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Case Study: Comparison between the Acoustic Performance of a Mixed Building Technology Building and a Conventional Building

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ABSTRACT

The objective of this work is to compare the acoustical performance of MBT (Mixed Building Technology) constructions and conventional buildings. The sound insulation performance of a MBT construction was assessed by tests done *in situ*. The results were compared with similar data from earlier measurements undertaken by the Building Physics Laboratory of the University of Minho in Portugal, and from simplified prediction methods.

The building where this comparison was done is a 3-storey building. The first 2 storeys were refurbished using conventional construction methods, but the 3rd storey was built using MBT methods, characterised by using lightweight materials, with high thermal insulation, and large fenestration areas. Based on the work undertaken, some conclusions and proposals for further work are presented.

1. INTRODUCTION

Developments in new construction technology can yield improvements in overall of building quality, and comfort for occupants. The acoustic performance is an important aspect in this [1, 2].

Mixed Building Technology (MBT) is one of these new technologies, which can offer original and important improvements in aesthetic, functional and economical terms. The improvements are a result of the favourable relationship between weight/thickness and insulation of the materials used in MBT construction.

Generally, MBT external and internal walls are thicker than those for than conventional buildings and use high absorption materials in the cavity of lightweight sandwich partitions. Conventional building solutions only involve small thicknesses of mineral wool in the cavity of double leaf hollow brick walls.

Mixed Building Technology (MBT) is a new construction concept that aims to integrate different construction methods in a single building. This concept is under development all over the world (and especially in Europe) as a result of recent recognition that there is a special need for higher quality in urban buildings. This requires the development of new and suitable strategies for architects, sociologists, urban planners, local authorities and engineers.

Important work has already been undertaken, under the auspices of the European Community, by way of COST projects, for example the COST Action C12 "Improving buildings' structural quality by new technologies" programme. The main objective of COST Action C12 is to develop, combine and disseminate new engineering technologies, to improve the quality of urban buildings, and to propose new technical solutions to architects and planners, to reduce the disturbances of the construction process in urban areas and to improve the eventual quality of living in the urban habitat.

Implementation of new technologies requires that construction should be undertaken in such a way that the building's overall cost (construction, maintenance and use) should not be increased and, if possible, reduced

Subjectively, the evaluation of the acoustic performance of buildings depends on each person's requirements, which in turn are based on their individual socio-economic and cultural heritage. Quantitative assessment can be based on measurable physical criteria, described in the specialized literature and in international standards.

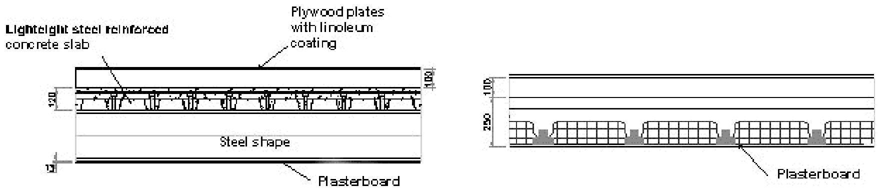
2. CONSTRUCTIVE ASPECTS OF THE BUILDINGS

For the purpose of this work to evaluate the acoustic performance of MBT buildings, an office building in Coimbra, Portugal, whose top floor was enlarged using MBT methods, was selected (Figure 1). The whole South façade of the MBT top floor has a glass curtain wall. The floor and roof slabs are 12 cm thick lightweight reinforced concrete, whereas the conventional construction lower floors are heavier, and typical of buildings in Portugal, with 25 cm thick beam and pot floor.

Figure 1. General view of the building where the MBT construction was implemented

The MBT structure is defined by a skeleton of steel, supporting the walls, the intermediate floors and the roof. The floor finishing is of plywood square plates with linoleum coating. This covering is located 10 cm above the slab to allow insertion of electric and PC cables. Under the slab there is a 13 mm thick plasterboard suspended ceiling (see Figure 2 and Table 1).

