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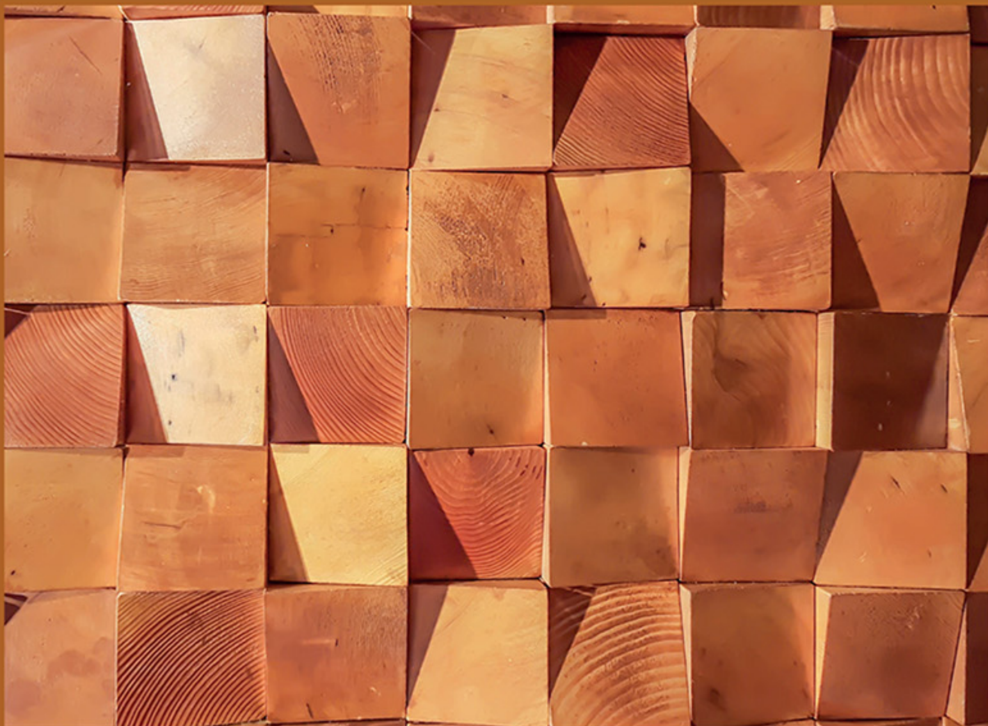

# SUSTAINABILITY AND TOXICITY OF BUILDING MATERIALS

## MANUFACTURE, USE AND DISPOSAL STAGES

Edited by
EMINA KRISTINA PETROVIĆ,
MORTEN GJERDE, FABRICIO CHICCA
AND GUY MARRIAGE

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WOODHEAD PUBLISHING
An imprint of Elsevier

Woodhead Publishing is an imprint of Elsevier
50 Hampshire Street, 5th Floor, Cambridge, MA 02139, United States
125 London Wall, London EC2Y 5AS, United Kingdom



ISBN: 978-0-323-98336-5 (print)
ISBN: 978-0-323-98356-3 (online)

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*Publisher:* Megan Ball
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Typeset by MPS Limited, Chennai, India

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# Introduction

We live in an increasingly complex world where anthropogenic behaviour is leading to conditions that are hazardous, not only to ourselves but also to all other life on the planet. Through our own actions, we have initiated the sixth great extinction of animal and plant life. In that context, we can see that while most human activity is conscious and deliberate, it is not always well informed. Indeed, sustainability science has clearly revealed to us how short-sighted many anthropocentric activities have been over time. Humans have become a dominating and polluting force on all elements of the environment, including the land, the lakes, rivers and seas and the very air we breathe. It is increasingly acknowledged that the way we are currently living simply cannot continue. Unfortunately, many of the alternative solutions are still being developed. We need to develop such alternatives and deploy those that are suitable as widely as possible, with urgency. However, we must also proceed with a critical perspective, as the prerequisite for this shift must be a well-informed understanding of the problems and that sound research-based knowledge informs the emergent solutions.

Our 28-chapter book offers a greater depth of insight on toxicity in the manufacture, use and disposal of building materials. We propose that more knowledge is needed when it comes to toxicity issues generally, but particularly around manufacture and disposal. While the book is based on the current understanding of what makes a material sustainable, we also call for an expansion of existing definitions and for notions of sustainability to recognise toxicity impacts through the whole life cycle of building materials. This links with stronger social and environmental sustainability by considering the close relationship of human health and well-being with that of other species and the planetary balance. While the current discussions are about the toxicity of building materials, links can also be made more widely to conversations about chemicals and other forms of pollution.

