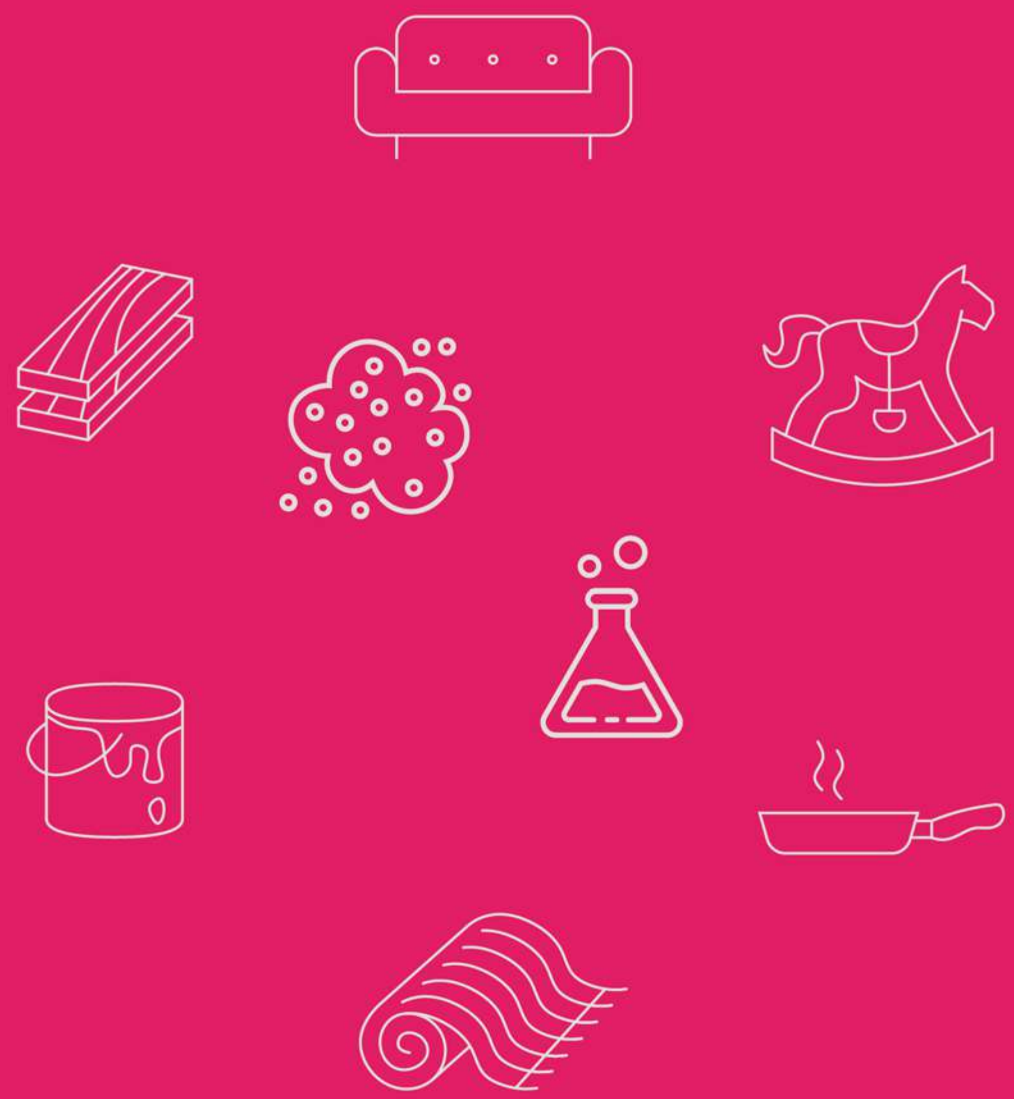
Non
Haz
City

BUILDING MATERIAL CATALOGUE
for tox-free construction

Interreg
Baltic Sea Region

Co-funded by
the European Union

SUSTAINABLE WATERS
NonHazCity 3



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Building Material Catalogue
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Editors
Auraplan Architects: Christiane von Knorre, Rose Schläfli
BEF Estonia: Heli Nommsalu
BEF Germany: Siobhan Protic
BEF Latvia: Daina Indriksone, Agnese Meija-Toropova
BEF Lithuania: Gražvydas Jegelevičius
BVB Service AB: Marianne Balck
City of Helsinki: Elisa Keto
City of Stockholm: Jenny Fäldt
Kaunas University of Technology: Jolita Kruopienė, Edgaras Stunžėnas
NOMAD architects: Florian Betat, Marija Katrīna Dambe
POMInnO Ltd.: Andrzej Tonderski
World Future Council Foundation: Mecki Naschke

Design
NOMAD architects: Florian Betat, Marija Katrīna Dambe

Assistant editors
BEF Germany: Sara Lohse, Antonia Reihlen
Goodpoint AB: Amanda Öhman, Emma Svensson Akusjärvi

Prompt engineer (Midjourney 6.0)
NOMAD architects: Florian Betat, Marija Katrīna Dambe

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SUSTAINABLE WATERS NonHazCity 3
NONHAZCITY
EU STRATEGY FOR THE BALTIC SEA REGION FLAGSHIP

CONTENTS

1 Introduction

Dear reader,
As you explore this comprehensive catalogue on sustainable construction, rest assured it's well-organized for easy navigation. Tailored for those in the construction or building sector, it offers an extensive overview on climate-neutral, circular, and non-toxic construction materials.

The primary goal is ambitious: eliminating hazardous substances from buildings, enhancing circularity, and promoting climate protection. Authored by contributors from over 22 institutions across eight European countries, this collective effort aims to promote a positive change in the construction industry. Join us on this transformative journey—there's much to take in, and we hope you find it both informative and enjoyable.

Happy reading!

1 The project and challenges it is tackling

The construction industry faces a critical challenge in its journey towards sustainability. It is marked by the urgent need to transform its practices into ones that are non-toxic, circular, and climate-neutral. With increasing public awareness on global environmental concerns, the necessity to revolutionise construction materials and methodologies has emerged as a fundamental task, driven by the responsibility to ensure a bright future for our planet.

