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Towards Developing a Modernized Wind Engineering Curricula

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Towards Developing a Modernized Wind Engineering Curricula

Abstract

The development of wind science and engineering (WSE) for civil engineering applications is still considered relatively young and thus has been taught fairly recently, for about 50 years, in some academic institutions. Therefore, it is unsurprising that there are limited wind engineering tracks within civil engineering programs worldwide, and no semblance of a standard or ideal curricula. An adequate education in wind engineering is of utmost importance to civil engineering, particularly to structural engineering, and ultimately to academia, since natural hazards including extreme wind events have been the main cause of destruction to our infrastructure systems and buildings especially in underdeveloped communities. Thus, such a frequent natural hazard has been threatening people's lives and their well-being. The goal of this research is to identify and propose an ideal path for wind engineering (WE) programs by studying the current state of wind engineering tracks within civil engineering programs offered worldwide and identifying their Strengths, Weaknesses, Opportunities, and Threats (SWOT). To achieve these objectives, this research (a) analyzed the different civil engineering programs that include wind engineering tracks offered worldwide and identified the academic institutions that have academic expertise and equipment including atmospheric boundary layer (ABL) wind tunnels, a fundamental tool for the research and study of wind events; (b) conducted a survey to all WE faculty and students doing research on these topics at Florida International University to gather information on the courses offered and the intention of the course, as well as information on what they believe could be offered or improved to enhance the courses and ultimately the curricula; (c) compared the programs that include wind engineering tracks to provide a modernized wind engineering curricula; and (d) proposed ideas, tools, and strategies that can be implemented to offer a better wind curricula for students in order to enhance their education and increase research in this paramount topic.

Keywords: Civil Engineering, Education, Structural Engineering, Wind Engineering, Wind Engineering Curricula, Wind Events

Background and Motivation

Wind disasters (WD), including hurricanes, tornados, and downbursts, are major natural disasters that frequently occur and have devastating power. Further, storm-related flooding as well as heavy rains wreak more havoc. WD have the potential to (1) cause substantial property damage and destroy infrastructure systems, including power, transportation, and communications; (2) impact significantly the economy of countries by causing significant economic losses due to infrastructure systems and property damage, power failure, evacuation, debris removal, and business interruption; (3) cause injury as well as aggravate respiratory conditions including allergy and asthma; and (4) threaten people's lives and well-being [1]–[3].

From 1960 until 2019, 11,360 natural disasters, where more than ten people died or more than 100 people were affected, were registered globally. From those, 8,781 were weather and climate related, 2,638 due to storms, including hurricanes, and 4.435 due to floods. Between 2010 and

2019, 2,850 natural disasters were recorded globally. They affected 1.8 billion people. 83 percent of those ND were climate and weather related [4]. It is estimated that weather and climate disasters, including drought, flooding, freeze, severe storm, hurricanes, wildfire, and winter storm caused over $2.475 trillion in the United States between 1989 and 2022. Only hurricanes, severe storms, and flooding caused over $1.895 trillion [5], [6]. Further, the average number of WD, including hurricanes, severe storms, and flooding, as well as the total economic losses per year, has been continuously increasing in the U.S. [5], [6]. Figure 1 presents the number of climate and weather events where overall damages and/or costs reached or exceeded $1 billion. Figure 2 presents the damage and economic losses of those events [5], [6]. In addition, cities and communities are becoming more vulnerable to WD since risk zones (e.g., coastal communities) are continuously being developed making cities and communities more vulnerable [1]. Hence, enhancing community resilience against WD as well as decreasing economic losses is of utmost importance for the cities' safety and communities' welfare [7].

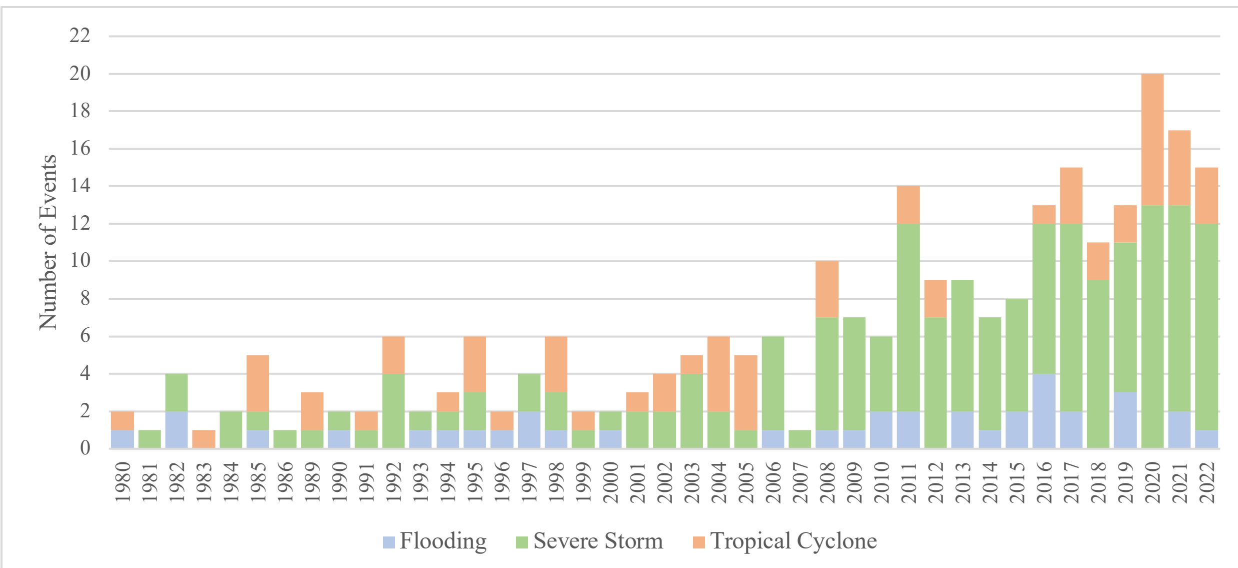

Figure 1. Total Number of Events per Year. Data adapted from A. B. Smith, "US Billion-Dollar Weather and Climate Disasters, 1980—Present (NCEI Accession 0209268)," NOAA National Centers for Environmental Information, vol. 10, 2020

