Fostering Transportation Workforce Development for the Blue Economy

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***Abstract*—This research-to-practice paper presents a strategy for educating future civil engineers in identifying Blue Economy strategies to develop more resilient coastal communities and transportation corridors. Coastal communities, essential hubs for population and economic activities, are increasingly vulnerable to hazards caused by extreme natural events due to their proximity to the ocean. Blue Economy, which advocates for the sustainable use of marine resources to promote economic growth and ecosystem health, is a focal point for these regions. Transportation corridors, lifelines for accessing jobs and opportunities in coastal areas, are exposed to heightened risks from natural events. This paper underscores the importance of preparing the engineering workforce community in designing a resilient transportation infrastructure that supports preparedness, mitigation, and post-disaster recovery efforts in coastal communities. The proposed framework for integrating Blue Economy principles into engineering education emphasizes the identification and implementation of strategies that enhance resilience and sustainability of coastal communities. A case study is included as a practical application of these concepts in coastal development.**

Keywords—transportation resilience, Blue Economy, coastal communities, engineering workforce, educational modules, natural hazards

I. Introduction

Natural disasters frequently occurred during the past decade in Puerto Rico, such as hurricanes, earthquakes, and floods, have exposed many of the vulnerabilities that face the residents of this Caribbean archipelago. These events have caused devastating economic damages [1], while awakening the need and interest for resilient infrastructure development and planning [2][3]. A sector that is typically impacted on those natural events are coastal areas, firstly because they are prone to floods, but also because their economic activities are usually connected to the marine environment, making them especially vulnerable. A growing Global interest in the development of infrastructure that supports nature-based solutions led to ambitious goals for implementing Blue Economy in coastal areas [4][5]. Blue Economy refers to the sustainable use and management of ocean resources for economic growth, improved livelihoods, and the preservation of marine ecosystems. It encompasses various sectors, including fisheries, aquaculture, tourism, shipping, and renewable energy, aiming to balance economic development with environmental sustainability [6].

With approximately 40% of the global population within 100 kilometers (about 62 miles) from the coast [7], coastal communities and their economies are an important focus to many countries. Islands are more critical to coastal hazards. As an example, there are 44 out of 78 municipalities in the coastal perimeter on the island of Puerto Rico. The importance of coastal regions includes environmental, economic, and social aspects. Coastal erosion protection and management are essential in providing shelter and food for organisms, while economic benefits include industrial capacity for ports, recreational activities such as fishing, and providing raw materials such as salt or sand [8]. These zones also host the most diverse social profile from disadvantage to the most industrialized and developed communities with the most advanced infrastructure. Marine and ocean economies are so important, that when compared to other countries, the marine gross domestic product (GDP) would make *The Ocean* the seventh largest economy in the world [4]. Given the economic, environmental, and social importance that the coasts and the marine environment have, goals to protect and continue developing these environments have been established. These goals involve integrating ocean recovery into the United Nations (UN) Post-2015 Agenda, addressing issues like habitat destruction, overfishing, and marine pollution, emission cuts to combat ocean warming and acidification, and meeting targets to protect at least 10% of coastal and marine areas by 2020 and 30% by 2030 for biodiversity and livelihood outcomes [4]. The

Blue Economy is expected to grow up to 2.5-3.0 trillion USD by 2030 [5]. This innovative approach aims to cultivate the marine economy while ensuring the robust preservation of the marine ecosystem, achieving sustainable resource utilization. To that end, a thorough understanding of coastal areas, critical infrastructure, economic and environmental factors, and climate change effects on the coast need to be studied to find the best solutions for resilient economies and the social wellbeing of these communities.

II. Developing Resilient Transportation Professionals

There are exposed and vulnerable coastal communities in Puerto Rico, a great example being the Piñones sector in the Municipality of Loíza (see 0), with 2,037 inhabitants and 58.6% of those below the poverty level [9]. This community presents various challenges and special conditions related to its economic drivers, such as the touristic and gastronomy locations, a limited connectivity to the transportation network, and their link to the marine economy. These factors would make communities like Piñones candidates that could benefit from the implementation of Blue Economy strategies, enhancing both the quality of life of the residents and their economic opportunities. A significant factor is the development of a reliable and equitable transportation system, since these systems work as the connectors and providers of economic opportunities within, and outside a given community. It also may provide a reliable supply chain infrastructure for rapid and efficient response during natural catastrophes.