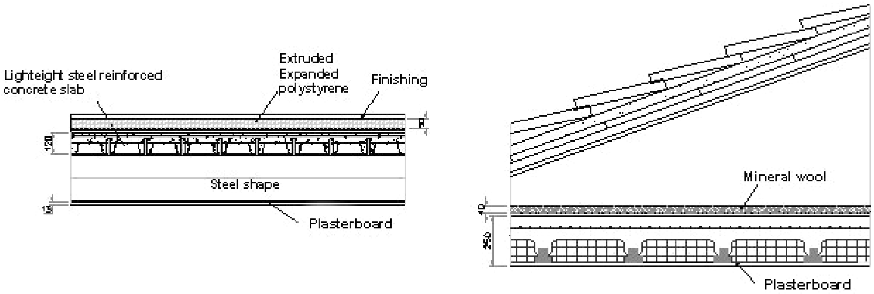
The floors and roof of the conventional part of the building are 25 cm thick beam and pot slabs. The floor finishing is wood and the ceiling plaster (see Figure 2 and Table 1).



MBT construction Conventional construction

Figure 2. Vertical cross-section of the MBT and of conventional floors

The MBT roof construction is 12 cm thick lightweight reinforced concrete slab with a 5 cm thermal insulation layer made of extruded expanded polystyrene. The conventional building roof is a non-ventilated attic insulated with a 4 cm layer of mineral wool placed over the ceiling slab (see Figure 3 and Table 1).



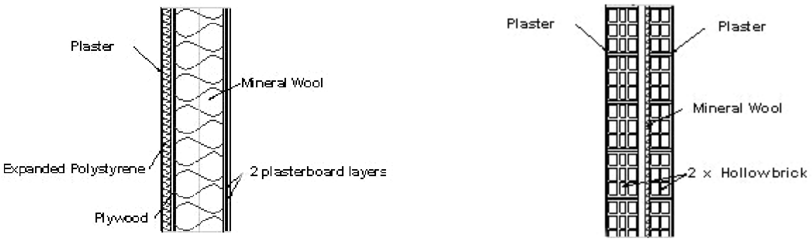
MBT coinstruction Conventional consrtuction

Figure 3. Vertical cross-section of the MBT and of conventional roofs

Table 1. Characteristics of the buildings floors and roofs

	MBT solution		Conventional	
	Floor	Roof	Floor	Roof
Area (m^2)	74.12	74.12	74.12	74.12
Mass (kg/m^2)	180	180	290	290

The MBT building external walls are lightweight sandwich with a plaster layer making the outer pane, a 5 cm thick layer of expanded polystyrene plus another of 25 cm of mineral wool and two 13 mm thick plaster board layers placed inside (see Figure 4 and Table 2). The conventional building external walls are double leaf (15 + 11 cm) hollow brick walls with 2 cm of mineral wool placed in the air cavity and finished with plaster on both sides (see Figure 3 and Table 2).



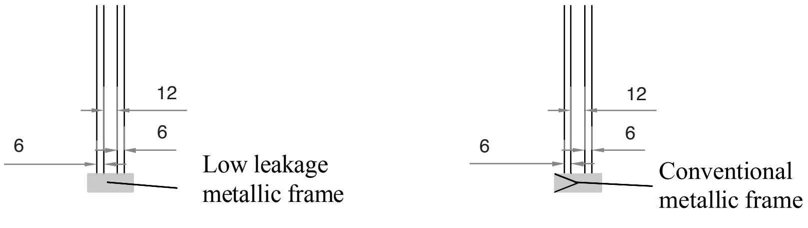
MBT solution Conventional solution

Figure 4. Vertical cross-section of the MBT and of conventional walls

Table 2. Characteristics of the MBT and the conventional external walls

Wall	MBT solution			Conventional		
	North	East/West	South wall	North wall	East/West	South wall
Area (m^2)	44.71	34.34	5.61	44.71	31.34	40.65
Mass (kg/m^2)	100	100	100	371	371	371

The MBT building windows are double glazed (6 + 12 + 6 mm) with a low-leakage metallic frame (see Figure 5 and Table 3). The conventional building windows are double glazed (6 + 12 + 6 mm) with a normal metallic frame (see Figure 4 and Table 3).