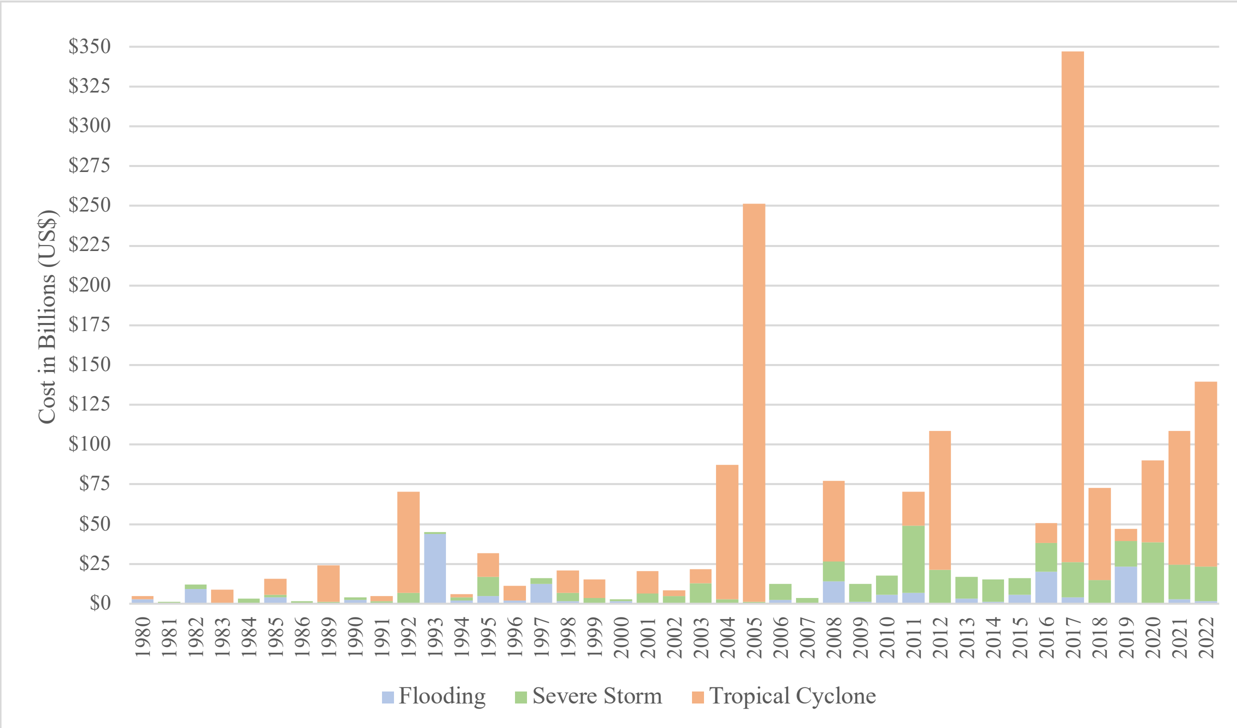

Figure 2. Total Cost in Billions (US$) per Disaster Type. Data adapted from A. B. Smith, "US Billion-Dollar Weather and Climate Disasters, 1980—Present (NCEI Accession 0209268)," NOAA National Centers for Environmental Information, vol. 10, 2020

Two paramount means to increase community resilience and welfare, decrease injuries and fatalities, decrease property and infrastructure damage, and consequently decrease economic losses due to WD are through wind science and engineering (WSE) education and research in the fields of civil and structural engineering. Educating and training future professionals is pivotal to better plan, design, and build cities and communities that are more resilient, better prepared, and less vulnerable to WD.

The discipline of wind science and engineering is still regarded as relatively young. As such, increasing space has recently been given to WSE education and dissemination [8]. Wind engineering (WE) emerged in the mid-1960s when Cermak conducted the first comprehensive study of wind loading on a structure for the construction of the World Trade Center Towers. This study was performed at Colorado State University, since, at that time, it was the only institution in the world that had an atmospheric boundary layer (ABL) wind tunnel [9]. WSE has only been taught for about 50 years and thus there are limited wind engineering (WE) tracks within civil engineering (CE) programs worldwide with limited streamlined or ideal curricula.

The goal of this study is to identify and propose a streamlined and ideal curriculum for WE tracks within CE programs. To achieve this objective, this research will study the current state of programs offered in the United States, Canada, and Europe to identify their strengths, gaps, weaknesses, limits, and opportunities for improvement. This will contribute to the improvement of WE education as well as to increase research on this topic.

Methodology

This study is guided by three research questions: (1) how many academic institutions in the United States, Canada, and Europe offer WE tracks within CE programs, what courses do they teach, and how many have ABL wind tunnels? (2) What is the current state of WE tracks, what are their strengths, gaps, limits, weaknesses, and opportunities? (3) How can institutions integrate more students into WE tracks within CE programs, increase their interest in wind events and their impact not only on infrastructure but also on communities and well-being, as well as encourage them to do more research on these topics?

