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On the Complementary Nature of Resilient Building Design and Wind Engineering

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Abstract

The wind engineering profession is well suited to engage and play a lead role in the emerging field of resilient design, which addresses the ability to bounce back and regain function quickly after a natural or man-made disaster. It is time to move beyond designs that leave structures standing but operating poorly or disconnected from critical infrastructural support. Given its accrued knowledge and practical skills acquired in dealing with extreme exogenous events since its inception, wind engineering can position itself in more major roles on projects in the urban environment. An exploration of the complementary nature of resilient building design and wind engineering reveals some interesting and important synergies that can expand and empower our profession to better serve clients, governments, and society. *Please note this paper originally appeared at the Americas Conference on Wind Engineering, Seattle, June 2013.*

Introduction

The rise of resilient design (previously called in the architectural literature, rather negatively, "passive survivability") within the architecture profession compels new ways for various relevant professional disciplines (planning, architecture, engineering) to contribute to building design in a complementary and synergistic manner. If a new building or retrofitted building is going to minimize its impact on the environment, be resilient in the face of multiple natural hazard challenges, and effectively serve its intended purpose over time then a comprehensive team approach, making use of non- or minimally-competing parameters between the involved professional disciplines, is needed. It is incumbent upon the wind engineer to become educated in a set of new concepts and to learn to work well in a transdisciplinary team context. Derickson and Cochran (2013) elaborate on the connectivity of the transdisciplinarity and resilience themes.

Temperature Control

The passive control of temperature in building design has been a routine component of modern architecture for years, via considerations as varied as sunshades, building aspect, building use, glazing choices, insulation parameters, HVAC choices, adjacent plantings, building colour, and wall/roof component choices making up the "skin" of the building. The wind engineer can become involved in this process by defining, for the architect, the common, seasonally-based, wind patterns around the building and the impact of proximate structures. For hospital or laboratory designs, that have stacks issuing noxious or odorous substances, it is routine to have this sort of physical modelling done in the wind tunnel, but a more conventional building also may benefit from a deeper understanding of large and small windspeed regions, as well as the somewhat fixed vortices around a new design, in order to show where facades may be cooled or heated by the effects of sun and wind. To date, wind engineers only encounter the need for this level of detail in flow patterns in rare and specialist structures such as the large optical telescopes and their operable enclosures, where small thermal effects can affect instrumentation or the optical characteristics of the proximate air around the telescope (Farahani, A., Kolesnikov, A., Cochran, L.S., Hull, C. and Johns, M., 2012). However, these skills could have a more universal value.

On a more domestic scale the need for resilient homes is highlighted by the possible impact of climate change and various forms of natural disaster. Notwithstanding the comments from some researchers like Professor Stewart Franks (Cameron, 2013) that "there is little empirical evidence that hydroclimatic extremes (flood, drought or bushfire risk) are any worse today than they have been in the past" it seems prudent to have our building stock harmonize with the ambient environment as much as possible. For example, homes should be designed for their location and be less dependent on reliable power for heating or cooling. Homes at low latitudes need plenty of natural ventilation, large verandas, and some elevation to promote air flow. Conversely, homes at mid to high latitudes need to be better sealed and be oriented to maximize solar gain. Reliable power and heating energy has confused rational design and disasters like New Orleans after Hurricane Katrina or the Brisbane floods show how useless a slab-on-ground, brick-veneer home is in these tropical locales during a summer without air-conditioning. The

Figure 1. A typical elevated (to catch some breeze) home in Brisbane has a large wrap-around balcony (for shade). This architectural style is often generically referred to as a "Queenslander". This is potentially more resilient than the modern designs that rely on air-conditioning for comfort and livability.

traditional, elevated-design, home (Figure 1) in those cities was quite livable without power, while the "modern" designs were not. The converse of an energy-deficient home, with poor solar gain, in a high-latitude winter is similarly a resilience failure.
An extreme example of inappropriate design was noted by the author while visiting Oenpelli in the Northern Territory in the 1980s. This small town is only twelve degrees south of the equator and yet, well-intentioned, government housing was of a lowrise suburban design more appropriate for Melbourne or Sydney. With no air-conditioning the homes were almost unusable by the indigenous population of Oenpelli. Newer homes in the town appear to be designed with the local conditions more in mind. That said, resilient design and natural ventilation are areas where wind engineers need to become more aware, and active, as a service to the design team.