We propose that materials offer a powerful vehicle to drive the necessary improvements and change the future course of history. Buildings have a considerable impact on the planet's resources, not only in the way they are created and disposed of but also in the ways they are used on a day-to-day basis, the way they are maintained and how they change during their full lifetime. It is also understood that the materials a building is made from will affect these outcomes, whether seen through the lens of greenhouse gas emissions, energy use or waste generation. However, while it is important to understand the operational, embodied and embedded energy in buildings and their links to carbon emissions, it is also essential to recognise a range of other impacts made by building materials. An exponential increase in the extraction of excavated resources has brought us close to their depletion. Shortages of materials such as sand and gravel have been predicted and, in some locations, we have seen the disappearance of entire islands. From a different perspective, we have seen the emergence of large industries that place human health and well-being low on the list of priorities. Toxicity that can arise with the manufacture and disposal has the potential to directly impact the lives of employees and those living close to the manufacturing facilities and disposal sites, even with very long-lasting effects. We have also seen a long history of inadequate responses, even when the dangers are clearly recognised. The slow response to addressing indoor air quality, which directly impacts the health of the users, provides one such example. Carbon footprints and energy use calculations can do little to describe such impacts.

Therefore knowledge around the sustainability of building materials remains incomplete. We urgently need to expand our understanding of the full effects that use of these materials can lead to. This book presents one vital step in that direction. This book is for the students and academics with an interest in sustainability and building materials, helping to deepen their knowledge around matters that are not included in existing quantifying tools. It is our hope that it will spark new research interests to help address existing gaps in knowledge. Architects and other building specifiers will gain from this book a better understanding of how the materials they use can affect the future viability of the planet. Most importantly, by foregrounding toxic aspects of building materials, matters that are often swept under the rug, we open up for discussion some of the uncomfortable truths that need to be addressed here and now.

The chapters address the sustainability and toxicity of building materials from several different research approaches, including case studies, applied and theoretical. The full lifespan of construction materials is considered, from their extraction and manufacture, through to installation and the in-use phase, as well as the eventual dismantling and disposal. By throwing light on these issues, we hope that greater understanding and awareness will lead to greater care around their use and their disposal in the future. While many building and furnishing materials are safe to use, in recent decades, some have had to be redesigned due to the recognition that these contain harmful chemicals.

We understand that we are addressing a sizable gap in knowledge, and the book can therefore be seen as a methodological sketch for examining toxicity issues related to building materials. We must also acknowledge that the book is not a homogeneous statement or methodology, and, in this light, some contradictions are inevitable. For example, while several chapters discuss the UN's Sustainable Development Goals (SDGs) as a positive framework for understanding sustainable aspirations, criticisms of the SDGs are also included. The same goes for the existing green building assessments, which are used by some chapters as the aim to aspire to, while noted as limited by others. We believe that these contractions belong in the same book as they capture the practices of the current time, presenting a cross-section of the current considerations in this area. Similarly, the discussions of the disposal of building materials appear more limited than discussions of the toxicity of other phases, and we believe that this is reflective of the lower level of scientific research in this area. This is why we are pleased to be able to include some emerging research on ecotoxicity of building materials once disposed. A number of the 43 contributors, despite being well-established academics and researchers in the field, reported that they were learning new facts and becoming surprised by details that emerged when they began looking at the manufacture and disposal sides more closely. We hope that the research community will continue to build on the matters discussed in this book. This is the only way to close existing gaps in knowledge about how building materials can affect people and the environment.

The book contains five parts, working through the issues around building materials. The first section, *Contextualising the importance of evaluating toxic impacts*, opens by contextualising the importance of evaluating materials and systems through examining a range of higher level considerations, including issues with evolving definitions of toxicity (Chapter 1), limitations with regulations (Chapter 2) and certification schemes (Chapter 3), then moves on to discuss the issues associated with greenwashing (Chapter 4) and a case study analyses the behaviour (Chapter 5) and concludes with a historical review of improvements or deteriorations the sustainability approaches over the recent decades (Chapter 6). This part presents new interpretative propositions for consideration of the sustainability and toxicity of building materials.

