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# NOTES

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Preface

The WindEEE RI has undergone significant transformations during the last two years. It has served as a catalyst in streamlining wind research at Western and in Canada through the creation of The WindEEE Research Facilities, comprised of three highly specialized infrastructure suites: the WindEEE Dome (the Dome), the Boundary Layer Wind Tunnel Laboratory (BLWTL), and the Three Little Pigs (3LP) facility. Notably, WindEEE Research Facilities recently received an MSI award from CFI, a prestigious award reserved for unique facilities providing critical support to Canadian research. Strengthened by the MSI award, the institute has broadened its collaborative horizons to encompass researchers from academic, industrial, and governmental sectors across Canada. Additionally, the institute received a prestigious award from the European Union Horizon Infrastructure program under a transnational project named Engineering Research Infrastructure for European Synergy (ERIES), facilitating collaboration with a consortium of 12 European natural hazard laboratories and researchers across Europe. It's worth noting that the WindEEE Research Institute is the only non-European entity within this consortium, included for its distinctive capabilities. In addition, WindEEE Research Institute has become more involved within the expanding domain of advanced research computing in Canada, achieved through collaborations with the Digital Research Alliance of Canada.

Since 2022, two Research Directors joined our ranks. Dr. Greg Kopp, who was recently honored with the prestigious Alan Davenport medal from the International Wind Engineering Association (IWEA), played a pivotal role in the successful CFI MSI initiative. The second new Research Director is Dr. Jin Wang. We also acknowledge the substantial contributions of Dr. EL Damatty and Dr. Siddiqui, the longstanding Research Directors at WindEEE. During the same time, the former Director of WindEEE, Dr. Horia Hangan, and Research Director Dr. Hassan Peerhossaini departed. Our profound gratitude extends to both for their invaluable contributions to WindEEE.

The main goal of WindEEE is to propel the establishment of climate-resilient and sustainable communities through groundbreaking research in wind and climate engineering. In pursuit of this vision, strategic research domains have been outlined based on WindEEE's core proficiencies (please see the attached Strategic Plan for more details):

(i) Severe Storm Hazards: research pertaining to severe weather hazards, encompassing both synoptic phenomena (e.g., hurricanes) and non-synoptic occurrences (e.g., tornadoes, downbursts) in wind systems.

(ii) Computational Wind/Climate Engineering Modeling: computational research targeting multifaceted climate-related challenges through multi-physics, and multi-scale simulations integrated with digital twins.

(iii) Wind Damage Mitigation and Passive Architectural Design: formulating inventive aerodynamic design/retrofit/mitigation strategies; as well as green passive building techniques and renewable energy systems.

(iv) Performance-Based Design: Through collaboration with international natural hazard laboratories, establishing comprehensive performance-based design guidelines for wind, and other stressors such as fire, earthquake etc.

(v) Climate Change Impact Assessment: assessing the impact of climate change on wind and climate testing methodologies as well as the design and retrofit practices of industry and government entities.

(vi) Training the Next Generation: training a diverse group of future wind and climate engineers; engaging with the K-12 community fosters inclusivity, encouraging underrepresented groups to partake in these fields.

Significant strides toward meeting these objectives have already been made. Notable achievements include 68 international journal publications, 62 conference proceedings publications, and the acquisition of $15 million in research funding by the WindEEE RI core faculty group during the 2021-2023 fiscal years. The concerted efforts of the research directors at WindEEE RI have shaped the institute's trajectory. During this phase, the WindEEE RI research directors have supervised 67 students (44 Ph.D. and 23 M.E.Sc.) and mentored 8 Postdoctoral Fellows.
The institute has also hosted a 'Wind Research Seminar Series,' fostering improved communication and collaboration among Western Engineering faculty, postdoctoral fellows, staff, and graduate students engaged in wind-related research.

Collaborative endeavors between the WindEEE RI, the Northern Tornado Project, and the Institute for Catastrophic Loss Reduction (ICLR) have cultivated a unique climate research environment. Both research and industry-funded projects at WindEEE RI continue to thrive. The designation as an MSI has spurred new pan-Canadian collaborations. Notable instances include recent collaborations with the National Research Council (NRC) on tornado research, and Environment and Climate Change Canada’s Climate Action projects, including collaborations with various Canadian Universities and Government Research Laboratories. Furthermore, collaboration with European researchers through the ERIES project has been a significant achievement.

Efforts are also directed toward fostering collaborations with research entities in the USA, particularly through the NSF (National Science Foundation) NHERI (Natural Hazard Engineering Research Infrastructure) facilities.

WindEEE has established a new governance structure (attached) to reflect its involvement in research across the globe, and its designation as a CFI MSI facility. This structure includes academic and industrial representation, with committees reporting to the Board of Directors and, ultimately, to the Vice-President (Research) and Provost of Western University. WindEEE’s structure has expanded over the past year to include increased representation from international industry, academia, and EDI experts outside Western, ensuring the expansion of innovative activities and support for research in Canada and across the globe. Committees such as the International Science Advisory, Finance, Business Advisory, EDI, and Operational Committees provide strategic input and recommendations to the Board of Directors regarding emerging priorities and innovations within the field of climate and wind engineering, positioning WindEEE for success.

In summary, these research priorities converge to establish a clear direction in the pursuit of creating a world-class research environment. With ongoing growth and progress, the WindEEE RI remains dedicated to being a global leader in climate/wind research and innovation.

Girma Bitsuamlak, Ph.D., P.Eng., F CSCE
Director
Governance Structure

WindEEE’s governance structure includes academic and industrial representation, with committees reporting to the Board of Directors, and ultimately to the Vice-President Research and Provost of Western University. WindEEE’s structure has been expanded over the last year to include more representation from international industry and academic experts outside Western University, to ensure it continues to expand its innovative activities and support research around the globe. Two external Committees and the Board of Directors provide the necessary inputs to the Director:

The **Board of Directors** sets the overall strategic priorities for WindEEE and, with input from the committees, ensures the WindEEE Research Institute meets its objectives. The Board of Directors meets twice per year and has 8 voting members, listed in Board Members.

WindEEE’s **International Science Advisory Committee** provides strategic input and recommendations to the Board of Directors regarding emerging priorities and innovation within the field of climate and wind engineering, to ensure WindEEE is well-positioned for success. The committee meets twice per year and has 6 members, listed in International Science Committee.

WindEEE’s Operations and Finance Committees work to ensure the facility operations meet Western University requirements.

The EDI & Training Committee has oversight for tracking and assessing success of EDI practices in relation to targets, and designing and implementing initiatives such as user and demographic surveys that inform WindEEE’s strategic planning process.
People

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Professor and Director, WindEEE Research Institute

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Professor and Research Director, WindEEE Research Institute

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Professor and Research Director, WindEEE Research Institute

Jin Wang, PhD
Assistant Professor and Research Director, WindEEE Research Institute

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Int’l Science Advisory Committee Chair / Prof. of Wind Engineering, University of Genoa

Int’l Science Advisory Committee Member / Initiative Leader, Climate Resilient Built Environment (CRBE), Construction Research Centre, National Research Council Canada

Anne Cope, PhD
Int’l Science Advisory Committee Member / Chief Engineer, Insurance Institute for Business & Home Safety

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Int’l Science Advisory Committee Member / Professor of Civil Engineering, University of Birmingham

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Board Member / Associate Vice-President (Research) Western University

Trevor Nightingale, PhD
Board Member / Director General, Construction Research Centre, National Research Council Canada, Government of Canada

Stéphane Renou, PhD
Board Member / President and CEO FPInnovations

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Board Ex Officio Member / Director of WindEEE Research Institute
Postdoctoral Fellows, Graduate and Exchange Students

Dr. A. Awol – Postdoctoral Fellow, Supervisor: Dr. G.T. Bitsuamlak
CFD model development and validation for wind engineering and building science applications

Dr. M. Kahsay – Postdoctoral Fellow, Supervisor: Dr. G.T. Bitsuamlak
Urban microclimate modeling for sustainable building design

K. Adamek – PhD Candidate, Supervisor: Dr. G.T. Bitsuamlak
Framework for multi-scale design of sustainable and resilient communities

T. Alemayehu – PhD (Completed), Supervisor: Dr. G.T. Bitsuamlak
Autonomous 3D urban and complex terrain geometry generation and micro-climate modelling using CFD and deep learning.

M. Bezabeh – PhD (Completed), Co-supervisor: Dr. G.T. Bitsuamlak
Performance based wind design framework for tall mass timber buildings

T. Birhane – PhD (Completed), Supervisor: Dr. G.T. Bitsuamlak
Aerodynamic optimization of long span bridge sections

D. D. Eneyew – PhD Candidate, Co-supervisors: Drs. G.T. Bitsuamlak and M. A. M. Capretz
Digital twin of smart buildings

A. Gairola – PhD Candidate, Co-supervisors: Drs. G.T. Bitsuamlak and H. Hangan
Numerical modeling of tornadic flow structure and roughness effect

T. Geleta – PhD Candidate, Supervisor: Dr. G.T. Bitsuamlak
Computational wind load evaluation for low rise buildings

T. Getachew – PhD Candidate, Supervisor: Dr. G.T. Bitsuamlak
Aeroelasticity and aerodynamic instability analysis of solar trackers

C. Howlett – PhD (Completed), Supervisor: Dr. G.T. Bitsuamlak
Aerodynamic and dynamic optimization of tall buildings

P. Manmatharasan – PhD Candidate, Co-supervisors: Drs. G.T. Bitsuamlak and K. Grolinger
Machine learning enabled modeling for climate resilient and sustainable buildings Present Position

J. Mekonnen – PhD Candidate, Co-supervisor: Drs. G.T. Bitsuamlak and M. A. M. Capretz
Digital twinning the built environment

A. Melaku – PhD (Completed), Supervisor: Dr. G.T. Bitsuamlak
A computational framework for aerodynamic and aeroelastic modeling of wind loads on tall buildings

B. Nighana – PhD (Completed), Co-supervisors: Drs. G.T. Bitsuamlak and F. Tariku (BCIT, Canada)
Optimization of advanced building integrated photovoltaic and thermal system with dual working fluid

T. Ochono – PhD Candidate, Co-supervisor: Drs. G.T. Bitsuamlak and K. Grolinger
CFD, Machine learning and building energy simulation integration strategies for net zero building design
Y. Solomon – PhD Candidate, Co-supervisors: Drs. G.T. Bitsuamlak and J. Wang
Performance based design for non-stationary winds-Tornado case study

M. Younis – PhD Candidate, Supervisor: Dr. G.T. Bitsuamlak
BIM integrated sustainable and resilient building design framework for Northern Architecture

H. Abdallah – MESc Student (Completed), Supervisor: Dr. G.T. Bitsuamlak
Implication of city growth on wind-induced loads for cladding and structural design

K. Current – MESc Student (Completed), Supervisor: Dr. G.T. Bitsuamlak
Experimental evaluation of ABL and downburst wind loads on elevated buildings

F. A. Hameed MESc Student, Supervisor: Dr. G.T. Bitsuamlak
Sustainable building design

C. Van Der Kooi – MESc Student (Completed), Supervisor: Dr. G.T. Bitsuamlak
Considerations for the tornado-resilient structural design of low-rise buildings

M. Vandewiel – MESc Student (Completed), Co-supervisors: Drs. G.T. Bitsuamlak and M.A.M. Capretz
CFD and deep learning based natural ventilation analysis in buildings

H. You – MESc Student (Completed), Co-supervisors: Drs. G.T. Bitsuamlak and A. Sadhu
Effects of city growth on tall building cladding fatigue

S. Breitkopf – PhD Exchange Student, Co-supervisors: Drs. G.T. Bitsuamlak and C. Hartz
Technical University of Dortmund Germany
Accuracy of wind-load determination based on CFD for design building structures

Z. Zhang – PhD Exchange Student, Co-supervisors: Drs. G.T. Bitsuamlak and P. Huang
Tonji University
Modeling with flow in wind farms

A. Piazza – PhD Exchange Student, Co-supervisors: Drs. G.T. Bitsuamlak and P. Repetto
University of Genoa Italy
Experimental estimation of aerodynamic characteristics and dynamic response of a tree model with a range of crown porosity

Dr. A. Enajar – Postdoctoral Associate, Supervisor: Dr. A.A. El Damatty
Development of software for the analysis of light frame wood buildings

Dr. A. Shehata – Postdoctoral Fellow (Completed), Supervisor: Dr. A.A. El Damatty
Progressive failure software for transmission lines under HIW

E. Abdelhadi – PhD Student, Supervisor: Dr. A.A. El Damatty
Assessment of behaviour of conical tanks under extreme wind loads

