

# A 2D discrete crowd movement model: pedestrian dynamics - crowd-structure interaction

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## INTRODUCTION: Modeling crowd movement

- Optimize the design and operation of a facility : safe and efficient circulation - effective emergency evacuation
- Pedestrians might interact with a vibrating structure: phase synchronization phenomenon (footbridges)

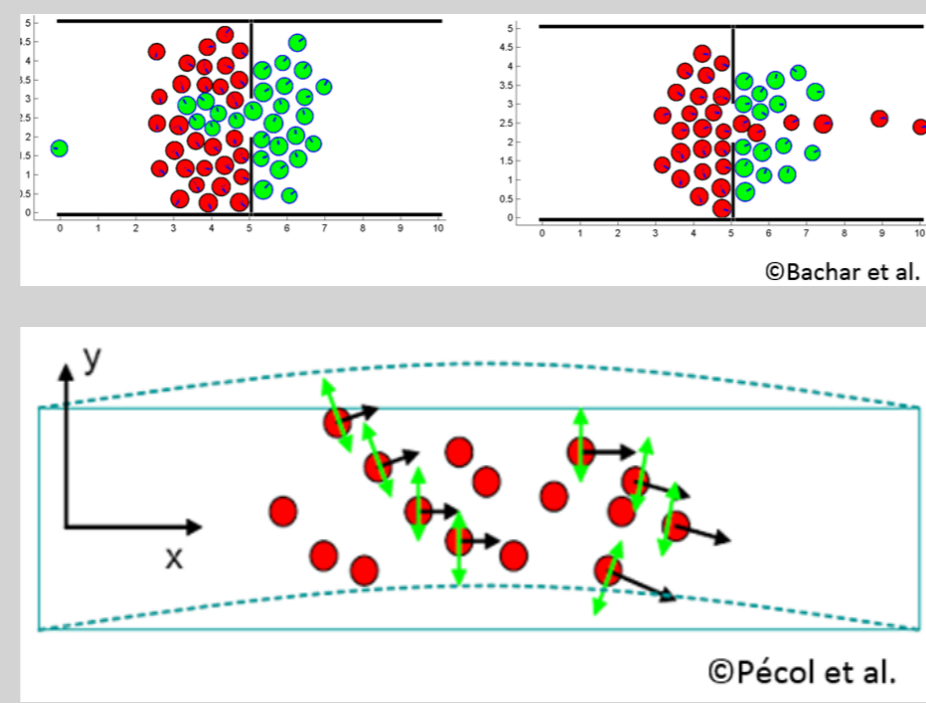
### Objectives

Develop a 2D discrete model

- Consider 3 degrees of freedom for the movement of a pedestrian
- Navigation strategies
- At-a-distance pedestrian interactions
- Crowd-structure interaction

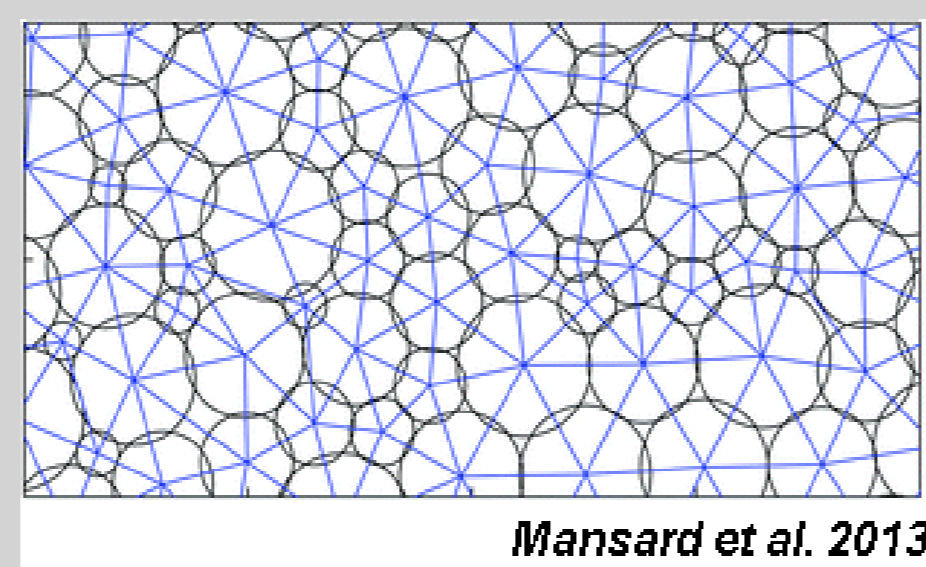
### Methodology

- Model crowd movement on a rigid floor
- Validate the model
- Model crowd-structure interaction for vibrating floors