Fig. 1. Community of Piñones, PR. (Images from Google Earth®).

Civil engineers have started to identify strategies and practices to enhance the sustainability and resilience of transportation corridors [10]. The United States Department of Transportation (USDOT) has developed scoring tools to assist professionals in the assessment of the risks and vulnerabilities of transportation assets to ensure multi-modal transportation system reliability and resiliency [11] [12]. The vulnerability of transportation assets is a function of exposure, sensitivity, and adaptive capacity [11] and its assessment focuses on how existing or planned transportation facilities may fare given current and future hazards to enable better prioritization in the decision-making process and the identification of feasible solutions and more effective adaptation measures [12]. Moreover, the effective application of these assessment strategies requires the development of the technical capacity of professionals that can be able to identify and analyze different perspectives and contexts of the coastal communities, the stressors, hazards, and related vulnerabilities, the specific needs of the local residents and visitors, and what are the most effective solutions and strategies to provide.

This paper proposes a methodology for the identification of coastal vulnerabilities, including assessing geographic and demographic variables, which will help in the decision-making process for enhancing economic drivers of coastal communities. This requires the familiarization of the subjects with the definitions and resources available and the use of Geographic Information Systems (GIS) to visualize and analyze strategies. Results include the development of modules for professionals and for the general community, which will get educated on the benefits of the Blue Economy and the potential from its implementation for coastal communities in Puerto Rico.

A. *From Research to Practice*

The Coastal Research and Education Actions for Transportation Equity (CREATE) University Transportation Center aims, among other goals, to educate communities and professionals to close the existing gap in technical and policies knowledge [13]. Fig. 2 outlines the general approach, which begins by assessing the challenges and needs, general and community-specific, of the transportation network (i.e., equity and accessibility) and the coastal infrastructure (i.e., condition and design). The data collection involves interviews and interactions with residents, local officials, academia, and practitioners. By understanding the local context and the risks (hazards, exposure, and vulnerabilities) from multiple natural events, innovative solutions and best practices can be studied, proposed, and implemented, yielding outcomes that affect the readiness level of the community. The experience from the assessment of a coastal community and its infrastructure, along the solutions, are gathered and synthetized to produce educational modules (in the form of seminars, papers, posters, meetings, and interactive media), directed towards professionals, the community, and decision-makers.

B. *Interactive Web Learning Hub*

Disseminating the results of this project is critical for educating and training stakeholders. The Interactive Learning Hub (IL-Hub) is a platform from the Coastal Research Center (CRC) that allows stakeholders to access webinars and educational activities related to resiliency, natural disasters, and coastal communities [14]. The implementation of the IL-Hub provides users with relevant information on topics of interest. CREATE is collaborating with the CRC to expand the IL-Hub platform to include topics related to transportation resilience and the Blue Economy.

C. *Ongoing Efforts*

Efforts are currently underway in CREATE to increase the understanding of variables and processes that impact the Blue Economy and to propose solutions. The material developed under CREATE focuses on educational purposes. An example of such efforts includes a technical meeting [15], targeted to civil engineering professionals and students, in which basic principles of the Blue Economy and a case study example were presented to illustrate a real-life application.