M. Abdelkader – PhD Candidate, Supervisor: Dr. A.A. El Damatty
Analysis and optimization of off-shore wind turbines

S. Abdelraouf – PhD Candidate, Supervisor: Dr. A.A. El Damatty
Behaviour and optimization of double-curvature roofs under wind loads

A. Ahmed – PhD Candidate, Supervisor: Dr. A.A. El Damatty
Progressive failure of transmission lines under synoptic wind

A. Ballate Delgado – PhD Candidate, Supervisor: Dr. A.A. El Damatty
Non-linear analysis of tall building under extreme wind loads

M. Hamada – PhD Candidate, Supervisor: Dr. A.A. El Damatty
Analysis and testing of transmission lines under tornado wind load

S. Maheux – PhD (Completed), Supervisor: Dr. A.A. El Damatty
Non-linear flutter behaviour of long span bridges

M. Niazi – PhD Candidate, Supervisor: Dr. A.A. El Damatty
Performance of multi-story wood building under lateral loads

M. Ramadan – PhD (Completed), Supervisor: Dr. A.A. El Damatty
Numerical models and design loads for wind turbines under downbursts

M. Sadek – PhD Candidate, Supervisor: Dr. A.A. El Damatty
Behaviour and testing for light frame wood buildings

M. Seleemah – PhD Student, Supervisor: Dr. A.A. El Damatty
Modeling of floors in LFW buildings

A. Torkey – PhD Student, Co-Supervisors: Dr. A.A. El Damatty and M. Zaki
Interaction between transmission lines failure and transportation infrastructures

S. Yu – PhD Candidate, Supervisor: Dr. A.A. El Damatty
Modelling and behaviour of wind turbine connections under extreme wind events

M. Ellassaly – MESc Student (Completed), Supervisor: Dr. A. A. El Damatty
A case study on medium and high-rise timber buildings

J. Ortiz – MESc Student (Completed), Co-Supervisors: Drs. A. A. El Damatty and H. Hangan
Experimental study on the loads induced by large-scale tornado on wind turbines

M. Seleemah – MESc Student (Completed), Co-Supervisors: Drs. A. A. El Damatty and A. Elansary
Structural behavior of composite conical water vessels under hydrostatic loading

D. Yao – MESc Student (Completed), Supervisor: Dr. A. A. El Damatty
Behaviour of transmission line conductors under tornadoes

S. Brusco – Postdoctoral Fellow, Supervisor: Dr. G.A. Kopp
Wind loads on buildings in tornadoes

Y. Guo– Postdoctoral Fellow, Supervisor: Dr. G.A. Kopp
Design wind loads for buildings

A. Mejorin – Postdoctoral Fellow, Supervisor: Dr. G.A. Kopp
Performance-based design requirements for wind-borne debris impacts on buildings

J. Wang – Postdoctoral Fellow (Completed), Supervisor: Dr. G.A. Kopp
Design wind loads for buildings
T. Acosta – PhD Candidate, Co-supervisors: Drs. G.A. Kopp and J. Wang
Wind loads on buildings in tornadoes

S. Boodoo – PhD Candidate, Co-supervisors: Dr. G.A. Kopp and D. Sills
Detection of severe convective storms using radar

O. Hernandez – PhD Candidate, Supervisor: Dr. G.A. Kopp
Evaluation of the gust-effect factor

E. Hong – PhD Candidate, Supervisor: Dr. G.A. Kopp
Detection and classification of tornadoes in forests

I. Ibrahim – PhD Candidate, Supervisor: Dr. G.A. Kopp
Climatology of downbursts in North America

A. Mejorin, PhD (Completed), Co-supervisor: Dr. G.A. Kopp
Dual PhD Degree with Iuav University of Venice
Wind-borne debris resistance of facades: identification of alternative impact test requirements

S. Stevenson – PhD (completed), Co-supervisors: Drs. G.A. Kopp and A. El Ansary
Wind effects on wood-frame houses

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Long-span bridge aerodynamics

Y. Xia – PhD (Completed), Co-supervisor: Dr. G.A. Kopp and Zhejiang University
Analysis of standing seam metal roofs subjected to extreme wind loads

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Effects of turbulence on long-span bridge aerodynamics.

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Design of stick-framed wood roofs under extreme wind loads

F. Jessa – MESc Student, Supervisor: Dr. G.A. Kopp
Identifying tornadoes from infrared remote-sensing imagery

F. Lavigne-Theriault – MESc Student, Supervisor: Dr. G.A. Kopp
Identification of hail swaths with drones

E. Marejka – MESc Student, Co-supervisors: Drs. G.A. Kopp and J. Wang
Wind loading analysis of standing seam metal roofs on low-rise buildings

N. Szilagyi – MESc Student, Co-supervisors: Drs. G.A. Kopp and A. El Ansary
Effective wind area for the design of roof sheathing under wind loading

C. Kellogg – PhD Student, Supervisor: Dr. K. Siddiqui
Investigation of droplet dynamics in a turbulent flow

K. Teather – PhD Student, Supervisor: Dr. K. Siddiqui
Investigation of phase change process in a circular geometry
S. Akber – MESc Student (Completed), Co-supervisor: Dr. K. Siddiqui
Numerical investigation of flow and thermal behavior in channels with PCM-filled thermal energy storage columns for potential application in photobioreactors

E. Blokker – MESc Student (Completed), Co-supervisor: Dr. K. Siddiqui
Optimization of porous geometry for collecting concentrated solar energy

I. Clapp – MESc Student (Completed), Supervisor: Dr. K. Siddiqui
Flow characterization over biomimetic fish scale arrays

L. Crnjac – MESc Student, Co-supervisor: Dr. K. Siddiqui
Design and development of a modular thermal energy storage System

C. Jaffray – MESc Student (Completed), Co-supervisor: Dr. K. Siddiqui
Development of a computationally efficient method for modelling thermal energy storage in packed beds of spherically encapsulated phase change material

C. Kellogg – MESc Student (Completed), Supervisor: Dr. K. Siddiqui
Investigation of droplet dynamics in a turbulent flow

M. Mahaffy – MESc Student (Completed), Supervisor: Dr. K. Siddiqui
Characterization of spray droplet behaviour in afterburner-like geometry

T. Acosta – PhD Candidate, Co-supervisors: Drs. J. Wang and G.A. Kopp
Effects of turbulence on the horseshoe-vortex system and wind loads of low-rise buildings

Y. Solomon – PhD Candidate, Co-supervisors: Drs. J. Wang and G.T. Bitsuamlak
Performance based design for non-stationary winds-Tornado case study

E. Marejka – MESc Student, Co-supervisors: Drs. J. Wang and G.A. Kopp
Wind loading analysis of standing seam metal roofs on low-rise buildings

Mokani J. – MESc Student, Supervisor: Dr. J. Wang
Gust effect factors of components and cladding wind loads on low-rise buildings
Facilities and Equipment

WindEEE Dome

The Wind Engineering, Energy and Environment (WindEEE) Dome, see Hangan (2014), is the world’s first 3D wind chamber and a certified LEEDs Silver facility. It consists of a hexagonal test area 25m in diameter and an outer return dome 40m in diameter. Mounted on peripheral walls and on top of the test chamber are 106 individually controlled fans and 202 louver systems. Additional subsystems, including an active boundary layer floor and “guillotine” allow for further manipulation of the flow. These systems are integrated via a sophisticated control system which allows manipulation with thousands of degrees of freedom to produce various flows including straight flows, boundary layer flows, shear flows, gusts, downbursts, and tornadoes. A pair of 5m diameter turntables and removable contraction systems accommodate a wide variety of test objects and wind speeds.

The WindEEE facility includes office space for industry, researchers, staff, and graduate students as well as meeting and conference spaces for collaboration.

Model WindEEE Dome (MWD)

The Model WindEEE Dome (MWD) is a 1:11 scale version of the WindEEE Dome. The MWD was originally used as part of the design validation for the full-scale facility and underwent significant flow studies. The MWD has many of the same features as the full scale WindEEE Dome and can produce the same flow scenarios. The model is located on the main Western University campus at the Boundary Layer Wind Tunnel Laboratory. Because of its inexpensive operation and maintenance costs, the MWD continues to serve as a tool for preliminary test validation/set-up, fundamental tornado research and demonstrations.
Boundary Layer Wind Tunnel Laboratory (BLWTL)

Established in 1965, BLWTL is considered the birthplace of the modern practice of wind engineering. Research done at BLWTL has made countless structures around the world safer and more economical, including iconic buildings and bridges such as the CN Tower and the Confederation Bridge. Building on this excellence, BLWTL was recently modified to enable testing of the effects of wind turbulence on gas flares, through a Technical Standard Safety Authority approved fuel handling system to burn gas compositions. It can burn these fuels in flares up to 4 inches in diameter, at wind speeds up to 10m/s in conditions replicating atmospheric turbulence. The tunnel has been modified to allow accurate measurement of emissions. The passive grid was also replaced with an active grid to allow the high Reynolds number turbulence simulations required to replicate atmospheric wind. BLWTL also has unique capabilities of simultaneous wave and wind testing, not found in any other wind tunnel in Canada, owing to its floors equipped with a water basin and wave generator.

Three Little Pigs (3LP) Laboratory

The 3LP laboratory is used to assess the capacity of a structure. Beyond evaluating wind loads, users turn to WindEEE’s 3LP, a facility that enables reproduction of realistic tornado and hurricane wind force to test homes at full scale. The pressure loading actuators (PLA) in the space between the reaction frame and the building or component to be tested apply fluctuating wind loads to study failure modes of complete structures and cladding systems. The primary innovations for 3LP were to (i) substantially increase the frequency response of the pressure controlling valve, (ii) allow for leakage through the component or cladding, and (iii) reduce the footprint of the unit size so that many could be mounted in proximity. The latter point was important so that spatial variations of pressure could be captured by mounting many PLAs and air-boxes adjacent to each other, over the building or component surface(s). The highly accurate and repeatable loading allows both system and component level impacts to be studied, removing the uncertainty caused by spatially complex wind loads. As a result, the PLAs have now been adopted by other preeminent international wind programs in the world such as the one at University of Florida, Institute for Business and Home Safety (IBHS) in USA, Tohoku University (Japan), and others.
WindEEE Dome Testing Capabilities

The WindEEE Dome can accommodate multi-scale, three dimensional and time dependent wind testing that no other facility can reproduce. WindEEE can be operated in a variety of configurations:

**Straight Flow Closed Loop**
- Straight flow closed loop utilizing one wall of 60 fans (4 high X 15 wide)
- Up to 30m/s with removable contraction
- Test section 14m wide, 25m long and 3.8m high
- Removable slotted wall assemblies
- All types of naturally occurring horizontal flows including: uniform, gusting, sheared and boundary layer flows
- Active floor roughness control
- Wide variety of scales up to 1:1

**Straight Flow Open Loop**
- Open mode utilizing 60 fans in reverse
- Uniform, gusting, sheared and boundary layer flows
- Up to 40m/s with removable contraction
- 5m diameter high-capacity turntable
- Outdoor test platform with
- Wind driven rain, debris and destructive testing
- Access for very large full-scale test objects

**Tornado**
- Replication of EF0-EF3 tornadoes
- Properly scaled tornado flow
- Geometric scale 1/50 to 1/200
- Velocity scale 1/3 to 1/5
- Variable swirl ratio
- Adjustable vortex diameter up to 4.5m
- 2m/s maximum tornado translation speed
- Floor roughness control

**Downburst/Microburst**
- Variable jet diameter (max 4.5m)
- Geometric scale ~1/100
- 2m/s maximum downburst translation speed
- Max 50m/s horizontal velocity
- Variable downburst offset and jet angle
- Combined horizontal and downward flows
WindEEE Dome Example Uses

WindEEE Dome has been utilized for many different types of projects and we are always discovering new uses for the facility and equipment. Just like the design of the facility, many of WindEEE’s capabilities are unique in the world. WindEEE allows for the first-time comparative testing of atmospheric boundary layer, downburst and tornado flows at the same scale. This allows for comparison of loads and responses of a given structure when exposed to these different wind events.

WindEEE’s different flow configurations can be used to determine pressures and dynamic response of various structures. Scale models of buildings (residential, commercial, industrial, hospital, high-rise), bridges, transmission towers, wind turbines and many others can be tested. Various techniques are used to simulate the effect of surrounding buildings, topography, and canopy to replicate the local site conditions.

WindEEE can also be used to test large scale, prototype, or full-scale objects to a wide variety of wind fields. Applications range from testing of full-scale solar panels and small wind turbines, large scale topographic and canopy models, large- and full-scale wind turbine components (blades, towers), building components, environmental measurement devices, unmanned flying vehicles, etc.