The second section, *Sustainability and toxicity issues with natural and conventional construction materials*, is an in-depth look at some of the most common building materials: timber (Chapter 7), timber processing (Chapter 8), bricks (Chapter 9), concrete (Chapter 10) and metals (Chapter 11), analysing their use and their material existence. From there, the discussion moves to the global issues from intense material extraction and production (Chapter 12), followed by a discussion of opportunities to almost forgotten uses of agricultural by-products (Chapter 13) and earth in construction (Chapter 14). This part significantly expands on what is commonly found in contemporary construction books, adding dimensions of toxicity and impact on human and environmental health.

The third section, *Sustainability and toxicity issues with synthetic and composite materials*, opens with an introduction to the family of polymers, plastics and coatings in buildings and sets some of the important parameters when interpreting their sustainability and toxicity (Chapter 15). This is followed by in-depth analysis of specific examples: expanded polystyrene (Chapter 16), issues with build-ups of environmentally persistent toxins indoors (Chapter 17) and the continuing use of formaldehyde in composite wood products such as MDF (Chapter 18). This part highlights a significant role current building practices have on global consumption of synthetic chemicals, many of which are recognised for their adverse health and energy impacts.

The fourth section, *Sustainability and toxicity issues with systems and built examples*, looks specifically at case studies of the application of certain materials, generally searching for nontoxic ways of making. It includes contemporary strawbale tiny house construction (Chapter 19), sustainable opportunities for kitchen joinery (Chapter 20), facade design for disassembly (Chapter 21), nontoxic application of cypress pine (Chapter 22) and design of wall systems which combine formal and material innovation (Chapters 23 and 24). These show a range of innovative work already underway using natural materials or better design approaches. Jointly, these highlight that considerations of building materials are often impossible to separate from the building systems that they help make.

The fifth section, *Emerging considerations*, is somewhat arbitrary title, because many chapters throughout the book contain excellent emerging considerations and insights. Within this context, we are using this part to signal four areas where more research is certainly needed, and the four chapters included here are suggestive of what is starting to trace outlines of what is still to come. This part opens with an exploration of opportunities for using digital fabrication to create structures capable of performing better on a range of parameters discussed throughout this book (Chapter 25). This is followed by a report on the current demolition practices compliant with some certification schemes (Chapter 26) and critically new insights on the ecotoxicity of common building materials (Chapter 27). This part concludes with an exciting review of digital technologies capable of facilitating easy knowledge navigation, towards addressing a range of the issues discussed throughout this book (Chapter 28).

Lastly, as the four editors of this large volume, we encourage you, the reader, to think carefully about your own actions, both in creating the problem and working towards a solution. We believe that the building industry can no longer continue to build in ways that are manifestly unsustainable and knowingly toxic to ourselves and many other species. Each one of us must be the change we need, and we hope that the information presented in this book becomes inspiration for further action. Our book opens up for further discussion on the subjects of toxicity and sustainability, and we hope that others will contribute towards the research and continue towards a healthier world for all to enjoy.

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# Section 1

# Contextualising the importance of evaluating toxic impacts

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# The importance of recognising the toxicity of building materials in manufacture, use and disposal stages for planetary sustainability and restoration

1

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In the last two centuries, human civilisation has progressed through industrialisation, modernisation and globalisation. These complex transformative forces have reshaped every aspect of human making, and building materials are not an exception. In the excitement of innovation and progress, many consequences appear to have been inadequately considered before the newly developed technologies became normal. As a result, humanity is currently facing a real potential of a collapse of a range of planetary systems. Yet in many areas, there is still a limited understanding of how to improve things.

This chapter explains that building materials could be an important part of the solution, and more specifically why better understanding of the toxicity of building materials could be a critical aspect for sustainable transitions. For this, it is especially paramount to consider toxicity in the manufacture, use and disposal stages, and the totality of possible adverse effects on human and environmental health. This chapter outlines the core existing issues with extensive extraction of resources from the planet and limited scientific knowledge on how harmful are such practices. It ends by proposing that a more holistic vision of sustainability of building materials should include a far greater understanding of their potential toxic effects.

## 1.1 We should use less of everything

Building materials present a high toll on planetary systems, because, as this section shows, they make more than half of extracted resources, and the extraction rate has been greatly accelerating in recent years.