MBT construction Conventional construction

Figure 5. Vertical cross-section of the MBT and of conventional walls

Table 3. Characteristics of the MBT and of conventional buildings windows

Windows	MBT solution			Conventional		
	North	East/West	South	North	East/West	South
Area (m^2)	10.34	-	49.44	10.34	3.00	14.40
Mass (kg/m^2)	30	-	30	30	30	30

Some details of the MBT construction are presented in Figures 6 and 7.

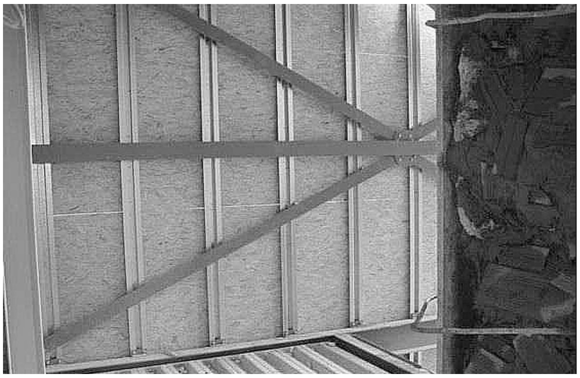


Figure 6. Details of the junction between floor and walls (MBT construction)

Figure 7. General view of the MBT floor construction

3. MEASUREMENT PROCEDURE AND STANDARDS

Characterization of the acoustic performance of the building involved measurement of sound insulation. In according with EN ISO 140 Standards, Parts 4, 5 and 7 [3, 4, 5], and the EN ISO 717 Standards, parts 1 and 2 [6, 7].

According to international standard EN ISO 140/5, the noise insulation of façades measured “in situ”, $D_{2m,n}$, is given by:

$$D_{2m,n} = L_{1,2} - L_2 - 10\ 1g\ (A/A_0) \qquad \text{dB} \qquad (1)$$

where $L_{1,2}$ is the average sound pressure level at 2 m distance from the surface of the façade; L_2 is the average sound pressure level in the receiving room; A the equivalent sound absorption area in the receiving room and A_0 the reference absorption area (10 m^2).

According to international standard EN ISO 140/4, the sound insulation of a partition measured “in situ”, D_n, is given by:

$$D_n = L_1 - L_2 - 10\ 1g\ (A/A_0) \qquad \text{dB} \qquad (2)$$

where L_1 is the average sound pressure level in the source room, L_2 is the average sound pressure level in the receiving room; and A and A_0 have the same meaning as in Equation 1. In the same way, according to international standard EN ISO 140/7, the impact sound insulation of floors measured “in situ”, L'_n, is given by the following equation:

$$L'_n = L_2 + 10\ 1g\ (A/A_0) \qquad \text{dB} \qquad (3)$$

L_2 is the average sound pressure level in the receiving room.

The standard EN ISO 717, parts 1 and 2 describes a rating method that fits a standard reference curve on to the measured sound reduction curve (D_n and L'_n). The resulting single figure values are termed ‘weighted sound reduction index’ ($D_{n,w}$) and ‘weighted normalized impact sound pressure level’ ($L'_{n,w}$).

The façades sound insulation index ($D_{2m,n,w}$), the floor weighted sound reduction index ($D_{n,w}$) and the floor weighted normalized impact sound pressure level index ($L'_{n,w}$), were calculated from “in situ” tests carried out in the MBT part of the building.

For measurement of airborne sound insulation, the equipment used comprises a rotating microphone boom (B&K Type 3923) and a sound source (class II IEC), (B&K Type 4224), with a conic diffuser, was used. For impact sound insulation measurement a tapping machine, (B&K Type 3204) was used. The measurement data were processed using a building acoustics program, (B&K type 5305).

According to the Portuguese Building Requirements [8] the airborne sound insulation index of façades must be greater than 28 dB for sensitive zones (exposed to $L_{Aeq} \leq 55$dB (A) between 7 h and 22 h and $L_{Aeq} \leq 45$dB (A) between 22 h and 7 h), and greater than 33 dB for other zones (normally named mixed zones). For partitions between dwellings the sound insulation must be greater than 50 dB, and for partitions separating dwellings from shops greater than 58 dB. The impact sound insulation index of floors between two dwellings must be less than 60 dB and for floors between dwellings and shops less than 50 dB.