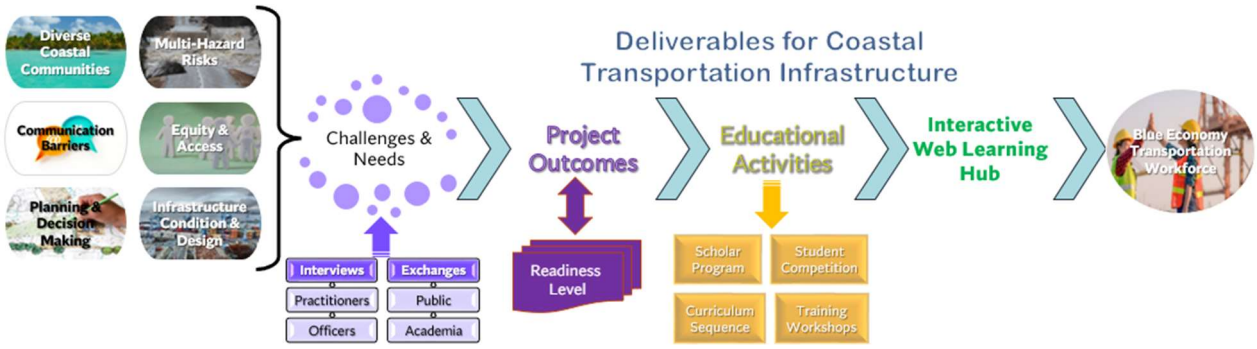

Fig. 2. Research-to-practice framework for Blue Economy workforce develpoment.

Continuing CREATE's efforts, underserved communities, especially those affected directly by coastal risks, will be surveyed to assess the real and perceived risks that these communities face. Data collection will be conducted using survey questionnaires and interviews to target residents and other stakeholders of selected coastal communities in Puerto Rico. Previous work has conducted surveys of communities of Puerto Rico to understand preferences on mobility alternatives through use of visualizations [16]. These communities face varying conditions regarding tourism and economic development, mobility and accessibility, infrastructure conditions, and demographic and economic status.

III. Project Approach

This section outlines the key points in the decision-making process that professionals should be considering in developing or adapting the transportation infrastructure to meet Blue Economy goals. For each section, examples applied in the context of Puerto Rico are shown. A case study approach is being used as the basis for research and education regarding Blue Economy within the CREATE project. As highlighted in Fig. 3, the suggested approach for Blue Economy consists of Exploration & Detection, Analysis, and Execution stages. These stages interact in a continuous process, which means that the implementation of a resilient corridor is an activity that requires a recurrent identification and analysis of conditions and risks, and the proper implementation of solutions, with an assessment of the results over time and further adjustments, accordingly.

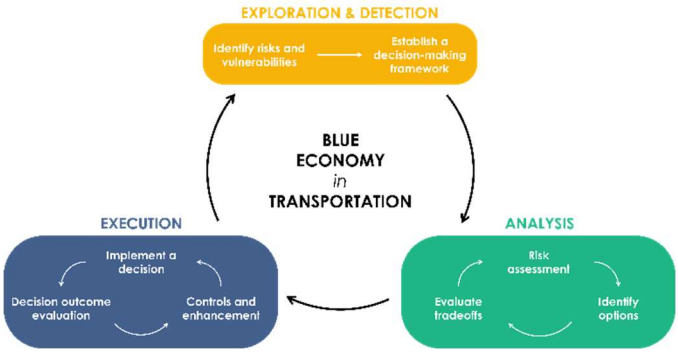

Fig. 3. Implementation methodology for Blue Economy.

Nonetheless, how to identify and analyze the local conditions, and what solutions to implement are the steps in which education will play a crucial role in developing professionals that are ready to apply Blue Economy principles. Thus, the purpose of this research-to-practice project is to use examples, in which communities and professionals are involved closely, to understand the factors that contribute to risk and resilience of their communities.

A. *Defining the Extension of the Coast*

The first step in the Exploration & Detection stage is understanding the type of environment and context under study. The coastal zone is a dynamic and vital environment. Coastal zones are among the most diverse and productive environments on the planet, encompassing natural elements such as basins, rivers, mangroves, corals, and coastal resources, and built infrastructure (seaports, airports, roads, buildings, and utility networks. This diverse ensemble provides broad social benefits by hosting various ecosystems, natural habitats, and built communities. Nonetheless, there is no universal definition as to what the extension of a coastal zone should be [8]. The lack of a consistent definition poses a difficulty to identify the infrastructure, economy, and communities affected in the coast. Voigt [17] defines the coast as the strip of land extending from the shore to the first major change in terrain features. In contrast, other studies define the extension of the coast as 60 to 200 kilometers (37 to 124 miles) measured inland from the shoreline [8].

