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State of the art in wind consulting: A perspective on the application of current advances in CFD and AI

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SUMMARY:
Knowledge and information backed by scientific research is the key to confident professional advice and on par with practical experience. The use of computational approaches in wind engineering has been an area of intense study for several decades and the industry is at a point today where CFD is used for more applications in wind and microclimate assessments, and with more confidence, than available research would have allowed 20 years ago. The widespread use of CFD in wind consulting and lessons learned from that process over the last few decades have further advanced the application of machine learning in wind and microclimate studies. The authors, who are professional wind and microclimate specialists/practitioners, share their thoughts on (1) the synergy and necessary relationship between research and consulting industries, (2) the importance of research and development in CFD for wind engineering practice, and (3) how advances in CFD and machine-learning in wind engineering have changed the consulting landscape (presenting some case studies) to deliver better, more efficient directions to solving challenges faced by the design community they serve.

Keywords: CFD, artificial intelligence, machine learning, wind comfort, consulting, environmental wind engineering

1. INTRODUCTION

Wind engineering is a niche and continuously evolving field. Therefore, there exists a close relationship between wind engineering researchers and practitioners/professionals. While research and practice has established wind tunnel (WT) as the most robust tool for practical wind engineering consulting, the advances in computational wind engineering (CWE) and particularly the applications of computational fluid dynamics (CFD) for wind engineering are enabling huge leaps in the consulting platform. In his paper, the authors, who are professional wind and microclimate specialists/consultants, share their thoughts on (1) the synergy and necessary relationship between research and consulting industries, (2) the importance of research and development in CFD for wind engineering practice, and (3) how advances in CFD and machine-learning in wind engineering have changed the consulting landscape (presenting some case studies) to deliver better, more efficient directions to solving challenges faced by the design community they serve.

2. SYNERGY BETWEEN RESEARCH AND CONSULTING

The aims of scientific research are to expand existing knowledge, make predictions, develop new ideas, or understand existing problems and find solutions. In the professional and consulting

industry, practitioners use knowledge and information backed by scientific research to find solutions to practical problems – existing or predicted – through applied research. A key difference between an academic setting, and the consulting environment is that applied research in the latter is at a much faster pace, in greater frequency and shorter project lifecycles. In professional wind engineering practice, work is solution/demand-driven, time-sensitive and the need for answers is immediate as the we serve an industry/community that is dependent on our work to advance theirs.

Scientific research and professional consulting practice are in a cyclical relationship. Professional wind engineering consultants use research-based ideas, knowledge, and solutions to help their clients find solutions to practical problems and design wind-responsive projects. Due to the fast-paced nature of work in professional practices, consulting companies also go through a substantially large number and variety of project cases compared to an academic setting in the same period. This in turn allows consultants greater visibility into real-life practical problems – many a times problems that are challenging, unique and lacking sufficient research backing to aid in the solution-development. Such challenges often establish a need for research and are directed to academic/scientific researchers, hence, completing the cyclical relation loop.

3. IMPORTANCE OF CFD RESEARCH IN WIND ENGINEERING PRACTICE

Knowledge and information backed by scientific research is the key to confident professional advice and on par with practical experience. This knowledge is not only of wind behaviour, but also of the practical applications and shortcomings of wind engineering tools. For the same reason, any theory, findings, and tools applied to real-world solutions are required to have a proven, repeatable, accurate and precise performance, and in the case of tools often an established standard for best practice, to reduce industry risk – meeting such expectations requires years, often decades of research.

Wind tunnels (WT) have been the established tool for studies that are heavily dependent on wind speed, turbulence, and pressure – this is a result of more than a century of development, trials, errors, strong research and validation against real on-site or full-scale data – both intentional and unintentional (feedback driven by the failure of structures or solutions). Computational wind engineering (CWE), and in particular computational fluid dynamics (CFD) applications to building/environmental wind engineering, has come a long way in the last several decades. The research and development curve has been notably steep in just the last 20 years. Even just 10 years ago, in the consulting industry, the choice between CFD and WT was clear in that CFD would be used only for qualitative, early-design, informational assessments with low impact on critical design decisions. Today, technological advances in the area are enabling a broader application of CWE to the point of CFD being a valid alternative to WT for many applications that may impact final design decisions. The widespread use of CFD in wind consulting and lessons learned from that process over the last few decades have in turn enabled advancements in the application of artificial intelligence (AI)/machine learning (ML) in wind and microclimate studies. This does not discount the limitations of each tool that has been established systematically through the same research that enable the use of those tools.

