May / June 2015

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# THE WIND ENGINEER

NEWSLETTER OF AMERICAN ASSOCIATION FOR WIND ENGINEERING

**In this issue:**



## CALL FOR NOMINATIONS

The AAWE is requesting nominations for the position of President Elect and for three Board Members (the terms of Steve Camposano, Anne Cope and Dorothy Reed are expiring).

Send your nominations to Chris Letchford at letchc@rpi.edu. Nominations will be accepted until June 30, 2015.

International Association for Wind Engineering

## Shape and Topology Optimization of Buildings and Bridges: The Next Frontier

TeamNatHaz: Enrica Bernardini, Sarah Bobby, Seymour M.J. Spence, Daniel Wei and Ahsan Kareem

The future of tall building design lies in defining structures that interact with their surroundings in order to create an efficient and sustainable urban habitat. One facet of this goal is to define structures that respond optimally to specific urban environments. To this aim, a multi-step optimization procedure has been developed that allows the thorough exploration of the building's aerodynamic and structural design space and, in particular, a computational fluid dynamics-driven metamodel-based multi-objective optimization strategy has been developed that allows the efficient identification of aerodynamically optimum building shapes. After finalization of a geometric form, the optimum structural system may be identified using innovative topology optimization strategies, recently developed by the authors, that center on the philosophy of probabilistic performance-based design and that rigorously model the inherently uncertain and aerodynamically sensitive nature of tall buildings. A schematic conceptually illustrating this process is shown in Fig. 1.

**Determining the Best Aerodynamic Shape**

While the structural system of a building is vital in resisting the external environmental loads, the external shape of tall buildings plays an important role in determining the intensity of the governing aerodynamic wind loads. It is known that tailoring the external shape of the structure is an efficient way to reduce its aerodynamic response [1]. However, it is difficult to predict how the aerodynamic behavior changes with the geometry. A trial-and-error approach to identify shape modifications that would generate the highest benefit, with tests carried out in the wind tunnel or through computational fluid dynamics (CFD) analyses, is not only very expensive but can also leave significant portions of the search space unexplored. In order to overcome this difficulty, the shape optimization method developed by the authors provides the possibility of automatically finding the shape that performs the best from an aerodynamic viewpoint through the use of optimization algorithms coupled with CFD

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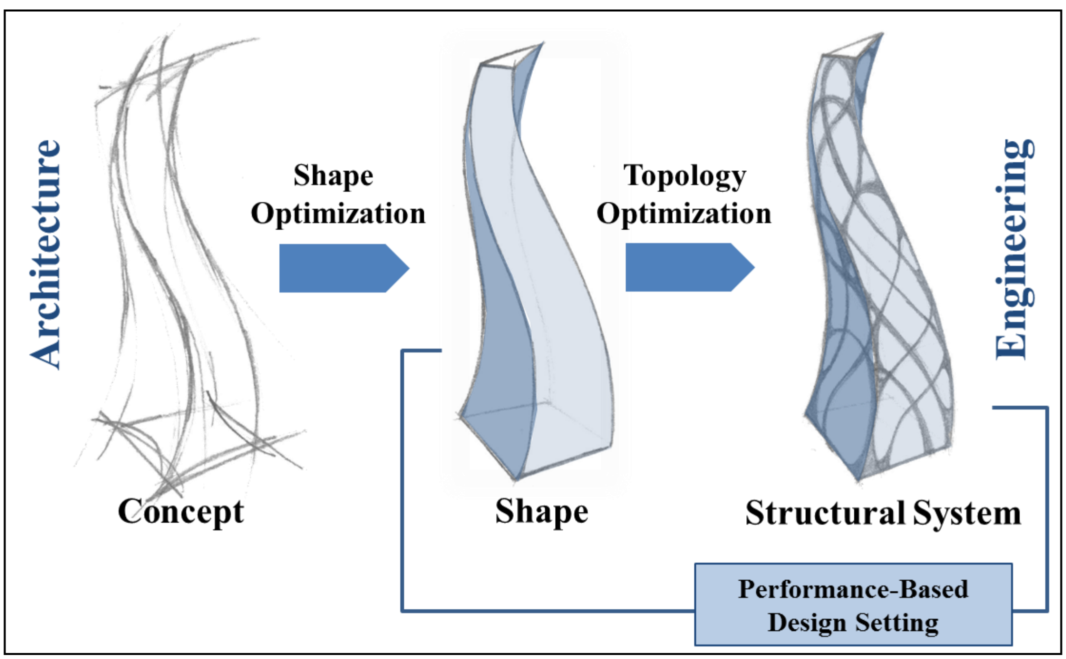


