PhD Position

Video-based vibration analysis of medium and high wood constructions

Laboratory: QUARTZ, thème VibroAcoustique & Structures – Formes Mécaniques (VAST FM)
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Project: *Optical identification and modeling of the nonlinear dynamics of high-rise timber buildings (DYNATIMBEREYES – ANR AAPG 2021)*

Description of the project DynaTimberEyes:

High-rise and mid-rise timber buildings represent an efficient solution for sustainable cities and ecological transition. Numerous huge projects of high-rise buildings are expected in the next 20 years, as the project of the Sumitomo 350-meter-tall wooden tower, planned in Japan for 2041. However, timber structures are lighter and less stiff than concrete ones, so they are more sensitive to vibrations and less comfortable. For that reason, the improvement of the knowledge of the dynamic properties of these structures is more and more needed.

The dynamics of such structures highlights specific nonlinearities due to the vibration of wood beam assemblies at relatively large amplitudes. The dynamic model of these structures is also very limited, especially in terms of modal damping estimation. Studies are ongoing worldwide to expand the knowledge database on these models and values [1, 2]. The common and accepted experimental method is to realize an Operational Modal Analysis with accelerometers. This procedure involves to use several costly sensors and to install them at different locations in the building. Then, to get an acceptable mapping of the building, the measurements shall be repeated by moving the sensors to other locations. A measurement campaign has several important drawbacks: access and authorization to the building are needed, sensors (and data acquisition systems) are very expensive, set-up, cable routing, and equipment transfer between subsequent measures are difficult and time consuming.

The proposed project will help the French building and civil-engineering industry and authorities by:

- *Improving the modeling of timber structures and in particular the nonlinear behaviour of wood beam assemblies,*
- *Offering an innovative methodology using cameras to capture the nonlinear dynamic behaviour of medium and high-rise timber structures,*
- *Responding to a measurement productivity issue, as the process is currently very time-consuming, and allowing a regular monitoring of structures,*
- *Responding to certification institutes.*

To achieve these objectives, the project is structured into three main work packages addressing specific research challenges (Figure 1):

- **WP1**: The development of a full-field vibration measurement procedure using camera(s) able to identify on a real high-rise timber building, with a good accuracy and quantified errors, the parameters needed for the digital twin model of the structure developed in WP3.
- **WP2**: The identification and modeling of the static and dynamic nonlinear behaviour of assemblies of timber structures in order to propose a nonlinear dynamic reduced order model to be identified in WP1 and introduced in the digital twin model of WP3.
- **WP3**: The development of a digital twin model of the timber structure with data assimilation techniques based on specific observers, designed with augmented state systems, in order to obtain the unknown parameters proposed in WP2 and identified in WP1.

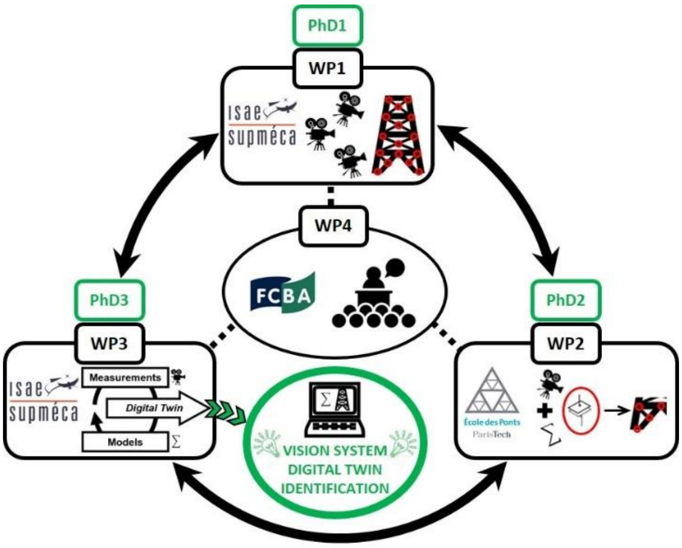

Figure 1. Outline of the project DynaTimberEyes.

PhD proposal:

This PhD proposal is part of the WP1, the objective of which is to develop a video-based measurement protocol to measure the vibrations of timber buildings and large structures in general. Video analysis aims at identify nonlinear properties of joints (WP2) and feed a digital twin of the structure (WP3).

The scientific challenge of the PhD relates to the fact that for vibration measurements of large civil engineering structures, such as buildings, towers and bridges, optimal and robust placement of cameras, operational conditions, accuracy, computational cost, noise and spatial resolution remain a great part of the scientific lock.