Equipment

WindEEE is furnished with a suite of equipment, instrumentation, and data acquisition systems to fabricate scale models and facilitate all types of wind related research and testing, including:

- High speed/high precision pressure scanning system
- Cobra probes
- 6 DOF force balances (multiple ranges)
- Pollution/scent dispersion system
- Multi camera Particle Image Velocimetry (PIV)
- Mobile LIDAR
- Full scale monitoring systems (masts, weather station, anemometers)
- Adjustable rain rake
- 6 DOF probe traverse system
- National Instruments data acquisition systems
- CNC hotwire
- CNC router
- FDM 3D printer
Current Research

Understanding near-ground tornado flows – pressure, shear and turbulence, and their importance in structural loading - ERIES-Tornado Near-Ground (TNG) at WindEEE

The destructive power of tornadoes is well-known, as is the consequent need for appropriate building design in tornado-prone areas. Despite this, the provision for tornado wind loading guidance in design codes has been limited by a lack of fundamental understanding of the behavior of these flows in the context of tornado-building interaction and therefore loading. While this situation has been somewhat improved with the development of the ASCE 49-21 code of practice, numerous gaps in our knowledge of near ground tornado flows exist. The research outlined in this proposal addresses several of these fundamental and outstanding issues, providing the vital experimental data to support theoretical developments which the authors have been working on for the last three years. The successful outcome of the proposed research will have considerable impact greater than the sum of its parts, with direct application beyond the ERIES consortium countries, ensuring that ERIES project has maximum leverage and impact on improved structural design. There has been considerable research undertaken within the last decade or so related to tornadoes and the corresponding wind induced forces arising from such phenomena. This has resulted in several vortex simulators being constructed around the world (at considerable cost), numerous numerical simulations (including the development of new analytical models and CFD simulations), and the development of a code of practice (ASCE 49-21). Whilst research has developed at a pace, in some cases, the enthusiasm of the community to make progress has resulted in several basic issues being overlooked, and results being interpreted beyond what would normally be considered suitable (reliable). If this continues, then we run the risk of inefficient structural design due to this lack of a true understanding of the underlying physics, with too much embedded carbon due to over-engineering or fundamentally unsafe designs – issues which run counter to the ERIES research goals.

Figure 1. WindEEE test setup for TNG

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Behavior of Telecommunication Lattice Towers to Thunderstorms Winds (acronym: BOLT)

The proposed work builds on previous experimental research conducted by the User Group Leader (UGL) on telecommunication lattice towers involving both ABL wind tunnel testing as well as full-scale monitoring.

The wind tunnel tests were carried out at the wind tunnel laboratory at the Department of Civil, Chemical and Environmental Engineering (DICCA) of the Polytechnic School of the University of Genova, which is a closed-loop subsonic circuit for aerodynamic and civil experiments. The ABL wind tunnel testing campaign was conducted on a sectional model of a 90 m high telecom lattice tower to emphasize the effect of ancillaries on the overall drag coefficient.

Full-scale monitoring was initiated in January 2021, and it involves the instrumentation of a 50 m telecommunication lattice tower located in Sânnicolau Mare, Romania. The purpose of the monitoring system is to collect long-term continuous and simultaneous high-quality wind and structural response data. The structure is equipped with both meteorological as well as structural monitoring sensors. The meteorological sensors comprise of a 2D ultrasonic anemometer and a temperature sensor whereas the structural sensors comprise of two 3D accelerometers as well as six strain gauges Figure 1. A video surveillance system made up of four cameras and aimed at capturing cloud activity during thunderstorms is also installed on the tower.

The scope of the proposed work is to investigate the behaviour of telecommunication lattice towers to thunderstorm winds by means of non-synoptic wind tunnel testing and field measurements.

The proposed work aims at complementing the existing full-scale data with non-synoptic wind tunnel test data at WindEEE thus offering a unique opportunity to advance the knowledge in thunderstorm research. The study will allow reproduction of complex downburst wind systems, in a controlled laboratory environment, like those observed in the field monitoring. These new wind systems will then be used to produce aerodynamic and aeroelastic data at WindEEE. Moreover, existing field-data will be used to calibrate wind tunnel test measurements. This will lead to the extension of the wind field and aerodynamic database which can be further utilized for codification purposes and for validating numerical and analytical models.

The expected outcome of the proposed work is the advancement of code-based design of telecom lattice towers to thunderstorm winds. A workflow diagram of the proposed research is shown in Figure 2 and WindEEE test setup for T50 under downburst wind shown in Figure 3.
Figure 3. WindEEE test setup for T50 under downburst wind.

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Numerical study of the sol-air temperature for building surfaces in urban-like surroundings

The sol-air temperature has been used as a convenient approach to compute the combined effect of convection and radiation to/from a building surface. However, the challenge of measuring longwave interactions between building surfaces and the surrounding (such as ground sky and other buildings), results in very simplified considerations. The longwave portion of the radiation fluxes is commonly assumed to be negligible or a constant depending on the orientation of the building surface (ASHRAE Handbook 2005).

This study attempted to introduce the impact of surrounding buildings on both the convective heat flux - through the convective heat transfer coefficient \((CHTC)\) and radiative heat flux – through the sol-air temperature \((T_{sol-air})\) from the surfaces of a target building. While most analysis covers effects from the aerodynamic response from the study building alone, the effect from surrounding morphology is only rarely discussed. These microclimatic modifications dictate how the building interacts with the larger environment.

Earlier research indicated changes in CHTC in relation to changes in the neighborhood building packing density. In continuance to the same work, detailed modeling of the roughness surrounding a study building is conducted to investigate the Tsol-air and CHTC near a building in urban setting. Firstly, an equivalent roughness scale is obtained for any real, arbitrary, neighborhood roughness based on its frontal and planar packing density designations. The equivalent model is then utilized to simulate various neighborhood density types in a CFD environment. The study considers a packing density range of 0 – 60%, up to 15 blocks of building, a steady 3-dimentional flow with Reynolds stress turbulence model, solar loads with surface to surface (S2S) radiation, and the gray thermal radiation model in different simulations.

Correlations of the sol-air temperature and CHTC are obtained in relation to the neighborhood’s density of the buildings near the study site. The relationship between sol-air temperature or CHTC and the nature of roughness around a building helps to get better estimate of the convective and radiative heat exchange from the building, which in turn ensures better building energy performance evaluation.

![Figure 1: Sol-Air Temperature distribution on building surfaces](image1)

![Figure 2: Sol-Air Temperature’s dependence on urban packing density for building surfaces](image2)

<table>
<thead>
<tr>
<th>Surface</th>
<th>Correlation ((T_{sol-air}))</th>
<th>COD ((R^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leeward</td>
<td>(11.619 \ln(\lambda) + 360.94)</td>
<td>0.96</td>
</tr>
<tr>
<td>Top</td>
<td>(13.164 \ln(\lambda) + 355.37)</td>
<td>0.97</td>
</tr>
<tr>
<td>Lateral</td>
<td>(9.3962 \ln(\lambda) + 354.48)</td>
<td>0.92</td>
</tr>
<tr>
<td>Windward</td>
<td>(9.1883 \ln(\lambda) + 340.49)</td>
<td>0.94</td>
</tr>
</tbody>
</table>

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CFD based simulation of bridge flutter

Suspension bridges are wind sensitive structures requiring aerodynamic design of the deck structure accounting for aeroelastic effects. Shape modifications to existing long-span bridges as in the case of the White Bronx Bridge (King et al. 2000) or development of aerodynamically efficient bridges as in the case of the proposed Messina Straight Bridge (Diana et al. 2002) have been mostly explored through a series of wind tunnel tests.

As a surrogate to the wind tunnel procedure, we developed a two-tier computational aerodynamic shape optimization (CASO) framework. The first tier involves automated shape modification based on design criteria established using aerodynamic parameters from computational fluid dynamics (CFD) analysis of static section models. The design optimization criteria are established with the objective of reducing the lateral wind load and improving its aerodynamic stability, i.e., suppressing the onset of flutter. The second tier involves assessing the aeroelastic performance improvement gained from the optimization through a detailed fluid-structure interaction (FSI) analysis of dynamic section models.

The figure below shows results from FSI analysis of a generic plate girder deck that mimics the shape of the First Tacoma Narrows Bridge deck (breadth-to-depth ratio = 5). The plots show the evolution of peak torsional response with reduced wind speed (Fig. 1a) for the base line H-shaped deck section (Fig.1b) and the modified section with triangular fairing (Fig.1c). The H-shaped section exhibits a sudden step change of response at reduced wind speed of about 4.2, which defines its critical wind speed for the onset of torsional flutter. Whereas the torsional response of deck section with optimized fairing grows with wind speed at mild slope. The plot demonstrates that appending triangular fairings allows to suppress the onset of torsional flutter. Furthermore, FSI result complements the robustness of tier-1 stability criteria established based on a reduced order CFD analysis to minimize the simulation time for CASO.

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Relative role of gravity and elasticity for the aeroelasticity of suspension bridges

Suspension bridges are wind sensitive structures for which aeroelastic modeling is required for studying wind effects. The wind load acting on the deck and suspension system is transferred to the towers and ground anchors through the pretensioned cables. The pretension in the suspension cables mainly derives from the weight of the suspended structure. Thus, the gravity induced pretension in the cables, elasticity of cables, the deck and the pylons contribute to the resistance of the suspension structure to wind. Quantifying the relative contribution of elasticity and gravity to the modal stiffness of the suspension bridges allows us to assess the relative significance the Froude number (the ratio of gravity resisting force to the inertial force) and the Cauchy number (the ratio of dynamic elastic force to the inertial force) for scaling wind speeds of aeroelastic models.

We developed a Finite Element Analysis (FEA) code to model the dynamics of suspension bridges using MATLAB, where the mass, elastic stiffness, gravity stiffness matrices of the bridge are assembled from the corresponding matrices of finite frame and cable elements. The 3D rendering of the finite element model for the Golden Gate Bridge (GGB, main span length = 1280m) is shown in Fig. 1a. Eigenvalue analysis was carried out to compute the structural modes. Fundamental symmetric and skew-symmetric mode shapes and frequencies of the GGB in the lateral, vertical, and torsional directions are shown in Fig. 1b. The relative participations of the deck, cables, and pylons to the overall modal stiffness of suspension bridges were computed using elastic stiffness of each element type, gravity stiffness of cables, and the computed mode shapes. The modal stiffness contribution factors for the first 20 modes of the GGB are mapped in Fig. 1c. For example, the stiffness of the first lateral symmetric mode (j = 1) primarily derives from gravity stiffness of the cables (80%), elastic stiffness of the deck (18%) and elastic stiffness of the pylon (2%). The stiffness of the first vertical mode (j = 2), which is asymmetric, arises mainly from gravity stiffness of the cables (95%) and elastic stiffness of the deck (5%). Whereas the stiffness of the first torsional mode (j = 8), which is asymmetric, is attributed to the gravity stiffness of the cables (65%), elastic stiffness of the deck (33%), and elastic stiffness of the pylons (2%). Thus, the relative role of gravity and elasticity to the aeroelastic response of suspension bridges is a function of the primary vibration mode excited by wind as lateral modes for drag buffeting and torsional modes for flutter.
The impact of interior scale geometry on natural ventilation and pedestrian level winds in cities

Inherently, cities are designed at multiple scales. From materials, rooms, levels, floors, cladding, building shape, street orientation, to block layout - all aspects of design, and how they relate to one another, mediate the relationship between people and weather. Specifically, it is difficult to fully understand how the many different details of a building change the wind flow field at different scales (i.e., materials change the flow field nearest to the surface and building shape alters a larger street scale area) and therefore we unconsciously interact with wind.

While wind engineering consultants are brought into earlier design stages, there is still a gap in knowledge of understanding wind at different scales of design on the design end. The impact and relationship of large scale and small-scale geometrical details on wind environment is mostly investigated separately. While it is efficient to focus on one scale at a time, it is also important to know the impact of one building on another - treating the city like an organism. This awareness would allow designers such as architects and planners to integrate wind criteria more thoroughly into design.

A design framework using case studies to visualize the relationship between geometric scales and different criterion of wind can help bridge this gap. In this study specifically, the objective is to demonstrate the importance of interior geometry on the competing designs of PLW and ventilation on the exterior vicinity of a building.

A study building with varying interior geometries located in an area of downtown Toronto is used as a case study and modelled in CFD. The change in the flow around the building is investigated to assess its optimality for PLW versus ventilation. In the future, additional case studies will be considered to formally layout the architectural building and urban design framework.