Building and Infrastructure Longevity

Resilient design is fast becoming a main feature of sustainability that guides engineers, architects and the responsible authorities that host new building projects in their cities. By incorporating larger return periods into the design process a somewhat natural resilience results. Most buildings are currently designed for a nominal 50 or 100 years. Many major buildings in our cities have reached these sorts of ages and may have received, or are about to receive, one or more renovations in this nominal life time. Thus, more resources have to be used in these refurbishments over and above the original construction costs. This expense falls to the owner and/or the tenants. If designers plan for the buildings to last, say, 200+ years the need for renovation is likely to be more cosmetic and driven by unforeseen technical change, rather than the inadequacies of systems like the structural and cladding components, for example. Additionally, these more thoughtful and robust designs, that will cost more initially, are likely to survive major building stresses like wind, civil unrest, fire, and even earthquakes. In recent years wind engineering laboratories have seen some voluntary increases in return period

Figure 2. After multiple natural disasters there may be a revision of the "rebuilding methodology" (after Cameron, 2013).

driven by client needs and/or choices (e.g. valuable contents, such as in a data center) and these inevitably are a consequence of some type of inherent resilient-design philosophy that may not even be recognized by the owner or design team.

In Australia a collection of extreme natural disasters (Cyclone Yasi, Brisbane floods, and more extensive bush fires than usual in 2013) has caused policy makers, designers and the general public to rethink the logic of rebuilding the damaged buildings and infrastructure to the old standard (i.e. simple replacement). Segments of major highways in both Queensland and the Northern Territory are being rebuilt, after flooding, above the 100-year flood level. A similar logic has caused the Brisbane City Council to allocate 10 M$ (a modest sum, given the extent of the problem) to buy homes in the highest flood-risk parts of the city for new parkland. In the field of wind design, the analysis of Cyclone Yasi's impact illustrated that many garage doors were too weak, and replacement doors have to be reinforced for higher wind pressures. Additionally, double doors are discouraged in new construction in favour of two single doors for the same reason.

The Australian mining industry is also confronting its traditional response to extended droughts, punctuated by severe floods, which has been hampered recently by the high turnover of staff in their industry. This results in the experiential knowledge base being fragmented and lessons having to be relearned; resulting in unnecessary expense. There is a commercial need to keep knowledge about the preparation for flooding or high-wind events available within an organization and for it to be readily accessible to personnel - even those who move from site to site within a mining boom environment. The National Climate Change Adaptation Research Facility has recently published a report entitled "Extractive Resource Development in a Changing Climate - Learning the Lessons from Extreme Weather Events in Queensland, Australia". Apart from some interesting observations about weather prediction and industrial preparedness there was one observation from this report that stood out; any growth in extreme weather events that does occur may actually generate "opportunities for innovation, entrepreneurship and new technologies" (Water Engineering Australia, 2013). It is likely that such opportunities will come from multi-source professional synergies that occur when transdisciplinarity is at the core.

These new technologies and the application of resilience to design for society's needs may well be a requirement, or even a necessity, for a desirable future; a concept emphasized by Lovins (2011) in his prescription for the next fifty years. In this recent publication from the Rocky Mountain Institute (RMI) new technologies (many already existing, albeit in niche areas) are discussed, along with rigorous financial justification, multiple examples, and pathways to achieve change. Lovins lobbies for major changes in how we use transportation, buildings, industry, power generation, and power distribution. The RMI team propose four scenarios for the United States (and, by implication, the world): (i) "Maintain" or continue on the same energy supply path we have today, (ii) "Migrate" or make slow changes to nuclear, renewables and clean coal, (iii) "Renew" or a substantial transition to multiple renewable supplies with demand-side flexibility, and (iv) "Transform" or a new system built from the load back, via energy efficiency and distributed resources, that permits fair competition between distributed resources at all scales over the next fifty years. Key to many of these scenarios to our future is the need for a more resilient approach to our structures and systems (Lovins and Lovins, 1982).

Smart Buildings

The growing use of Building Information Modeling (BIM) in the building design community (and the eventual adoption of it by the ownership team in the maintenance and occupancy of the new building) is resulting in better designs with fewer errors requiring hurried design changes on site during construction. The result is more resilience and fewer flaws in the final product, but if this is to be truly effective the design, construction and commissioning phases need to be more integrated. This concept of Integrated Project Delivery (IPD) is illustrated in Derickson and Cochran (2013).

BIM is still, however, going through its growing pains. For example, file transfer between BIM software platforms, called IFC (Industry Foundation Class) transfer, routinely produces errors and a common universal protocol for doing so has been developed (ATC-75, 2013) for use in future software.