To address these three questions, this study (a) analyzed the different WE tracks within CE programs offered in the United States, Canada, and Europe and identified the academic institutions that have crucial equipment for research and study of wind events, such as atmospheric boundary layer (ABL) wind tunnels; (b) conducted a survey to all WE faculty and students doing research in this paramount topic at Florida International University to gather information on the courses offered and the intention of the course, as well as information on what they believe could be offered or improved to enhance the courses and ultimately the curricula; (c) compared WE tracks offered in different academic institutions to provide a streamlined and ideal wind engineering curricula; and (d) proposed ideas, tools, and strategies that can be implemented to offer a better wind curricula for students in order to enhance their education and increase research in WD.

Investigating academic institutions that have WE tracks within CE programs in the United States, Canada, and Europe

This study was initiated by identifying all academic institutions that have WE tracks within civil engineering programs, the courses they offer, as well as those that have an ABL wind tunnel through both literature review and analysis of academic institutions' websites. To identify the educational institutions that have WE tracks within CE programs and do research in this topic in the United States, Canada, and Europe, this study (a) carried out an extensive google search with the keywords "wind engineering programs", "programs in wind engineering", "wind engineering", "wind engineering in civil engineering", and "wind engineering courses", but many of the results returned programs pertaining to wind energy and sustainability; (b) explored publications in the Journal of Wind Engineering and Industrial Aerodynamics (JWEIA) to identify faculty specializing in WE as well as their affiliations; and (c) explored several associations for wind engineering, including the American Association for Wind Engineering (AAWE), the International Association for Wind Engineering (IAWE), and the Wind Hazard and Infrastructure Performance Center (WHIP-C), to identify organizations, academic institutions, and faculty that are members of such associations, as well as their affiliations. This extensive investigation allowed to identify academic institutions offering courses in WE and/or doing research in this topic.

Once all the academic institutions were identified, the authors investigated the wind engineering courses and their descriptions by reviewing the institutions' course catalogs and/or other university-related web pages. To identify the courses, the authors looked for courses that contained the keywords "wind", "wind engineering", "hurricane", "boundary layer", "bluff body", and "storm" within their title and/or description. This search included undergraduate and graduate courses.

With this information, this study compared the diverse WE tracks within CE programs offered in the United States, Canada, and Europe to identify their strengths, gaps, weaknesses, limits, and opportunities for improvement.

Survey Design

This study utilized a mixed-methods sequential explanatory design to collect and analyze both quantitative and qualitative data from faculty and students. The administered survey included a demographic section and a total of six questions The first question intended to identify what instructional tools and methods, including projects, hands-on experience, and research could increase students' interest as well as enhance their learning. The next question aimed to identify if students and faculty consider ABL wind tunnel a fundamental tool for WE tracks and/or programs. The two following questions intended to identify (a) the courses offered in the academic institution; and (b) the courses that students and faculty thought should be incorporated to increase learning and ultimately enhance the curricula. The last two questions aimed to identify why institutions struggle to recruit and retain students, as well as the tools and strategies that could help institutions overcome these challenges, integrate more students, and increase research.

Finally, this study analyzed all the data gathered from the literature, academic institutions, and surveys and proposed several strategies, ideas, and tools that can help institutions offer a better wind curriculum, enhance learning and interest, integrate more students to WE tracks within CE programs and increase research in this paramount topic. Figure 3 presents the research overview.

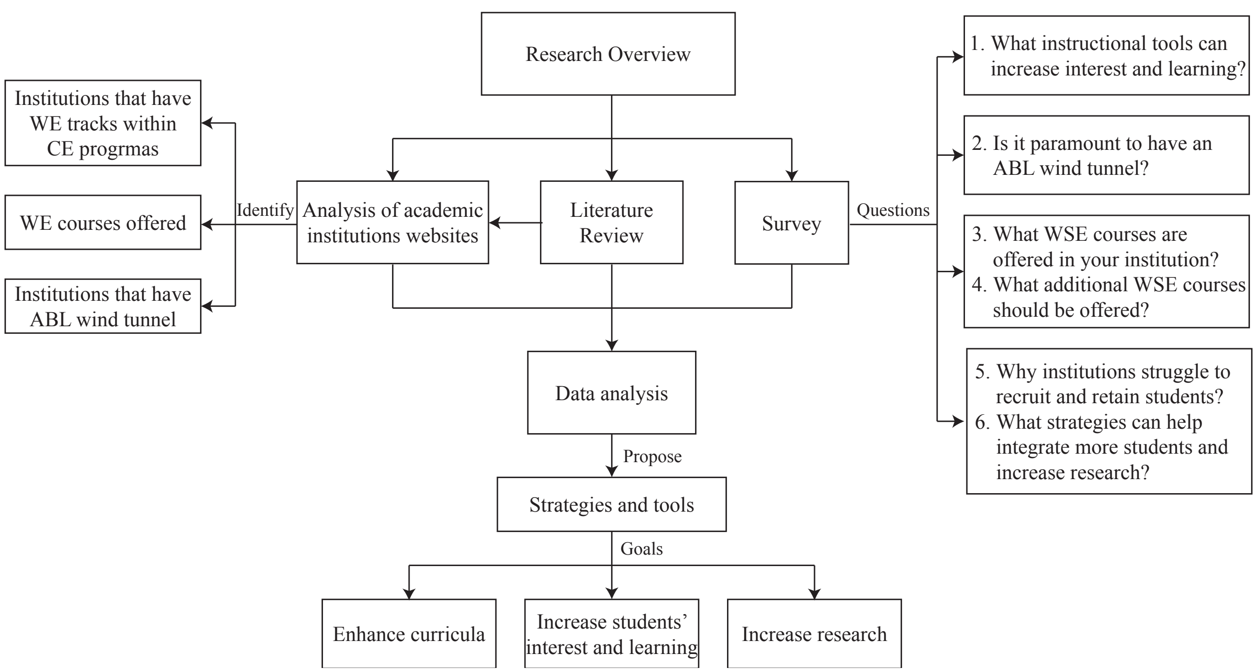

Figure 3. Research Overview

Results and Discussion

This study began by identifying the most recognized wind engineering tracks within civil engineering programs in the United States, Canada, and Europe. Table 1 shows the academic institutions that have WE tracks withing CE programs, the courses they teach as well as the course intent, and whether the academic institutions have an ABL wind tunnel or not.