Figure 1: Downtown Toronto CFD case study investigating flow around buildings

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Toward smart-building digital twins: BIM and IoT data integration

Digital twin technology has emerged as a promising solution to optimize energy consumption, improve occupant comfort, and reduce environmental impact in smart buildings. By virtually replicating the static and dynamic building characteristics through real-time connectivity between the virtual and physical counterparts, smart-building digital twins offer a powerful tool to optimize building operations. However, the lack of interoperability between Building Information Modeling (BIM) and Internet of Things (IoT) data sources presents a significant challenge that hinders the full potential of digital twin technology for smart buildings. To address this challenge, this study presents a novel multi-layer digital twin architecture called BIM-IoT Data Integration (BIM-IoTDI) that enables semantic interoperability among smart-building digital twin applications. The proposed architecture is accompanied by a detailed framework based on an ontology-based query mediation method that provides integrated BIM and IoT data access. The feasibility and effectiveness of the BIM-IoTDI architecture and framework are evaluated through an experimental model. The results demonstrate that the BIM-IoTDI architecture and framework are better suited in effectively fulfilling the real-time update and semantic interoperability needs of smart-building digital twins compared to existing BIM-IoT integration approaches.

Figure 1: BIM-IoTDI architecture for smart-building digital twin

Figure 2: Case study monitoring real-time application—displaying sensor readings

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An investigation of the effect of surface roughness on the mean flow properties of “tornado-like” vortices

The Davenport wind loading chain formally conceptualizes that the wind effects experienced by a structure depend on an integrated effect of (i) the wind climate as governed by the storm, (ii) the local wind exposure as dictated by the terrain conditions, (iii) the aerodynamic characteristics (shape) of the structure and (iv) dynamic characteristics (structural properties) of the structure. This framework has provided a systematic approach for estimating wind loads on buildings using scaled models in a wind tunnel such that the wind load estimates can only be as accurate, or less, as the least accurately represented link of this chain in the laboratory. As a result, employing an intricate combination of spires, barriers, and roughness elements to replicate the terrain conditions and match full-scale velocity profiles is a well-established procedure in the study of wind loads arising from conventional boundary layer flows that are typical of synoptic wind systems.

Despite current advances in modeling “tornado-like” vortices (TLVs), both physically and numerically, to study the effect of tornadoes on the built environment, the same level of sophistication in matching the terrain conditions has not yet lent itself to the study of tornado wind loading. Most aerodynamic studies on the interaction of tornadoes with buildings have considered a smooth floor, presumably corresponding to open terrain conditions. This is in part due to the lack of good quality full-scale, near-ground velocity measurements to serve as target profiles and in part due to a lack of consensus on the effect of terrain on tornado wind field.

This study presents the results of large eddy simulations of “tornado-like” vortices (TLVs) of swirl ratios in the range of 0.22 to 1.00 over five ground roughness scenarios. The results indicate that roughness enhances flow convergence and reduces the core radius near the ground, except at the transition swirl ratio. Our study supports the widely reported claim that surface roughness has an effect similar to a reduction in swirl ratio. A reduction in core radius is accompanied by a speed-up in the tangential velocity due to the principle of conservation of angular momentum. The trends in maximum tangential velocity are, however, more height-sensitive due to the competing effects of depleting angular momentum in the surface layer and speed-up due to enhanced flow convergence. The results indicate that the effect of surface roughness on TLV characteristics is strongly dependent on the external swirl ratio. The lack of consensus in the literature is due to the limited range of swirl ratios and roughness considered in those studies.

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LES-based components & cladding wind loads

The application of Computational Fluid Dynamics (CFD) for the purpose of wind load evaluation requires extensive validation. The validation process involves the collection of high-quality benchmarking experimental data and the application of state-of-the-art CFD methods. This study aims at producing high-quality wind tunnel experiment and conducting high-fidelity Large-Eddy Simulation (LES) of the TTU building. The TTU low-rise building was tested in the Boundary Layer Wind Tunnel Laboratory of Western University at 1:50 scale as shown in Figure 1. The corresponding LES model is setup by using the Divergence-Free Spectral Representation (DFSR) inflow generator. The inflow has been tuned by correcting for the deviation from the target experimental wind field at the incident flow location. The WALE SGS model is used. The ground is set as no-slip boundary condition. The model is fitted with 456 taps distributed over the roof and walls. Similarly, the LES model is setup with 456 probes at the same location. The wind field data of the experiment is collected using cobra probes at a sampling frequency of 1600 Hz. Analogously, the empty domain LES is used to obtain the wind field. A total of seven wind directions were compared between BLWT and LES.

Figure 2 shows the comparison of the representative profiles and spectrum. The results show a promising agreement to the target. Figure 3 shows the enveloped contour of mean, standard deviation, and peak Cp values from the BLWT in comparison to the LES. The results show a promising agreement. The one-to-one comparison of the local Cp statistics is given in Figure 4. Considering the number of data points (i.e., 456 x 7), the overall agreement is very good. The extreme values have some difference that are attributed to taps located very close to the edge making it specially challenging to capture using the current mesh. The normalized mean absolute error (NMAE) is within 15% for all cases. Finally, the C&C loads are compared between LES, BLWT, and ASCE 7-22 provisions. The results are promising.

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Aero-structural optimization of tall building

Recent trends in city development have shown a dramatic increase in the construction of tall buildings. Buildable space within cities is becoming limited, forcing designers to expand upwards by creating taller and more slender buildings. These buildings are more susceptible to wind-induced forces, and the design for wind performance commonly govern the structural systems. Designers have been pushing the limit of the current design practices and structural systems in order to create taller buildings. A key limitation within the current design process of tall buildings is the separation of disciplines. The exterior shape, i.e. the architecture, and structural system are designed separately from each other while the dynamic response of the structure is affected by both. Tall building design problems are multidisciplinary. A design framework which combines the exterior form and the internal structural system and optimizes them as a single unit is needed to address the limitations within the current design practice.

Topology optimization has been used to improve structural systems and exterior forms within aerospace engineering. Topology optimization determines the optimal material distribution to resist the applied loads while using less material. This method is adopted to produce structural systems for tall buildings to improve stiffness while remaining lightweight. The framework optimizes both the structural system and the exterior form while conforming to the architectural and structural engineering constraints.

Generative AI tools have shown recent growth in various fields such as image generation, natural language processing and drug discovery. These flexible tools can be training to understand complex relationships and synthesis realistic results are a reduced computation cost. For tall building design, the various non-linear and complex relationships between disciplines can be estimate using these generative AI models. Linking these models with an optimisation algorithm allows designer to consider a wider range of design options while reducing the computation time.

The multidisciplinary aspect of the optimization process is managed within the BIM environment. BIM allows data from different designers (architects and engineers) to be collected in a single model and then be accessed by everyone. The optimization objective(s) and constraints from each designer can be indicated within the model, using the parties’ respective terminology. Based on each parties’ requirements, the framework can generate a set of possible designs which best meet the designer’s objective(s). Using the BIM model as the central database ensures that the exterior form and structural system are coupled, creating the aero-structural dynamic optimization framework. The proposed framework will outline the importance of multidisciplinary aero-structural optimization while designing tall buildings. Rather than optimizing separate components (exterior geometry and structural system) of the building, the different components will be optimized as a single unit enhancing the performance at a system level. Designers will be able to use the framework to create safer, cost-effective tall buildings which reach greater heights while using less material.

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Figure 1: Mean Flow and Pressure Prediction around Building Cross-Section using a Convolutional Neural Network (CNN)

Figure 2: Conceptual Aero-Structural Optimization for Tall Buildings
Climate resilient and sustainable building for the north

In austere environments, such as northern regions, remote communities face many challenges, such as permafrost warming and significant infrastructure deficit. With the increasing demand for soil stabilization methods beneath structures, adapting building designs has become vital for a sustainable and resilient future in the northern climate.

This report presents some results of a study investigating the airflow around northern architecture and the thermal load produced by buildings and assessing their impacts on the permafrost ground. More specifically, it proposes a developed framework integrated with Building Information Modelling (BIM) and Computational Fluid Dynamics (CFD) environments to quantify the effects of infrastructure development on the frozen ground through Heat Transfer Coefficient (CHTC) analysis. It demonstrates that wind speeds and directions significantly influence the permafrost layer under the northern climate through the downwash effect, which transfers the heat from building surfaces to the ground. This effect is more pronounced when the building is close to the ground surface and has restricted airflow.

The significance of this work; it addresses the growing need for climate-resilient and sustainable building practices, particularly in northern areas, where climate change impacts are becoming more pronounced. Further, it provides insights into the key considerations and strategies for climate-resilient and sustainable buildings in northern regions. It highlights the importance of adopting elevated building design in such areas. It also strengthens our understanding of climate change impacts and suggests solutions to increase the ability to adapt to changing climates.

Figure 1: Temperature distribution as a function of wind velocity for buildings with different elevated height

Figure 2: Influence of building height on CHTC distribution from various wind speeds

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Evaluating the influence of ventilated BIPV systems

Over the last century, architects and engineers designed and constructed buildings at a fast pace to support the population’s growing rate with a greater focus on structural stability. However, with the increase of sustainability and climate change awareness, standard building designs are being further analyzed and researched in the goal of minimizing its energy usage. Building integrated photovoltaics (BIPV) is a novice area of research that incorporates solar panels within the building’s façade. This can be of benefit whether the integration is the building’s flat roof, sloped roof, or walls. BIPV walls have better solar access in isolated and high-rise buildings. The disadvantage that comes with a BIPV system is the thermal stress that solar panels experience due to heat energy formation causing a decrease in the product’s lifetime. This also leads to an increase in the building’s cooling load in hot climate regions where the high temperature air doesn’t support adequate conductive/convective cooling.

Heated solar panels in a BIPV system will dissipate heat in both directions favoring the path of least thermal resistance. This research will study the dissipation pattern by looking at the solar heat island effect and the internal greenhouse effect in more detail considering the following controls: space comfort conditions, wall and insulation, and outside weather conditions Figure 1. Presented research will evaluate the influence of different configurations of a ventilated BIPV system on a building’s cooling load in comparison to the control state of no ventilation. Ventilation will be induced with the use of different heat sink designs. These evaluations will be carried out using Computation Fluid Dynamics (CFD). This experimental method will result in the optimal ventilated BIPV system that is strategic for hot climate regions. The desired outcome of this implementation is a reduced/eliminated panel cooling load and an increased product lifetime.
CFD for wind-load determination: Validation of CFD models through wind tunnel data

The objective of this research topic is to identify the relevant aspects that are still lacking for a successful implementation of Computational Fluid Dynamics (CFD) simulations during the design process of buildings. In order to reliably apply CFD simulations in the field of wind load determination on high-rise buildings a thorough validation of the results and studies regarding the accuracy-influencing parameters are required.

For the validation of the CFD simulations wind tunnel tests were run at the Boundary Layer Wind Tunnel Laboratory (BLWTL) during a 3-month stay as Visiting Research Student with a scholarship of the Heinrich Hertz Foundation. Based on the Davenport chain this study focuses on the correct depiction of the characteristic wind climate on the one hand, and on the resulting wind effects on high-rise buildings on the other hand.

Due to the influence of the correct depiction of the atmospheric boundary layer (ABL) on the resulting wind-loads, the first test cases aimed at precisely measuring the ABL generated in the wind tunnel around the turntable. With transverse gear the three velocity components were measured with Cobra Probes at different locations over the height.

The second part of the tests aimed at measuring the pressure distribution over the standard CAARC building model for the validation of the aerodynamic response e.g. the peak overturning moments at different angles of attack. Through own tests the sensitivity of wind tunnel tests and the accuracy affecting parameters could be studied to compare with CFD simulations throughout the research project. The possibility to run wind tunnel test provides a very valuable aerodynamic collection for validation.

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Experimental estimation of aerodynamic forces and aeroelastic behavior on tree model with a range of crown porosity

Trees play a crucial role in the urban environment because they help reduce smog and air pollution, mitigate stormwater, decrease the heat island effect by providing shade, and contribute to mental and physical health. However, little is known about tree aerodynamics.

The objective of this project is to study the aerodynamic forces and aeroelastic behavior of a Camphor tree prototype. To achieve this, a wind tunnel test was conducted at BLWTL, Western University of London, Canada.

The aeroelastic model was constructed using high-strength aluminum rods, and a 3D-printed cladding was added to achieve the correct mass. Five different model configurations were created by assembling varying quantities of leaf clusters to simulate different crown conditions throughout the year, with 100%, 75%, 50%, 25%, and 0% of leaves.