Once designed, however, the ability of a new building to control it's own response to external influences, via sensors, and actively control building elements using the building's "brain", will yield more desirable home and work spaces. Thus, the term "smart building" refers to both the design and operational processes encompassed by BIM and the clever computer control of the building's functionality during operation (e.g. thermal optimal energy consumption, efficient lighting, motion-triggered lighting, efficient elevator traffic control, power generation and allocation via PVs and architectural wind energy, electrochromatic glazing and/or powered shading devices, grey water direction and use, biometric tenant recognition, to mention a few). As discussed in some depth by Mortimer (2013), the building, automobile, and aviation industries are all taking initial steps into the exciting area of electrochromatic glazing. Figure 3 illustrates the general principal of using an electrochromatic film sandwiched between two layers of glass. When a small electrical potential (typically around 1 volt) is applied the vision glass becomes darker and the magnitude of the voltage controls the darkness of hue as seen in Figure 4. As a provider of design pressures for the cladding on new buildings the wind engineer needs to be aware of these technical advances in order to be an effective design-team member; knowledge of new technologies and how they may, or may not, impact the advice he or she gives is essential. Transdisciplinary skills will allow the wind engineer to be a far more valuable design-team member. This so-called "T-shaped"

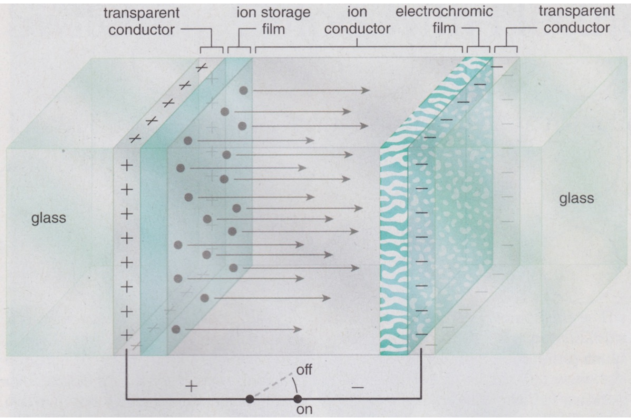

Figure 3. A schematic representation of the electrochromatic material sandwiched between glass layers (after Mortimer, 2013).

Figure 4. A window laminated with electrochromatic materials, tungsten oxide and Prussian blue, can be switched from transparent to dark blue as the voltage varies (after Mortimer, 2013).

professional (broad knowledge in many fields and an expert depth in one) will allow our chosen profession to grow beyond commodity status in the eyes of architects, engineers and developers.

The wind engineer can, and should, get more involved in the modern building design and do so at an earlier time in the process. Advice could be quite simple, such as how velocity data from a rooftop anemometer may be adjusted for building interference and so used by BIM to place tracking PVs, wind turbines and sunshades in a stow position when a thunderstorm or hurricane approaches. At the other end of the spectrum, wind engineer's early design advice should involve more complex topics like better building orientation, shape, stiffness or damping choices to improve the dynamic response to both common or rare wind events. Client attention, education, and coaxing will be needed to get us to the design "table". However, with the increasing technology and complexity of our building stock an informed wind engineer has a lot to offer.

Sea Levels and Temperatures

In some coastal areas the design of beachside buildings to deal with the potential of climate-driven rising ocean levels (albeit small changes) or surges and wave action from hurricanes/ cyclones is needed for resilient design. For example, the inclusion of a sacrificial ground floor with frangible walls, combined with deflecting sea walls or a large open seaward public space, will improve the sustainability of projects close to the sea (an increasingly common and desirable location). If longer return periods are to be included in the move to resilient design, then estimates of likely altered external ocean conditions become a more important forcing function for the design team to consider. Here the wind engineer, oceanographer, and atmospheric scientist become valuable transdisciplinary members of the design team.

Figure 5. Giving the subway grates in New York City a bit more height will aid in the resilience against flooding from above (after Wilson, 2013).

The recent flooding in New York City, caused by Hurricane Sandy, has generated a variety of simple ideas to aid in improving the local resilience. The flooding of the subway system can be made a rarer event by raising the openings to the subway used by pedestrians and by the ventilation system. Figure 5 shows a raised stainless steel kerb to reduce the likelihood of water ingress below.

If there is to be an increase in the frequency and/or intensity of hurricanes and cyclones due to increased sea-surface temperatures then policy choices made at the local, state and federal level, which may be quite different, will need input from our professional societies (AAWE, AWES, ABEV, etc.) and perhaps we should not wait for these responsible authorities to come knocking. We should make our presence known in a persistent manner; highlighting the substantial "brain trust" we have accumulated at, say, ICWE, APCWE or AWES events. Engineering reserve and shyness are not required.