If the latter definition is applied for Puerto Rico, with the main island having a north-south extension of 56 kilometers (approximately 35 miles), the whole territory would be classified as a coastal zone. This surely will not be adequate as it is not considering the geographic factors that divide the coast from the rest of the island much closer to the shoreline. Independently of how far from the shoreline the coast is defined, there is always an active interaction and dependency of the coast and its inland neighborhood. Thus, the need to have area-specific definitions of what constitutes the coast given geographic aspects. Coastal flood maps along with the shoreline definition and the Limit of Moderate Wave Action (LiMWA) lines will help define the specific needs of a coastal zone. An example of such a map is shown in Fig. 4, where the coast zones of the municipalities of San Juan, Guaynabo, and

Cataño are shown along with recommended flood zones and main highways. In general, a maximum of LiMWA within 5 kilometers (3 miles) are observed in some areas Puerto Rico. It is important to understand that this is a convenient definition, but necessary the most inclusive, based on the 100-year flood extension delineated by FEMA in the United States, which may not be available in other countries in the world.

B. *Critical Infrastructure*

In evaluating the risks a coastal area is exposed to, it is necessary to identify critical infrastructure prone to coast-related disasters. The Department of Homeland Security defines 16 key infrastructure sectors in the United States, with assets, systems, and networks—whether physical or virtual—so essential that their disruption or destruction could severely impact security, the national economy, public health, safety, or a combination of these areas [18]. These pieces of infrastructure are essential for the proper functioning of society, the economy, and the well-being of the inhabitants. Critical infrastructure commonly found in coastal areas include ports and harbors, airports, energy plants, water treatment and distribution facilities, wastewater treatment plants, communication facilities, highways and roads, emergency services, schools, military installations, and natural resources and environmental protection. The critical infrastructure in coastal zones may be visualized by the utilization of maps, that allows to see the relative position of flood zones, or the sea level rise (SLR) predictions. Fig. 5 shows the flood zones, state highways, energy facilities, and treatment plants in Puerto Rico, clearly demonstrating which of the infrastructure elements might be at risk and need a flood-ready mitigation. Notice this is an example, and for more specific areas, other types of risks and infrastructure (like hospitals, police stations, fire stations, and government facilities) may be included. Also, protected natural areas, residential zones, and other special areas might be included to assess their risks and vulnerability.

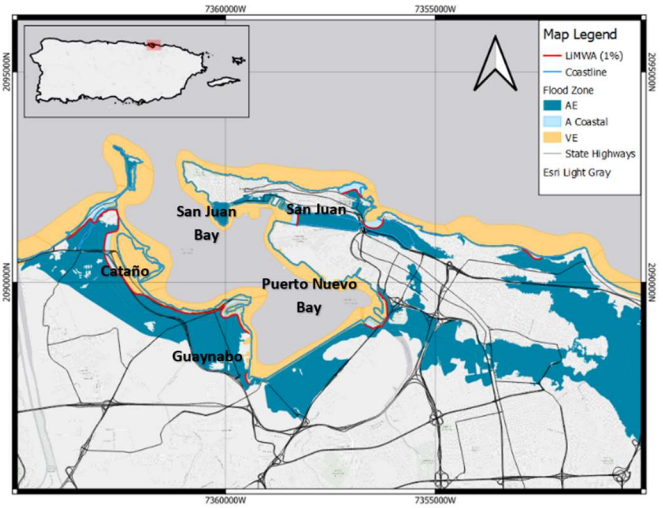

Fig. 4. Flood zones along the Municipalities of San Juan, Guaynabo, and Cataño (data from https://gis.pr.gov).

C. *Resilient Transportation Systems*

It is essential to consider transportation routes, pivotal for the sustainable development of coastal regions, facilitating the transportation of essential items such as food, supplies, and consumer goods. The evaluation of a community's accessibility is based on residents' ability to engage in essential activities. The goal is to enhance the adaptability of transportation infrastructure to climate change, particularly crucial for developing countries and regions, and especially those situated in coastal areas. Developing countries often lack the financial resources to build comprehensive transportation infrastructure, making them more vulnerable to adverse ever increasing weather conditions and rising sea levels compared to developed countries [19].