The wind tunnel test setup consisted of four Cobra probes to measure wind speed and assess the flow, a force balance to measure the loads on the tree, two accelerometers (one at the center of the crown and one at the end of the trunk) to record tree movement and a Kinect V2 sensor for area estimation. Three different terrains with increasing turbulence intensities were used during the test to observe the tree's behavior.

The frontal crown area and crown porosity are crucial factors in estimating the drag force and drag coefficient on a tree. However, due to the stiffness of the branches and leaves, reconfiguring the tree crown in the airflow proved to be challenging.

This study also allowed for the estimation of the tree's aeroelastic behavior. Bending moments at the base and relative moment coefficients were calculated based on the measurements taken during the test. In the field of aeroelasticity, the displacement of the center crown and the structural damping of the model were analyzed. Some of these results were compared to the findings of Hao et al. (2020), who tested the same model but with different leaves, to observe the influence of crown shape, mass, and porosity on the tree model's behavior.

### Figure 1: Aeroelastic model
- a) Configuration with 0% leaves
- b) Configuration with 100% leaves

### Figure 2: Kinect V2 Sensor
- a) Normal Image
- b) Depth Image recorded during wind tunnel test

### Figure 3: Crown centre displacement time-history

### Figure 4: Peak drag coefficient vs wind speed

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Large-eddy simulation of wind-turbine wakes over two-dimensional hills

It is generally recognized that the wind environment over topography becomes much more complicated, which makes energy-yield estimates and structural health more uncertain than ideal conditions. Although complex terrain may not be ideal site for wind farms, it becomes increasingly appealing from the wind energy industry’s point of view because the best locations are becoming occupied and there are no better alternatives. However, very little is currently known about the effect of hills with different slopes on the mean wind speed and turbulence in turbine wakes as well as the impact of reverse flow on the turbine performance.

Therefore, this study sets out to gain a fundamental understanding of the characteristics of wind-turbine wakes and the turbine performance over 2D hills with different slope gradients. The chosen 2D hills could represent typical hilly terrains with and without flow recirculation in the wake of the hills. The wind turbine is parameterized as actuator disk model (ADM) and hilly terrain is modeled by immersed boundary method. With the presence of the turbine wakes, the mean streamwise velocity increases in the wake of the hills due to the conservation of mass flux. The turbulence levels tend to drop below those of flat ground case on the windward side of the hills. An obvious decrease in them is found behind the hills with the presence of the turbine wakes. The power production increases on the windward side and reaches a peak at the crest (1.8 and 2.6 for the gentle hill and the steep hill, respectively). It is found that the hilltop is the optimal location for turbine placement because the turbine harvests more wind energy due to the speed-up effect and suffers less fatigue loading due to the lower turbulence levels. Wind turbines should not be placed in the wake of steep hills because the reverse flow has a serious impact on the power performance.

Figure 1: Profiles of the mean stream-wise velocity in the vertical mid-plane of the domain for turbine wakes over (a) flat ground, (b) gentle hill, and (c) steep hill (solid line: turbine case; dashed line: no-turbine case)

Figure 2: Stream-wise turbulence intensity in the vertical mid-plane of the domain for turbine wakes over (a) flat ground, (b) gentle hill, and (c) steep hill (solid line: turbine case; dashed line: no-turbine case)

Figure 3: (a) Power performance of the turbine sited at different positions (b) Velocity around the turbine sited at \(x/D = 2.5\) in the gentle hill case. (c) Velocity around the turbine sited at \(x/D = 2.5\) in the steep hill case

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Development of Software for the Analysis of Light Frame Wood Buildings (Wood3D)

A simplified analytical model was developed previously to compensate for the detailed finite element model of the shear wall into two link elements that represent the flexural and shear properties of the walls. A database of detailed finite element of shear walls was developed which includes all wall variables. The wall variable includes the wall's length, stud spacing, stud size, sheathing type, nail spacing, king studs' size, and tie-rod size. The finite element models were established by preparing MATLAB code to call and analyze the SAP2000 commercial software. Once the outputs of each detailed finite element model are recorded, equivalent flexural and shear properties of the walls are evaluated. The wall flexural and shear properties will be used later by the designer to model 3D wood building. The second task of this work is to prepare a MATLAB code that reads the user ETABs model and evaluate the main forces acting on each wooden wall, i.e., shear, compression, and tension. The user ETABs model replaces all the wooden walls with two link elements and a rigid beam. The MATLAB code will modify the user ETABs model by assigning new flexural and shear properties based on the wall's properties from the database developed earlier. Next, the MATLAB code will run the later ETABs model and export the results. A Wood3D interface was developed to include the excitable MATLAB code as shown in the figure.

Figure 1: Analytical building envelope model in ETABs

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Analyzing the effect of wind on steel water-storage conical tanks

Water tower-vessels in the form of truncated conical tanks exist extensively around the globe. Those vessels are commonly made of steel by welding curved panels together circumferentially and longitudinally to form the conical shape. The design of elevated water-storage steel conical tanks is motivated by the lack of proper design provisions for conical tanks under the effect of wind loads in the Canadian code of practice. Currently, the design is based upon a rough approximation by replacing the cone with an equivalent cylinder where this approximation results in a state of stresses which is the farthest it can be from being accurate not to mention being conservative.

My research will be divided into two main phases: the first phase of my study focuses on creating sophisticated analysis of steel conical tanks under the effect of different types of wind to get clear understanding of the pressure associated with wind using more than one technique. First, an experimental approach will be used along with creating a CFD model of the test. Upon validation of the CFD modelling approach using the values obtained from the experiment, more CFD models will be created to cover a wide spectrum of tanks’ dimensions and correspondingly create well-established references of the effect of different wind types on pressure, drag and drift acting on the tanks’ bodies.

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Effect of foundation flexibility on the loads acting on offshore wind turbines

Several studies have emphasized the importance of modelling foundation flexibility of fixed base offshore wind turbines (OWT). In the current design codes, the default modelling of the connection between the substructure and the seabed is rigid connection, meaning that soil stiffness and damping are disregarded. Including the soil structure interaction (SSI) would give a softer model which reduces the natural frequencies of the turbine and make them closer to the frequencies of the external loads which may lead to resonance. This research aims, in its first stage, at reproducing the stiffness of the soil pile system in FAST, which is aero-hydro-servo-elastic simulation tool for OWT, simulates the foundation of wind turbines as fixed connection. The second stage will be developing an integrated optimization of the OWT to minimize the cost of both the tower and monopile.

Firstly, a detailed 3D finite element model (FEM) of the NREL 5 MW wind turbine is developed by ABAQUS software to simulate the blades, tower, true monopile with embedded length, and soil. The output displacement and rotation at the seabed from ABAQUS model is then used to simulate SSI in FAST through Apparent Fixity (AF) method. This method in FAST used to reproduce the stiffness of the flexible foundation by modeling the monopile under seabed as an imaginary cantilever beam fixed at a certain length below the seabed. The results are compared with the available results in the literature which show good agreement. It is concluded that ignoring foundation fixability leads to underpredictions of structural dynamic response of offshore wind turbine.

Secondly, sensitivity analysis of aerodynamic loads, hydrodynamic loads, and foundation flexibility will be implemented to examine their effects on OWT loads and frequencies. Lastly, a structural optimization model for OWT support structures will be developed based on the coupled parametric FEM and genetic algorithm (GA) to minimize the mass of the support structure under multi-criteria constraints.

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Structural optimization and aerodynamic behavior of double-curvature cable domes

The significant flexibility and light weight of double-curvature cable domes make them highly sensitive to wind loads. In addition to their aesthetic appearance, double-curvature cable domes have better stability and rigidity than the corresponding positive ones. As a newly developed form of cable domes with double-curvature, and due to the lack of clear regulations in the current design codes on the structural design and wind action on complex structures in general, and this form in particular, this research aims, in its first stage, at developing a form-finding technique and an optimized procedure for preliminary designs of double-curvature cable domes. The second stage focuses on the study of structural performance and aerodynamic behavior of this type of structures under wind action.

Firstly, an intensive parametric study considering different shape parameters (such as the arrangement of cables and struts, rise and sag ratio, curvature to diameter ratio, lengths of struts etc.) is performed to obtain an optimized form in terms of total weight and max displacement. This parametric study depends on a newly developed NURBS-based form-finding algorithm and an incremental-prestressing iterative optimization algorithm that can find a feasible form of the dome according to the required shape parameters and design it to the minimum weight at specific target displacement.

Secondly, the performance of steady RANS and SAS are evaluated in reproducing the wind pressure distribution for double-curvature roofs. The CFD models are validated by the results of a wind tunnel on a hyperbolic paraboloid roof from the literature. Lastly, the aerodynamic damping and natural frequencies of vibration of such structures with several close natural frequencies will be examined experimentally and numerically as a measure of the wind-structure interaction of such structures.

Figure 1: 3D View of a double-curvature cable dome

Figure 2: Representation of the dome saddle surface by NURBS curves

Figure 3: Pressure-coefficient distribution on the roof

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Dynamic failure analysis and testing of transmission lines under downburst loads

Transmission lines (TL), as vital infrastructures, are susceptible to natural hazards, including severe thunderstorms. During thunderstorms, a strong jet of air impinges on the ground and creates outflow wind, which is known as downburst. Based on an extensive research program conducted at Western University, load cases simulating the critical effect of downburst on TL structures were developed and incorporated into the ASCE-74 (2020). In this study an investigation is performed to compare between the effect of the synoptic wind loads defined by different international standards and the downburst load cases of the ASCE-74 (2020) on TL. When a tower fails, it starts to rotate about a certain point along the tower height. The tension forces in the attached conductors change resulting in an increase in the forces transferred to the adjacent tower. If the adjacent tower cannot withstand these forces, a cascade failure of several towers will then occur. This cascade failure is investigated in the current study by conducting nonlinear dynamic analysis of multiple towers in a TL segment. To contain the cascade failure, an end tower is usually placed at specific locations along the line. A test of an end tower is carried out at WindEEE under simulated downburst. The purpose of this test is to investigate the response of end towers and the conductors to downburst loads. During the test, the base reaction and the top acceleration of the tower are recorded, in addition to the tension forces, the displacements, and the accelerations of the conductors. The results of the tests are used to assess the adequacy of the new ASCE downburst provisions in designing end towers to resist downbursts.

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Nonlinear behavior of tall reinforced concrete buildings applying the ductility-based approach

The design of tall buildings to withstand wind loads has traditionally relied on codes and standards that often neglect the complexities of inelastic behavior. A performance-based wind design (PBWD) approach inspired by seismic engineering principles aims to overcome the limitations of the current design under wind loads and enhance the predictability and reliability of tall buildings. This research applies a ductility-based approach framework that extends the concepts of seismic design merged with the wind effects to produce a sustainable strategy and improve building resilience. The primary focus of this approach is to reduce only the resonant component of the wind response.

The case study involves a 19-story reinforced concrete building, previously tested in the Boundary Layer Wind Tunnel Facility, for which a finite element model has been developed.

In the first stage of this study, a static approach will be employed to investigate the influence of mean wind speed on the building's nonlinear behavior. A parametric study will vary wind speeds and reduction factors, followed by a non-linear static pushover analysis to assess the structural response.

In the second stage, a full nonlinear dynamic analysis of the building model will be conducted to assess the effect of structural nonlinearities and evaluate the expected degradation of strength and stiffness. Furthermore, the research will explore the potential for a test protocol simulating wind-induced inelastic cycles.

Finally, appropriate reduction factors for varying mean wind speeds will be proposed.

Figure 1: 3-D finite Element Model in ETABS

Figure 2: Framework for the ductility-based approach

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Angle and end transmission lines towers behavior under tornado wind load

Electrical energy plays a vital role in many aspects of daily life. United States and Canada are active zones for tornadoes with approximately 800 to 1,000 tornadoes per year. Severe wind events in the form of downbursts and tornadoes are referred to as High Intensity Winds (HIW). Such events are responsible for more than 80% of all weather-related transmission line failures worldwide despite this fact, the current codes of practice for transmission line structures do not account for wind loads resulting from tornadoes events. In these codes, the specified design wind loads are based on large scale storms with conventional boundary layer wind profile, which is different than the tornado profile. The forces acting on the structure depend on the location of the storm relative to the structure. Therefore, it is important to identify the tornado and downburst locations that lead to the maximum structural responses. This is challenging for transmission lines, where the wind forces resulting from tornadoes vary along the span of the lengthy conductors and along the height of the towers. Thus, the behavior of angle and end lattice transmission towers will be assessed under tornado wind loads. The research proposed in this study will build on the findings, developments and experience gained during the previous research program. The objective is to develop guidelines for designing transmission line structures to resist HIW events and to use these findings in codes of practice.