Reports on global extraction patterns tend to group materials into biomass, fossil fuels, metal ores and nonmetallic minerals (Krausmann et al., 2018; Oberle et al., 2019; Plank et al., 2022; Schandl & Eisenmenger, 2006; Schandl et al., 2018). Some

Sustainability and Toxicity of Building Materials. DOI: https://doi.org/10.1016/B978-0-323-98336-5.00001-7

building materials are made from each of those, but it is possible to make a general estimate of the total portion of materials extracted for construction. : In 2017 just under half of the global extraction was for nonmetallic minerals which included sand, gravel and clay, which are all primarily used for construction (Oberle et al., 2019). Because building materials also fairly significantly feature in all other groups of extracted materials, it is reasonable to estimate that, in 2017, building and construction contributed to well over half of extracted materials globally.

On the other hand, since the 1970s, the global extraction of resources for all uses has tripled, nearing 100 gigatons extracted annually (Oberle et al., 2019). Material extraction and processing are currently responsible for at least half of the global greenhouse gas emissions, and more than 90% of biodiversity loss and water stress (Oberle et al., 2019). Building materials play a significant contribution to this. The rate of acceleration since 2000 is especially confronting, and some project that the total global level of extraction might again double by 2050 (Krausmann et al., 2018).

The explanation for these striking trends is that since the 1970s the global population has doubled, and the gross domestic product has increased fourfold (Oberle et al., 2019). More recent acceleration is explained by the middle-income countries, especially China, catching up with the high-income countries in terms of material consumption (Plank et al., 2022). Nevertheless, the high-income countries have had a history of high levels of extraction for a longer period, which means that currently that is where there is already a strong stock of materials in use, creating a suitable setting for recycling and closing the loop type of strategies.

An analysis of material flows in 2010 noted that 37% of nonmetallic minerals were downcycled into materials for backfilling during new construction, 77% of all metal was recycled at the end of use, and even around 20% of biomass materials come from recycling (Krausmann et al., 2017). Much of those recycling uses are for construction.

Nevertheless, overall, increases in extraction of materials directly relate to increases of waste. Of all materials extracted between 1900 and 2015, just over one-quarter (27%) were still in use, in buildings, infrastructure and other objects, while 72% were since returned to the environment as waste (Krausmann et al., 2018). Therefore this significant problem of intense and increasing material extraction goes together with an intense and increasing problem of waste. Importantly, both extraction and waste adversely impact planetary health.

Another aspect of this increase is the exponential growth in the development of synthetic chemicals and the production of plastics and other products consuming those. Based on the data from Binetti et al. (2008), CAS (2017, 2023), and Statista (2023), Fig. 1.1 illustrates these increases and the comparability in their general patterns.

The solution to these issues is to decouple human development from these negative impacts and learn how to achieve growth without the need to consume more of newly extracted materials, with a reduced level of disposal, reliance on synthetic chemistry and on fossil fuels. In recent years, a range of international organisations are proposing and envisioning elements needed for such transitions (European Environment Agency (EEA), 2019; International Energy Agency (IEA), 2022; Oberle et al., 2019). However,

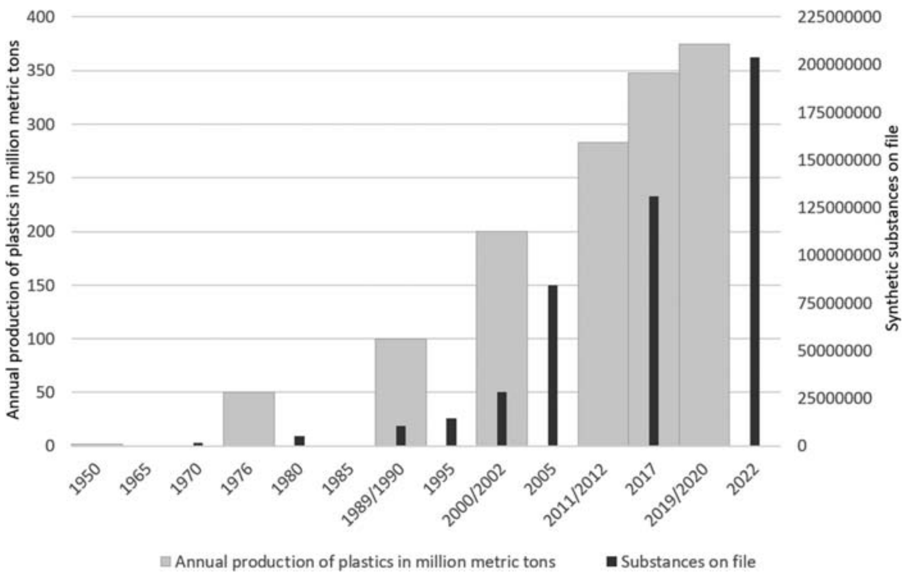


**Figure 1.1** Comparison of the increase of number of invented synthetic substances on file and global production volume of plastics. Both showing similar patterns of increase.
*Source*: Author's chart based on data from Binetti et al. (2008); CAS (2017, 2023); Statista (2023).