In Figure 8 a general view of the room where the measurements were conducted is presented.

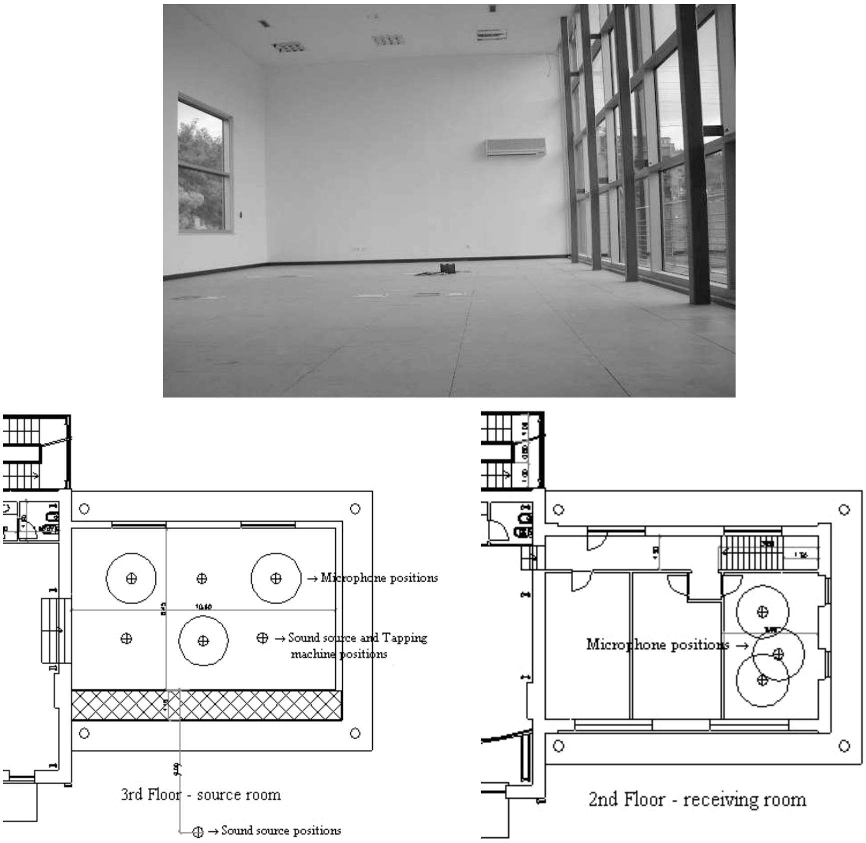


Figure 8. General view and schematic plan of the rooms where the measurements were conducted, showing the microphone, sound source and tapping machine positions

4. ESTIMATION OF SOUND INSULATION

In addition to "in situ" measurement the sound insulation was also estimated, using a "mixed" method, that adjust analytic models to experimental analysis [9], based on the method of Meisser [10]. In this method, for a double layer element, the increase in sound transmission loss is 6 dB (i.e. according to the Mass Law), each time the elements' mass or frequency double.

According to this method the airborne sound reduction index is obtained by following 8 steps:

1. Determine the sound reduction index at 500Hz;

$$R_{500Hz} = 13.3 \text{ Log } (m) + 13.4 \text{ dB} + D_{if.}$$

where: $D_{if.}$ = 0 dB to single-leaf walls; $D_{if.}$ = 2 dB for lightweight panels with small air cavities; $D_{if.}$ = 4 dB for heavyweight panels with 2 to 4 cm air cavities; $D_{if.}$ = 6 dB for heavyweight panels with more than 4 cm air cavities; and $D_{if.}$ = 9 dB for heavyweight panels with 5 to 10 cm air cavities filled with absorbent material.