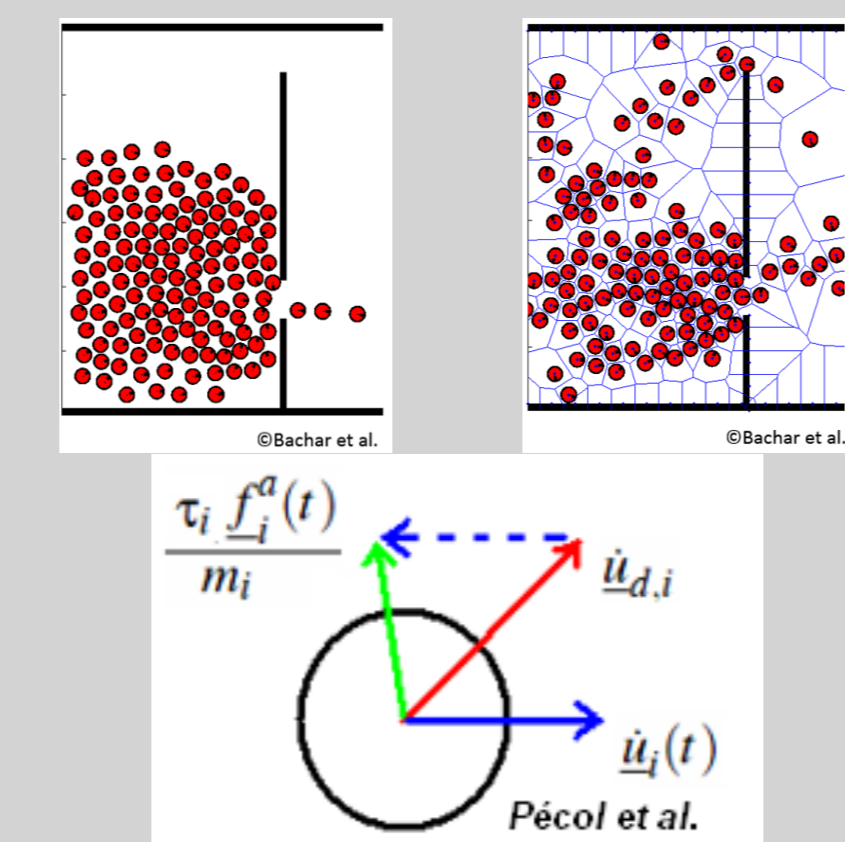


### The 2D discrete model

- Granular media- Non smooth mechanics (Frémond, 1995/ Dal Pont et Dimnet, 2008)
  - Detect contacts: Delaunay triangulation
  - Manage contacts : prevent interpenetration and define the nature of the collision using a pseudo-potential of dissipation
  - Determine the after collision velocity  $v^+$  as a function of the before collision velocity  $v^-$



- Adaptation to pedestrian dynamics
  - Choosing a navigation strategy:
    - The shortest path (Eikonal equation)
    - The shortest path (Eikonal equation + voronoi diagram)



- Introduction of the navigation strategy into the granular model

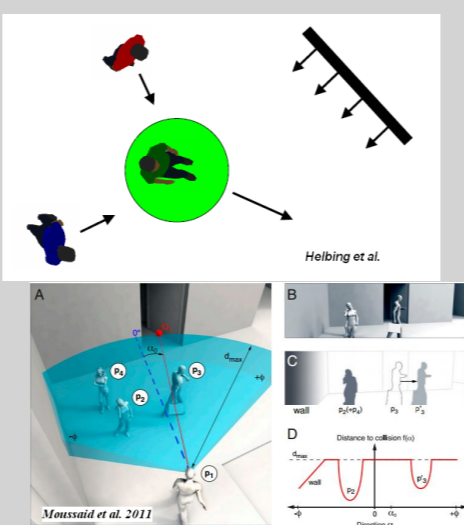
$$\underline{f}_i^a(t) = m_i \frac{\|\underline{u}_{d,i}\| \underline{e}_{d,i}(t) - \dot{\underline{u}}_i(t)}{\tau_i}$$