**Figure 1: Schematic illustrating optimization framework**

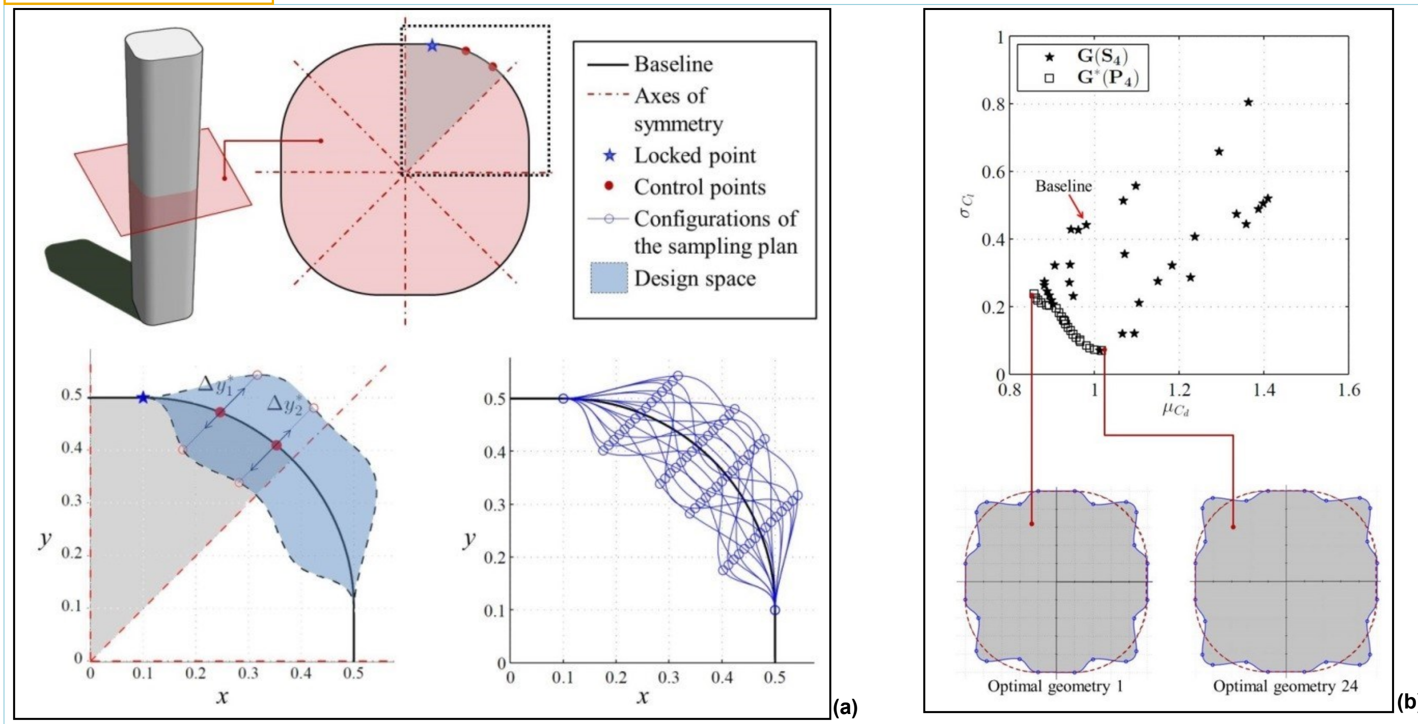


**Figure 2: (a) Geometric characteristics and 15 configurations of the samples used for metamodel calibration; (b) Pareto front in the objective function space and two Pareto-optimal geometries**

