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SUSTAINABILITY OF ACOUSTIC MATERIALS AND ACOUSTIC CHARACTERIZATION OF SUSTAINABLE MATERIALS

Victor Desarnaulds[a,b], Ezilda Costanzo[a], António Carvalho[c] and Blaise Arlaud[b]

[a] Ecole Polytechnique Fédérale de Lausanne (EPFL), Laboratoire de Construction et Conservation, BP 2 225 (station 16), CH-1015 Lausanne, Switzerland
[b] Bureau eng. G. Monay, 25, av. Vinet, CH-1004 Lausanne, Switzerland
[c] University of Porto, Faculty of Engineering, Acoustics Lab., P-4200-465 Porto, Portugal
victor.desarnaulds@epfl.ch

Abstract
In the current western society, sustainable development becomes an increasingly significant goal in the evaluation and promotion of constructions. This paper briefly recalls the main methods for construction sustainability evaluation and the environmental impacts associated with various types of building techniques. It presents an evaluation of the sustainability of certain traditional insulating materials (glass, rock or wood wool), which are largely used in building acoustics, and presents the acoustic performances (airborne/impact sound insulation and sound absorption) of alternative materials recommended for their "sustainable" properties. These materials are either natural (cotton, cellulose, hemp, wool, etc.) or recycled (rubber, carpet, cork, etc.). A global comparison of the various characteristics is carried out for traditional and alternative materials.

INTRODUCTION

Sustainable construction can be defined as the creation and responsible management of a healthy built environment based on resource efficient and ecological principles. It is the way construction sector contributes to sustainable development, trying to match its three components: environment, economy, and society. In the last ten years, necessity to measure such issues has led to research on sustainability performance indicators, assessment methods and tools.

At the scale of materials and building, noise pollution is taken into account besides a number of sustainability aspects. Designing and improving acoustic environment, on the other hand, is linked to a choice of particular building techniques and materials that imply different environmental performance more than acoustic performance. An aware design should mediate between these issues, which are sometimes contradictory. This paper briefly synthesise some information and design criteria to make them meet.

ENVIRONMENTAL ASSESSMENT AND DESIGN

Methods and tools on building environmental performance make use, at different detail level, of Life Cycle Assessment (LCA) [1]. They analyse the potential impacts that derive from the life history of a building product: material extraction, production, transport, construction, operating and management, de-construction, and disposal, recycling and reuse [2]. For designers and decision makers, results are available as "ecoprofiles". They may refer to partial life cycle, depending on the product and the scope of the analysis (i.e. from cradle to gate or to installation on site). They can resume Life Cycle Inventory (LCI) data - resources input, emissions to air, to water, waste - or even environmental impacts caused by such flows. Impact indicators vary with the particular assessment method. In Switzerland, Ecoinvent [3] collects both LCI data and some impact assessment results such as Cumulated Energy Demand (CED) and Non-Renewable Energy Resources (NRE) fraction, Global Warming Potential (GWP) and Acidification Power (AP) (Figure 1).

BRE Eco-profiles [4] supply a final score (eco-points) by weighing normalised impacts on climate change, acid deposition, eutrophication, eco-toxicity, ozone depletion, minerals extraction, fossil fuel depletion, water extraction, human toxicity, waste disposal, transport pollution and congestion. Normalisation takes into account a typical UK citizen. Evaluation of some insulation products, from cradle to their installation on site, shows the following results: EPS (15 kg/m^3) 0.028 pt., Rockwool (45 kg/m^3) 0.020 pt., Rockwool (33 kg/m^3) 0.016 pt., recycled newspaper cellulose 0.002 points.

Eco-indicator '99 [5] is an impact assessment and eco-design method which supplies a final score, by weighing potential damages: damage to human health, expressed as the number of life years lost and lived disabled; damage to ecosystem quality, expressed as the loss of species over an certain area in certain time; damage to resources, expressed as the surplus energy needed for future extractions of minerals and fossil fuels. Inputs and outputs of products' processes are addressed towards eleven impact categories: carcinogens diseases, respiratory diseases from organics and inorganic substances, climate change, radiation, reduction of ozone layer, as regards damages to human health; eco-toxic substances, acidification and eutrophication, land use as regards damage to eco-system quality; mineral and fossil fuels consumption, as regards resources depletion. Calculation of the damages these impacts cause is carried on.