Table 1: Academic Institutions that have WE tracks within CE programs (United States, Canada, and Europe)

University	Courses	Course Intent	ABL Wind Tunnel	Program Citation
Concordia University Montreal, Canada	Wind Engineering and Building Aerodynamics	Effects of wind on building structures and their environment.	Yes	[10]
University of Western Ontario Ontario, Canada	Wind Loads on Building Components & Cladding	Introduction to wind loads and effects on building components and cladding.	Yes	[11]
	Wind Engineering	Fundamentals of wind engineering and wind-structure interaction		
	Computational Wind Engineering (CWE)	Introduction to CWE. Focus on modelling of wind flow in the built environment with Computational Fluid Dynamics (CFD).		
	Boundary Layer Meteorology	Introduction to ABL and its properties.		
	Bluff Body Aerodynamics	Advanced fluid mechanical aspects of bluff body aerodynamics.		
Clemson University South Carolina, USA	Wind Engineering & Laboratory	Effects of wind on buildings, bridges, and other structures.	Yes	[12]
Colorado State University Colorado, USA	Wind Engineering	Influence of wind on humanity and applications to structures.	Yes	[13]
	Wind Effects on Structures	Analysis of wind effects on buildings and structures.		
Florida International University Florida, USA	Topics in Wind Engineering	Fundamentals of wind engineering, wind-structure interaction and design loads for extreme winds, tornadoes, and hurricanes.	Yes	[14]
	Applications of Probability and Statistics to the Analysis of Wind Engineering Experimental Data	Probability and statistics applied to wind engineering problems, techniques used in wind tunnel testing, and data analysis tools.		
	Design of Tall Buildings	Analysis and design of modern high-rise structural systems.		
	Hurricane Engineering and Global Sustainability	Impact of hurricanes and the role of engineers to achieve sustainable coastal communities around the globe		

Johns Hopkins University Baltimore, USA	Wind Engineering	Fundamentals of wind engineering, wind-structure interaction, computational wind engineering, and design loads for extreme winds, tornadoes, and hurricanes.	No	[15]
	Lateral Forces: Analysis and Design of Building Structures	Introduction to the development and application of earthquake and wind loadings on building structures, dynamic response to lateral forces, and design and detailing of lateral force resisting elements.		
Louisiana State University	Hurricane Engineering	Analysis and design of structures to resist hurricanes and natural hazards.	Yes	[16]
	Natural Hazards and the Built Environment	Engineering impacts and implications of hurricanes, floods, earthquakes, and natural hazards on the built environment.		
Rensselaer Polytechnic institute New York, USA	Wind Engineering	Fundamentals of wind engineering and wind-structure interaction.	No	[17]
Stanford University California, USA	Physics of Wind	Introduction to ABL and its properties, including measurements and simulations of ABL flows.	No	[18]
Texas Tech University Texas, USA	Boundary Layer Meteorology	Analysis of boundary-layer turbulent transfer processes.	Yes	[19]
	Dynamics of Severe Storms	Observations and theoretical studies of severe storms. Conceptual and numerical models of storm structure and development.		
	Wind Engineering	Fundamentals of wind engineering, wind-structure interaction, and design loads for extreme winds, tornadoes, and hurricanes.		
	Risk Modeling of Natural Disasters	Risk analysis, modeling, and management.		
University of Alabama at Birmingham Alabama, USA	Wind and Seismic Loads	Methods for calculating loads on structures caused by extreme winds and earthquakes	No	[20]
University at Buffalo New York, USA	Wind Engineering and Turbulent Flow	Fundamentals of wind engineering and wind-structure interaction.	Yes	[21]
University of Florida Florida, USA	Wind Engineering	Wind-structure interaction and design loads for extreme winds, tornadoes, and hurricanes.	Yes	[22]
University of Illinois at Urbana -Champaign Illinois, USA	Wind Effects on Structures	Fundamental aspects of wind engineering, characteristics of the wind and its effect on structures and the environment.	No	[23]

University of Notre Dame Indiana, USA	Wind Engineering	Analysis of structural response due to wind loading and design for high wind loads.	No	[24]
	Advanced Topics in Wind Effects on Structures	Advanced topics in the characterization of atmospheric turbulence, wind-structure interaction, and mitigation of dynamic wind effects on structures.		
Politecnico di Milano Milano, Italy	Wind Engineering	Fundamentals of wind engineering, wind-structure interaction and techniques to design and perform wind tunnel testing.	Yes	[25]
The University of Genova Genova, Italy	Wind Science and Engineering: Origins, Developments, Fundamentals and Advancements	Evolution of the wind knowledge and humans' ability to exploit beneficial aspects of wind as well as to protect from the harmful ones.	Yes	[26]
	Novel developments in Wind Engineering	Emerging technologies that can be applied to wind engineering, including methods of collecting full scale data, novel modeling techniques, new analysis techniques, and wind-structure interaction approaches.		
University of Birmingham Birmingham, UK	LM Wind Engineering and Bluff Body Aerodynamics	Fundamentals of wind engineering, wind-structure interaction, and wind loading loads for extreme winds.	Yes	[27]
Università degli Studi di Firenze Florence, Italy	Wind Engineering	Fundamentals of wind engineering and wind-structure interaction.	Yes	[28]