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analyses. First, the building's shape is parameterized, with a unique geometry corresponding to each set of values assumed by the parameters, i.e. the design variables (Fig. 2(a)). The aim is to minimize a number of objective functions (for example, along-wind and across-wind response parameters), expressed in terms of the design variables. In addition, constraints are formulated to control desired features of the shape, as for instance the minimum floor plan area, or the maximum change in shape with respect to the baseline geometry. Due to the fact that the various objectives can be competing, a set of Pareto-optimal solutions will exist, see Fig. 2(b). This optimization problem is solved using evolutionary algorithms (EAs), which allow for the robust treatment of the multi-objective nature of the problem; however, as these methods require a large number of function calls (on the order of thousands) while the CFD analyses that are required for the function evaluations are computationally expensive, the direct use of EAs coupled with objective function evaluation through CFD is unfeasible. The strategy that has been proposed to solve this problem relies on the use of metamodels [2]. A limited number of CFD analyses are carried out to build the metamodels, which replace the true aerodynamic functions and are much less computationally expensive to evaluate. The optimization is then carried out, using the metamodels, to identify Pareto-optimal solutions. These will coincide with the optima of the true functions, provided that the approximation is sufficiently good. The quality of the approximation is assessed using a validation process; if this is not satisfactory, a strategy for the metamodel improvement is implemented. Indeed, in the extremely complex case of bluff-body aerodynamics, characterized by great sensitivity to small geometric modifications, the construction of a metamodel capable of correctly approximating the real functions with a limited number of sample points is a challenging task. Currently, studies on the most appropriate metamodels to adopt (i.e. kriging, basis functions, neural networks etc.), their calibration and improvement strategies are underway.

## Configuration of Structural System using Probabilistic Performance-Based Topology Optimization

There is an ever increasing awareness that, if building systems are to be defined that truly respond to society's need for a safe and economic built environment, then the concepts of performance-based design (PBD) must be fully embraced. Recent work in this area has also highlighted how PBD cannot truly be achieved without rigorously accounting for the uncertainty that affects all aspects of hazard modeling and response prediction, therefore leading to the development of what are generally termed probabilistic PBD frameworks. In the case of extreme structures such as tall buildings, the incorporation of probabilistic PBD strategies in the structural design has to occur at the very outset and therefore at the conceptual design stage. This implies that the concept of probabilistic PBD must be used to define an appropriate framework for performing topology optimization. This can be achieved by posing and solving a topology optimization problem characterized by performance constraints that are imposed on response parameters such as top floor displacements and interstory drifts, as shown in Fig. 3(a). Topology optimization problems are by definition characterized by extremely high-dimensional design variable vectors that are necessary for providing an adequate resolution of the inevitably large design domain. This, coupled with the probabilistic nature of the performance constraints, makes the problem under consideration computationally challenging. To overcome these difficulties a novel decoupling approach has been developed that practically allows the information gleaned from a handful of simulation-based performance assessments to be used in order to define optimal structural systems that rigorously satisfy the probabilistic performance-based constraints imposed on the design [3]. This approach was used to determine the optimal bracing scheme for a lateral load resisting frame, as shown in Fig. 3(b), and efficiently determined a bracing scheme that met probabilistic constraints on the interstory drifts of the structure under wind loads. The independence between the number of performance assessments, carried out in a very limited number of sequentially identified design points, and the size of the design variable vector, allows this approach to be extremely efficient.

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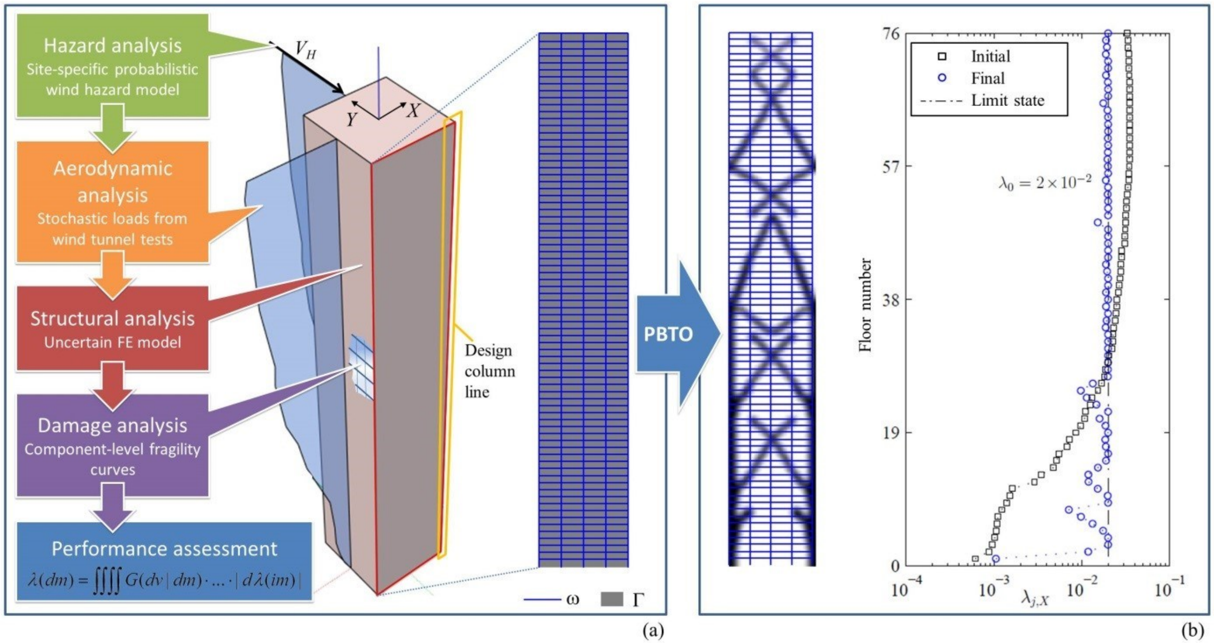