this is an aspiration impossible to achieve without an excellent understanding of the totality of implications of human activities in terms of materials on the planetary system. In order to support this process, it is essential to understand the totality of issues associated with extraction, manufacture, use and disposal of building materials. And this is especially important for building materials, because by making a true improvement in this one group of materials, as it happens the largest, more than half of the global material flows could be improved.

The first step is to bring our professional and educational awareness to the range of issues with the sustainability and toxicity of building materials.

## 1.2 We should know more about toxicity

One of the issues with the high level of material extraction and consumption globally is that there is a limited understanding of just how harmful some of the compounds currently in everyday use actually are. In fact, some report that currently there are adequate health characterisations for only about 500 chemicals, and those are mainly the more harmful ones (EEA, 2019). Of the about 100,000 common industrial chemicals, about 10% are fairly well characterised for their hazards, another 20% have limited characterisation, while for the remaining majority of about 70,000 chemicals there is 'hardly any information on their hazards and exposure' (EEA, 2019). Other, older, estimates are similar (Binetti et al., 2008), showing the slow progress in this area.

For some aspects of harmful impacts, limitations to what is scientifically known are even greater. For example, just over 1% of industrial chemicals have data on bioconcentration, while as little as 0.23% of those have been fully evaluated for their biodegradation half-lives (Milieu Ltd, 2017). Similarly, although more than 1% of industrial chemicals are considered to have potential to be persistent organic pollutants, these are still to be fully evaluated for this potential (Milieu Ltd, 2017). There is a need for more of scientific knowledge on what is harmful.

Further to that, there are issues with how we are managing even those chemicals where hazards are already known. For example, in 2007 European Union (EU) set up a new approach on Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) aimed at addressing existing gaps in knowledge, and currently this is arguably the most progressive approach in the world. Unfortunately, REACH partially restricts or bans only about 60 individual chemicals and some groups of chemicals (Milieu Ltd, 2017). Yet, hazardousness is known in association with a staggering 60% (by weight) of the 35,000 chemicals currently commonly consumed on the EU market in volumes above 1 metric ton per year (Milieu Ltd, 2017). This means that even when we have adequate scientific knowledge that certain chemicals are problematic, these are not effectively regulated against. In 2020 an EEA report expressed the same view when stating that 'current measures are insufficient' (EEA, 2019).

In an earlier work, the author completed an analysis of patterns with recognition and removal of health risks from building materials (Petrović et al., 2017; Petrović, 2014). This work showed that the process generally took about 20–40 years from the initial studies of the adverse health impacts to some clearer regulatory action. Unfortunately, even for the most recognised risks it was impossible to find an example of a full success. As discussed in section 1.3.1.1, lead is still used in manufacture despite being one of the most documented hazardous materials, and we are still learning about its impacts on health. Further to that, new substances, like nanoparticles, entered manufacture even when from the start concerns of their possible adverse effects were evident. (Nanoparticles were anticipated to impact the human body in a similar way to microparticles, such as asbestos (Donaldson & Poland, 2012; Sanchez et al., 2009).)

Nevertheless, in recent years, some progress has been made in at least starting to set the ambitions and goals to make improvements in this space. In 2020 the European Commission has adopted a Chemical Strategy for Sustainability which is part of the EU's zero pollution ambition, as part of the European Green Deal (European Commission, 2020). In 2022 the UN Environmental Assembly committed to create an international legally binding agreement to end plastic pollution by 2024, and the hope is that this agreement will address the full life cycle of plastics, including production, design and disposal (IEA, 2022). Initiatives like these have a potential to stimulate acceleration in addressing the existing gaps in knowledge, and limited implementation strategies.

What this review shows is that currently the whole world is working with a sizable gap in knowledge when it comes to scientific understanding of the toxicity of various chemicals. As a consequence, all reputable and formalised records on harmfulness should be considered as conservative and reasonably likely to underestimate toxicity to people and the environment.

