

## Toxicity of building materials: a key issue in sustainable construction

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To avoid the use of toxic building materials is one of the principles of sustainable construction. However and contrary to general beliefs, current residential buildings frequently contain many toxic building materials, some of which even comply with legal regulations. Part of the problem is because architects and civil engineers have no form of knowing the toxicity of building materials. The other part is economically related. Some regulations about toxicity limits are influenced by economic reasons. For instance, although scientific evidence about the toxicity of lead plumbing has existed for quite some time, legal regulations avoid imposing very tight thresholds because of the cost of lead pipe substitution (in Europe that could cost almost 200,000 million euros). It is then no surprise to see that the related Directive (98/83/CE) established a 15-year delay period before the 10 µg/l lead content threshold is enforced. This paper discusses some cases of toxic building materials by reviewing previously published work, it also covers the emission of volatile organic compounds from paints and varnishes, the toxicity of impregnating agents, materials that release toxic fumes during a fire, asbestos-based materials, radioactive materials and lead plumbing.

**Keywords:** toxic materials; lead plumbing; VOCs; radioactivity; asbestos

### 1. Introduction

Our planet faces a major challenge that if not solved, or if it is just postponed, may lead to the end of our civilisation, as we know it. Humans use many kind of resources, including non-renewable ones, leaving traces of pollution in the consumption process, and only a few people consume the majority of resources to make things worse (Meadows *et al.* 1972, WWI 2009). The immediate effects of civilisations' consumption patterns, with the consequences for nations and for future generations, have never been revealed in inter-generational and inter-geographic dimensions (Stern 2006). A recent report of the Intergovernmental Panel on Climate Change (IPCC 2007) mentioned that rising sea levels would have, therefore, approximately 200 million refugees. Environmental worries in the modern society have increased since 1972 when the United Nations Conference about the Environment took place in Stockholm. But it was only in 1987 that they gained a wider impact after the publication of the report 'Our Common Future', also known as the Brundtland Report (Brundtland 1987), in which the concept of sustainable development first appears as the one 'that allows the fulfilment of current needs without preventing the needs of future generations'. The construction industry is responsible for the depletion of large amounts of non-renewable resources and for the carbon dioxide gas emissions. To achieve a more

sustainable construction, the European Union recently established that in a medium term, raw material consumption must be reduced by 30% and that waste production in this sector must be cut by 40%. Although sustainable resource consumption is of paramount importance for sustainable construction, building material's toxicity is no less important. While our ancestors lived in buildings made of raw materials, nowadays residential buildings contain thousands of chemicals and heavy metals, polluting indoor air or contaminating tap water. Thus causing several health-related problems such as asthma; itchiness; burning eyes, skin irritations or rashes, nose and throat irritation; nausea; headache; dizziness; fatigue; reproductive impairment; disruption of the endocrine system; impairing child development and birth defects; immune system suppression and cancer. Beyond the toxicity of indoor building materials, one must not forget also the toxicity potential during the production of such chemicals. Remember for instance the Bhopal disaster that occurred in India, in 1984, when a cloud of methyl isocyanine caused almost 15,000 deaths and health problems in almost 200,000 human beings (Varma and Mulay 2006, Satyanand 2008). During the production of chemical materials, hazardous wastes are generated, and that impact must be associated to building materials containing these chemicals. The most common toxic chemicals are the following:

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### 1.1 Dioxins and furans

Dioxins and furans are the chemical waste generated in the industrial process evolving chlorine as it occurs in PVC production. Dioxins and furans are extremely toxic and bio-cumulative (IARC 1997, Lanting *et al.* 1998). This has hazardous effects in biodiversity by contaminating all of the food chain (Oppenhuizen and Sijm 1990, Tillitt *et al.* 1993). According to Thornton (2000) in the last four centuries the concentration of dioxin and furans in sediment cores from the Baltic region and in two German lakes increased from zero to almost 100%. Furthermore, chemical analysis carried out on dolphins in the northern Pacific Ocean revealed dioxin and furan concentrations between 13 and 37 million times higher than water concentrations (Thornton 2000). Several scientist groups already suggest that chlorine industrial-based production should be prohibited (Flores *et al.* 2004).