Complex building elements (roofs, internal partitions, external walls, etc.) can be analysed. Issues like compatibility between constructional layers, durability, cost and different building stages can be taken into account: particularly building "running" phase, when maintenance, replacement and eventual disposal relevantly contribute to increase the final potential environment damage score (Figure 2).

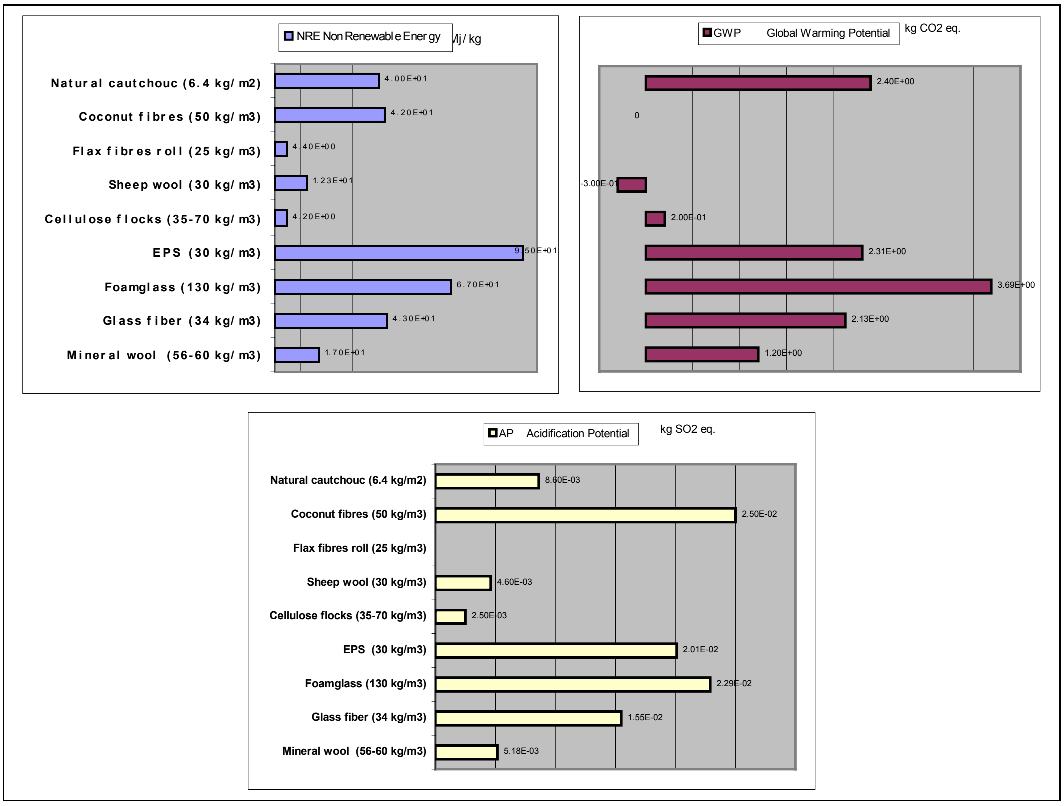

Figure 1 – Comparison of environmental impacts of traditional and natural insulations from cradle to gate. Sources: Ecoinvent, ETH-ESU (CH), IBO (A)

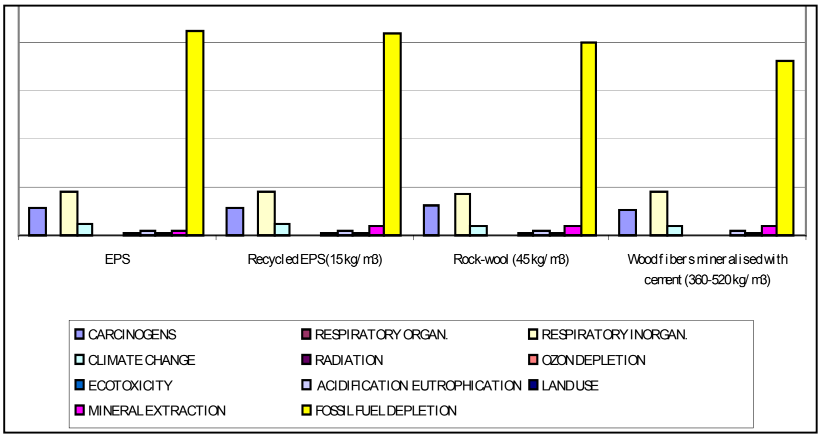

Figure 2 - Evaluation (in points) for insulation layers by the Eco-indicator ’99.

