# CAUSALITY ANALYSIS OF LARGE-SCALE STRUCTURES IN URBAN FLOWS

Esteban Lopez[1†], Ricardo Vinuesa[2], Soledad Le Clainche[3], Adrián Lozano-Durán[4], Ankit Srivastava[1]
[1] *Dept. Mechanical, Materials, and Aerospace Engineering, Illinois Institute of Technology, Chicago, IL, 60616, USA*
[2] *FLOW, KTH Royal Institute of Technology, SE-100 44 Stockholm, Sweden*
[3] *School of Aerospace Engineering, Universidad Politécnica de Madrid, E-28040, Spain*
[4] *Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, MA, 02139, USA*
[†] *E-mail: elopez8@hawk.iit.edu*

The aim of this work is to analyze the formation mechanisms of large-scale coherent structures in urban fluid flows, with focus on the so-called arch vortex. As shown in Figure 1 (left), this vortex is formed on the leeward side of wall-mounted obstacles, and this structure has an important impact on the transport of pollutants in urban areas. To this end, we assess causal relations between different proper-orthogonal-decomposition (POD) modes obtained from well-resolved large-eddy simulation (LES) data (slightly coarser than direct numerical simulation) of a number of urban configurations similar to that shown in Figure 1 (left). The causal relations are identified by conditional transfer entropy, which is an information-theory quantity which estimates the amount of information contained in the past of one variable about another, and as such offers a value indicating the predictive power available in the history of such variables. When applied to kinematic systems, transfer entropy reveals underlying dynamics driving different entities of the system, differentiating between causes and effects for each variable. This allows for an understanding of the origins of different phenomena in the flow, with the aim of identifying the modes responsible for the formation of the arch vortex. A preliminary study has been carried out to determine the causal relations present in the nine-equation model of near-wall turbulence developed by Moehlis *et al.* [1]. The aim of this is to verify the ability of the proposed method to identify causal interactions we expect to see a-priori. As shown in Figure 1 (right), some of the most prominent causal relations are analogous to those reported by Lozano-Durán *et al.* [2] in turbulent channel flow, namely: Mode 2 $\leftrightarrow$ Mode 4 (mean-flow instability in the spanwise direction); Mode 2 $\rightarrow$ Mode 6 and Mode 2 $\rightarrow$ Mode 9 (lift-up mechanism); Mode 6 $\rightarrow$ Mode 4 (roll generation). The complete contribution will contain an analogous analysis on the dominant POD modes of various urban environments, with the goal of shedding light into the mechanisms of pollutant transport in cities.

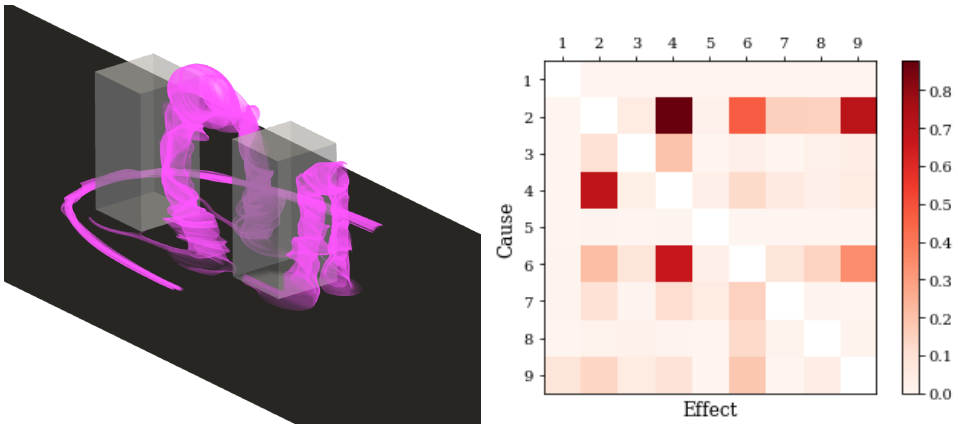


**Figure 1.** (Left) Streamlines in a simplified urban flow illustrating the arch and horseshoe vortices; flow from left to right. (Right) Causality analysis performed on the model by Moehlis *et al.* [1].

## References

[1] J. Moehlis, H. Faisst, and B. Eckhardt, "A low-dimensional model for turbulent shear flows," *New J. Phys.*, vol. 6, p. 56, 2004.
[2] A. Lozano-Durán, H. J. Bae, and M. P. Encinar, "Causality of energy-containing eddies in wall turbulence," *J. Fluid Mech.*, vol. 882, p. A2, 2020.