- Management of at-a-distance interactions

- a repulsion force

$$\underline{F}_{ij}^{rep} = A \exp[(r_{ij} - d_{ij})/B] \underline{n}_{ij}$$

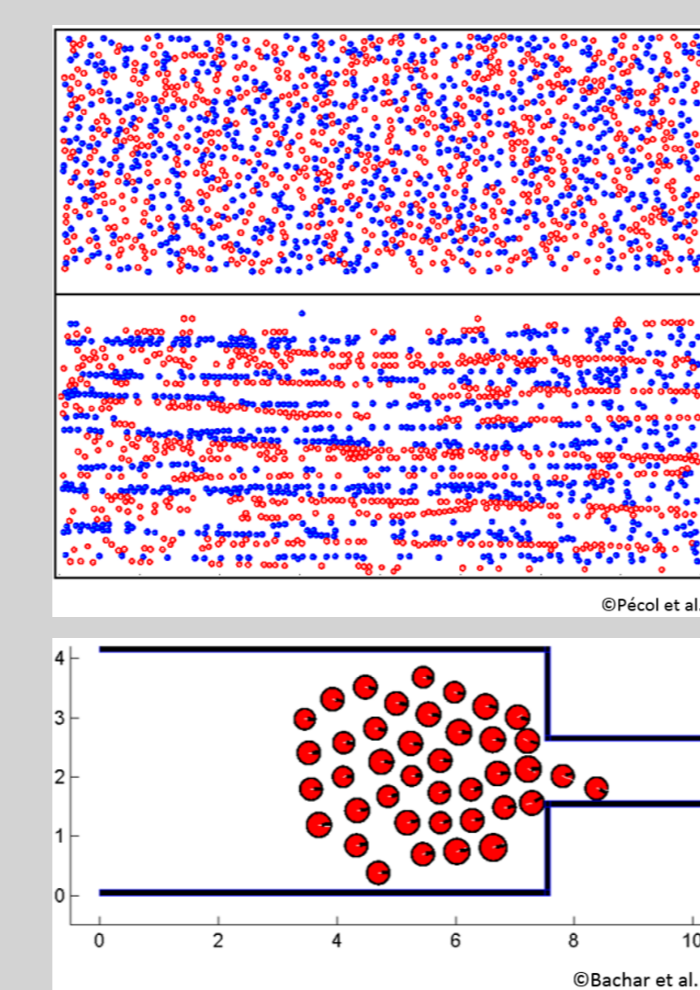
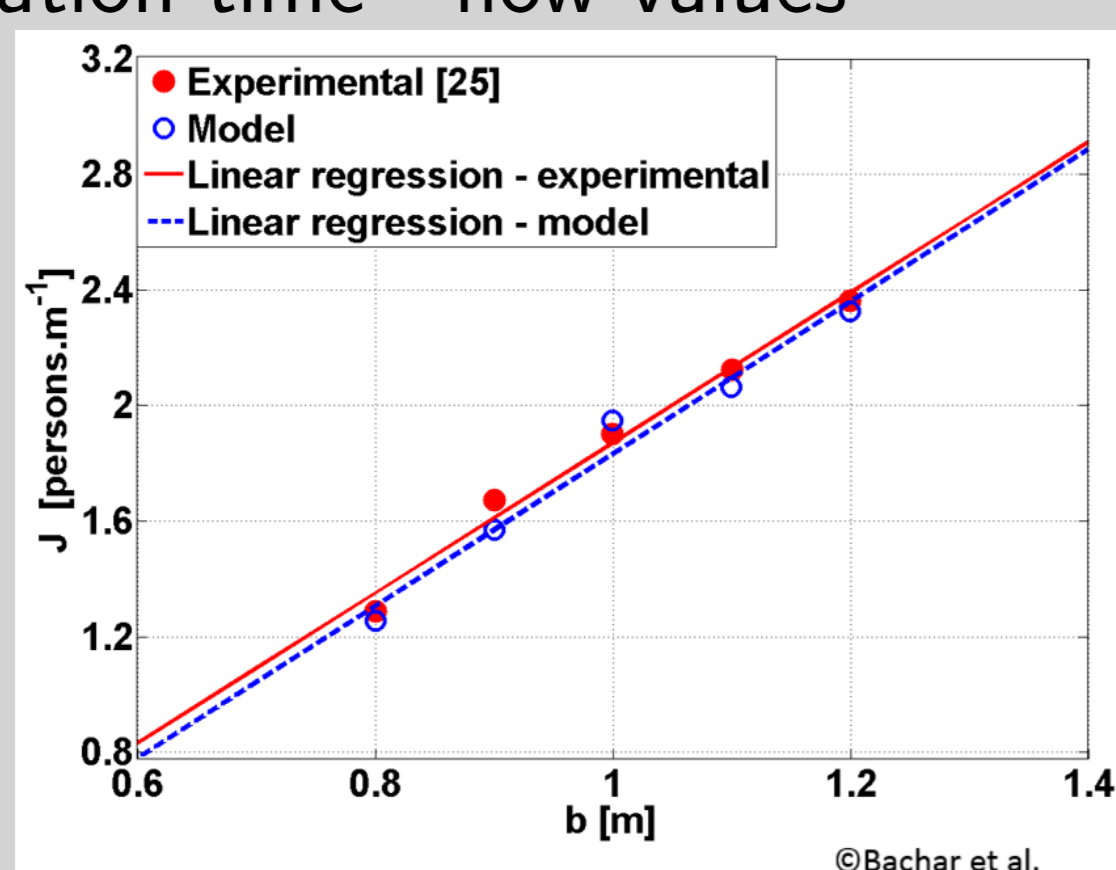
- a vision field