Bush Fires

Resilient design in high-forest-fuel areas can be as simple as clearing sufficient land around residential or commercial buildings, or as complex as building material choices, stand-alone water supplies and external sprinkler systems. If buildings are expected to survive proximate forest or bush fires the designer needs to understand the ambient potential fuel load and wind influences (both the approaching atmospheric wind probabilities and fire-induced thermal winds that can self drive a major forest fire). Work done on modeling large-area fires (e.g. Stout 1985) may help to better understand this threat. In addition, the application of CWE to these thermally-driven flows is an area of more recent research. Wind engineers should be familiar with free computer programs, like the NIST FDS package, that can assist in this work.

Trees proximate to buildings can be in conflict with modern, green-home design where the architectural community recommends vegetation (deciduous trees) near west facades to block summer sun to minimize cooling loads. In winter the naked trees allow for solar gain and aid in the heating process. However, substantial foliage near a structure is not desirable from the wildfire or bushfire perspective.

Earthquake Design

In strong earthquake regions the structural design is often controlled by earthquake loads and wind loads are secondary. What many designers don't realize is that wind may start to impact structural design for taller buildings, as the natural frequency of the structure decreases with height and the energy input into the structural system moves from the high-energy portion of the earthquake spectrum to the more energetic part of the wind spectrum. Additionally, facade design will still benefit from a site-specific, building-specific, wind-tunnel study, since the design philosophy may be such that the facade is not expected to survive a major earthquake, while still keeping the envelope intact during a major hurricane. A more detailed list of "contradictions and synergies" is discussed by Gibbs (2013).

Water Collection and Conservation

In many parts of the world it is becoming increasingly common (even a legal requirement) for rain from the building roof to be collected into an internal or external cistern that forms part of the building design. This water supplements that brought into the project from the city supply and often addresses non-potable uses, such toilet flushing and hand washing. Estimates of the potential water supply via rainfall can be influenced by the effects of wind (often associated with strong rainfall) on the roof catchment area. Rain "shadows" and water build up areas caused by rooftop protuberances and parapets may impact water collection goals. The vertical surfaces of tall buildings are often ignored rainfall catchment areas, but in a windy storm huge amounts of water fall off the facade that could be caught for later use. Figure 4 shows a tall office building that inadvertently does

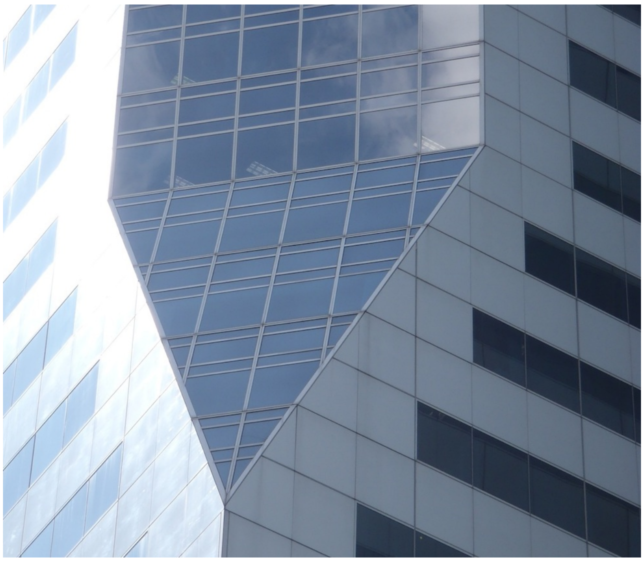

Figure 6. A Brisbane building that, in heavy thunderstorm downpours, unintentionally concentrates the water running down the facade via the crystal cut shown here, yielding a water spout landing in the middle of the intersection.

that in strong thunderstorms, via the "crystal cut" portion of the facade focusing the flow off the vertical wall above; resulting in a substantial "spout" of water off the lower corner of the triangle into the middle of the intersection below. Perhaps mechanisms like this could aid in water collection in our dense cityscapes.

Conclusions

Our relatively small field of wind engineering has matured from the niche areas of building/bridge wind loads, outdoor pedestrian comfort, and atmospheric dispersion to providing advice in almost all parts of the design of cities, suburbs, offices and homes that define where many of us live. As a profession we need to actively expand our influence from the simple provider of load, velocity or dispersion data to a trusted advisor of how the atmosphere impacts the built environment. The complementarity between resilient design and wind engineering is a natural and vital arena in which our discipline can grow to better serve clients, which include other professionals. In facing this opportunity, the wind engineer's role needs to expand to encompass design assistance with "T-shaped" professional specialist/generalist knowledge that should give our clients, governments, and society solutions to the many challenges facing our future.

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