All academic institutions previously mentioned additionally offer the course Structural Dynamics, which addresses structural response to dynamic loads, including wind and seismic effects, for SDOF and MDOF systems. It is important to mention that this course is widely offered in many programs at several academic institutions and not exclusively in the institutions mentioned in the previous table. Furthermore, as it may be observed in Table 1, several academic institutions offer similar courses that may have different names but cover similar content. In fact, 16 out of the 19 educational institutions presented in this study offer the course "Wind Engineering", or a slight variation of the name, which covers the fundamentals of wind engineering and wind-structure interaction. Three academic institutions, University of Western Ontario, Florida International University, and Texas Tech University offer four or more courses related to WE, thus having the most comprehensive WE tracks within their CE programs. Those three academic institutions offer the course "Wind Engineering" and two of them, University of Western Ontario and Texas Tech University, offer the course "Boundary Layer Meteorology". In addition to those courses, the three aforementioned academic institutions offer different WE courses. All the courses presented in Table 1 are semester-long.

There are some academic institutions that have wind engineering courses in other programs different than civil engineering, including (1) Iowa State University in the United States, that offers Wind Engineering course in its Engineering Mechanics program [29]; (2) Politecnico di Milano in Italy, that offers Wind Engineering course in its Mechanical Engineering program [30]; (3) Politecnico di Torino in Italy, that offers Computational Fluid Dynamics and Wind

Engineering in its Mathematical Engineering program [31]; and (4) Bauhaus-Universität Weimar in Germany, that offers several courses related to wind engineering and natural disasters in its Natural Hazards and Risk in Structural Engineering program [32]. Further, there are academic institutions that have an ABL wind tunnel, but that do not offer any courses in WE, such as Florida Tech University in Florida, USA. Even though there may be more WE courses offered in other institutions worldwide, this study will focus on programs offered in the United States, Canada, and Europe that were identified by (a) conducting literature review; (b) exploring publications in JWEIA to identify faculty specializing in WE as well as their affiliations; and (c) exploring AAWE, IAWE, and WHIP-C to identify organizations, academic institutions, and faculty that are members of such associations, as well as their affiliations.

This research then utilized a mixed-methods sequential explanatory design to collect and analyze both quantitative and qualitative data from faculty and students. The recorded data included a diverse group of individuals, including females, males, and multiple races. The demographics are presented in Figure 4. This research surveyed all Ph.D. students and faculty within the discipline of WE working at the natural hazards engineering research infrastructure (NHERI) Wall of Wind (WOW) Experimental Facility. This facility, which is funded by the National Science Foundation (NSF), is one of the largest ABL wind tunnels worldwide and the only one that can simulate hurricane wind speeds up to and including Category 5 Hurricane on the Saffir-Simpson scale [33], [34]. Thus, rendering and reflecting the sample to be representative.

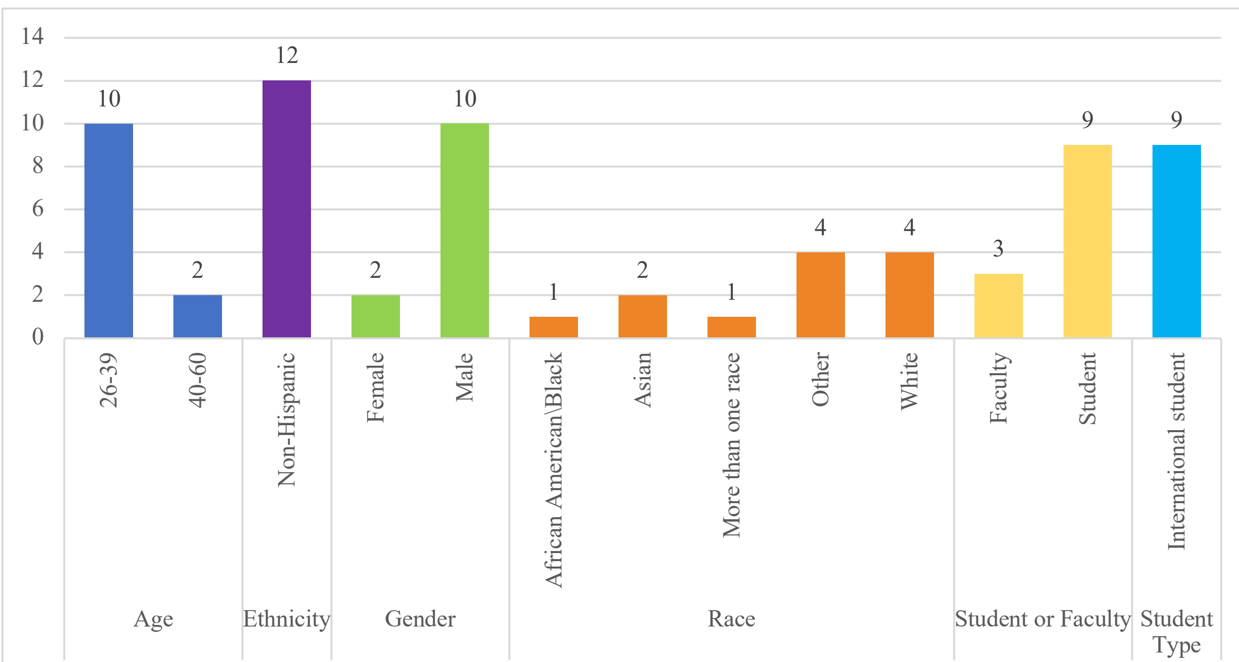

Figure 4. Socio-demographics

The first part of the survey intended to identify the instructional tools and methods that help increase students' interest in WE as well as enhance their learning, including (a) exposing students to realistic research and working environments; (b) experimental learning and hands-on experience as a means to reinforce the concepts taught in the classroom; (c) wind-tunnel experience to increase interest and research; (d) projects as well as group projects; (e) a streamlined curricula as a means for equitable quality educations and equal opportunities for all; and (f) wind-tunnel as a fundamental tool for WE tracks. The results of this study show that faculty and students consider that exposing students to realistic research and working environments, experimental learning and hands-on analytical and experimental wind-tunnel experience are the most significant factors to increase students' interest and enhance learning. These results are shown in Figure 5.