SUSTAINABILITY DESIGN CRITERIA FOR INDOOR ACOUSTICS

The previous paragraph shows how insulating materials and technical solutions have very different environmental performances. Some more evident design prescription can be derived from these analyses.

In a common internal heavyweight partition wall with an interposed insulating layer, concrete or bricks masonry, are responsible for most of the potential "damage". They imply high-energy demand for production process and for transport, mainly influencing human health damage category by respiratory diseases due to inorganic fuel combustion air emissions. The fixation system of the insulation layer supply higher eco-impacts than the particular insulation material. In case of gluing by polyurethane adhesive, the main impact is given by carcinogens and respiratory diseases from inorganic substances. Mechanical assembly, typical of lightweight partition solutions, is then preferable. In the operating element, matters of material and layers physical-chemical compatibility and durability, which determine the real life cycle of the partition (commonly 40 years), should be considered. The damage, in this case is considerably higher, due to maintenance and eventual renovation processes, which can double the final evaluation score.

Traditional sound insulation products

Regarding wood derived products it is preferable to adopt native materials in order to reduce transport energy. Finished product indoor VOC emissions, notably formaldehyde from coverings, surface treatments, perforations and holes, may remarkably affect human health by respiratory diseases. Parameters like ratio between panel surface and volume of the room and ventilation are to be taken into account to evaluate the real risk.

Concerning cork, an advantage in comparison to wood, is that it is possible to eliminate biological pollutants by a preventing heating process (380°C), avoiding the use of other chemicals.

Production of expanded polystyrene obtained from oil-derived products, demands more energy than fibre insulations bonding processes; adoption of fibres insulations is more recommendable to reduce fossil fuel consumption. EPS organic air emissions release, possibly affecting human health, does not entail particular impacts on users and labourers: emissions depend on age after production and they are irrelevant during installation and use.

Glass and rock wools may release free fibres harmful to labourers and future occupants. Later, no heat power can be recovered and disposal is previewed in non-inert waste landfill. On the contrary, end of life of expanded polystyrene is more eco-compatible: heat power can be retailed during incineration and recycling is possible. Original use of recycled EPS boards can reduce ecosystem toxicity, and lower the use of resources by a 0.5% rate. Inorganic expanded insulation like foam glass has a higher risk of harmfulness to human health because of possible air emission of silica during installation. Wood fibres' boards are less harmful than inorganic ones. Production implies a lower energy demand and impacts on resources is lower owing to their recyclability. Possibility of mechanical screwing can avoid up to 30% of potential damage in a 40 years partition wall’s life. When adopting wood fibreboards nailed to a wooden frame, the final eco-indicator score is up to 7 times lower than the EPS board glued solution.

Natural sound insulation products

The more natural and less treated the materials are, the higher they perform in energy saving. Vegetal fibres, moreover, contribute to the absorption of CO_2, (negative impact value) helping against climate change. This does not guarantee other performances: fungal and moulds attack and dampness risk, but also treatments to prevent them are often more critical if considering indoor health use issues. Cellulose insulation (*isofloc*) from recycled newspapers appears to match energy and raw materials saving and health issues. Production requires very little energy and is not polluting. Dust of paper fibres has no indoor polluting known risk; no measurable migration of dust into living accommodation should occur with proper use; no radiation emission is released. It is recyclable and owing to its durability, no maintenance is required if properly installed.

ACOUSTIC CHARACTERIZATION OF SUSTAINABLE MATERIALS

The acoustic performances, regarding airborne sound insulation of single and double leaf partition, impact sound insulation as well as sound absorption are reviewed for various alternative materials recommended for their "sustainable" properties and compared with performances of traditional materials.

Airborne sound insulation of single-leaf partition

For 31 cm thick hemp bricks (700 kg/m^3), the sound insulation is only Rw = 43 dB without roughcast [10]. The sound insulation grows to 45 and 47 dB with one or two coatings, which then correspond to the prediction with the mass law adapted for bricks (1). The porosity of hemp bricks, favorable for the sound absorption (see below), must be taken into account for sound insulation. Other data gives higher values for walls made of denser hemp bricks: 38 dB for 8 cm thick (*Isochanvre*) and 52 dB for 20 cm thick. In situ measurements of homes made from hemp, leads to values as high as $DnTw$ = 57 dB (63 dB for traditional construction according to BRE report 2002 at Haverhill).