### Validation of the 2D discrete model

Reproducing self-organizational phenomena

- Pedestrian arch formation
- Lane formation in counter flow
- Funnel shape in front of the bottleneck
- Evacuation time - flow values



### A discrete model for crowd-structure interaction

- Pedestrian-bridge dynamic interaction (lateral vibrations)
  - The equation describing the dynamic behaviour of the footbridge projected onto the lateral mode

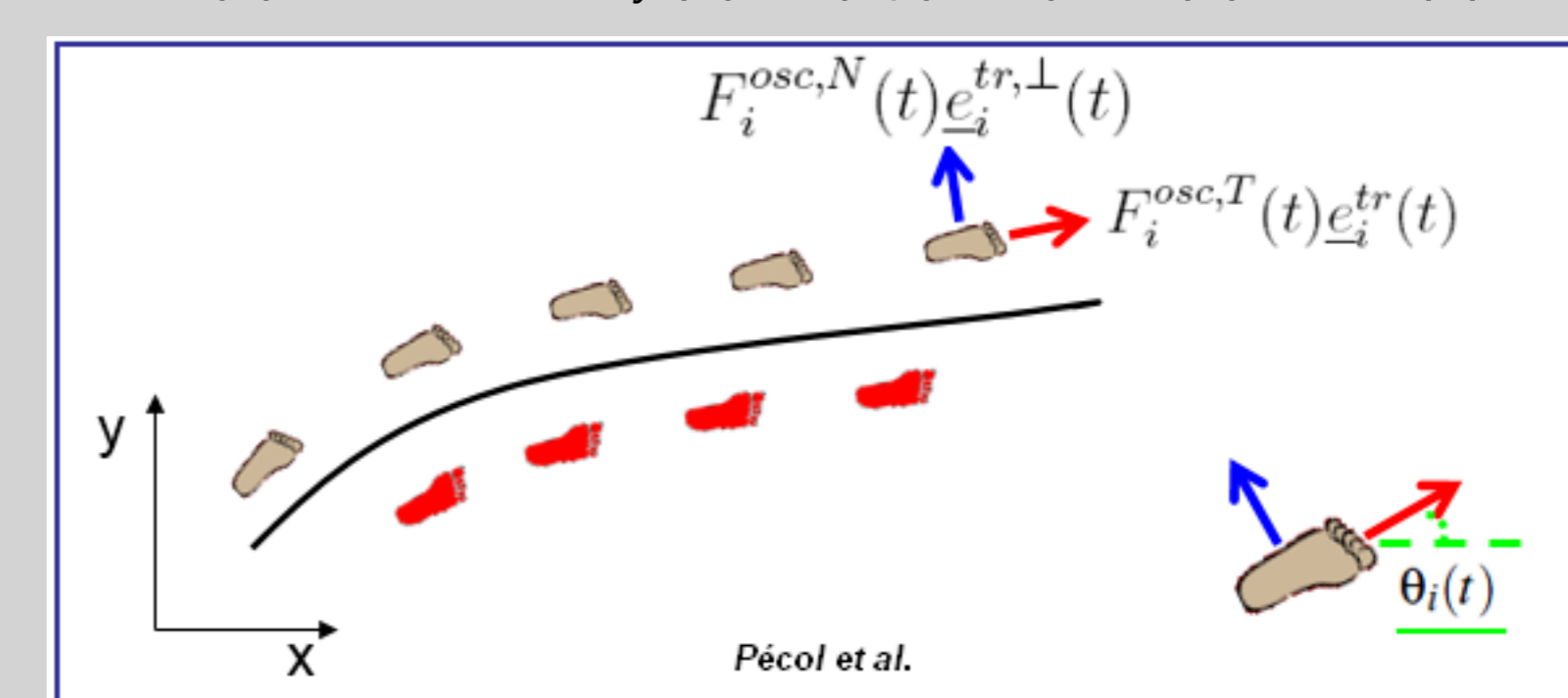
$$M_{str} \ddot{U}_y + C_{str} \dot{U}_y + K_{str} U_y = \sum_{i=1}^N \psi_1(q_i^x) F_i^y(t)$$

