Challenges for acoustic calculation models in "Silent Timber Build", Part 1- FEM

Delphine BARD[1]; Juan NEGREIRA[1]; Jean-Luc KOUYOUMJI[2]; Gérard BORELLO[3]; Catherine GUIGOU[4]

[1] Lund University, Sweden

[2] FCBA, France

[3] InterAC, France

[4] CSTB, France

ABSTRACT

The project "Silent Timber Build" will develop new prediction tools for timber structures. There are several challenges that have to be overcome to provide a full prediction tool. The differences in weight, stiffness and density for wooden structures compared to traditional, heavy and more homogeneous structural material have repercussions on how the sound propagates throughout the structures, affecting the sound and vibration insulation performance and also theories to be used in prediction models. Finite element simulations have proved to be useful in the design phase in a certain low and very low frequency range. By further developing reliable finite element tools for low frequencies, the performance of future wooden constructions can be predicted in a full frequency range, saving both time and money as all calculations, and modifications can be done during the design phase. However the upper limit for using FEM has to be further investigated and then be merged with statistical methods. This article, following another article Part 2, will focus on medium and high frequency range calculations. For full-scale building, Virtual SEA method, as analytic and SEA approaches will be used in frequencies low enough in order to optimize the overlap to FEM.

Keywords: Sound, Insulation, Transmission I-INCE Classification of Subjects Number(s): 51.4

1. INTRODUCTION

The costly process of using test buildings is common, even though the obtained measurement results are not directly applicable to buildings of slight different construction. Prediction models, despite their highly usefulness for designing new buildings and preventing severe and costly changes in the aftermath of construction, are still very much lacking today. The conjunction of several methods, namely the Finite Element Method (FEM) and Statistical Energy Analysis (SEA) for developing efficient and robust predictive tools over the whole frequency range of interest is of crucial importance if time and costs are to be saved. The latter will be one of the main aims of the aforementioned “Silent Timber Build” project.

[1] Delphine.bard@construction.lth.se

2. FEM (FINITE ELEMENT METHOD)

Partial Differential Equations (PDE) arise in the mathematical modelling of many engineering problems. The analytical solutions of PDEs are often either impossible or impracticable to obtain by use of classical analytical methods. The FE method is a numerical approach by which boundary value differential equations, both linear and non-linear, can be solved in an approximate manner.

2.1 FE models: High frequency issues

The main drawback of the FE method in using it in vibro-acoustic analyses is that its frequency range of applicability is restricted to the low frequencies (up to approximately a couple of hundreds Hertz). As the response of the structure is requested for higher frequencies, shorter wavelengths must be resolved and smaller details in the geometry become increasingly important. The modelling of finer and smaller details is a challenging task. On top of that, it becomes practically impossible to perform the analyses due to the extensive size of the resulting FE models even using model order reduction. Another disadvantage when calibrating models is that results are highly dependent on input data, making material properties an important factor to tackle in detail. Likewise, there are some other factors like workmanship which are out of control, that make the calibration even more difficult.

2.2 FE models: Medium frequency issues

When frequency increases, as seen previously, taking into account all available modes would require too large FE models to be tractable by current computers. It would also be a useless action as the local modes are very sensitive to structural imperfections. Their intimate behavior description needs then to take into account by statistical methods. When structural defaults are incorporated in the model at the FE scale, the resulting FE model is made stochastic. Stochastic FE modelling is an extensive domain of research, leading to search for reduced models [1,2] for limiting CPU from supercomputer and obtaining decent resolution time and robust dedicated statistics about analysed systems and underlying materials, all features not really available for timber frame buildings. More affordable alternate modelling techniques have to be addressed for building acoustics.

3. CALIBRATION OF FE MODEL

3.1 Study case: Timber Volume Element based buildings (TVE)

The box-assembly construction method is treated in detail in the Silent Timber Build project. The reason for this choice being the steady increase in the industrial production of volume buildings, which makes the development of a thoroughly appropriate engineering prediction model to seem more feasible than before, due also in part to the standardisation of the building technique. In this method, also called timber volume element (TVE) based buildings, prefabricated box-like modules containing floor, walls and ceilings together with electrical, heating, water sanitation and ventilation installations (cf. Figure 1), are stacked together to assembly the complete building. A distinct advantage often present in this type of building system as regards vibrations and acoustic performance is that, for any two volumes placed above the other, the upper volume contains the upper part of the floor to it, being the ceiling comprised in the lower volume. An elastomer is usually inserted in between the two volumes. It is precisely the fact of having an elastic strip between any two volumes one above the other, the floor of the one above and the ceiling of the one below being split from one another, that distinguish volume technique from more traditional lightweight building technique [3]. The elastomers placed along the flanks, together with some tie plates and metal studs, are the only mechanical contact between two adjacent TVEs, its reducing the flanking transmission markedly if the correct elastomer is used; see Figure 2.