### 1.2 Phthalates

These are the chemical compounds formed due to phthalic acid. Phthalates are used to soften plastic materials. Several studies show that phthalates are very toxic to human health (Lovekamp-Swan and Davis 2003, Hauser and Calafat 2005, Heudorf *et al.* 2007, Swan 2008, Wolff *et al.* 2008, Meeker *et al.* 2009).

### 1.3 Volatile organic compounds

These are the atmospheric pollutants released from the building materials which contain organic solvents like paints and varnishes. The reduction of indoor ventilation to minimise energy consumption (as it often happens in Portugal) contributes to increasing the effects of volatile organic compounds (VOCs) in human health (Sterling 1985, Samfield 1992, Hansen and Burroughs 1999). The importance of this subject will require awareness for everyone; mainly those who will have a major role in climate

Table 1. Cancer agents detected in paints.

Cancer agent	Likely source
Chromates	Primers, paints
Cadmium	Pigments
Benzene	Solvents
Methylene chloride	Paint strippers
Styrene	Organic solvents
Nikel compounds	Pigments
Dichlorobenzidine	Pigments
Lead	Primers, dryers, pigments
Antimony oxide	Some pigments
Nitropropane	Organic solvent
Tetrachloroethylene	Organic solvent

change issues as in the case of professionals working in construction-related activities (industry or academia). The present paper covers emissions of VOCs from paints and varnishes, the toxicity of wood impregnating agents, the materials that release toxic fumes during a fire, asbestos-based materials, radioactive materials and lead plumbing.

## 2. Emission of VOCs from paints and varnishes

Several authors confirm the release of VOCs from paints and varnishes (Kostianien 1995, Kwok *et al.* 2003). More recently, Salasar (2007) studied VOCs emissions in solvent- and water-based paints stating that their form is responsible for VOCs emissions, which is 520 times higher than the latter. Paint can also be a source of several cancer agents (Table 1). In Portugal, the legal Decree No. 181/2006 of 6 September corresponds to the EU Directive No. 204/42/CE (21 April 2004). This legislation intended to put a threshold on the VOCs emissions from paints and varnishes (Table 2). One can see that beyond 1 January 2007, the VOCs emissions must be reduced, and beyond 1 January 2010 they must be reduced even more. This means that until the new low VOC paints and varnishes are introduced into the construction market, we all have been breathing very high levels of VOCs.

Table 2. Threshold VOCs emissions from paints and varnishes, Portugal legal Decree No. 181/2006 of 6 September.

Product	Type	Beyond	Beyond
		1 January 2007 (g/l)	1 January 2010 (g/l)
(a) Non-glossy paints for interior walls and ceilings	BA	75	30
	BS	400	30
(b) Glossy paints for interior walls and ceilings	BA	150	100
	BS	400	100
(c) Paints for exterior walls with mineral substrate	BA	75	40
	BS	450	30
(d) Paints for interior and exterior wood and metal substrates	BA	150	130
	BS	400	300
(e) Varnishes and lasures for interior and exterior purposes	BA	150	130
	BS	500	400

Note: BA, water-based paints; BS, organic solvent-based paints.

### 3. Toxicity of wood impregnating agents

Although wood is an excellent example for sustainable building, it has low resistance to biologic degradation (fungal and insect attack) (Morrell 2002). Until very recently, wood preservation would mean the use of impregnating agents (insecticides or fungicides) like creosote or others based on salt impregnation like copper, chrome and arsenic (CCA). However, these salts are highly toxic also bio-cumulative. When they are in contact with rainwater, most part of these salts are leached away, contaminating the environment. Since 1 January 2004, the US EPA forbade the use of CCA for wood preservation (Edlich *et al.* 2005). As to creosote, it contains cancer potential agents (ASTDR 2002, Smith 2008); therefore, since 2001 Directive 2001/90/EC, a process was initiated to ban the use of creosote in wood treatment purposes. Some studies mentioned that wood used in railway cross ties has a high content of creosote (Thierfelder and Sandstrom 2008) so they must be seen as hazardous wastes, meaning that they must be properly immobilised and they can no longer be reused (Pruszinski 1999). The same should happen to all the creosote-treated wood, which in the near future would become construction and demolition waste.