Notably, the selection of a few camera devices with high-resolution and/or a network of middle range cameras will respond to specific requirements such as synchronization capability, frame rate compatibility with the building dynamic, transportability and easy installation. Then, specific analyses will be conducted in order to predict and quantify errors related to acquisition conditions in the in-situ campaign: weather, not optimal lighting and camera positioning, uncontrolled excitation (wind), etc. For the post-processing stage, a particular attention will be paid on the best features to track (corner, edges, texture, ...) and the computer video techniques to adopt (optical flow, DIC, MSER, motion magnification ...) [3, 4, 5]. Video analysis will focus on the dynamics of timber structures at different scales, in laboratory under controlled excitation and in-situ under Operation Modal Analysis (OMA). Figure 2 summarizes the case studies that will be faced in this project. The results will be extrapolated from measurements on reduced scale building thanks to a similitude law dedicated for wood structures.

When filming a real building, one cannot add neither targets nor speckles. The field of view is so large and displacements so small that many cameras are required. Moreover, the measurements could be polluted by weather conditions and varying light. To reach the WP1 and PhD goal progressively, we will start studying the kinematic and deformation of a basic wood structure in laboratory (Figure 3(b)). Results obtained by edge and material texture detection will be compared to classical feature detection (targets or speckles). Then, we will use a timber frame construction (Figure 2 (d)) placed on a shaker table at FCBA to study the use of a low-cost camera network with edge detection. Results will be compared to more classical approaches (accelerometers + virtual sensors). Finally, we will use these techniques outdoors on large-scale timber structures (Figure 2(e-f)), by adapting image processing algorithm to meet the weather conditions difficulties (light variation, vibrations of camera due to wind, partial observation of the building, ...). Emphasis will be placed on 3D vibration field tracking and on errors quantification.

Figure 2. Experimental case study of the DynaTimberEyes project.

Bibliography

[1] C. Faye, L. Le Magorou, P. Garcia, J.C. Duccini, *Experimental investigations on seismic behaviour of conventional timber frame wall with OSB sheating, proposal of behavior factor,* International Council for Research and Innovation in Building and Construction (CIB-W18), Working Commission W18A – Timber Structures, Vancouver, Canada, 2013.

[2] Y. Verdret, S.M. Elachachi, C. Faye, P. Garcia, *Modélisation du comportement d'un mur à ossature bois sous action sismique*, Les Annales du Bâtiment et des Travaux Publics, N°6, December 2013.

[3] M. Bornert, F. Brémand, P. Doumalin, and al., *Assessment of digital image correlation measurement errors: Methodology and results*, Exp Mech, 49(3):353–370, 2009.

[4] D. Gorjup, J. Slavič, and M. Boltežar, *Frequency domain triangulation for full-field 3d operating-deflection-shape identification*, MSSP, vol. 133, p. 106287, 2019.

[5] F. Renaud, S. L. Feudo, J.-L. Dion, and A. Goeller, *3D vibrations reconstruction with only one camera*, MSSP, vol. 162, p. 108032, 2022.

Skills required

Master degree in civil or mechanical engineering with solid background in structural dynamics. Some skills in experimental testing would be an advantage, as well as skills or first experience in video analysis and image processing.

Partners/Contacts

The thesis will take place mainly in the Paris area at ISAE-Supméca with regular contacts and exchanges with ENPC. Periods of testing in Bordeaux in the premises of FCBA are planned (see Figure 2).

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Navier Laboratory is a joined research unit of Ecole des Ponts Paris Tech, Univ Gustave Eiffel and CNRS (UMR 8205) with a renowned expertise in the experimental, theoretical, and numerical investigation of the mechanical and physical properties of materials and structures for civil engineering applications.

FCBA is an industrial technological institute composed of 340 people, 120 of them being involved in research working for the whole forest-based sector including: forestry, pulp and paper, wood construction and furniture with different activities such as innovation, research and development, technical assistance, certification, testing, standardization, and training information.

At **ISAE SUPMECA**, Quartz Laboratory works on Tribology and Materials, Static and Dynamic Study of Mechanical Systems, Vibrations, Acoustic and Structures (VAST), Sustainable Systems, Engineering of Mechatronic and Multi-physical Systems. The VAST team is engaged in this project. Research activities of VAST are performed with academic and industrial partnerships mainly in vibration damping modelling and measurements in assembled structures.

Requested documents of application

- Curriculum Vitae
- Letter of intention
- Grades (Master's and previous years)

Contact to apply

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