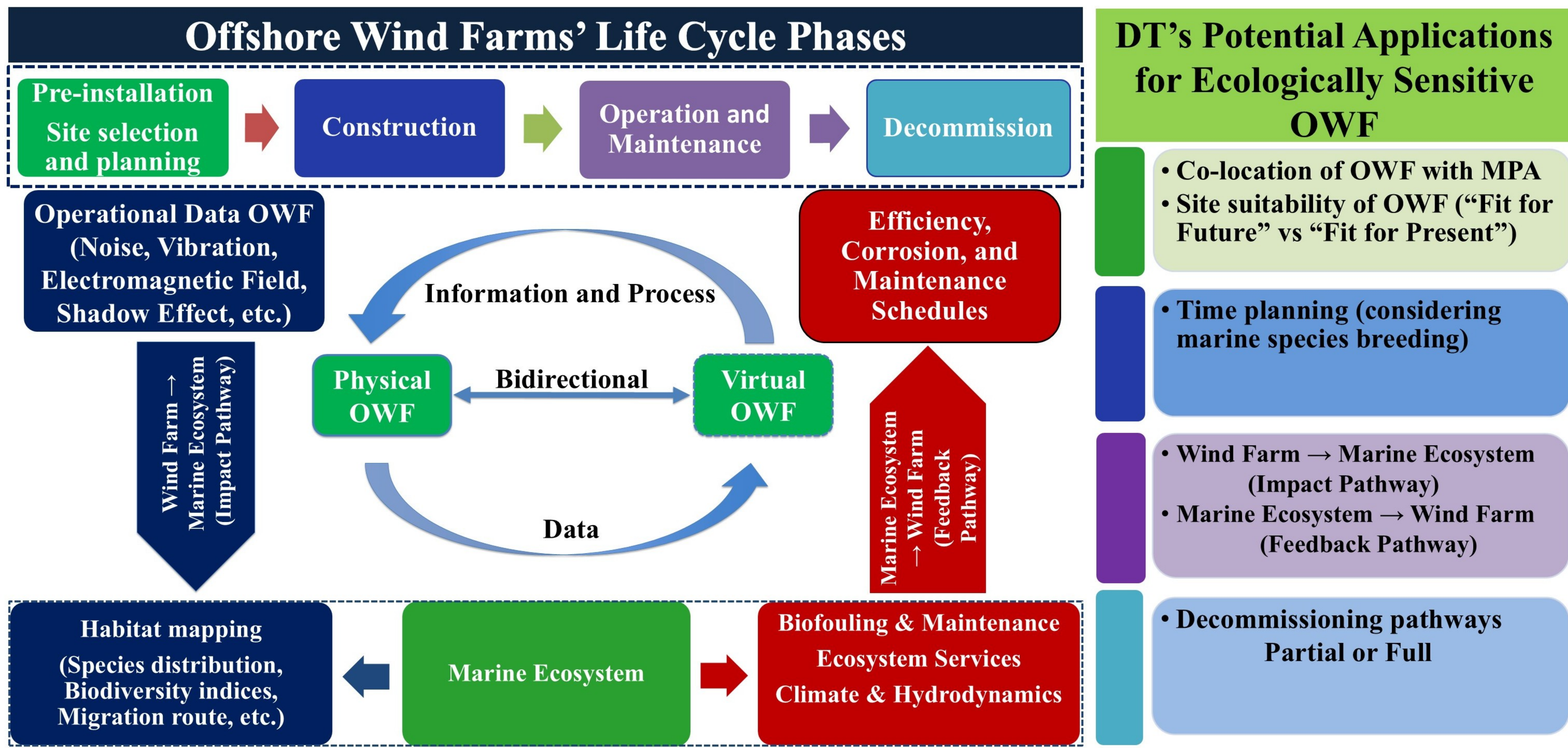


Figure 2: Application Domains of DTs: Linking OWF Life Cycle Phases with Marine Ecosystem Dynamics

Source: created by authors based on [4],[5],[6],[7],[8],[9]



### Outcomes

This project will generate critical insights into the role of DTs for mitigating the environmental impacts of wind turbines. Digital Twin applications hold relevance in several domains (Figure 2): (i) **site selection and long-term planning**, by integrating present-day conditions with future (25-year horizon) climate and ecological projections; (ii) **environmental and biodiversity monitoring**, through real-time tracking of bird flight paths, marine mammal distributions, and seabed dynamics, coupled with predictive modeling of bird collision risk, noise propagation, and cumulative ecological effects; (iii) **operations and maintenance optimization**, enabling predictive maintenance of turbine components, minimizing unplanned outages, and reducing disturbance to marine ecosystems; (iv) **resource and supply chain sustainability**, including material footprint assessment, logistics optimization, and circular economy strategies; and (v) **decommissioning and end-of-life planning**, where DTs can assess ecological outcomes of complete or partial removal of the installation, including artificial reef formation and habitat recovery.

By engaging a wide spectrum of stakeholders such as policy-makers, regulators, industry representatives, indigenous communities, and public, the project will prioritize the most contextually relevant applications for Nova Scotia. This approach will support evidence-based decision-making, balancing renewable energy expansion with ecological integrity and social acceptance.

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