### *1.2.1 Limitations of existing building materials knowledge*

Unfortunately, this overarching issue with limited scientific understanding filters into other existing knowledge systems. For example, conceptually, life cycle assessments (LCA) is a ground-breaking holistic way of quantifying the totality of impacts of materials and products on the planetary systems (Ghose et al., 2020; Simonen, 2014). However, LCA can only be based on the existing scientific knowledge, and when it comes to toxicity, that means working with a sizable gap in knowledge. This gap in knowledge inevitably translates into LCA outcomes that will need revising as more knowledge emerges. In addition, even the information which is already available through the LCA is not extensively used: one study found that even when the LCA of whole buildings is calculated, human toxicity aspect was reported for only 3 out of 105 buildings (Dong et al., 2021). The same study found that climate change and energy depletion were the two categories which were given greatest attention, while other categories were often overlooked (Dong et al., 2021). This might be reflective of the greater availability of information about energy and climate impacts, but nevertheless, it adds to the argument that more knowledge on toxicity is needed for the LCA and other similar systems to become more accurate in this area, and better balanced overall. For that, built environment professionals should be more familiar with the information discussed in this book.

## 1.3 Improving definitions of toxicity

Potentially, the issue with limited knowledge about the harmfulness of industrial chemicals comes from the way toxicity and related harmfulness issues have been historically considered. Toxicology started to develop from the trial and error efforts of the hunter-gatherer to source foods safe to eat (Hayes, 2020). By the 16th century some physicians observed toxicology as a paradox: ‘The right dose differentiates a poison and a remedy’ (Hayes, 2020), and complex discussions followed considering if some poisons are more ‘universal’ than others (Hedesan, 2017). Conceptually, these discussions were important to shift the thinking away from the simplifications that things can be classed as toxic/nontoxic, because the actual impacts and boundaries are often much more complex (Hayes, 2020). While toxicology as a science developed from this core concept which emphasises the importance of the dose, more recently this approach has been criticised as failing to recognise a range of other harmful effects (Langston, 2010).

The only toxic response which is very easy to directly measure and demonstrate is acute toxicity, whereas an exposure leads to a swift lethal response in the study animals. Such exposure is clearly toxic. However, at a lower dose the same substance might not lead to an equally lethal response (Philp, 2001). This is why the theory of no observed adverse effect level (NOAEL) was developed and to a large extent still dominates toxicology (Mow et al., 2020). The NOAEL approach can be defined as the highest dose without a demonstrably harmful effect on the well-being of an animal (Mow et al., 2020). Human civilisation has a long history of using the NOAEL approach when evaluating the risks and managing the use of substances which are known to be toxic in high doses.

However, since the rise of synthetic chemicals during the first half of the 20th century, scientific understanding has been developed to capture and describe a range of adverse effects more complex than acute toxicity and the NOAEL approach. It is much harder to establish thresholds for low-level exposures, and this is even more challenging for chronic or long-term exposures (Philp, 2001). Delayed responses and cumulative effects also took time to be recognised because these often resulted in less obvious toxicity, not harming organs directly. Late 20th century science struggled to fully describe the more complex issues with carcinogenesis, endocrine disruptors, harm to the unborn child, but also multigenerational impacts which intensify with distance (Langston, 2010). Adding to the list, we are increasingly aware that some toxic substances remain in the environment as environmentally persistent toxicants (Stockholm Convention, 2023).

All of these complexities with the definitions of toxicity itself contribute to challenges when trying to act in this area.

### 1.3.1 Examples of historical issues with recognition of toxic impacts

Currently, there are many historical examples of toxicological understanding of the growing harmfulness while the substances are already in manufacture and in use. Two short stories about lead (Pb) and vinyl chloride present useful examples.

#### 1.3.1.1 Lead

Despite being recognised as a toxic since the start of metallurgy (Lesser, 1988; Riva et al., 2012), in 1907 US Dutch Boy Lead White paint displayed Pb as 90% of its content, and leaded petrol was introduced in the 1920s (Warren, 2000). This was possible because the NOAEL paradigm dominated, and lower levels of exposure to Pb did not have easily observable symptoms (Warren, 2000). However, in 1943 research work of Byers and Lord suggested that Pb poisoning is not reversible, but rather that it can affect children's behaviour and intellect for 10 years or more (Silbergeld, 1997). More recently, new understanding has emerged of the 'decelerating' response to Pb toxicity, which means that there is no safe level of exposure to Pb (Lanphear & Birnbaum, 2017). During the 1970s a range of regulations against Pb were introduced, and new regulations continue to be introduced – however, Pb is still being used in recent years in manufacture is a staggering over 10 million metric tons globally (Statista, 2023). Among a range of other adverse impacts, it is now known that Pb is an environmentally persistent pollutant and the heritage of its use will be with us for a long time to come especially at those impactful low levels.