Figure 1: Schematic Layout of transmission line system model

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Shear buckling testing of wood sheathing panels

Wooden sheathing panels are integral components of Light-Framed Wood Shearwalls, offering substantial resistance to lateral loads due to their inherent in-plane stiffness. These panels, adhering to the standard dimensions of 1220×2440 mm, are securely fastened to studs and rails using nails. Among the failure modes observed in shear wall segments under lateral loading is the out-of-plane deformation of sheathing panels, wherein the nail-based connections fail to reach their ultimate load-bearing capacity. It is noteworthy, however, that research on this phenomenon has been confined to smaller plywood dimensions and diverse edge loading conditions.

The prevailing Canadian wood design code (CSA O86-14) provides a conventional buckling equation that governs the determination of critical shear stress in a sheathing panel featuring simply supported boundaries along all edges. This formulation operates under the assumption of uniform shear stress distribution along the edges.

The scope of this study encompasses a representative sheathing panel of dimensions 1220×2440 mm, affixed to four standard edge studs measuring 38×89 mm, employing the customary nail spacing. Experimental shear buckling tests are conducted within a purpose-designed framework located at the structural laboratory of Western University. Complementing these tests, a meticulously validated nonlinear finite element model is developed to effectively replicate the intricate shear buckling behavior and the subsequent post-buckling response of the sheathing panels.

The primary objective of this research is to ascertain the conformity of sheathing panels, reinforced with intermittent nail supports, to established buckling theories when subjected to pure shear loading conditions. Notably, this investigation transcends the confines of the prescribed code equation. Furthermore, a critical facet of the study involves identifying the contextual parameters dictating the emergence of sheathing panel instability as a salient failure mode within Light-Framed Wood walls. The insights gleaned from this inquiry will substantiate the formulation of prudent design recommendations, geared towards enhancing the robustness and performance of such structures.

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Detailed and simplified numerical analysis of multi-storey light-frame wood buildings and introducing an optimization scheme for minimizing the cost of light-frame wood buildings

Wood possess high levels of strength and durability corresponding to its lightweight, which makes it a perfect choice as a construction material for mid-rise buildings. Modeling Light-Frame Wood (LFW) floors is complicated as the typical LFW diaphragm is composed of studs, sheathings, nails, and concrete cover. The non-linear behaviour of the nails with the orthotropic nature of wood makes the modelling of LFW building challenging. Moreover, LFW floors are neither fully rigid nor flexible which imposes more challenges when modelling. As such, modeling detailed LFW floors are very computationally expensive and makes it not practical for practitioners. Therefore, developing a simplified LFW floor model that is able to capture the behaviour of the detailed LFW floor model is of high importance. The current study aims to develop and validate simplified LFW floor models, as well as developing an optimization scheme to minimize the cost of LFW structures.

The first stage of the current study will include the development of detailed numerical models for the floor diaphragm including all of its individual components. Those detailed models will be used as a benchmark for simplified LFW floor models, developed by either link elements or thin orthotropic shells, which can simulate accurately the stiffness of the floors. The developed models will be then be validated against a controlled experiment at WindEEE, where a one-story LFW building will be constructed and tested under wind loads.

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Investigation of transmission towers' cross arms failure mode resulting from tornadoes

Transmission lines are very long structures as they can span kilometers. That makes them highly susceptible to being hit by tornadoes. Tornadoes belong to High Intensity Wind (HIW) events which are severe and localized events. Due to their localized nature, they tend to apply different wind pressures on conductors of adjacent spans. This difference leads to introducing net longitudinal forces on the tower and out-of-plane bending moment on the cross arms. This can result in a local failure in the cross arms which may also propagate to other failures in the transmission line.

The critical location of tornado causing this specific failure should be obtained through a parametric study. Then, the forces on the cross arms can be evaluated. These forces depend on many parameters such as the own weight of the conductor, its sag ratio, its pretension force, conductor’s diameter, and the length of insulation string. After finding the forces for each case, it will be tested if they lead to failure of the cross arm. In addition, these forces can be compared to the forces resulting from the case of conductor failure that is generally used in design by utility companies. The importance of considering the difference in adjacent conductor loads due to tornadoes will then be assessed.

Figure 1: Transmission tower cross arm diagram

Figure 2: Tornado velocity components

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Resilience of transportation electrification and critical infrastructure during disruptive events

Originally conceived as a means to address climate action, the evolution of transportation electrification has gained significance within the context of frequent natural hazards and other disruptive events. In this research, the term 'disruptive' encompasses both man-made and natural disaster occurrences such as power outages, cyber-security breaches, wildfires, floods, and more. The influence of transportation electrification extends to critical urban infrastructure, including transportation networks and the power grid. To ensure a sustainable Electric Vehicle (EV) rollout, a comprehensive and accessible EV Charging Infrastructure (EVCI) must be strategically planned across urban transportation networks. Moreover, this infrastructure must possess the capability to operate effectively during disruptive events, some of which may necessitate evacuation scenarios. The objective of this research is thus to investigate the synergy between transportation electrification and critical infrastructure; including transportation networks and the power grid, during disruptive events. First, this research shall conduct a diagnostic analysis to describe the adequacy of EVCI during disaster events. Secondly, this research shall further dwell into identifying the optimal locations of EVCI considering the impact of these disaster events. Finally, this research shall develop an algorithmic approach to plan evacuation routes considering EVCI accessibility, fairness while allocating resources, as well as road safety hazard. The significance of this research holds substantial implications in: 1) Enhancing the endurance of transportation networks and power grids amid disruptive occurrences, 2) Advancing the adoption of electric mobility to contribute to climate action objectives, and 3) Integrating EVs into disaster management strategies.
Behavior of wind turbine structures under tornado loadings

The wind turbine industry has been developing rapidly during the past decade in Canada. As of December 2021, wind power generation capacity reached 14,304 megawatts (MW), which provides nearly 10% of the Canadian electricity demand. Such structures are usually constructed in rural regions where high intensity events, such as tornadoes and downbursts, could happen frequently. None of those wind events are considered in the current design guidelines. The economic loss due to the failure of wind turbines under such conditions is tremendous. Therefore, this research aims to study the behavior of wind turbines under different tornado loadings in order to provide corresponding design guidelines.

Firstly, due to the random nature of tornado events, an intensive parametric study will be carried out to determine the critical tornado configurations. A numerical code so called HIW-TUR was developed at Western to take on such tasks. Innovative modifications have been made to obtain more accurate results. In the current version Multiple airfoil data sets, blade self-weight, and blade angle of twist are considered accordingly. Validation is made through comparing the blade and tower root bending moments with FAST under one dimensional flow.

Secondly, dynamic analysis will be carried out for the critical tornado loading case(s), which is(are) obtained from HIW-TUR, in FAST. The difference between quasi-static analysis and dynamic analysis will be discussed. Tornado turbulence will be introduced based on the results obtained from recent experiments at WindEEE. Results will be compared with the bending moments obtained under IEC design load cases. The critical tornado configurations and the optimal blade pitch angle will be proposed in order to minimize the effect of tornado loadings to wind turbine structures.

Lastly, the bending moments and shear forces obtained under the critical tornado loading case will be used for wind turbine connection designs. With the help of a high-resolution finite element model, the behavior of the bolted-flange connections can be accurately predicted. Therefore, the optimal bolt type, bolt number, bolt spacing, and pretension force will be suggested.
Effects of the tornado curvature streamlines on the aerodynamics of a low-rise structure

Methodologies to predict the aerodynamic loading induced by tornado winds and to support wind engineers to design structures able to withstand such kind of phenomenon are still lacking. The peculiar aspects linked with tornadoes, such as the translational and rotational wind speeds relative to the tornado core and the vertical wind field, are likely to significantly alter the building aerodynamics and wind loading, if compared with the classical framework relevant to synoptic winds. To gain knowledge about these aspects, modern tornado simulators as the WindEEE Dome at the Western University constitute an invaluable tool.

This work analyzes the aerodynamic pressure patterns induced by tornado-like flows generated at the WindEEE Dome on a prototype of a low-rise structure. This has plan dimensions of 183 mm and 275 mm, while its eave height is 78 mm and the ridge height (H) is 80 mm. The tornado-like flows are characterized by a swirl ratio $S = 0.76$, and a core radius of about 400 mm near ground level. Therefore, the simulated tornadoes are characterized by multiple sub-vortices, and their size is about 3 times the characteristic dimension of the building. The tornado-like flow is generated through the action of a bell-mouth which travels along one axis of the WindEEE. The pressures on the building are measured through 204 pressure taps that are nearly uniformly distributed on the building model. The ambient ground pressure is measured through a total of 173 pressure taps radial-symmetrically distributed on a plywood circular plate whose radius is 1118 mm, thus enabling the separation between the aerodynamic effects (Fig. 1) and those associated with the pressure gradient of the tornado. The wind field induced by the tornadoes is captured by four cobra probes installed in proximity of each building corner at a height of 98 mm (1.23H) above the ground.

Several mean and rms aerodynamic pressure patterns induced by tornado-like flows on the building result deeply distinct from those generated by straight-line atmospheric boundary layer (ABL) winds, suitably calibrated according to Cobra probe measurements. Remarkable localized suctions on the leeward walls and on the roof may be noted Figure 2. The velocity measurements allow the definition of the tornadic streamlines. These let transpire remarkable variations of the local wind field in terms of magnitude and, even more, of curvature Figure 3 affecting the building in correspondence of the pressure patterns picked from the two cases. These may directly affect the size of the separation bubbles on the wall, as well as affecting the development of the vortical structures on the roof.

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Figure 1: Conditionally-averaged (on the position of the bell-mouth, indicated in red) mean aerodynamic pressure patterns on the building and on the ground.

Figure 2: Zoom on the conditionally-averaged mean aerodynamic pressure patterns on the building, with indication of the wind field in its proximity.

Figure 3: Tornado curvature streamlines, based on the location picked in Figure 1 and 2.
Tornado wind loads on low-rise buildings

Tornadoes are one of the most violent and deadliest natural events. In the last 20 years in the US, tornadoes have caused more fatalities than tropical storms and hurricanes, and considerable economic damage. The greatest hit is taken by mobile and residential homes where 73% of all fatalities in the US have occurred. The lack of design against such wind forces can be explained as tornadoes are considered rare events given their small occurrence probability and scale.

Tornadic wind fields differ from those of the Atmospheric Boundary Layer (or straight winds) in that the wind loads depend on the static pressure field, complicating design. Vortex simulator facilities have been used to study the structure of tornado-like vortices and to simulate tornado loads in low-rise buildings with great success. However, these facilities are limited by how fast they can move a vortex past a building, and the time and cost it takes to run the experiments.

This research uses a simulation-based method to overcome these limitations. The method involves the use of a numerical tornado wind field with a storm passage approach to simulate the passage of a tornado past a low-rise building, an aerodynamic model that accounts for the building aerodynamics and the effect of static and internal pressures, and finally a Monte Carlo simulation is performed varying the tornado characteristic and the building location relative to the tornado path. The objective is to identify the configurations that yield the worst loads and understand what is driving them and how the different tornado parameters affect the loads.

The simulation generates a tornado track step-by-step and records for each passage useful information like tornado characteristics, wind magnitudes, minimum distance from the path center to the building, building orientation and worst load combination. With this information, the passages that yield the worst loads or some selected ones can be simulated again in depth to obtain time histories of the wind magnitudes and directions, horizontal and vertical forces, this allows to identify the relative position between the building and the tornado and the contributions of static, internal, and aerodynamic loads that result in the worst case. The following figures show the streamlines of the tornado wind field and the position of the building at the moment where the maximum lift force in the building roof is reached.

![Figure 1: Streamlines and wind directions at the moment of maximum lift force.](image1)

![Figure 2: Isometric streamlines and wind directions at the moment of maximum lift force.](image2)

Two building configurations are used, an enclosed case simulating the usual leakage present in most buildings and a case with a dominant opening simulating an open or failed window or door.

It has been found that for the enclosed building case, fast-moving tornadoes with relatively high radial to tangential speed ratios produce the worst loads, the internal pressure is unable to equalize the static pressure drop inside the tornado core given the rapid tornado translation speed and the low building porosity creating a pressure differential that can result in bigger loads. In the case of the opening, slow-moving tornadoes with average radial to tangential speed ratios and the wall with the opening facing the wind produce the worst cases as the effect of the static and internal pressures is lessen by the higher building porosity and slower tornado translations speeds, however the aerodynamic pressure has a bigger effect on the internal pressure because of the opening.