Sound insulation of ecological bricks made of clay Monomur is presented in table 1 according to their thickness. Like for hemp, the sound insulation is well predicted by the mass law for brick walls: $Rw = -15 + 118\ M - 119\ M^2 + 50.5\ M^3 - 7.06\ M^4$, where $M = \log(m)$, m in kg/m^2 (1). It may be noticed that the density of these two types of bricks is low that implies very thick walls.

Table 1 - Sound insulation of ecological bricks made of clay Monomur according to their thickness

Rw (dB)	43	45	47	49	51
Thickness Monomur (cm)	24	30	36	42	49
Thickness trad. terracotta (cm)	10	12.5	15	20	25

Airborne sound insulation of double-leaf wall

The effect of various sound insulating layers in double-leaf partition is analyzed for heavy and lightweight walls.

For heavy walls, a comparison of various materials used as insulation in heavy double wall (2x 7 cm of concrete) was conducted by the Frauenhofer Institute [6]. It shows that the sound insulation obtained with low-density animal wool (Sheep, 26 kg/m^3) or heavy vegetal (latex-coco, 735 kg/m^3) wool is equal or better (1 dB in case of compressed insulation) than mineral wool with same thickness (table 2). In comparison, air (-4 dB) or polystyrene, give a much lower sound insulation (5 dB for normal and 3 dB for EPS-T elasticized).

For lightweight walls, a comparison of various materials used as insulation in lightweight double wall (gypsum board 13 mm with wooden frame) was conducted by Delta [7]. It shows that flax or cellulose give approximately the same sound insulation than glass wood in lightweight double walls. The cellulose seems to be a little better (1 dB) in loose fill than in batts. For high insulation (2 gypsum boards, 15 cm insulation with double wood frame), the flax seems to be a little less effective.

These results are confirmed by measurements conducted on lightweight double walls made by wood (2 cm board) with 9 cm cellulose filling (recycled paper *Isofloc* 50 to 67 kg/m^3; Rw = 48 to 50 dB) or 45 mm wood wool (*Pavapor* 155 kg/m^3) and 2 cm air gap (Rw = 46 to 48 dB). In both cases the sound insulation is equal or lightly better (1 to 2 dB) than with mineral wood of same thickness (37 to 50 kg/m^3).

A thin layer of cork (6 mm, 125 kg/m^3, elasticity modulus 16 kg/cm^2) between 2 gypsum boards does not increase significantly the sound insulation [8]. However, if a rubber cork is used (900 kg/m^3, elasticity modulus 110 kg/cm^2), an increase of 6 dB is observed. The sound insulation with a thicker layer of cork (4 to 5 cm) with or without an additional thin rubber cork layer is much lower (about 10 dB) than the corresponding thickness of mineral wood. Because of additional damping effect, the sound insulation is generally slightly better with a direct contact instead of air gap between the (dense) insulating material and the external (gypsum or wood) board.

Table 2 - Comparison of various materials used as insulation in heavy double wall.

Rw (dB)	Air	Polystyrene SE 30 70 kg/m^3	Polystyrene PTSE 38 70 kg/m^3	Mineral wool, 70 kg/m^3	Sheep wool 26 kg/m^3	Latex-coco 735 kg/m^3
4 cm insulation + 2 cm air	65	64	66	69	69	69
6 cm ins. comp. to 4 cm	64	62	63	67	68	68

Table 3 - Comparison of materials used as insulation in lightweight double wall.

Rw (dB)	Glass wool, bats, 15 kg/m^3	Flax, batts, 35 kg/m^3	Cellulose, batts, 25 kg/m^3	Cellulose, loose-fill, 50 kg/m^3
1 board, single frame, 10 cm insul.	40	40	40	41
2 boards, single frame, 10 cm insul.	---	46	---	46
2 boards, double frame, 15 cm insul.	62	60	---	62