#### 1.3.1.2 Vinyl chloride

Vinyl chloride is the monomer of the polyvinyl chloride (PVC) (Chapter 15). In 1930 vinyl chloride was studied for its toxicity from single exposure on guinea pigs (Patty et al., 1930). When tested in high doses, it led to deaths of guinea pigs, but the study found no clear organ damage at lower doses (Patty et al., 1930). Therefore the researchers recommended considering vinyl chloride as a possible surgical anaesthetic, and it was since explored for such applications (Oster & Carr, 1947). The approach taken by the 1930 study clearly exemplifies the NOEAL approach and focus on acute toxicity. However, since then vinyl chloride has been recognised as carcinogenic (Group A), it can cause autoimmune response and is suspected of causing genetic defects (PubChem, 2023). None of these were tested in the initial study. Rather, the carcinogenicity of vinyl chloride was recognised in response to health issues seen in the workers involved with PVC manufacture (IARC, 2012).

### 1.3.2 Other poorly recognised adverse impacts

Endocrine disruptors have had a history of even slower recognition, with early regulations against them introduced early in the 21st century. Endocrine disruptors further violate the traditional toxicological definitions of harmfulness, because rather than being dose dependent, they might have greater effects at lower doses, and depend on the timing, age, and what the endocrine system is doing at the time of exposure (Langston, 2010). There is still much of emerging science in this area, although environmental exposure investigations already show that we have examples of species in one region struggling to express male features, while in another region the same struggle is with female features — both contributing to decreasing fertility rates in a range of species including our own (Langston, 2010).

Within this context perhaps it comes as no surprise that the first documented case of asthma dates from the mid-19th century acceleration of industrialisation in Britain (Spengler & Chen, 2000). A British physician who observed the case as a possible unusual disease, took another 10 years to find seven additional cases to confirm this assumption (Spengler & Chen, 2000). Yet, in 2004 a multidisciplinary literature review established that the increasing incidents of asthma and allergy throughout the developed world since around 1970 are probably due to environmental changes, because the period was not long enough for changes through genetic evolution (Sundell, 2004). Supporting this, in 1990 it was reported that 20% of the population suffered from an allergic disease (Spengler & Chen, 2000), while this doubled to 40% by the report from 2015 (Rueter et al., 2015). Conditions like asthma and allergies might be related to the increases of particle matter in the air, but changes of the chemical composition of those particles would be also contributing, because these are increasingly human-made in origin.

Taken together, human manufacture nowadays uses a range of synthetic chemicals and other known hazards, and the full impact of those is impossible to anticipate. While we are recognising biodiversity loss as an issue, we should also continue working on understanding better the evolution of the health of those species still remaining, including our own. Toxicology is evolving, but the belief in the simplicity of NOAEL approach is still ingrained in the existing structures, and it will continue to require consistent effort to push against those assumptions. Unfortunately, that means that the simple binary of toxic/nontoxic will remain out of reach, and we should actively embrace more complex understanding of the impacts on human and environmental health.

The issues with the history of focus on acute toxicity and the NOAEL approach contribute to delays in the recognition of the toxicity of various compounds. Further to that, it is possible that similar assumptions underlay the slow rate of change after the issues are formally recognised – after all, often enough there are no directly observable adverse effects from using problem substances in manufacture. However, it is essential to fully move away from this model in order to achieve a holistically better approach to building materials which are supportive of human and environmental health.

## 1.4 Expanding understanding of what should be protected

The narratives used to justify and stimulate decreases in toxicity have been continually evolving. In the battle for the recognition of toxicity of Pb, emerging understanding that children were more impacted was an early catalyst for some action early in the 20th century (Rabin, 1989; Warren, 2000). Rachel Carson's *Silent Spring* (1962) proposed an argument against the world without bees and pollination, with a potential of leading to starvation. In the 1980s Sick Building Syndrome was a popular term, specifically coined to elect a strong emotional reaction and therefore a chance of action (Sundell, 2004; World Health Organisation, 1983). Each of these narratives presented opportunities for biases and blind spots. To decrease the toxic impact of Pb on children, paints for children emerged, and generally the level of Pb in paints started to drop, but the practice of using Pb in manufacture continued, and with it, exposures of the workers and the exposed outdoor environments (Warren, 2000). Carson's book made a decisive contribution to the banning of dichloro-diphenyl-trichloroethane, while conversations about the possibility that other chemicals might also be harmful still continued on a case-by-case basis. Public discussions of Sick Building Syndrome led to greater improvements of ventilation standards than removal of the problem chemicals in the materials found in the buildings (Petrović, 2014), which are also still reviewed on a case-by-case basis.

