EVIBOIS: Monitoring of the Vibratory Behaviour of Tall Timber Building

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Context and objectives

State of the art

Structural health monitoring (SHM) is facing several scientific issues related to (1) the building specific response for normally equivalent buildings, (2) paucity of experimental data in normal and abnormal condition, and (3) the operational and environmental conditions effects. Timber constructions are lighter and less stiff than conventional buildings (e.g., steel or reinforced concrete buildings), resulting in a different behaviour about horizontal vibrations (Ostman and Kallsner 2011) and (Schmidt et al. 2018). For timber constructions, since the development is recent, experimental testing is necessary to better understand the behaviour (Abrahamsen et al. 2020). Feldmann et al. (2016) showed differences in modal behaviour between normally equivalent timber building (e.g., solid timber with concrete core, timber frame with timber core and timber frame with concrete core). Most of the studies are punctual measures (Reynolds et al. 2015) and do not take into account long term, seasonal and/or daily effects. Abrahamsen et al. (2020) showed that wind leads to risks for comfort of final users in tall timber buildings. The EVIBOIS project aims at improving our understanding of the dynamical behaviour of high-rise timber construction, by studying the case of CLT building with no concrete core, located in Grenoble, France.

Fig. 1 : The “Haut-Bois”, R+8 (left), concrete stairwell (middle), R+5 (right)

Studied building: The “Haut-Bois”

The “Haut-Bois” is a set of two residential timber buildings of 56 apartments, 5 and 8 storeys high (18 m and 28 m respectively) and covered with zinc cladding (Fig 1). There is no concrete core in the buildings. Current storeys are made of Cross Laminated Timber (CLT) for shear walls and floors, Glulam (GL24h) for beams and some I-section steel beams. Each timber building is dynamically separated from the concrete stairwell by seismic expansion joints.

Methods

Data acquisition

A semi-permanent monitoring (still going after 20 months) is installed at the top of building, it's composed of three velocimeters Lennartz 3D-5s. A full-scale measure is also performed to define a reference for the modal identification. The concrete stairwell is also measured once to understand the transmission of vibrations through the building and the stairwell. A weather station Vantage Pro 2 Davis Instruments is installed next to the "Haut-Bois" to register ambient temperature, wind speed, wind direction and ambient relative humidity.

Analysis methods

Two methods are used to analyse the time series: FDD for modal analysis (modal shapes and natural frequencies) and RDT for damping (Reynolds et al. 2016).

Results and discussion

Results presents the vibratory behaviour of the building and its variations over time. Three modes are clearly identified at frequencies f_{E1} = 1.88 Hz, f_{N1} =2.46 Hz and f_{Z1} = 2.76 Hz. The analysis of the mode shapes shows that the first mode is flexion on the axis East, the second mode is flexion on the axis North and third mode is torsion around the Z axis (Fig. 2).

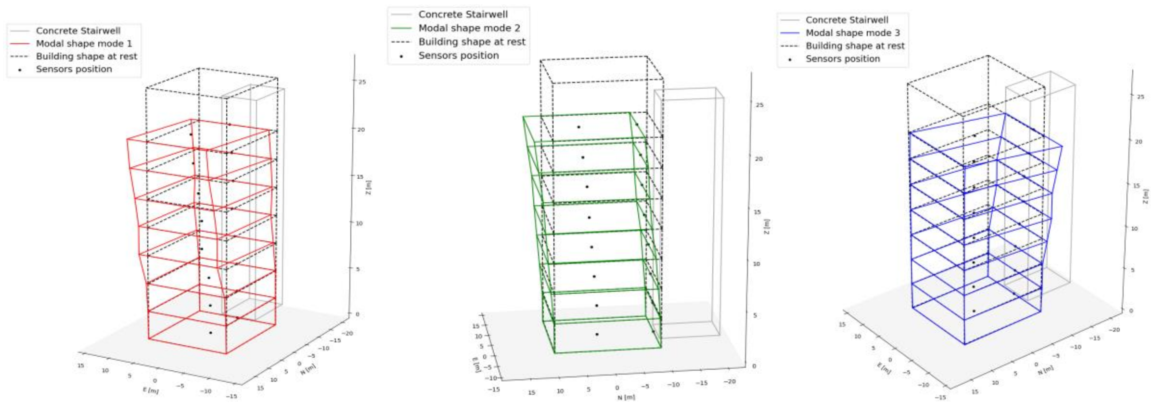

Fig. 2 : Modal shapes of the 8 storeys timber building

Fig. 3 shows the evolution of the fundamental frequency, the relative humidity, the temperature and the wind velocity over the first year of occupancy. Many analysis can be derived from these data, some will be presented in the poster, such as observing the evolution of one modal frequency in respect to the temperature (Fig. 4) or in respect to the relative humidity (Fig. 5).