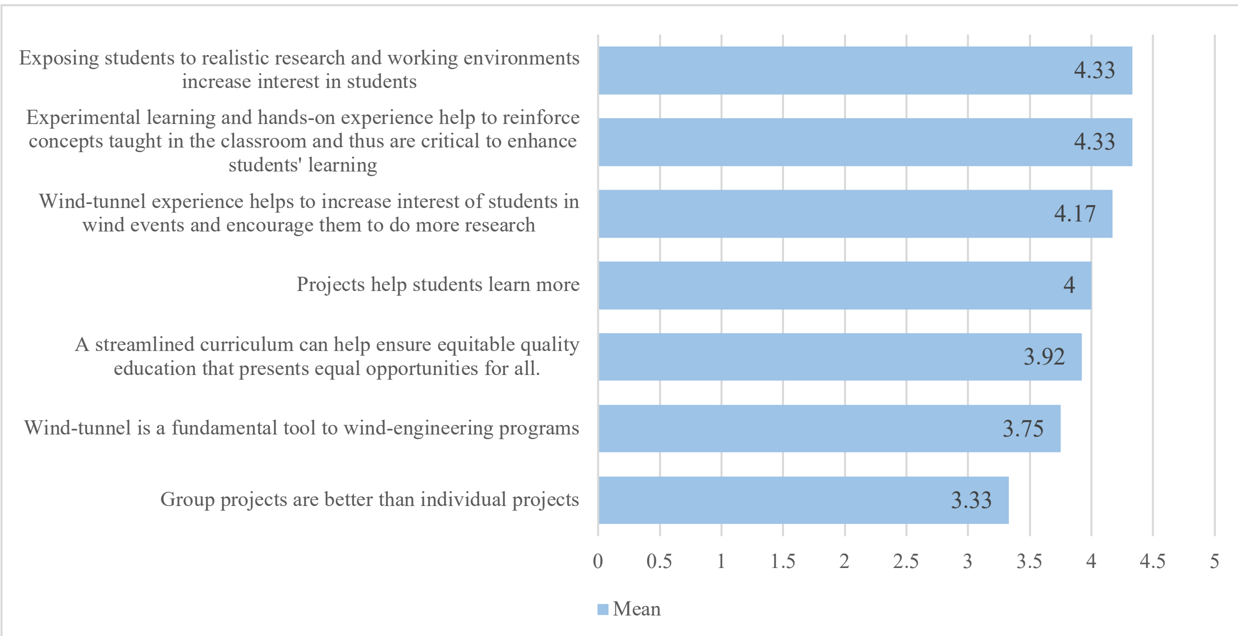

Figure 5. Faculty and students' level of agreement with the presented statements

The next question aimed to identify if students and faculty consider ABL wind tunnel a fundamental tool to offer WE tracks within CE programs in academic institutions. The results of this study show that even though students and faculty consider ABL wind tunnel paramount to increase students' interest and encourage them to do more research in wind engineering, it is not necessarily a fundamental tool for WE tracks. The results show that 41.67 percent consider it a fundamental tool, while 50 percent do not, as shown in Figure 6.

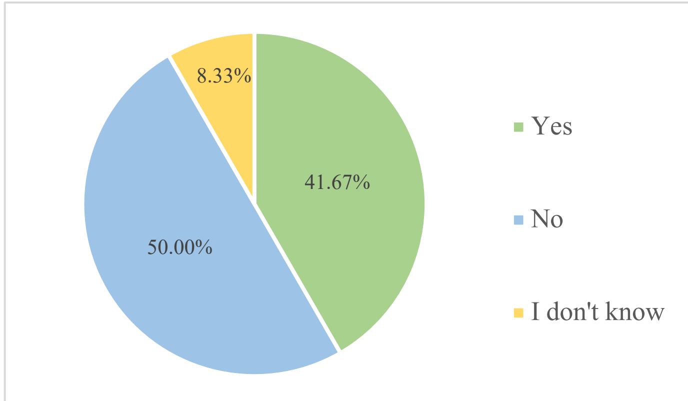

Figure 6. Do you think it is paramount to have an atmospheric boundary layer (ABL) wind tunnel to offer WE tracks within CE programs?

The results presented in Figure 6 are consistent with the results shown in Figure 5. It can be observed that although wind tunnel experience increases interest in WE as well as research in this topic, not having an ABL wind tunnel should not be an impediment to offer such tracks within CE programs at other educational institutions.

This study also recorded qualitative data that aimed to identify (a) the courses offered in the academic institution, which are shown in Table 1; (b) the courses that students and faculty thought should be incorporated to increase learning and ultimately enhance the curricula; (c) why institutions struggle to recruit and retain students; and (d) the tools and strategies that could help institutions overcome these challenges, integrate more students, and increase research.

The courses that faculty consider important to incorporate in the curricula to increase students' learning and enhance the curricula are Computational Fluid Dynamics (CFD), Bluff Body Aerodynamics, Thunderstorm Effects on Structures, and Experimental Testing and Data Analysis in Wind Engineering. Further, students consider beneficial to incorporate the following courses: Effects of Wind on High-Rise Structures and Dynamic Response of Wind Excited structures. Additionally, they reported that courses related to advanced statistics as well as statistics applied to wind engineering, data analysis and programming, and forensic engineering could be beneficial for WE tracks within CE programs. Students also reported that they would like to have courses that are more related to the design of buildings for wind loads instead of pure wind engineering. These data is presented in Figure 7.