### 4. Materials that release toxic fumes during fire

Another case of building materials toxicity is related to materials that release toxic fumes during a fire. Some studies show that the majority of deaths during fires are due to inhalation of toxic fumes, and that the deaths are increasing since the 1980s, which maybe due to the fact that the amount of combustible materials inside households have increased in the last three decades (Gann *et al.* 1994, Hall and Harwood 1995, Wu 2001, Levin and Kuligowski 2005). Liang and Ho (2007) studied the toxicity during a fire of several insulation materials concluding that polyethylene foam and polyurethane foam have a toxicity index (TI) above 10, thus meaning a very high toxicity (Figure 1). The IT is obtained from the emissions of 14 different combustible gases to form a deadly concentration after 30 min exposure. These authors recommend that polyethylene foam and polyurethane foam should not be used unless covered by non-combustible materials. Others (Doroudiani and Omidian 2010) say that polystyrene decorative mouldings should be avoided because polystyrene is a very combustible material, which releases toxic fumes during a fire. They also say that new polystyrene with flame-retardant properties is now being produced, but it also releases other toxic substances.

### 5. Asbestos-based materials

Asbestos covers several mineral fibres with 5- $\mu\text{m}$  length and 3  $\mu\text{m}$  in diameter such as chrysolite, crocidolite, amosite, anthrophyllite, tremolite and actinolite. It was not until the

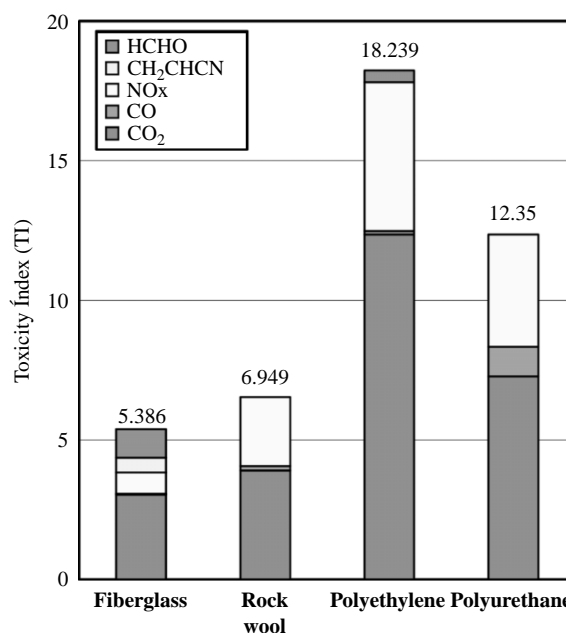


Figure 1. Average value of TI (Liang and Ho 2007). (Reprinted with permission from Elsevier © 2007).

1960s that a relation between asbestos exposure and several specific diseases was established by the scientific evidence. By that time, only some mineral fibres (crocidolite – blue asbestos and amosite – brown asbestos) were judged as toxic and responsible for pleural mesothelioma from which most patients died, 12 months after being diagnosed (Bianchi *et al.* 1997, Jarvholm *et al.* 1999, Azuma *et al.* 2009). Chrysolite (white asbestos) was left aside because it was thought that it had a low toxic risk and that is why asbestos continued to be produced. Only in the 1980s with the Directive 83/477/CEE, the asbestos problem started to be taken more seriously. In Portugal only after 6 years, the Decree No. 284/89 of 24 August came into practice the content of Directive 83/477/CEE. After some years the Directive 91/382/EEC, which has enforced even more strict caution about asbestos, and finally Directive 2003/18/EC prohibited the production of asbestos-based products. In the meantime, scientific evidence proved that all mineral fibres present a cancer risk as asbestosis (lung damage due to acid formation in an attempt of the body to dissolve the asbestos fibres) (Akira 2010) or even lung cancer or other types of cancer (Ladou 2004, Silverstein *et al.* 2009, Antonescu-Turcu and Schapira 2010). Four years later, Portugal adopted the Directive 2003/18/EC by issuing the Decree No. 266/2007 of 24 July which defines a threshold risk (value of limit exposition) when asbestos fibre concentration is higher than 0.1 fibre/cm<sup>3</sup>. Although some may think asbestos is no longer a problem let, we cannot forget the vast number of fibre cement materials, which are asbestos, based which are still in place. Portugal, for instance, has almost 600,000 ha of fibre cement asbestos roofing sheets. One may argue that