Also, these data can be used to identify how much each environnemental variable command the dynamic behaviour of the structure. A multilinear regression is used to calculate the partial coefficients α, β, γ and ε (error) that provide the best assessment of the fundamental frequency f_1, based on the temperature T, the Relative Humidity RH, the wind velocity W and the initial fundamental frequency f_{1_0}:

$$f_1 = \alpha\, T + \beta\, RH + \gamma\, W + f_{1\_0} + \varepsilon \quad (1)$$

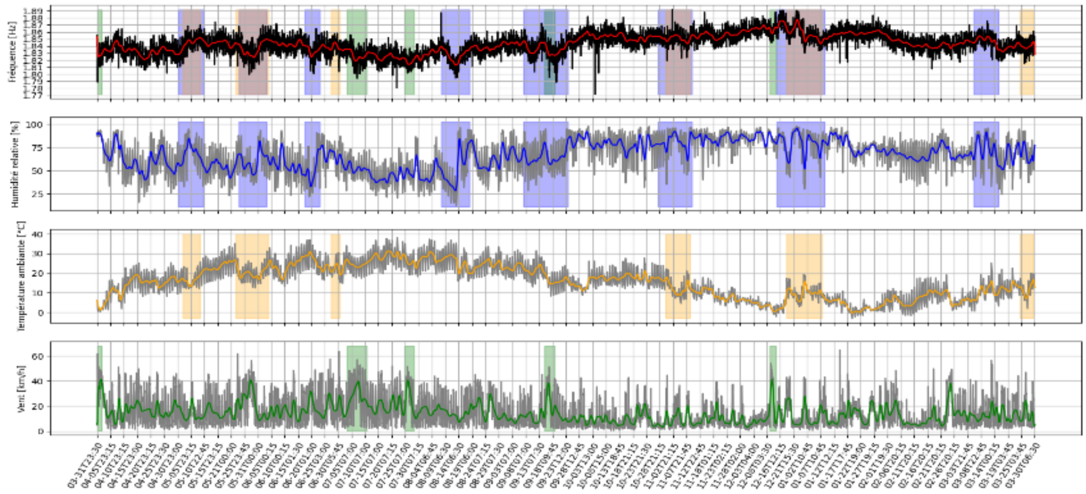

Fig. 3 : Evolution of the modal parameters and environmental data over time. Black or grey line represent the value over a window of 1 hour, the colored lines represent the moving average value over 24h.

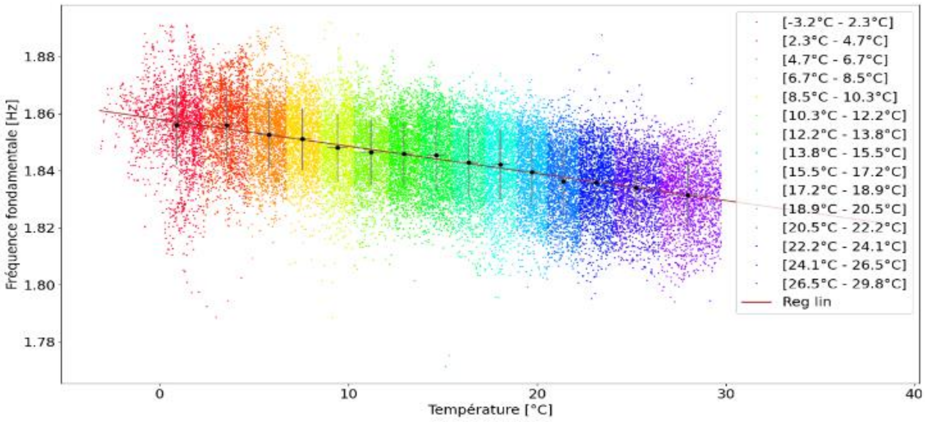

Fig. 4 : Fundmanetal frequency versus temperature. Colored dots are the frequency (over 1 hour of observation), each color represent a range (15 quantiles) of temperatures. Black dots are the average value of a temperature range (grey lines are the standard deviation). The linear regression of the black dots is also displayed.