Hidden within many conventional construction materials are hazardous substances that find their way out of the material and into the surrounding environment, including air, rivers and oceans through wastewater discharge, and organisms by direct contact. Therefore, such materials pose a significant threat to many ecosystems and human health. These substances encompass a range of compounds. Their presence and accumulation in the tissues of living organisms, sediments, and water can exert considerable stress on ecosystems and their biota. Additionally, hazardous substances can pose direct threats to human health through breathing or touching. These substances, when present in construction materials, can contribute to air pollution, water contamination, and various health issues for those near these materials. Sadly, the impact does not stop there; hazardous substances often prevent circularity measures by limiting reuse or recycling, impairing the respective reduction of greenhouse gases.

The NonHazCity 3 project addresses this issue directly. Building upon the success of the two previous projects within the NonHazCity program which focused on everyday items contaminated with chemicals, this project's objective is to develop solutions for the climate-neutral, circular, and non-toxic production of construction materials. The main goal is to eliminate hazardous substances from buildings, preventing their entry into systems altogether and by that, improving circularity as well as climate protection.

The path to achieving this transformation is challenging. Therefore, more than 22 institutions from eight European countries are acting in a joint effort. After the development of guiding documents (solutions) such as this catalogue, fact sheets for professionals, a consumer app helping with decision-making during renovation, a DIY guide, and more; pilot projects will be launched in the Baltic Sea region over the next two years. These projects are designed to test the developed solutions under local conditions, illuminating the pathway toward a more sustainable future.