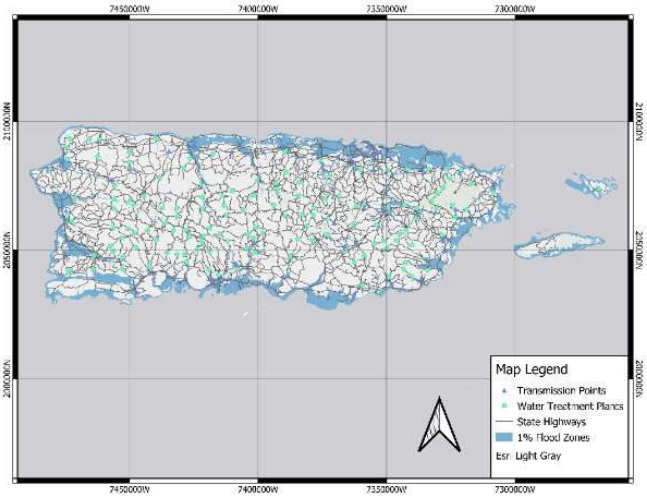

Fig. 5. Critical infrastructure and one percent flood zones in Puerto Rico (data from https://gis.pr.gov).

Webb et al. [10] identify common coastal highway vulnerabilities in the U.S., which include SLR, storm surges, sedimentation, floods, erosion, and wave action. Resilient corridors that serve coastal communities and provide them with a greater level of serviceability need to withstand the forces of nature, while preventing damage to its surrounding environment. This will require comprehensive transportation hybrid systems that are effective and, equally important, strong physical infrastructure. Nature-based solutions use natural materials and processes to mitigate risks and vulnerabilities, and include marsh, beach nourishment, pocket beach, and dune restoration [10]. These solutions may be practical for some applications, while not for others, thus thorough analysis of data shall be conducted prior to the implementation of a solution. Green and gray infrastructure are combined to provide more effective protection and safety in coastal environments [20][21].

D. *Economy and Environmental Concerns*

Coastlines represent the access point for maritime transport, which is responsible for the shipping of 80% of the globally traded goods. Furthermore, tourism and leisure sectors generate significant income and employment. For instance, in the United

States, 85% of tourism relies solely on beach visits [22]. Coastal areas play a pivotal role in the economy of countries, and to maintain this, there is a need for implementing sustainable development of resources and the environment along the coastlines, fostering the country's economic growth [19]. Consequently, attention must be directed towards coastal communities whose economic activities revolve around the sea. Various impacts, including the loss of ecosystem-provided services, particularly affect these communities, with fisheries being sensitive to negative influences from sectors such as drilling, mining, aggregates, shipping, and aquaculture, mediated by marine ecosystems [23].

The exclusion of coastal communities poses direct risks to food security and rights. Livelihoods depending on marine ecosystems can suffer adverse impacts due to environmental degradation, displacement, and dispossession [23]. Coastal areas, often located downstream of rivers, form alluvial plains. Climate change in coastal cities not only significantly impacts weather fluctuations compared to inland cities but also results in significant problems such as rapid sea-level rise, frequent and severe climatic events, massive losses from marine disasters, and severe impacts from meteorological disasters.

IV. Conclusion

The vulnerability to natural disasters of coastal communities worldwide highlights the critical need for resilient infrastructure. Coastal regions, with their economic significance and environmental advantages, are at risk of devastation from natural events such as hurricanes, earthquakes, and floods. The impact of natural events in coastal communities is exacerbated by the susceptibility to flooding and the economic dependence on marine activities, which makes them especially vulnerable. Puerto Rico serves as a poignant reference, where recent extreme natural disasters have exposed vulnerabilities and underscored the urgent need for resilient infrastructure in support of the blue economy.

The ongoing educational approach proposed by CREATE, currently in its conceptual stage, will offer a practical solution by providing professionals and communities with the case-study-based knowledge and tools necessary for sustainable and resilient practices that will result in better preparedness in the face of extreme natural disasters. This initiative enhances the quality of life and economic opportunities of residents while ensuring the long-term prosperity of coastal areas. Efforts like CREATE, which prioritize education and community engagement, are crucial steps toward a sustainable and resilient future for coastal regions worldwide.

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