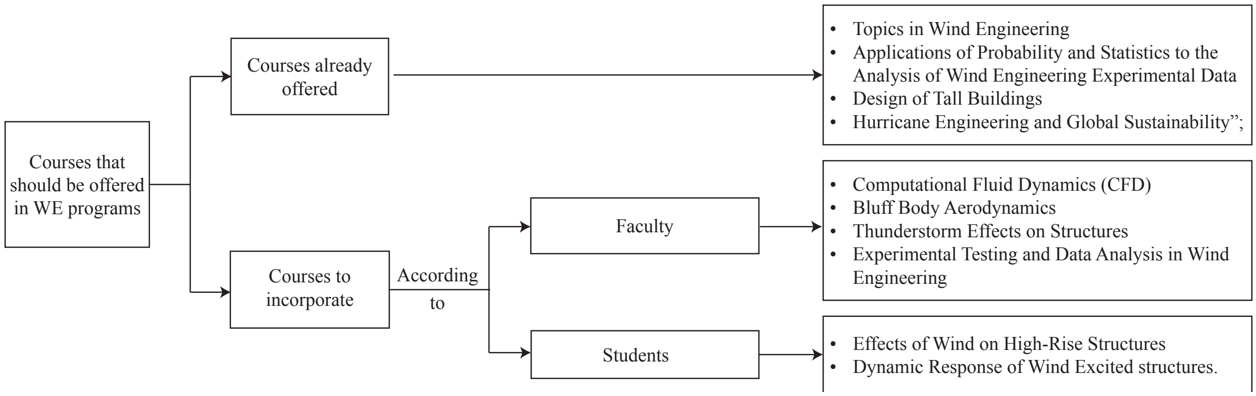

Figure 7: Important courses to incorporate in WE tracks within CE programs

The results of this study show that students and faculty consider that the most contributing factors to why institutions struggle to recruit and retain students are (1) financial difficulties, including lack of sufficient funding and low salaries; (2) mental health of students; (3) lack of interest in PhD programs; (4) lack of proper orientation; (5) no internship course; (6) not enough courses in wind engineering; and (7) employment demand. These results are presented in Figure 8.

Finally, students and faculty reported several strategies, ideas, and/or tools can help institutions integrate more students to WE tracks within CE programs and increase research, including (1) incorporating more workshops; (2) outreach activities and/or wind tunnel tours to increase interest; (3) introducing wind engineering in undergraduate curricula or/and in high schools through summer camps, courses, or modules in physics courses; (4) increasing funding to new students; (5) incorporating CFD courses and wind tunnel testing in the curricula; (6) undergraduate research opportunities; and (7) connecting to future societal needs, including demand for natural hazard engineering jobs. These strategies are shown in Figure 8.

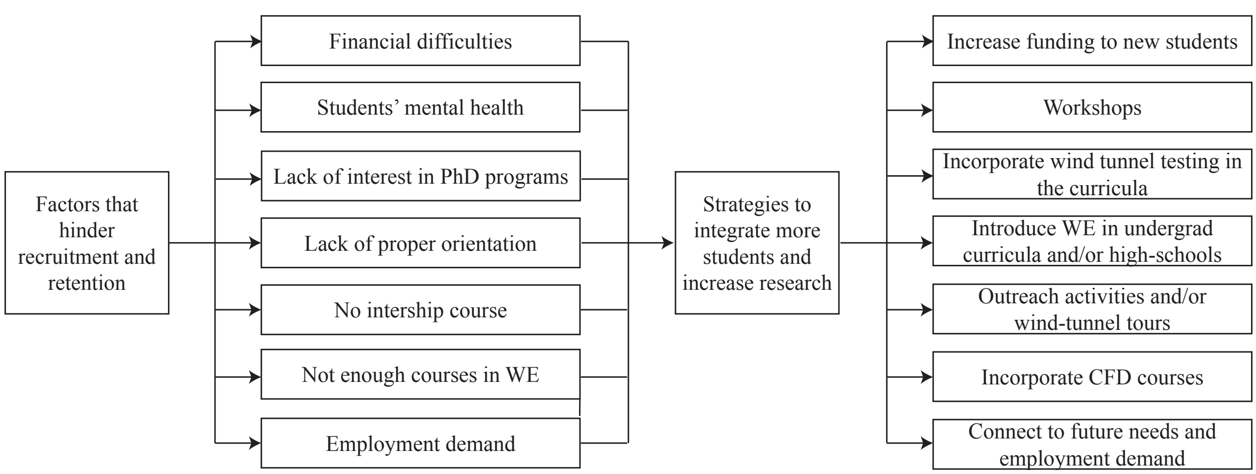

Figure 8: Factors that hinder recruitment and retention and strategies to integrate more students and increase research