Imagine healthy buildings. Natural, healthy, durable, efficient. Picture a future where what we build with contributes to both human well-being and the planet's health. These materials come from renewable sources, created with minimal environmental impact. They are designed for efficiency and durability, ensuring they last. And when they reach their end of life, they are reborn: transformed, repurposed, or recycled. Reducing waste, conserving health, resources, and habitats.

These materials make us feel good because they symbolise a commitment to a brighter, responsible future. To make this dream come true, people around the world are working on such materials. There is still a long way to go, but we have also come a long way already. Let us continue this journey together. With this catalogue, we invite you to explore today's sustainable materials (and more).

This catalogue is dedicated to promoting sustainable construction. Its aim is to provide a comprehensive overview of a wide range of sustainable construction materials, their ecological properties, applications, and contributions to a circular, climate-neutral living environment, free of hazardous chemicals. Our intention is to empower municipalities, building project leads, architects, designers, contractors, homeowners, and DIY enthusiasts with the knowledge they need to make sustainable choices when selecting construction materials for their projects.

Fig. 1
View of a Nordic housing district. Image generated with Midjourney 6.0

The catalogue can help…

… to understand the current challenge.

Transforming cities into safe, non-hazardous spaces is a significant challenge in fostering sustainable construction and in line with the global sustainable development goals. The NonHazCity program, particularly the ongoing INTERREG project NonHazCity 3, is actively addressing this challenge by developing, testing, and communicating solutions for stakeholders in the construction and building sector.

… to identify sustainable construction materials.

The core of our catalogue is a compilation of sustainable construction materials and building elements that serves as a practical compass for navigating the realm of sustainability within the construction sector. Chapters 3 and 4 provide essential insights to encourage readers to make informed decisions that align with the three pillars of the NonHazCity Project: Toxicity, Circularity, and Climate. In the context of the NonHazCity Project, "Toxicity" refers to eliminating hazardous substances in construction materials, "Circularity" is the aim to promote a closed-loop and sustainable approach in material design and use, and "Climate" focuses on achieving climate-neutral production practices.

It brings together a curated collection of sustainable construction materials across various categories, helping people on their journey toward making more sustainable choices.

For each material or intermediate, characterisations, including chemical content (toxicity), circularity and climate neutrality aspects, are presented. The underlying approach is to assess groups of materials rather than specific products from manufacturers. Hence, the descriptions will not highlight specific products. This way, a general assessment for materials is provided, while detailed assessments for specific products of manufacturer X, are not. For further information at the detail level, we encourage you to contact the manufacturer directly.

… to retrieve information on chemical content of commonly used construction materials.

In addition to searching for sustainable construction materials, the catalogue's chapter 5 – Substances in building materials – enables the search for specific chemicals. The chapter also lists in which construction material respective chemicals are found. These descriptions offer easy access to information on which group of chemicals may be expected in what kind of construction materials. Hence, an extensive list on what materials may need to be (re)considered during product procurement is provided.

… to find useful (eco)labels and certifications, databases, platforms, other information sources and legal requirements.

The catalogue additionally provides chapters on legislation; databases, platforms and information sites; as well as labelling and certification systems: Chapter 7 delves into databases, platforms and information sites offering insights for various target groups. Chapter 6 explores legislation in the BSR, and chapter 8 is dedicated to certifications and (eco)labels, focusing on different types of ecolabels, discussing EPDs, and highlighting labels for certification of entire buildings, rather than individual construction materials.

2 Glossary

The glossary has been developed as a reference for all NHC3 project publications. Here one can find explanations to terms that are commonly used in the project and can help to understand the overall context.

Additives — substances with specific functions that are added to a material, such as plastics or rubber, to provide them with a certain technical quality. Examples are softeners, which are added to e.g. PVC to make it flexible or cross-linking agents, which are added to polymers so they form a stable structure with links between polymer chains.

Architect's service Phases in the planning of buildings
- Establishing the basis of the project
- Preliminary design
- Final design
- Building permission application
- Execution drawings
- Preparation of contract award
- Assisting award process
- Project supervision
- Project control and documentation

Background database — is a database that is designed to store and manage data that is not directly accessed or modified by end-users.