2. Sketch the predicted mass law curve of sound reduction index versus frequency for the two-leaf partition (6 dB/oct.).
3. Calculate of first eigenfrequency relating to transverse vibration by bending, and redesign the curve, with the correspondent loss of insulation (negligible if f < 100 Hz, and reaching 6 to 8 dB for thin lightweight panels)
4. Calculate the resonance frequency of the panels for the double partition, and superimpose on the mass law curve showing the corresponding loss of insulation (negligible if f < 100 Hz, reaching 6 to 8 dB for windows)

$$f_{ress} = \frac{\sqrt{\rho . c^2}}{2\pi} \sqrt{\frac{1}{d}\left(\frac{1}{m1} + \frac{1}{m2}\right)} \tag{4}$$

where c is velocity of sound in air (m/s); mi the mass per unit area of the panel (kg/m^2}; ρ the density of the material (kg/m^3) (ρ_{ar} = 1,18 kg/m^3); and d the air cavity width, in m.

5. Calculate the critical frequencies, and superpose on the mass law curve (a loss of insulation of 4 dB for cork, 5 dB for expanded polystyrene, 6 dB for wood, 7dB for plasterboard, 8 dB for concrete, 9 dB for brick and 10 dB for glass, steel and aluminium)

$$f_c = \frac{c^2}{1{,}8\, h} \sqrt{\frac{\rho}{E}} \tag{5}$$

where *h* is thickness of the element; and E the Young modulus.

6. Calculate the resonance frequency of the air cavity, for double walls, and redesign the mass law curve with the correspondent loss of insulation (it can reach 3 to 4 dB for windows)

$$f_1 = \frac{c}{2d}, f_2 = 2\frac{c}{2d}, ..., f_k = k\frac{c}{2d} \tag{6}$$

where d is the air cavity width, in m.

7. Delineate the curve corresponding to the theoretical frequency law (8 dB/oct. for frequencies above the resonance frequency of the mass-air cavity), outside the zones where there may be insulation loss.

8th - Finally adjust the sketch of the sound reduction index curve, (as shown in Figure 9, for the glazing area of the MBT construction)

If the a partition is constituted of n elements of areas A_1, A_2, to A_i of sound insulation indices R_1 R_2 to R_i, the weighted composite sound reduction index R, for a given frequency band, is:

$$R = 10\log\left(\frac{\sum_{1}^{n} A_i}{\sum_{1}^{n} \frac{A_i}{10^{(Ri/10)}}}\right) \tag{7}$$

For the impact noise insulation index, the estimation was done using a simulation model [11, 12]. In Table 5 the estimated values are presented.

5. MEASUREMENT AND ESTIMATED RESULTS

In Table 4 the measurement results obtained for the MBT construction and the conventional construction are summarized. Included in Table 4 are the results estimated using the method in Section 4, shown in brackets.

Table 4. Buildings acoustic performance – measured and estimated values

Element type	$D_{n,w}$	$L'_{n,w}$	$D_{2m,n,w,w}$
MBT construction			
South façade (90% glass + 10% opaque)	-	-	29.9 (34)
East/West façade (0% glass + 100% opaque)	-	-	50.4 (60)
North façade (19% glass + 81% opaque)	-	-	40.0 (41)
Floor	53.4 (43)	69.9 (69)	-
Conventional construction			
South façade (26% glass + 74% opaque)	-	-	33.1 (39)
East/West façade (9% glass + 91% opaque)	-	-	35.2 (43)
North façade (19% glass + 81% opaque)	-	-	33.9 (40)
Floor	48.3 (43)	77.2 (79)	-

Additionally, in Figures 9 and 10 some spectra results are presented. Figure 9 shows the measured and estimated results for the East/West and South façades, and Figure 10 the sound insulation of the floor, both for airborne and impact sound.