cement materials containing asbestos have a low toxicity risk but it is also true that cement will lose its binding capacity under environmental erosion, and that some cracking accidents could take place releasing asbestos fibres. Therefore, it is not possible to say that the people working (or living) under those roofing sheets are not subject to fibre concentration higher than the VLE threshold or if people subject to a fibre concentration below VLE will not develop cancer problems after a long-term exposure.

## 6. Radioactive materials

The use of waste materials with some form of radiological contamination is known to be a matter of concern to public health because exposure over a long term even of low doses can develop cancer formations (ICRP 1990). In general, building materials do not show radioactivity levels that deserve concern (Papaefthmiou and Gouseti 2008), but the same cannot be said about some industrial by-products used for concrete production such as phosphogypsum, some blast furnace slags and some fly ashes (Table 3). Some phosphogypsum possesses heavy metals and radioactive elements such as radium ( $^{226}\text{Ra}$ ), lead ( $^{210}\text{Pb}$ ) and uranium ( $^{238}\text{U}$ ,  $^{234}\text{U}$ ) that come from phosphate rocks (Rihaneck 1971). The use of phosphogypsum with a concentration level of 370 Bq/kg (in which 1 Bq corresponds to 1 nuclear disintegration per second) has been prohibited since 1992 (EPA 1992). The Euratom (1996) threshold is 500 Bq/kg. Since different phosphate rocks possess different radioactivity levels, not all the phosphogypsum can be considered to be radioactive (Canut 2006). Another important case of radioactive contamination is related to radon, a radioactive gas that can be found in some types of phosphogypsum and can be toxic in indoor air with low ventilation rates (Kovler 2009). In most cases, radon comes from the ground in granite areas, but the source can be from granite floor materials thus polluting indoor air. Chen *et al.* (2010) analysed 33

different types of granites and mentioned that only two of them had exhalation rates above 200 Bq/m<sup>2</sup>d. These authors studied the joint influence of the indoor air ventilation rate and the granites exhalation rates serving as floor materials, concluding that the highest exhalation rate of granite serving as floor material in a place with a low ventilation rate (air changes per hour, ACH = 0.3) contributed only to 18 Bq/m<sup>3</sup> of the total concentration (Table 4). To ACH levels near zero of high exhalation rate, granite can effectively be responsible for toxic radioactive concentrations. Other cases of radioactive building materials can be found in the literature, in Sweden 300,000 residential buildings were made with concrete based on aggregates from a uranium mine (alum shale). Recent studies revealed that infants and children were more prone to develop leukaemia-related diseases (Axelson *et al.* 2002).

## 7. Lead plumbing

Due to its low corrosion characteristics, lead has been used as water pipe material since the Roman Empire (Hodge 1981, Dutrizac *et al.* 1982, Nriagu 1983). Several authors mentioned that lead plumbing is responsible for health problems, because a film of corrosion products is formed on the pipe's surface that eventually will be leached away, thus contaminating water (Zietz *et al.* 2009). This contamination is particularly toxic to infants and children, causing behavioural problems and intellectual impairment (Pocock *et al.* 1994, Canfield *et al.* 2003, Wilhelm and Dieter 2003). Troesken (2006) refers to several cases of lead poisoning due to lead plumbing during the last two centuries, a problem as big as the Chernobyl or Bhopal disasters. This author states that not only in the USA thousands of children have died due to lead poisoning but also many suffered from intellectual impairment. A blood lead content higher than 10 µg/dl is considered to be the threshold for lead poisoning

Table 3. Typical and maximum activity concentrations in common building materials and industrial by-products used for building materials in Europe (Kovler *et al.* 2002, Kovler 2009).