Figure 1 - TVE manufacturing

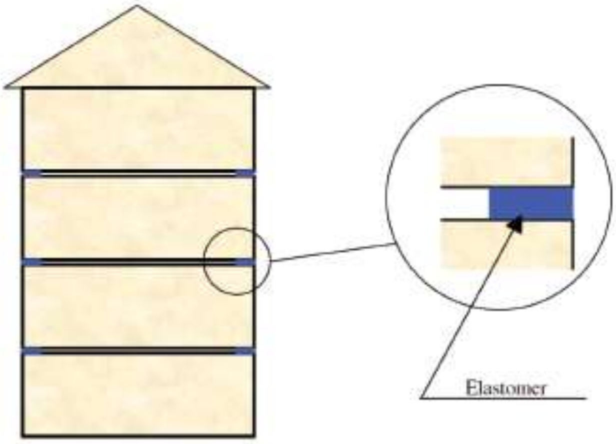

Figure 2 - Box-assembly building method [3]

Considerable amount of research on lightweight timber buildings has been carried out. According to [3], however, there is still a lack of systematic studies dealing specifically with volume based element buildings. It is still a question; therefore, to what extent the knowledge regarding traditional lightweight buildings attained thus far is directly applicable to volume system. FE prediction tools must then be developed in order to better understand and improve the performance of such buildings, a method for calibrating models with measurements as input being taken up herein.

4. STRUCTURAL DYNAMICS ANALYSIS

In [4], a general method for creating accurate and reliable numerical models mimicking a specific real problem is presented. The method will be applied to the problem in question under study here, i.e. a TVE-based building, discussions about its advantages and limitations in this particular case being also explained.

4.1 Model Description

A whole TVE (cf. Figure 3) with inner dimensions 3.6x 8.6x 3 m^3, is intended to be modelled using Abaqus [5] and calibrated following the aforementioned method [4]. In so doing, one could eventually assemble various modules to form the complete building.

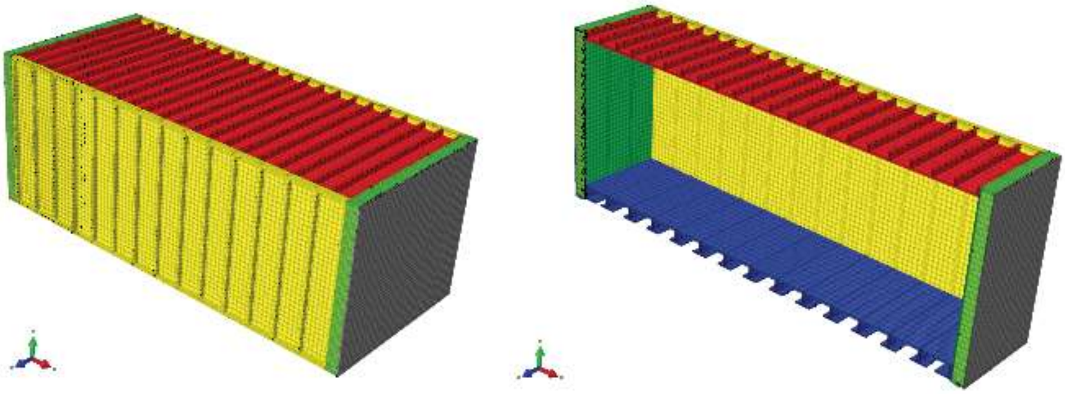

Figure 3 - Single TVE (left) and a cross-section of the TVE (right). The floor is shown in blue, the ceiling in red, the apartment separating walls shown in yellow and the façade walls in green. Weather boards on the outside of the facade vertically embracing TVEs when stacked are shown in grey.

The drawings of one such building, specifically those pertaining to Lindbäcks Bygg's project Brunnby Park in Upplands Väsby (Sweden), together with a list of materials employed in its construction, are shown in Figure 4 & 5. The material properties used in the modelling were either provided by the manufacturers or assessed via measurements, as it will be later on explained. Due to the complexity when assessing damping and also due to the numerous different materials existent in the real structure, a global damping extracted from measured data was assigned to all materials, instead of considering individual damping for each material.