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Estimation of debris flight trajectories of roof cover from low-rise buildings

Extreme wind events affect the urban environment heavily damaging buildings and one of the major causes of building damage is due to wind-borne debris impact, especially on the building envelope. In extreme wind events, debris can originate from the failure of materials and pieces from source buildings and other man-made structures. Roof cover elements can be blown away, becoming wind-borne debris that can endanger people and property, hitting surrounding buildings at high speed.

Codes and standards have been developed over decades, but the combination of increased wind actions, an old building stock, and meteorological events with different characteristics from the past are the main reasons for wind-induced damages. Roofing cover elements such as roof tiles, shingles, roof sheathing panels are frequently recorded failing in extreme wind events. For this reason, this project aims to estimate the flight trajectory of such elements when failure occurs, from a low-rise building.

A 2D Monte Carlo numerical model for debris failure and flight analysis is presented and validated in this study. This model considers the roofing element fixing technologies, and the “source building” aerodynamics. The failure mechanism, and the flight assessment are, therefore, used to ultimately calculate the flight trajectory. The failure mechanism considers the building where the wind-borne debris could originate from, and the technical installation of the object, and therefore a probability of failure. The “debris flight” depends on the equations of motions that have been developed in the existing literature and on experimental simulations that took to the estimation of the probability function, depending on various aerodynamic parameters such as the Tachikawa number.

This tool enables designers to consider case-specific building settings to assess debris generation of roof cover from low-rise buildings.

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Flow over biomimetic fish scale arrays

Vehicles such as cars, trucks, boats, and planes are exposed to drag forces which increase fuel consumption and decrease efficiency. Features from nature are often utilized in engineering applications as nature has optimized these structures. One such application is the surface of fish scales which while they have some structural benefits, little work has been done to investigate the hydrodynamic importance of these scale arrays. In recent years, researchers have explored fish scale arrays numerically and experimentally demonstrated their ability to delay the transition from laminar to turbulent flow. However, the lack of a detailed experimental flow characterization over these fish scales arrays has made it difficult to draw conclusions about the mechanisms driving these phenomena. Additionally, the lack of understanding into the influence of scale shape has led to a lack of standardization among existing tests. A thorough understanding of the flow over these scale arrays will help to advance our knowledge of this passive drag reduction mechanism and enable the design of advanced surfaces which utilize these mechanisms to reduce drag in engineering applications.

Therefore, this study provides a detailed experimental investigation, alongside a parametric numerical analysis to expand the understanding of flow over biomimetic fish scale arrays. The techniques include experimental Particle Imaging Velocimetry (PIV), and Computational Fluid Dynamics (CFD). The objective is to identify a surface pattern that has the potential to reduce surface drag in transportation systems. Three scale geometries were considered in laminar flow conditions including circular, diamond, and flat back patterns. Experimental results for the circular geometry revealed four unique flow behaviours within the boundary layer over the scale arrays. Flow recirculation, stream wise velocity streaks, wall normal vorticity streaks, and alternating span wise velocities were induced throughout the boundary layer due to the unique surface topography. Simulation results for all three scale geometries suggested larger variations are found over the diamond scale array resulting in a greater friction drag reduction compared to the other geometries tested. Overall, overlapping scale arrays present unique flow behaviours, and scale geometry plays an important role in the impact of these behaviours on friction drag. Therefore, unique surface topographies such as fish scale arrays have the potential to contribute to drag reduction and emissions reduction within the transportation sector.

Figure 1: Experimental stream wise velocity magnitude contours 2 mm from the scale array at 0.12 m/s.

Figure 2: Numerical region of negative stream wise velocity representing the region of flow recirculation at 0.12 m/s.

Figure 3: Numerical streamwise component of the skin friction coefficient along the scale centerline over all scale geometries at 0.12 m/s.

Figure 4: Schematic of the four unique flow behaviours found over the overlapping fish scale array.

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Design and development of a modular thermal storage

In the Canadian residential sector, space and water heating contribute about 80% of total energy consumption. About half of this energy comes from natural gas, a non-renewable fuel that contributes to greenhouse gas emissions and global warming. Solar water heaters and electric heat pumps provide alternative options, but face limitations. Solar systems are unreliable due to daytime only availability and weather dependency, while peak-hour electricity costs hinder heat pump feasibility. Thermal energy storage (TES) technology addresses these challenges by storing energy from the sun when available, or from a heat pump during off-peak hours, to supply it consistently as needed. Phase-change materials (PCM) are often used in TES systems as they offer high energy storage density through latent heat of fusion, storing 5 to 20 times more thermal energy per unit volume compared to conventional sensible heat systems. However, the low thermal conductivity of PCMs remains a significant obstacle for achieving optimal charging and discharging rates in TES systems.

Considering the large-scale use of natural gas in residential applications in Canada, there is an urgency to switch to an alternate heating option. A TES system is a crucial component to make solar energy a reliable alternative and heat pump an economically feasible option. Although there has been significant research conducted on improving heat transfer to PCMs and PCM-based TES systems, very few commercially available products exist and are implemented in the energy grid. In addition, current systems are not modular which limits their storage capacity and functionality. Hence, there is a need for a modular PCM-based TES system to be developed and implemented in the energy grid.

The present research seeks to design and develop a modular thermal energy storage system to provide space and water heating for residential spaces. Methods of increasing the effective thermal conductivity of the PCM are being explored including using an aluminum honeycomb finned structure, and stainless steel wool.

Three benchtop prototype modules were created, each containing 1.25kg of phase-change material (PCM). The first module serves as the baseline case, consisting solely of PCM. The second module incorporates an aluminum honeycomb finned structure, while the third module incorporates steel wool. All modules are constructed using acrylic and feature four stainless steel tubes that enable water to flow through the module in four passes.

The experimental studies will focus on analyzing the charging and discharging rates of each design, aiming to assess and compare the effectiveness of utilizing a finned aluminum structure versus steel wool to enhance the effective conductivity of the phase-change material (PCM). The outcome of these experiments will be used to facilitate the design of a full-scale modular system.

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Fuel droplet detachment characteristics

Studying the detachment of fuel droplets is applicable to many fluid areas especially involving combustion operations and helps to understand the fundamental characteristics and behaviours being exhibited. However, the purpose of this research is focused on jet engines where the effects of gravity on the droplets are negligible. By neglecting the effects of gravity, the natural tendencies of the droplet behaviours and characteristics can be better observed compared to gravity assisted detachments.

This study uses a rising airflow, miniature, recirculating acrylic wind tunnel to allow the fuel droplets to detach in the upwards direction against the gravitational force. This is done by inserting a small needle (0.21 mm ID) pointed upwards into the centre of the acrylic section at mid height. The needle is supplied the liquid from a small, pressurized tank to allow for a very low, consistent flow rate for each test. The tests are run using four different airflow velocities ranging from 15 to 20.1 m/s and five different fuels; Kerosene, A2 fuel, A3 fuel, C1 fuel, and C5 fuel; and water as a reference. The droplet detachments are recorded using backlit shadowgraphy where a continuous laser is used to illuminate a small area behind the droplets and a high speed Photron SA4 camera records the droplets from the opposite side at 250 to 1000 frames per second depending on the test. The images are processed using an in-house MATLAB code to track the droplet diameter, velocity, and detachment rate.

Droplet characteristics and flow behavior around a wedge-shaped bluff body

The behaviour and influence of liquid droplets are also being studied for the flow around a wedge-shaped bluff body in a low disturbance wind tunnel. This is done to study a jet engine afterburner like system using a spray bar, acting as the fuel injector, placed upstream of the bluff body, acting as the flame holder. The spray bar has a single injection stream of water pointed upstream at the height of the leading edge of the bluff body and is supplied by a pressurized water tank. The water pressure and wind tunnel velocity are varied to allow the experiments to be run at varying momentum flux ratios ranging from 15 to 120.

A particle image velocimetry (PIV) setup is used to measure the air and water droplet flow around the bluff body. This consists of a 120 mJ Nd:YAG laser which is split and expanded into two vertical sheets, one above and one below the bluff body and a 12MP high speed camera. The laser sheets illuminate the seed particles to allow the camera to capture images of a slice of the bluff body from the side view. Back-to-back image pairs are recorded and processed using an in-house MATLAB code. This allows the particle movement between the images to be tracked and used to create instantaneous velocity fields which can be masked and corrected and used to create contour plots of the flow behaviour experienced around the bluff body.

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Figure 1: Consecutive Images of A2 Fuel Droplet Detachments

Figure 2: Raw PIV Instantaneous Velocity Field q120

Figure 3: Corrected Instantaneous Velocity Field at q120, White Areas are Masked Out and Black Area is Bluff Body
Fundamental study of phase change in a circular encapsulation

Reducing reliance on fossil fuel based energy production is critical to combat climate change. This requires an overall reduction in energy consumption via energy conservation or the increased integration of renewable energy sources. Thermal energy storage applies to both strategies. Firstly, wasted heat can be recycled to reduce the need for power production. Secondly, the main barrier to renewable energy sources is their intermittent nature. Fossil fuel power generation can be increased quickly to meet times of high demand, whereas renewable energy cannot. Large-scale energy storage facilities would allow the energy from renewables to be stored until needed. Thermal energy storage systems are good candidates for this application as they have high cyclic efficiencies and long lifetimes, among other relative advantages.

Latent heat thermal storage systems that take advantage of the large amount of energy associated with a change of phase are an attractive alternative to sensible heat thermal storage systems, which rely on a change in temperature to store energy. Latent heat systems typically have an increased energy density and a lower range of operating temperatures. Although, currently their use is limited as the low thermal conductivity of the typical storage media (called phase change materials or PCMs) inhibits the ability to transfer heat to charge and discharge the system effectively. This issue is generally not shared by sensible heat systems; thus, latent heat systems are not yet practical.

In order to design better systems, it is necessary to have a good model of the physics involved with the phase change process. Although, the phase change process is very complex and not well understood at present. This study is intended to improve the understanding of the underlying fundamental physics of phase change, specifically in the common configuration of a spherical or cylindrical encapsulation of PCM. In this case, the charging process is examined in which the PCM is allowed to sink and float in the liquid.

In order to effectively characterize the transient processes, it is desired to capture both the temperature and velocity flow behaviours. Particle image velocimetry was used to measure velocity, a non-invasive optical technique using tracer particles embedded within the liquid PCM. Additionally, a novel, non-invasive approach to remotely measure the internal PCM temperature field using an infrared camera is being implemented, such that the temperature and velocity behaviors can be measured simultaneously. With the transient flow behaviors captured, the heat transfer behaviors can be studied in detail, allowing the improvement of current models to design better latent heat energy storage systems.

![Figure 1: Streak flow visualizations showing the flow patterns at various stages of melting (60 min, 90 min, 120 min)](image1)

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Gust effect factors of components and cladding of low-rise buildings

In North America, the majority of low-rise buildings are constructed using light-framed wood. However, these light-framed buildings are susceptible to significant damage during strong windstorms, resulting in considerable economic loss, injuries, and sometimes fatalities. It has been observed that roof components, such as sheathing and covering, are particularly vulnerable to severe damage, which can be hazardous. Post-disaster surveys have provided evidence that failure of roof coverings accounts for much of initial damage. Therefore, there is a significant need to accurately estimate the wind loads on Components & Cladding (C&C) of building roofs to increase the resilience of low-rise buildings and mitigate the risks of damage to these structures.

The gust effect factor method has been widely used for estimating the overall structural response along wind direction. This study examines if and to what extent the gust effect factor method can be applied for estimating C&C wind loads. A low-rise building with a 1:12 roof slope and dimension of 125’ × 80’ × 40’ (length × width × eave-height) in NIST database was analyzed. The roof is divided into three different zones, namely corner zone, edge zone and inner zone, consistent with NBCC 2020. For the corner zone, non-Gaussian distributions of C&C wind loads are observed due to conical vortices. Neglecting body-generated turbulence effects, as gust effect factor model does, would result in the underestimation of the measured gust effect factor. The effective wind area is found to be a reasonable parameter to capture the tendency of gust effect factors for edge zone and interior zone. The decreased gust effect factor for larger effective wind area is attributed to the reduced correlation/coherence of wind pressures over larger areas. Further study on developing gust effect factor model considering body-generated turbulence effects is necessary.

Figure 1: Building layout: isometric view of building, and tap layout on roof.

Figure 2: Zone demarcation.

Figure 3: Gust effect factors of (a) corner zone, (b) edge zone, and (c) inner zone.

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# Publications


Conferences

1. Melaku, A. F., Bitsuamlak G. T., 2022, “A high-fidelity fluid-structure interaction framework for computational aeroelastic modeling of flexible structures”. 2022 SimCenter Symposium, Texas Advanced Computing Center, The University of Texas at Austin, Austin, USA.