In order to step outside of similar shortcomings, it is now important to more proactively consider the interconnectedness of a range of parameters. Many of the chemicals which are harmful for humans are also harmful for animals, but currently less information is available on the toxicity on animals and plants. While ventilation could effectively improve indoor air quality, some of the fumes expelled that way are already part of atmospheric chemistry (Gopikrishnan & Kuttippurath, 2021), and there is no scientific clarity what these additional loads might do in the atmosphere. With ventilation, we seem to have been assuming that outside and out-of-sight meant that the toxicity problems were gone and solved. But climate change is clearly demonstrating that expelling combustion gases did not solve the problem of their harmfulness − rather, it shifted the issue from harming those running the combustion process, to eventually harming the atmosphere. Therefore it is essential to move away from the single focus approaches to toxicity, and human health as the main motivators for change, and consider issues more holistically.

There are other inequalities. The health of all humans appears not to be treated as equal. Currently, more attention seems to be given to the consumers and users, those that have more of a choice, than the workers making the same products, or installing these, who often have more limited employment choices. Further to that, manufacture and issues associated with manufacture are more visibly discussed than the issues with extraction and disposal. The environmental harm of the large mines or the role of forestry slash in flooding appear to be still fairly invisible. Even more invisible appear to be accidents involving toxic synthetic chemicals, yet, they continue to happen at a high environmental cost of all living things (The Guardian, 2023). It is essential to bring all of these issues into consideration when selecting the building materials responsible for generating them. Because, these are all aspects of the externalised costs of human and environmental harm which are currently not adequately understood nor effectively factored into the purchase price of materials and goods. To remedy that, we need to consider more carefully all that goes into the materials, their manufacture, use and disposal.

## 1.5 Conclusion

This chapter introduced some of the core weaknesses in the way the sustainability and toxicity of building materials in their manufacture, use and disposal are currently discussed. The level of extraction of materials is accelerating at an unprecedented pace, which is increasing the importance of rethinking what can be done differently, better. It is paramount to move to a culture of using less and keeping building materials in use for much longer. It is important to disregard availability of relatively cheap and easy to access building materials and treat each and every bit of the materials we use as precious. In reality, each bit of the materials we use has already had a very real impact on the planetary system, it is our responsibility to use these with economy and respect, and continue using and reusing these for a long time. We should use all materials to their fullest possible extent, reuse and keep reusing in the magnificence of their preciousness.

The extensive material extraction also reminds us that atmospheric disbalances associated with climate change are not the only aspect of planetary needs that need urgent addressing: we also need solutions for the biodiversity loss throughout a range of aquatic and terrestrial ecosystems. Due to the extensive use of synthetic and environmentally persistent substances, we might be experiencing chemical disbalances throughout a range of planetary scales, which are currently impossible to fully quantify using existing scientific knowledge. This means that addressing climate change is not enough. Rather, it is essential to equally consider all possible adverse impacts, which are outcomes of anthropocentric activities, and start fixing these by proactively rethinking our practices.

For this to be truly possible it is essential for the built environment professionals to become more familiar with the issues related to the sustainability and toxicity of building materials in their manufacture, use and disposal. It is important to know what we are changing and why. But also, it is important to develop effective strategies to drive new knowledge generation.

As this chapter shows, by paying more attention to toxicity, together with other impacts, building materials can help us restore health across species, the natural environment and throughout the planetary system. It is important to consider these as interconnected, and work through unified approaches that simultaneously provide a range of improvements. This can also help us restore a deeper relationship with nature and with indigenous knowledge, all along furthering our science. Building materials can also help address the inequities in contemporary society by ending the toxic manufacturing and installing jobs, and eliminating buildings and homes that are substandard for the health of their users. In times, when it is easier to see problems than solutions, this sets a vision of one desirable trajectory.

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