Discussion of Results

The results of this study highlight the differences between the diverse wind engineering tracks within civil engineering programs offered in the United States Canada, and Europe. As shown in Table 1, most academic institutions presented in this study offer the course “Wind Engineering”, which covers the fundamentals of wind engineering and wind-structure interaction. The University of Illinois at Urbana – Champaign offers the same course under a different name: “Wind Effects on Structures”. In fact, 9 out of the 19 education institutions presented in this study only offer this course. The only universities that do not offer that course are (a) Stanford University, that only offers the course “Physics of Wind”, which is an introduction to ABL and its properties, including measurements and simulations of ABL flows; (b) Louisiana State, that offers “Hurricane Engineering”, which covers the analysis and design of structures to resist hurricanes and natural hazards, and “Natural Hazards and the Built Environment”, which covers the engineering impacts and implications of hurricanes, floods, earthquakes, and natural hazards on the built environment; and (c) the University of Alabama at Birmingham, that only offers the course “Wind and Seismic Loads”, which covers methods for calculating loads on structures caused by extreme winds and earthquakes. Three institutions only offer two courses including “Wind Engineering”. These institutions are: (1) Colorado State University, that offers “Wind Effects on Structures”; (2) Johns Hopkins University, that offers “Lateral Forces: Analysis and Design of Building Structures”; and (3) University of Notre Dame, which offers “Advanced Topics in Wind Effects on Structures”. The University of Genova offers the following two courses “Novel Developments in Wind Engineering” and “Wind Science and Engineering: Origins, Developments, Fundamentals and Advancements”. Finally, Louisiana State University only offers two courses “Hurricane Engineering” and “Natural Hazards and the Built Environment”.

The most comprehensive WE tracks within CE programs are offered by three academic institutions: (1) University of Western Ontario, that offers the five following courses “Wind Loads on Building Components & Cladding”, “Wind Engineering”, “Computational Wind Engineering”, “Boundary Layer Meteorology”, and “Bluff Body Aerodynamics”; (2) Florida International University, that offers the four following courses “Topics in Wind Engineering”, “Applications of Probability and Statistics to the Analysis of Wind Engineering Experimental Data”, “Design of Tall Buildings”, and “Hurricane Engineering and Global Sustainability”; and (3) Texas Tech University, that offers the following courses “Boundary Layer Meteorology”, “Dynamics of Severe Storms”, “Wind Engineering”, and “Risk Modeling of Natural Disasters”.

Most academic institutions presented in this study have an ABL wind tunnel, with the exception of seven: Johns Hopkins University, Rensselaer Polytechnic institute, Stanford University, University of Alabama at Birmingham, University of Illinois at Urbana – Champaign, and University of Notre Dame. Despite this, it can be observed that not many offer a wide variety of courses pertaining to WSE. Incorporating more courses in such institutions is critical to increase interest and research in WE, as well as to provide equal opportunities for students graduating from these programs.

Incorporating courses related to advanced statistics and data analysis and programming could also enhance WE curricula. Furthermore, courses related to natural hazards and risk modeling as well as forensic engineering could further increase students' interest and provide job opportunities.

The results of this study show that several instructional tools and methods can help to increase students' interest and learning, including exposure to realistic research and working environments, experimental learning, wind tunnel experience, as well as hands-on experience. Further, the results show that faculty and students consider ABL wind tunnel of utmost importance to increase interest and encourage more research in wind engineering. However, they do not consider this a fundamental tool for WE tracks within CE programs.

Finally, the results of this study revealed that several strategies can help institutions integrate more students to WE tracks within CE programs and increase research in this paramount topic including: (1) incorporating wind engineering workshops and outreach activities, where students and/or future students can learn more about WSE as well as about job opportunities in this field; (2) providing wind tunnel tours to give a closer look to this fundamental tool in WE, highlight research that is being conducted in this field, and increase interest; (3) introducing wind engineering in undergraduate curricula and/or in high schools through summer camps, courses, or modules in physics courses to expose students earlier to this field; (4) increasing funding and salaries to students, as well as providing financial workshops to teach students about all available financial resources and how to better manage their finances, since many students have financial difficulties; and (5) connecting to future societal needs, including demand for natural hazard engineering jobs.

Limitations and Future Work

The results of this study presented the differences between WE tracks within CE programs offered in the United States, Canada, and Europe. Furthermore, the authors highlighted strategies that can be implemented to improve WE curricula and increase students' as well as research on this topic of utmost importance. This research acknowledges some limitations. The number of faculty and students' responses may look limited. However, this research surveyed all Ph.D. students and faculty within the discipline of WE working at the NHERI Wall of Wind (WOW) Experimental Facility. This facility, funded by NSF, is one of the largest ABL wind tunnels worldwide and the only one that can simulate hurricane wind speeds up to and including Category 5 Hurricane on the Saffir-Simpson scale [33], [34]. Therefore, their expertise and their impact in the WE discipline is extremely high. Thus, rendering and reflecting the sample to be representative. The recommendations are preliminary and future work could investigate the research at several educational institutions that have WE tracks within CE programs in order to refine them and further improve WE tracks. This would contribute to providing streamlined and ideal wind engineering curricula.

Conclusions and Recommendations

The results of this study highlight the differences between the diverse wind engineering tracks within CE programs offered globally. Only one academic institution offer five courses on WE and two academic institutions offer four courses on this paramount topic. An adequate education in wind engineering is of utmost importance to civil engineering since natural hazards including extreme wind events have been the main cause of destruction to our infrastructure systems and buildings especially in underdeveloped communities. Therefore, offering adequate WE tracks within CE programs in educational institutions as well as increasing research in this topic is paramount to better educate and train students and future workforce.

This research recommends that several courses should be incorporated in WE tracks within CE programs to better the curricula and enhance education in this topic. These recommendations are based on the results of this study and the responses obtained from faculty in the wind engineering field and Ph.D. students doing research on this topic. The courses recommended are the following:

- Wind Engineering
- Computational Wind Engineering (CWE) / Computational Fluid Dynamics (CFD)
- Bluff Body Aerodynamics
- Thunderstorm Effects on Structures / Dynamics of Severe Storms
- Experimental Testing and Data Analysis in Wind Engineering
- Wind Effects on Structures, including high-rise buildings
- Design of Tall Buildings
- Hurricane Engineering
- Experimental Testing and Data Analysis in Wind Engineering

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