8. Melaku, A. F., Bitsuamlak, G. T., 2022, “Predicting the dynamic response of a tall building using large-eddy simulation and time-domain analysis”. The 14th Americas Conference on Wind Engineering, Lubbock, TX, USA.


42. Zhao, S., Kopp, G.A. & Ge, Y., 2022, “Investigation of aerodynamic characteristics of a bridge section under accelerating winds”, 14th Americas Conference on Wind Engineering, Lubbock, TX, USA.

43. Wu, C.-H. & Kopp, G.A., 2022, “Two-dimensional vortex particle simulation of the separated flows induced by impulsively started cylinders”, 14th Americas Conference on Wind Engineering, Lubbock, TX, USA.


52. Akber, S., Siddiqui, K. and DeGroot, C., 2022, “Numerical investigation of the thermal response of a channel flow with PCM-filled thermal energy storage subjected to varying temperatures for potential applications in photobioreactors” Columbus, Ohio, USA.


Grants

Canada Foundation for Innovation (CFI) / $3,887,057 / 2023 – 2029
Major Scientific Research Facility Wind Engineering, Energy and Environment Research Facility (WindEEE)

Bitsuamlak G.T.

ERIES - Engineering Research Infrastructures for European Synergies / $1,100,000 / 2022 – 2026
European commission research directorate - Horizon Europe Framework Programme (HORIZON)

Bitsuamlak G.T.

National Research Council Canada, Research Contract - 2022 / $15,000.00/ 2023
Technical solutions for climate adaptation of commercial roofs

Bitsuamlak G.T.

University of Illinois at Urbana Champaign - Technical Service agreement / $25,000 / 2023
Tornadic wind load evaluation for data center

Bitsuamlak G.T.

WZMH Architects – Technical Service Agreement / $11,000 / 2023
Preliminary tornadic load evaluation

Bitsuamlak G.T.

Natural Sciences & Engineering Research – Alliance Grants / $30,000 / 2022 – 2023
Ontario Centre of Innovation - C2C | Collaborate 2 Commercialize (VIP) / $30,000 / 2022 – 2023
Aspire Food Group – Alliance VIP Match / $15,000 / 2021 – 2022
Numerical modelling of indoor environment for energy-efficient bio-manufacturing facilities

Bitsuamlak G.T., Capretz, M.A.M.

British Columbia Institute of Technology (BCIT) Subgrant / $50,000 / 2022 – 2023
Sustainable building research collaboration

Bitsuamlak G.T.

National Sciences & Engineering Research Council (NSERC) / OCI / HASSCO Grant / $75,000 - 2023 – 2024
Development of a retrofit system for conical tanks

El Damatty, A.A

National Sciences & Engineering Research Council (NSERC) / OCI / HASSCO Grant / $75,000 / 2022 – 2023
Modelling of Timber Buildings

El Damatty, A.A.

National Sciences & Engineering Research Council (NSERC) - Discovery Grant / $260,000 / 2022 – 2027
Resilience of transmission line structures to extreme wind events

El Damatty, A.A.
MITACS / $45,000 / 2021 – 2022
Nonlinear section test in the wind tuned for cable-supported bridges
**El Damatty, A.A.** King, P and Maheux, S

Canadian Severe Storms Lab, Strategic priorities fund, Western University / $1,000,000 / 2022-2024
**Kopp, G.A.** and **Goda, K.**

Institute for Catastrophic Loss Reduction Research Grant / $900,000 / 2022-2027
Northern Hail Project: Uncovering the meteorology, climatology, and impacts of hailstorms in Canada

National Sciences & Engineering Research Council (NSERC) - Alliance Grant / $1,800,000 / 2022-2027
Northern Hail Project

Mitacs Accelerate Grant / $785,000 / 2022-2027
Northern Hail Project

Canadian Space Agency / $1,179,500 / 2023 – 2026
The Western Skylark: a 3U CubeSat for next-generation tracking of migratory wildlife using the Motus and ICARUS telemetry systems
J. Sabarinathan (PI), S. Bonner, C. Guglielmo, J. Long, K. McIsaac, Y. Morbey, and **K. Siddiqui**

Western University - Carbon Solutions / $200,000 / 2023 – 2025
An integrated solar-powered heat pump and modular thermal storage system to offset natural gas usage for heating applications.
A. Straatman (PI), **K. Siddiqui**, J. Pearce and C. Hunsbergen

Environment and Climate Change Canada / $3,786,000 / 2022 – 2027
Improved multi-scale GHG emissions modeling from urban environments to enhance mitigation strategies.
**K. Siddiqui** (PI), **G.T. Bitsuamlak** (Co-PI), and nine others

Natural Sciences & Engineering Research Council (NSERC) Discovery / $172,500 / 2023 – 2028
A framework for evaluating tornado-induced wind loads on low-rise buildings
**Wang J.**

Western Strategic Support Seed – Western University / $25,000 / 2023
A method for quantifying turbulence effects on aerodynamics of low-rise building
**Wang J.**

Western University / $100,000 / 2022-2027
Start-up grant
**Wang, J.**
Honors, Awards, Keynote talks

Plenary Speaker, Recent experimental and computational advancements in assessing wind effects on flexible structures. Structural Membranes 2023, Valencia, Spain
Bitsuamlak G.T.

Keynote Speaker, CFD based synoptic and non-synoptic wind load evaluation: validation and benchmark testing. ASCE SEI and NIST Workshop on Advancement of Computational Wind Engineering, Reston, USA, 2023
Bitsuamlak G.T.

Introduction to WindEEE Research Facilities. Western University Alumina Seminar, London, Canada, 2022
Bitsuamlak G.T.

Keynote Speaker, Engineering Architecture. Urban City Center Lecture (Addis Ababa Municipality), Addis Ababa, Ethiopia
Bitsuamlak G.T.

Keynote Speaker, Climate resilient and sustainable buildings. 3rd International Conference on New Horizons in Green Civil Engineering, Victoria, Canada, 2022
Bitsuamlak G.T.

Bitsuamlak G.T.

Keynote Speaker, International Collaborations on Natural Hazards Research. National Science Foundation: Natural Hazard Summit, Washington DC, United States of America Main
Bitsuamlak G.T.

Keynote Speaker, Digital Research Infrastructure Needs in Canada. Digital Research Alliance of Canada – Industry partnership workshop, Ottawa, Canada, 2021
Bitsuamlak G.T.

Keynote Speaker, 11th International Conference on Advances in Wind and Structures, South Korea, 2022
El Damatty A.A.

Keynote Speaker, Center for Energy and Advancement Through Technological Innovation, virtual, Canada, 2021
El Damatty A.A.

Pratley Award for Best Paper on Bridges, Canadian Society for Civil Engineering, 2021
El Damatty, A.A.

Western Engineering Award for Excellence in Research, Western University, 2021
El Damatty, A.
Elected Fellow of the Canadian Academy of Engineering, 2021
El Damatty, A.

IAWE Davenport Medal, International Association for Wind Engineers, 2023
Kopp, G. A.

Keynote Speaker, Effects of turbulence and building geometry on cladding design pressures, 21st Australasian Wind Engineering Society Workshop, Sydney, Australia, 2023
Kopp, G.A.

Understanding, predicting, and mitigating severe storms in Canada, Engage Western: President’s Address & Breakfast, London, Canada, 2023
Kopp, G.A.

Keynote Speaker, Observations from the July 15, 2021 Barrie Ontario Tornado, Ontario Structural Wood Association Annual General Meeting, Toronto, Canada (virtual), 2022
Kopp, G.A.

Webinar, Consolidating Chapters 27 & 28 for ASCE 7-28, Metal Building Manufacturers Association Annual Research Symposium, Atlanta, USA, 2022
Kopp, G.A.

Fellow, Canadian Academy of Engineering, 2022
Kopp, G.A.

Jack E. Cermak medal, American Society of Civil Engineers, Structural Engineering Institute & Engineering Mechanics Institute, 2021
Kopp, G.A.

2021 Scruton Lecture, Re-visiting the wind tunnel method for determining wind loads on low buildings: How accurate does the wind tunnel simulation need to be? Institute for Civil Engineers, London, UK.
Kopp, G.A.

Keynote Speaker, Experimental characterization of the phase-change behavior, 13th International Conference on Thermal Energy: Theory and Applications, Baku, Azerbaijan, 2022
Siddiqui K.

Invited Speaker, Turbulence effects on aerodynamics of buildings ranging from low-rise to high-rise, Seoul National University, Seoul, South Korea (2023)
Wang, J.

Invited Speaker, Determination of wind loads on main wind force resisting system of rigid buildings.
Civil Seminar, Western University, London, Ontario, Canada, 2022
Wang, J.
Events

Shad at WindEEE 2022 (07-26-2022)

Western University is the latest top university to join with Shad, a prestigious program which brings the best and the brightest high school students to university campuses across the country every July for an intense program that helps them reach their full potential. Shad, founded in 1980, has become known as an incubator for innovation and entrepreneurship among these students who specialize in STEM (Science, Technology, Engineering and Math). With an impressive list of 15,000 alumni which includes 30 Rhodes Scholars, Shad has seen a record number of applications for two years straight.

Western becomes the 12th host university campus around the country for the one-month residential program with places highly sought after by students who go through a rigorous competition and application process.

Each year, the Shad program has a specific theme built around a current economic and social problem. The students collaborate to develop a unique innovative product or service that addresses the issue. As part of this engineering and design challenge, teams are taught how to build a business and marketing plan, and design and build working prototypes. Winning projects advance to national judging and results are celebrated each fall.

A typical day at Shad includes experiential learning, from class to labs and beyond. Students are inspired by university professors, business leaders, entrepreneurs, and innovators, who help them set aspirational goals and envision their own extraordinary potential.

In the Summer of 2023, WindEEE Research Institute had the privilege to be one of Western’s hosts for the Shad group. The day at WindEEE started with a presentation for the 80 guests about the Dome’s capabilities, followed by a facility tour and a tornado simulation. Students were tasked to design the largest tower capable of withstanding downburst winds using non-perishable goods. After the design challenge, all non-perishable goods were donated to a local food bank in London.
Thornton Tomasetti Collaboration (08-15-2022)

Also in 2022, WindEEE hosted a team from global scientific and engineering consulting firm Thornton Tomasetti for a two-day workshop. The teams worked to determine how to utilize the WindEEE Research Facilities and Advanced Research Computing for modeling of the impacts of hurricanes, tornadoes, downburst on the built environment both for new design/retrofit and forensic applications. Thornton Tomasetti and Western experts shared their experiences with each other. These collaborations are leading to new projects.
The Latest Wild Weather Trends at WindEEE (09-13-2022)

Thirty-five guests from the Insurance Institute of Ontario came to WindEEE to learn from an expert panel of 6 engineers involved in various forms of climate change and weather research at Western. The panel included members of WindEEE and from the Institute for Catastrophic Loss Reduction, an independent not-for-profit research institute affiliated with Western:
- Glenn McGillivray, Managing Director, Institute for Catastrophic Loss Reduction
- Dr. Girma Bitsuamlak, Head of the WindEEE RF
- Dr. Keith Porter, Chief Engineer, Institute for Catastrophic Loss Reduction
- Dan Sandink, Director of Research, Institute for Catastrophic Loss Reduction
- Aaron Jaffe, Northern Tornadoes Project, Western University
- Simon Eng, Northern Hail Project, Western University
This event included live demonstrations of various ICLR research mechanisms and of WindEEE’s operational capacity.
ICLR 25th Anniversary Celebration (10-18-2022)

The Institute for Catastrophic Loss Reduction (ICLR) was established by Canada’s property and casualty (p&c) insurance industry as an independent not-for-profit research institute affiliated with Western University. For 25 years, institute researchers have been working tirelessly to reduce the impact of severe weather and earthquakes on Canadians. WindEEE hosted a celebration to commemorate this occasion, where 75 ICLR guests were given the opportunity to meet Institute staff and researchers, and to discover ICLR’s new interactive exhibits focused on reducing the impacts of weather extremes on Canadians. Tornado and downburst simulations were also demonstrated in the test chamber for the ICLR guests.

Professional Engineers Ontario London Chapter Tour (03-22-2023)

WindEEE staff and faculty directors provided a tour, presentation, and facility demonstration for 15 guests from PEO’s London Chapter. Shown below is Dr. Girma Bitsuamlak providing a presentation to our guests.

Professional Engineers Ontario (PEO) is the provincial association of professional engineers that self-regulates its 63,000 members in the province of Ontario, Canada, including more than 2400 members from the London Chapter.

A Chapter’s primary function is to distribute and discuss information about policies and decisions made with respect to regulation of the engineering profession. It offers a forum for its members to discuss issues of concern for engineers and society.