- The dynamic equation for pedestrian  $i$

$$F_i^y(t) = -m_i \psi_1(q_i^x) \ddot{U}_y(t) - m_i \ddot{u}_i^{tr,y}(t) + |F_i^{osc,T}| \sin(2\phi_i(t)) \sin(\theta_i(t)) + |F_i^{osc,N}| \sin(\phi_i(t)) \cos(\theta_i(t))$$

- Phase equation for each pedestrian : the Kuramoto equation

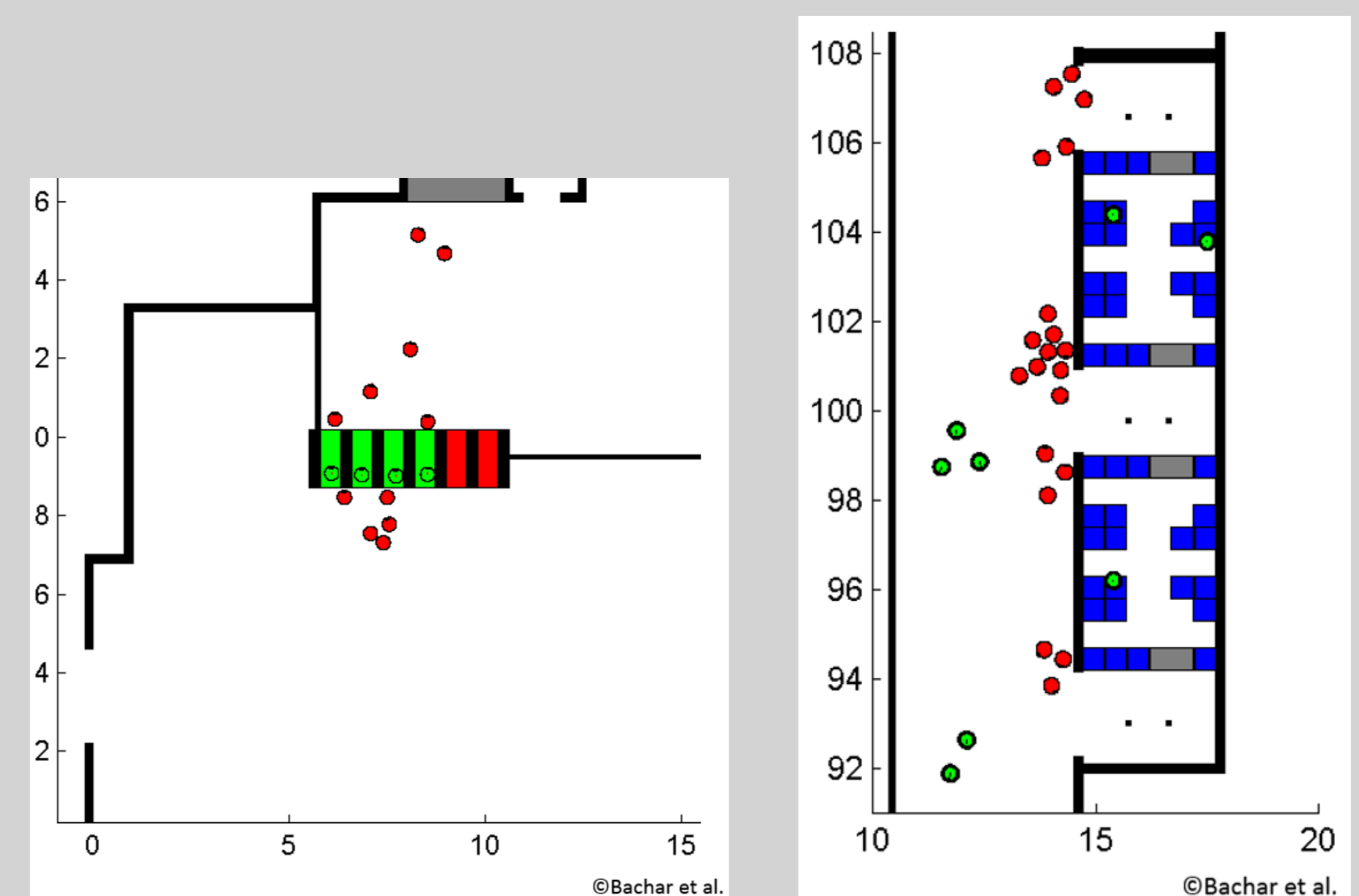
$$\dot{\phi}_i(t) = \omega_i + \epsilon_i A_y(t) \psi_1(q_i^x) \sin(\psi_{str}(t) - \phi_i(t) + \alpha)$$