Impact sound insulation

For many decades, many natural and recycled materials (cork, rubber, wood wool, coconut fibers, cardboard, etc.) are successfully manufactured and used for impact sound insulation. They can either be used directly as floor finish or under a floating floor (structural support element) or surface (linoleum, wood parquet, ceramic, etc.). When carefully designed and with appropriate use, their acoustical efficiency is generally as good as other traditional products (rock or glass wool, polyurethane foam, extruded or expensed polystyrene, air bubbles in PVC envelope, etc.). Many data are published in scientific papers (in particular in this conference) or as results of normalized test from the various commercialized products. As example, the reduction in the weighted normalized impact sound pressure level is presented for various agglomerated cork thickness and density under 3 different floors finishes [9]. The table below shows that better results (ΔLw = 17 dB) are obtained with 3 mm (0 to 3 dB better than 5 mm) under a linoleum (0 to 1 dB better than wood parquet and 3 to 4 dB better than ceramic tiles) and whatever the cork density. As other example, commercialized hemp underlays (76 kg/m^3, *Haga Iso-Hanf*) provide an attenuation of ΔLw = 17, 19 , 22 dB for 7, 13, 24 mm thickness.

Table 4 - Reduction in the ΔLw for various agglomerated cork types.

ΔLw Cork layer (dB)	170 kg/m^3		190 kg/m^3		425 kg/m^3		445 kg/m^3	
	3 mm	5 mm	3 mm	5 mm	3 mm	5 mm	3 mm	5 mm
Linoleum 3.2 mm	-	-	17	16	17	16	16	15
Wood parquet 10 mm	16	15	16	16	15	16	15	15
Ceramic tiles	14	12	14	12	14	11	15	12

Sound absorption

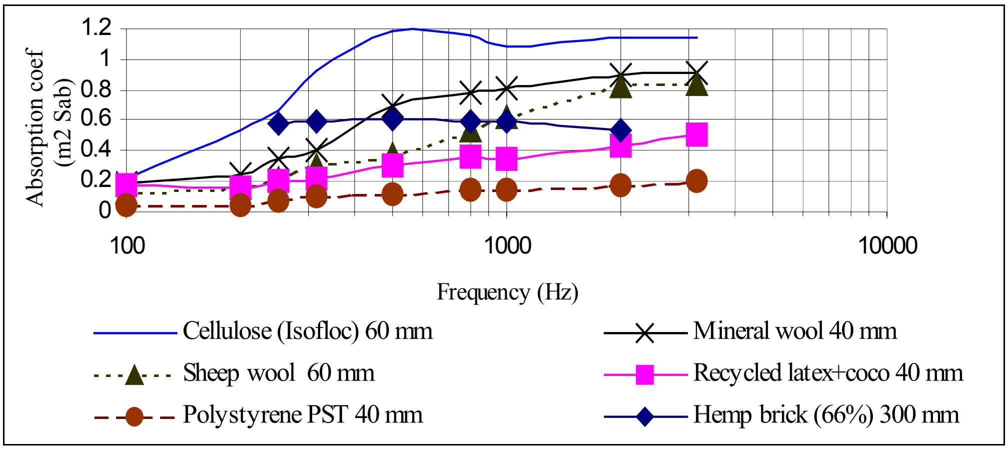

Figure 3 – Sound absorption coefficient of various materials

Natural and recycled materials are also used as sound absorbers in room acoustics. With the exception of recycled paper (cellulose), their absorption coefficient are however lower than for mineral (glass or rock wool) but better than for polystyrene (Figure 3) [6].

SUMMARY

No absolute design panacea exists when dealing with environmental performance. Evaluation (preference to preserve human health, ecosystem quality or resources) always entails subjectivity and on purpose priorities. The whole of performances, both environmental and functional, change when changing production processes, assembly and adoption of different products, sometimes in a discordant way. Natural insulations are to be considered preferable. Moreover, when more common product adoption is required, easy maintenance and simple deconstruction by mechanical systems, waste separation possibility and recyclability are worthless alternatives.

Because of low density and high rigidity, walls made of alternative bricks (hemp or clay) are very thick and provide fair airborne sound insulation.

For heavy and lightweight double-leaf partition, various alternative sound insulating layers (sheep wool, latex-coco, flax, cellulose, wood wool) are equal or better than mineral wool with the same thickness. For these animal or vegetal materials, it is however difficult to time durability without specific processing. Cork is not very effective regarding the usual airborne sound insulation purposes.

For impact sound insulation, natural and recycled materials (cork, rubber, wood wool, coconut fibers, cardboard, etc.), correctly designed and used (directly as floor finish or under a floating floor or surface), are generally as good as other traditional products.

These "sustainable" materials can also be used in room acoustics, even if their absorption coefficient is generally lower than mineral wool.

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