Material	Typical activity concentration (Bq/kg)			Maximum activity concentration (Bq/kg)		
	$^{226}\text{Ra}$	$^{232}\text{Th}$	$^{40}\text{K}$	$^{226}\text{Ra}$	$^{232}\text{Th}$	$^{40}\text{K}$
Construction materials						
Concrete	40	30	400	240	190	1600
Light-weight concrete	60	40	430	2600	190	1600
Ceramic bricks	50	50	670	200	200	2000
Concrete blocks	10	10	330	25	30	700
Natural stone	60	60	640	500	310	4000
Natural gypsum	10	10	80	70	100	200
Industrial by-products						
Phosphogypsum	390	20	60	1100	160	300
Blast furnace slag	270	70	240	2100	340	1000
Coal fly ash	180	100	650	1100	300	1500



Table 4. Radon concentration ( $\text{Bq/m}^3$ ) due to radon exhalation from floor material according to the ventilation rate (Chen *et al.* 2010).

Radon exhalation rate ( $\text{Bq/m}^2 \text{ d}$ )	ACH				
	3	1	0.3	0.15	0
5	0.03	0.09	0.3	0.6	5
10	0.06	0.2	0.6	1.2	25
50	0.3	0.9	3.0	5.9	123
100	0.6	1.8	6.0	12	246
300	1.8	5.5	18	35	737

(Labat *et al.* 2006, Tararbit *et al.* 2009), being associated with cardiovascular death and cancer development. Khalil *et al.* (2009) mentioned that a blood lead level higher than  $8 \mu\text{g/dl}$  is responsible for increased mortality of coronary heart disease. Others (Menke *et al.* 2006) found out that a blood lead level higher than  $2 \mu\text{g/dl}$  was associated with myocardial infarction and stroke mortality. Eventhough health-related risks due to lead pipe poisoning were known from quite sometime, in fact many cities in the USA tried to prohibit lead-based plumbing in the 1920s which was not enough to stop the counter actions of the lead pipe industry (Rabin 2008). In the 1970s, the World Health Organization (WHO) still admitted  $300 \mu\text{g/l}$  as the threshold for lead in drinking water. Since then, this value has fallen significantly (Table 5) as suddenly the toxic risks of lead plumbing were made clear. Some how this threshold evolution is quite similar to the asbestos problem, in which increased patterns of restrictions were adopted until finally the final prohibition came. It is then no surprise to see that the related Directive (98/83/CE) established a 15-year delay period before the  $10 \mu\text{g/l}$  lead content threshold is enforced. This delay period is related to the cost of pipe substitution if the  $10 \mu\text{g/l}$  lead content threshold was to be enforced immediately. For Portugal, the survey carried out in 1995 under the Directive (98/83/CE) revealed 1,177,300m of lead pipes, as for Europe this amount reached almost 50 million metres. The replacement costs applied back then were almost

Table 5. Threshold evolution for lead in drinking water in the last decades.

Legal regulation	Year	Threshold for lead in drinking water ( $\mu\text{g/l}$ )
WHO	1970	300
Directive (80/778/CEE)	1980	50
Directive (98/83/CE)	From 25 December 2003 to 25 December 2013	25
	After 25 December 2013	10

34,000 million euros (Papadopoulos 1999). Estimates that are more recent refer to 200,000 million euros (Hayes 2009).

## 8. Conclusions

This present review confirms that a large amount of building materials present some form of toxicity. They may be toxic to the environment during the production stage or by polluting indoor air, by releasing toxic fumes during fires or simply by poisoning drinkable water also increases toxicity in building materials in the last decades, due to the reuse of industrial by-products and even some industrial wastes. Part of the problem is because architects and civil engineers have no form of knowing the toxicity of building materials meaning that something must be done at that level to address this problem. Unfortunately, one cannot count only on legal regulations because several building materials that comply with legal regulations thresholds remain toxic to human health. The toxicity of building materials relates to the existence of health-related investigations confirming this toxicity. Nevertheless, one must not forget that the past has showed us that some building materials that were considered safe or just inert have revealed to be very toxic afterwards. Furthermore, in some cases, legal regulations are influenced by economic reasons in the first place and only afterwards with the consequences for the human health. All this suggests that the choice of sustainable materials should see building materials as a key issue.

## Note

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