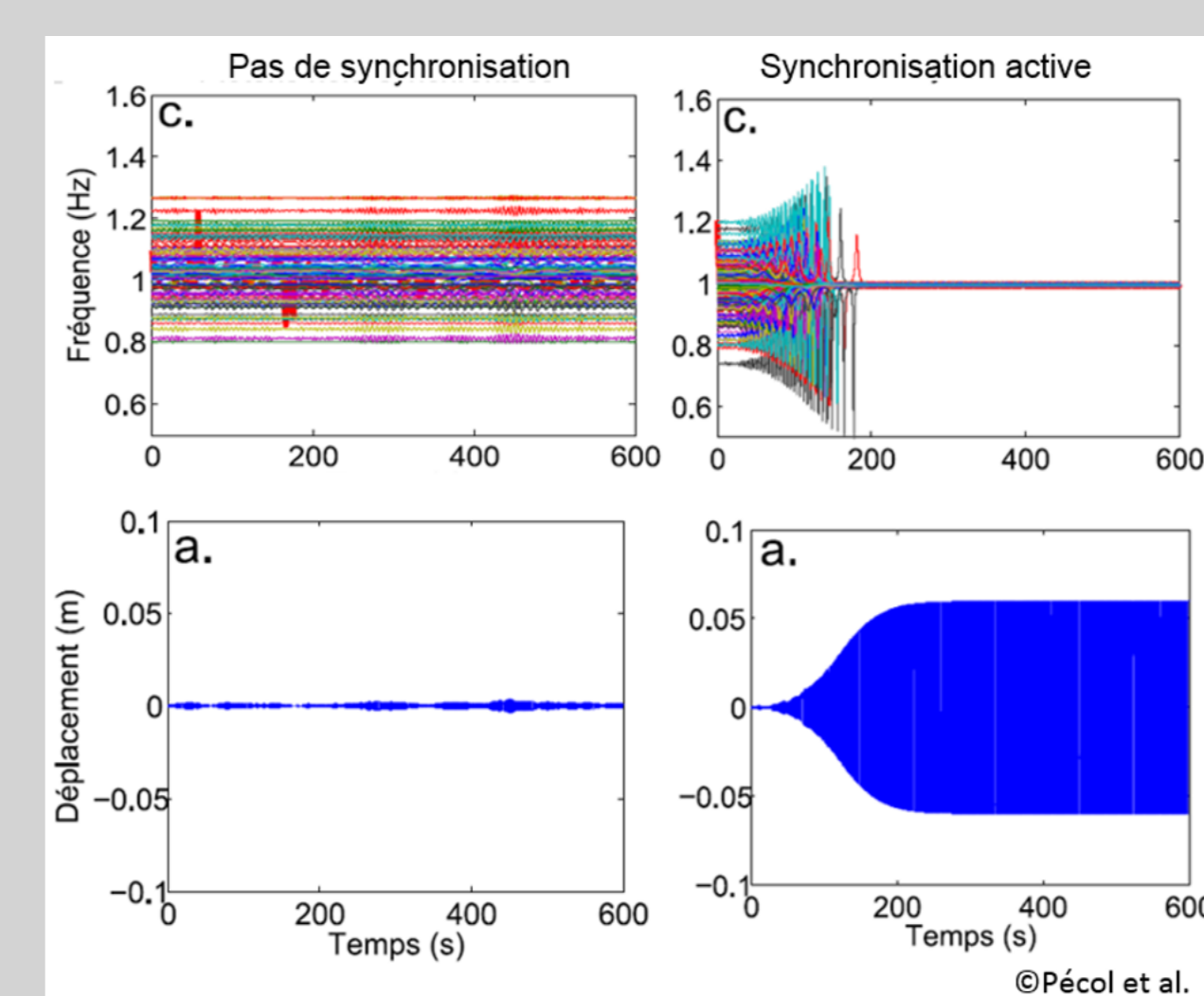
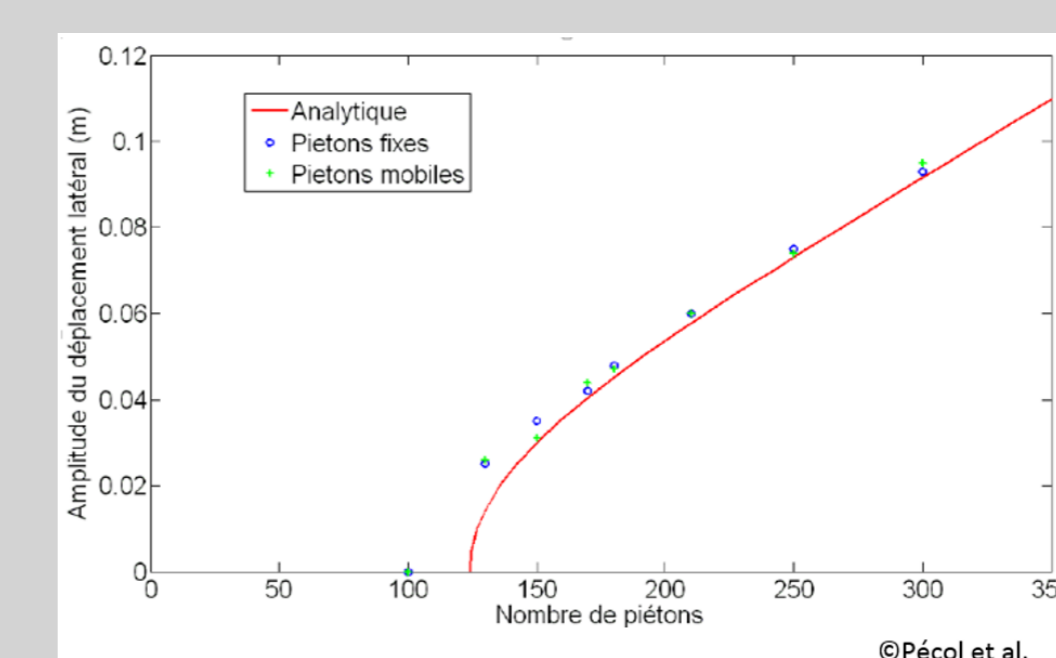
- Analytical study : Determining the critical number  $N_c$ , the post-critical amplitude of oscillations  $A_y^{pc}$  and the synchronization frequency  $\omega_{syn}$

### Applications to real situations

- Estimating the dwell time of the trains in the Noisy-Champs station (Zoi Christoforou)



- Numerical simulations of the north span of the Millennium Bridge



### Ongoing work - perspectives

- Non deformable agents (represented by circular disks)
- A sensibility analysis of the different input parameters using a Krigeage model
- Model the turbulence phenomenon using a cohesion factor
- Study crowd structure interaction by representing pedestrians by self-entrained oscillators