Many view CFD-based approaches as competition to experimental or wind tunnel-based approaches. In reality there is no competition – the wind engineering community has consistently

established the distinct limitations and strengths of computational and experimental approaches. In wind engineering practice, it is important to use the right tool for the problem in order to represent the problem realistically and achieve a solution most efficiently – speed, cost and performance quality and repeatability are key. CFD and wind tunnel are just some of the tools in a consultant's toolkit and should be used complementarily. It is also important for the tools to be used by experienced practitioners who understand the nuances and limitations of each tool in the specific area it is being applied to and the proper interpretation of results produced – for example, knowing that aerodynamics in relation to windmills and urban aerodynamics for pedestrian comfort are distinctly different, or understanding that the coloured contours in CFD results are heavily subject to program quality, user error in scaling and output selection. Table 1 illustrates some assessment areas that we, as consultants, feel comfortable using CFD and WT for – our comfort and confidence is derived from scientific research that supports precise and accurate simulation of relevant flows for each application with high-quality solution verification and validation.

Table 1. Tools/Approaches consultants use for various assessments

Tool/Approach	Wind Tunnel	CFD LES	CFD RANS	AI/ML
Structural Loads	✓	✓**		
Paver/Furniture Uplift	✓	✓**		
Cladding Pressures	✓	✓**		✓***
Pedestrian Comfort	✓	✓	✓	✓***
Pedestrian Safety	✓	✓*		
Forensic Analysis	✓	✓*	✓**	
Topography Study/Profile Dev.	✓	✓*		
Urban Ventilation	✓*	✓	✓	✓**
Indoor Ventilation		✓	✓	
Particle transport or trajectory (Rain, sports, etc.)		✓	✓	

*Requires substantial validation and sometimes may be more time-consuming than other approach.
**Appropriate for qualitative studies on select simple structures, early design-stage, or parametric studies. Wind tunnel approach is preferred.
*** Appropriate for qualitative assessments for early design advice

4. APPLICATION AND PROSPECTS OF CFD AND AI/ML TOOLS IN WIND CONSULTING PRACTICE

Advances in CFD and machine-learning in wind engineering are changing the consulting platform. To explain this, the authors will present case studies to demonstrate the versatility in consulting quality, time and avenues enabled by the application of CFD and AI/ML based tools independently and/or to complement WT-based assessments.

4.1 Balance between time and quality of data, and in turn project cost

Most building projects undergo multiple design and development stages. While detailed quantitative information on wind speeds and pressures is imperative to the final design, lower resolution qualitative information is often sufficient for early-stage massing or building-orientation or siting decisions. Cheaper and quicker approaches like CFD (RANS) and AI allow consultants to do quick parametric assessments to inform such early-stage advice without the time or cost burden that a WT or LES study would impose. Aerodynamic shaping of tall towers, façade cladding loads and pedestrian level wind are some areas where CWE provides notable advantages

in early-stage design solutions before detailed assessments using WT studies.

4.2 Holistic assessment and solution development

Most available research addresses one wind problem or area at a time. Following in the same steps, traditionally, wind consultation also took a discrete "symptom-based" approach where interconnections between different wind problems were an afterthought rather than a proactive consideration traditionally. For example, blocking winds for pedestrian comfort may affect snow drift accumulation in the winter, or the consideration for natural ventilation and urban flow when designing high-density (naturally blockage generating) masterplans. CWE, using the right tools, allows for the simultaneous assessment of multiple interconnected disciplines without additional burden to project timelines and costs could very well be a challenge if WT was the only option.

4.3 City Planning and Livability in City Development

Many cities have recently begun incorporating and prioritizing the idea of livability which encourages only climate-positive masterplans. This idea requires multi-disciplinary assessments addressing urban heat island effects, sunlight access and shade, thermal comfort, air quality, ventilation, pedestrian comfort, and mobility, etc. The ability to perform holistic assessments (Section 4.2) is a game changer here. Additionally, with the widespread use of CWE/CFD by wind consultants and the confidence derived from established research, cities are also incorporating CFD assessments into planning bylaws. Consultants can now support Cities by aiding developers and city planners at different stages of a project or planning life cycle, in different technical depths, customized to the needs of the development stage.

5. CONCLUSIONS

As responsible consultants, it is important to acknowledge the advantages and drawbacks of different approaches available to conduct assessments for different wind problems. When done responsibly, CWE and WT used in a complementary manner opens a plethora of opportunities and avenues for wind engineering practitioners to customize their service lines. All of this allows consultants to deliver better, more efficient directions to solving challenges faced by the design community they serve. None of this would be possible without the synergetic relation between the wind engineering research community and practitioners, a relation that is only enhanced by the collective mindset of advancing the field of wind engineering.

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