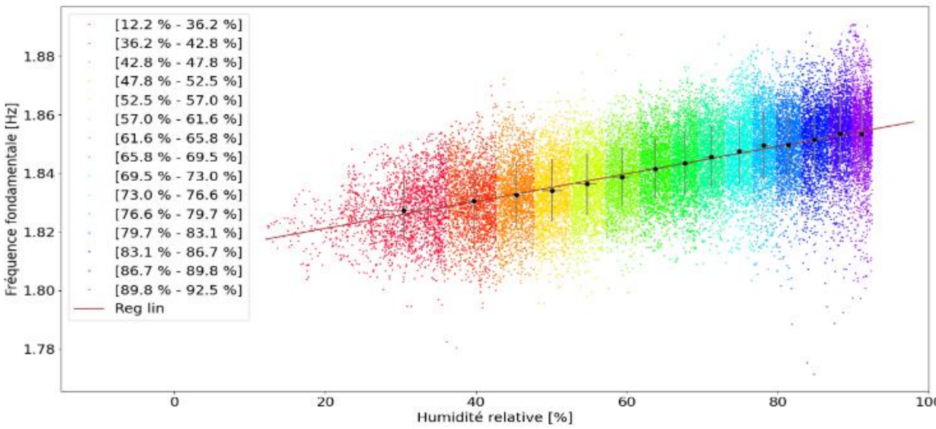

Fig. 5 : Fundmanetal frequency versus relative humidity. Colored dots are the frequency (over 1 hour of observation), each color represent a range (15 quantiles) of relative humidity. Black dots are the average value of a relative humidity range (grey lines are the standard deviation). The linear regression of the black dots is also displayed.

Fig. 6 presents the comparison between the modeled fundamental frequency (blue curve) and the mesured one (red curve). The global trends of the curves are similar and most of the variations are described. This approach is currently being developped for other dynamical properties, such as modal dampings and modal strain energies.

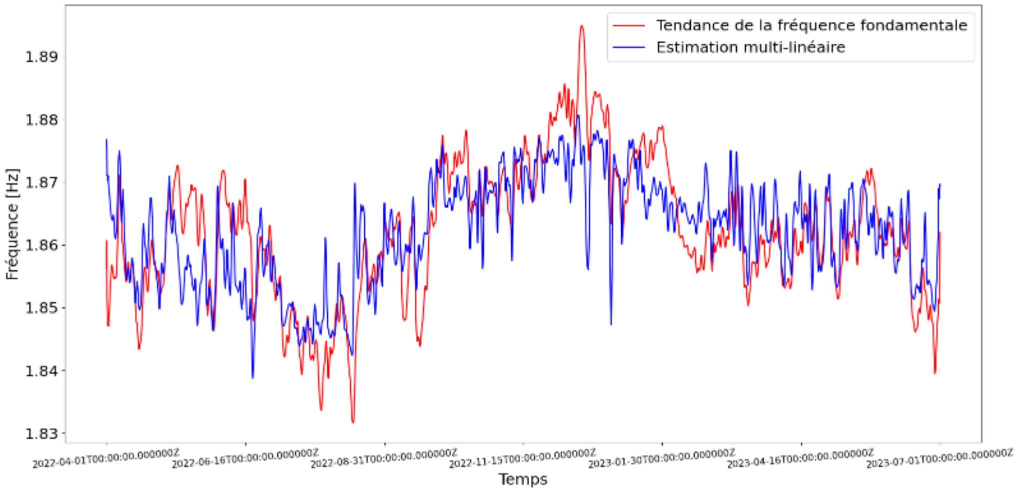

Fig. 6 : Estimation of fundamental frequency using environmental multilinear model

Conclusion

The specificity of this project is the vibrational monitoring of a 8 storey timber building by continous measurment over a long period of time (20 months so far). Combined with environnemental measurments, the evolution of the dynamic parameters can be observed and correlation between environnemetal phenomenon and these evolution can be studied. Base on a multilinear regression, the current work aims at ranking the environnemental contributing factors of the dynamic properties evolutions.

One outlook is to study the link between these dynamic properties and user’s comfort. For example in studying in more detail the damping (as it is a major mitigating factor in vibration discomfort and in-situ measurements are relatively rare). Another example is to compare the analytical method of Eurocode 1 (2010) to determine the maximal caracteristic acceleration to the measured one and the threshold proposed in ISO 10137 (2007).

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