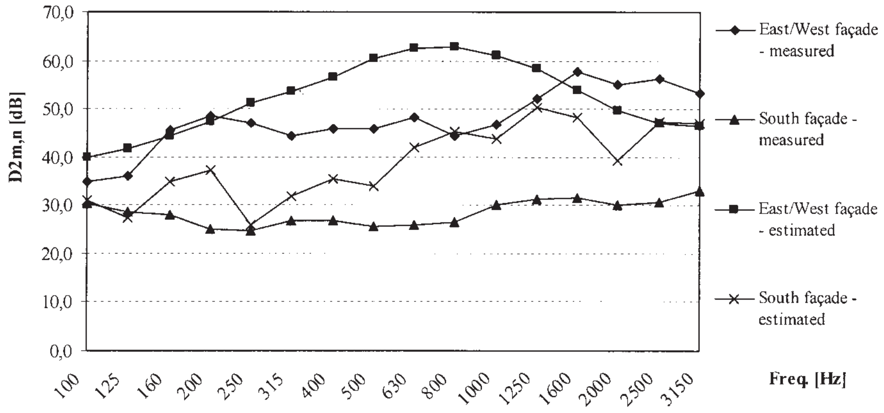


Figure 9. Façade sound insulation for the MBT construction

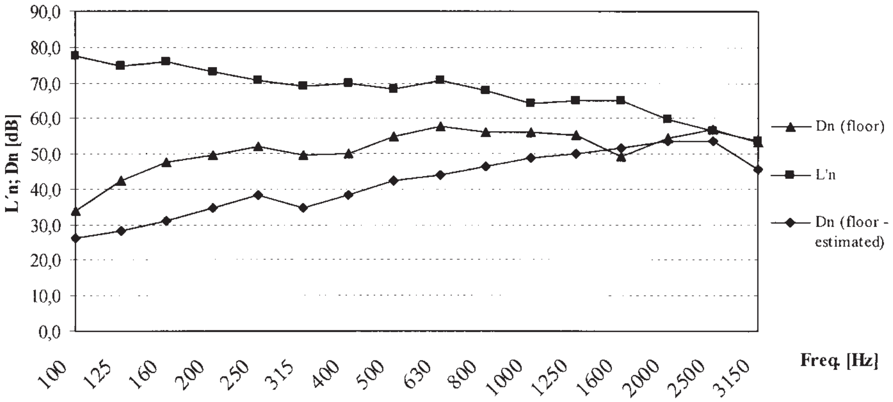


Figure 10. Sound insulation of the floor for the MBT construction

5. CONCLUSIONS

MBT construction is usually characterized by the use of lightweight materials and the adoption of fenestration areas. These two aspects have a significant impact on the sound insulation performance of the building and on acoustic comfort. At the design stage therefore, to assure good sound insulation performance, the designer should have available detailed performance data from specialised literature or measurements performed by certified laboratories.

From the measurements undertaken, it can be concluded that in almost all cases the MBT construction exhibits better acoustic performance than the conventional construction. The better quality of the glazing and good quality windows frames, and higher levels of acoustic absorption provided by the material placed in the air cavities, contribute to the good acoustic performance.

In spite of the higher mass of the conventional building floor construction, the careful finishing and suspended ceiling of the MBT floor construction, which has low stiffness and is backed with mineral wool quilts provides better airborne sound insulation. For the same reasons the MBT floor construction provides better impact sound insulation. Although the conventional building floor has a higher mass, the air gap and the mineral wool quilts between the floor and suspended ceiling increases the airborne and reduces the impact sound insulation the MBT floor.

It can be concluded that the acoustic performance of MBT construction is quite good. A good example of this better performance is the East/West wall. It has 100 kg/m2 mass per unit area and a weighted sound reduction index of 50 dB. A conventional wall with the same mass wouldn’t have a sound reduction index greater than 40 dB. Another example is the South wall. It is a glass curtain wall achieving a sound reduction index of 30 dB. In a conventional building with such large windows are unlikely to achieve more than 26 dB sound reduction index.

With regard to the MBT floor, in spite of its mass being almost half of the conventional building, the corresponding sound reduction index is 5 dB higher and the weighted normalized impact sound pressure level index is 7 dB lower than the conventional building.

It is apparent that there are some discrepancies between measured values and estimated values This may be due to the inaccuracy in applying existing models to predict the performance of non-homogenous MBT construction elements. This highlights the need for urgent development of appropriate prediction methods for this purpose. An example is the measurement and estimated data for the South façade. The estimated curve in Figure 9 suggests the existence of two significant dips in the sound insulation curve at the critical frequency and cavity resonance frequency. This does not show up in the measurement data for the South façade, where neither mass law performance or resonance frequencies are apparent.

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