**Figure 3: (a) Problem setting; (b) Optimal lateral load resisting system obtained from the application of the performance-based topology optimization (PBTO) algorithm.**

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### Concluding Remarks

This note presented the development of innovative tools for the definition of tall buildings that respond optimally to their urban environments and are characterized by a high level of material efficiency. These tools are envisaged to be embedded in the conceptual design stage when significant geometric modifications are feasible, and in the preliminary design stage, when innovative and robust structural systems can be defined. The results that have been obtained, although preliminary, illustrate the potential of the proposed strategy in opening the door to the systematic exploration of the design space of tall buildings, with the aim of defining truly optimal and therefore material-efficient structures whose performance satisfies robustness and reliability requirements imposed by the specific urban environments to which they belong.

### Acknowledgments

Support for this work was provided by the NSF Grant No. CMMI-1301008.

### References

[1] Kareem, A., Kijewski, T., and Tamura, Y. (1999). “Mitigation of motions of tall buildings with specific examples of recent applications.” Wind & Structures 2(3): 201-251.

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[3] Bobby, S., Spence, S.M.J., Bernardini, E., and Kareem, A. (2014). “Performance-based topology optimization for wind-excited tall buildings: A framework.” Engineering Structures 74:242-255.

## New Americas Region Wind Engineering Society

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The Mexican Association for Wind Engineering (MexAWE) was formally welcomed into the IAWE fold by Prof Yukio Tamura and the IAWE Board on 09 February 2015. The development of this new professional wind-engineering society in the Americas Region has been spearheaded by Prof. Roberto Gomez of UNAM. It joins the similarly new Brazilian society (ABEV) to double the number of national groups within the Americas Region. Thank you to Prof Gomez and his team for their efforts in creating their own national wind engineering association.

Other associations within South America are in the process of being created and this will strengthen wind engineering in our region of the IAWE. Currently discussions are ongoing with Argentina (Argentine Wind Engineering Association, AWEA), Colombia (Colombian Association for Wind Engineering, CAWE), and Paraguay (Paraguayan Association for Wind Engineering, PAWE). We hope that these nascent wind-engineering societies will develop into full national associations within the IAWE in the near future.

## Kareem delivers 2015 John A. Blume Distinguished Lecture at Stanford

Dr. Ahsan Kareem delivered the 2015 John Blume a Distinguished Lecture at Stanford. The lecture series organizes by the John A. Blume Earthquake Center established in 1974 after John A. Blume, often called the "father of earthquake engineering." Dr. Blume was a world-renowned structural engineer who dedicated his professional life to the advancement of structural engineering that spanned more than fifty years,

The John A. Blume Distinguished Lecture is given once a year by a structural engineer whose career best exemplifies Dr. Blume’s outstanding achievements. In its history, the topic of this lecture was for the first time on wind. Kareem spoke on the Cyberinfrastructure Enabled Analysis, Simulation, Design and Monitoring of Structures under Winds a microcosm of future Cyberinfrastructure based SimCenter for hazard mitigation.

The seminar provided a guided tour of the complex dynamic wind-structure interactions experienced by tall building and long-span bridges in turbulent atmospheric winds through the eye of a cyberinfrastructure enabled virtual collaborative platform VORTEX-Winds.

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