The elastomers used at the junctions were modelled with dimensions 100x95x25 mm^3, their being meshed with hybrid linear elements denoted in Abaqus as C3D8RH in order to avoid numerical issues. The distance c/c (centre-to-centre) between two blocks was set to 600 mm as in reality. The computational mesh for the rest of the parts involved was obtained using hexahedral solid 3-D stress finite elements (C3D20) with 20 nodes and quadratic interpolation. The element size was decided based on the wavelengths expected to occur in the model.

Full coupling between all individual parts within the TVE was considered. This is believed to be the real case in constructed buildings, as discussed with the manufacturers, albeit some other alternatives were also tried following the method's steps as it will take up later.

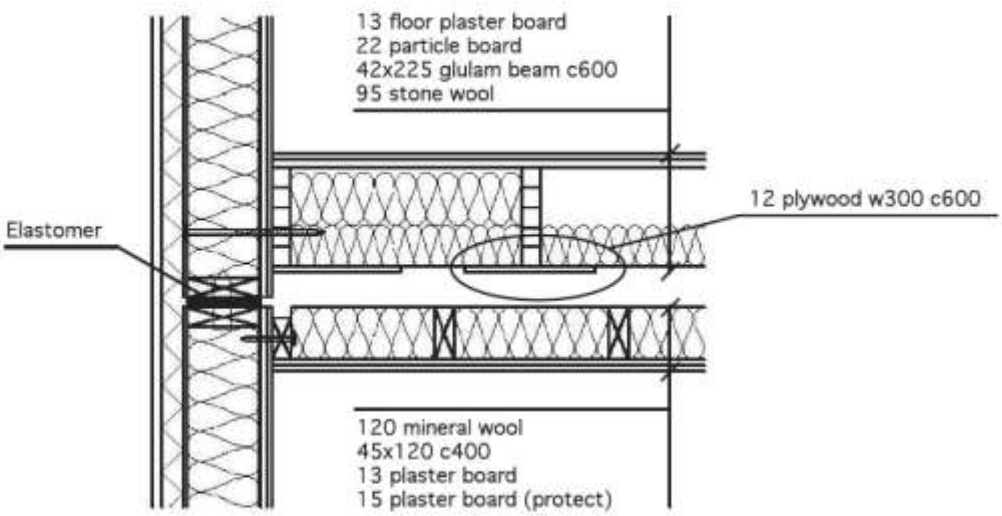

Figure 4 - Drawings of a TVE-based building - Facade walls.

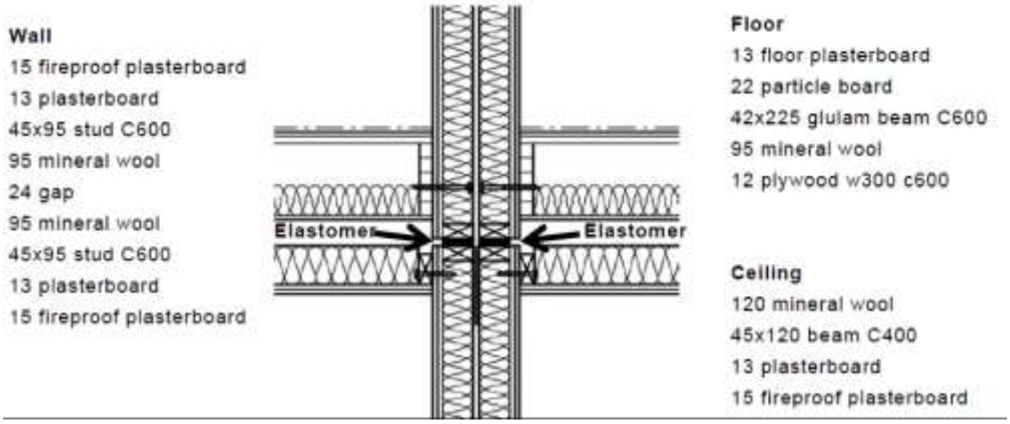

Figure 5 - Drawings of a TVE-based building - Apartment separating walls.

4.2 Modelling step by step

The model of one TVE described before in Section 4.1 was achieved and calibrated following [4]. In general terms, one could see the method [4] as a procedure which aims to fulfil four different objectives. First, an FE model of the structure to be studied is set up and analysed by performing several sensitivity analyses. Secondly, the latter model is calibrated until its response matches the measurement's output. Subsequently, effort is put into making the FE model numerically efficient so it can be used as a predictive tool. Finally and once the prediction tool is created, design improvements of the structure in question can be carried out by modifying features in the model and checking its performance before the structure is actually built.

As one can see, the process is iterative and requires very much knowledge of the structure to be modeled, as little changes in, e.g. material properties, connections, boundary conditions, and the like, could lead to drastic and even unrealistic results, if they are to be compared with real measurements.

5. CONCLUSIONS

Prediction models, despite their being highly useful for the designing of new buildings, through their serving to prevent the need of severe and costly changes in the aftermath of construction, are still very much lacking nowadays. It requires deep understanding of the dynamic behaviour of such structures and the use of FE models that represent the geometry of the buildings in great detail, since small structural modifications can have a strong effect on the vibration transmission paths. The first steps for the development and calibration of an FE prediction tool for an TVE-based building were here taken up in this paper by applying the method presented in [4]. Once the predictive tool is established, different features (e.g. structural modifications, fulfilment of psycho-vibratory indices) could be addressed during the design phase as depicted in Figure 6, its saving time and money for both builders and constructors. The latter validated FE prediction tool is valid up to approximately 200 Hz, statistical methods being required above that frequency, its being taken up in the companion paper, i.e. Part 2.

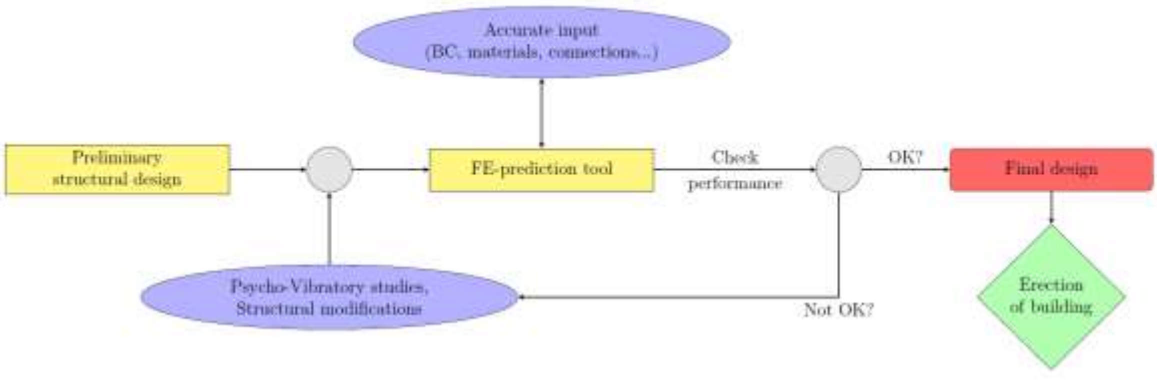

Figure 6 - Flowchart of the design process of a building using numerical prediction tools.

ACKNOWLEDGEMENTS

Authors would like to acknowledge all R&D Partners of Silent Timber Build project: SP Wood Technology, Sweden, Lund university, Sweden; CSTB, France; FCBA, France; InterAC, France; Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., Germany; Fraunhofer-Institute of Building Physics IBP, Germany; GU - Graz University of Technology, Austria; SINTEF Byggforsk, Norway; Lignum, Switzerland; Fundación Tecnalia Research & Innovation, Spain. As well as the Industrial Partners: CEI-Bois European Confederation of Woodworking Industries BWW; Fristad Bygg; WSP Environmental; SAU; Bauer Holzbau GmBH; Norgeshus AS; Finish Wood Research.

REFERENCES

1. C. Soize, Medium frequency linear vibrations of anisotropic elastic structure, La Recherche Aerospatiale (English edition), 5, 65–87 (1982)
2. C. Soize, Reduced models in the medium frequency range for general dissipative structural-dynamics systems, European Journal of Mechanics, A/Solids, 17(4),657–685 (1998)
3. F.Ljunggren, A. Ågren, Potential solutions to improved sound performance of volume based lightweight multi-storey timber buildings. Applied Acoustics 72(2011) 231–240.
4. K. C. Park, Analyses, Model Tests and Design Modifications for Vibration/Noise Mitigation, Lecture notes (presented at Lund University October 28, 2013), Center for Aerospace Structures, Department of Aerospace Engineering Sciences University of Colorado at Boulder, CO, USA.
5. Dassault Systèmes, Abaqus theory manual, Version 6.11, 2012.