Basta — one of three assessment systems in Sweden that assess construction material/ products.

Biocide — a biocide is defined as any substance or combination thereof, as provided to the user, that includes or produces one or more active ingredients. Its primary purpose is to eliminate, deter, neutralize, impede, or otherwise exert control over any detrimental organism, employing methods other than mere physical or mechanical actions.

Bioaccumulation — the increase in concentration of a substance in an organism over time. Bioaccumulative substances tend to be fat soluble and are hardly or not broken down by the biota.

Biomagnification — also known as bioamplification or biological magnification, is an ecological process that refers to the increasing concentration of a substance, such as a toxic chemical, in the tissues of organisms at successively higher levels in a food chain. This phenomenon is particularly significant with substances that are fat-soluble and not easily broken down or excreted, such as many persistent organic pollutants (POPs).

BNB (Bewertungssystem Nachhaltiges Bauen) — engl. Sustainable Building Assessment System, is a system that provides a framework for evaluating and assessing the sustainability performance of buildings.

Byggvarubedömningen, BVB — One of three assessment systems in Sweden that assess construction material/ products.

Carcinogen (GHS) — means a substance or a mixture which induce cancer or increase its incidence.

CAS-Number — the chemical abstract service number is assigned to substances by the chemicals abstract service. Each number unambiguously identifies one substance. CAS numbers are used world-wide.

Chemical compound — a molecule formed by the reaction of other chemical compounds or chemical elements that has a unique structure, chemical and physical properties.

Chemical of Concern (CoC) — Chemical compounds or substances, which have hazardous properties and cause concern to human health or the environment. Among CoCs, three categories can be distinguished:
- Chemicals for which risk reduction action has been agreed on at an international level (e.g. a chemical being listed under the Stockholm Convention on Persistent Organic Pollutants)
- Chemicals for which scientific evidence exists to advance risk reduction action. These include chemicals that have been regulated at national or at regional level (e.g. chemicals that have been restricted for certain uses in China or the EU).
- Chemicals for which evidence for risk to human health or the environment is currently emerging from scientific research, but which are not yet regulated.

CoC of categories 1 and 2 are subject to mandatory regulations (e.g. bans or strict limit values). Addressing the third category of CoCs can be part of a high-ambition and proactive approach to chemicals management and can go beyond regulatory compliance.
According to the EU Chemicals Strategy for Sustainability "Towards a Toxic-Free Environment" substances of concern include, in the context of this strategy and related actions, primarily those related to circular economy, substances having a chronic effect for human health or the environment (Candidate list in REACH and Annex VI to the CLP Regulation) but also those which hamper recycling for safe and high quality secondary raw materials.

Chemical product — a chemical substance or a chemical mixture that is sold for industrial and/or for consumer uses. Examples include glues, lacquers or polymer compounds.

Chemical substance — a chemical substance is a form of matter that has constant chemical composition and characteristic properties. It cannot be separated into components by physical separation methods, i.e., without breaking chemical bonds. Chemical substances can be simple substances, compounds, or alloys.

Chemicals inventory — tool enabling a systematic approach to managing information on chemicals purchased and used in a company. The tools may range from simple excel-sheets to sophisticated material management systems provided by large IT firms.
The chemicals inventory typically lists all raw materials of a company and specifies the content of chemicals with hazardous properties, by indicating at least the name, CAS number, type of hazard (e.g. via GHS hazard statements) and the concentration in the raw material.

Circularity — concept of a closed-loop system for resources, materials, and products, which maintain the value and utility of resources and products for as long as possible, minimises waste and maximises resource efficiency. It promotes recycling, reusing, refurbishing, and sharing, while prioritizing easy repair, upgradability, and disassembly. It aims at removing hazardous substances from the material cycle to enable a circular economy that reduces environmental impact.

Climate neutrality — Concept of a state in which human activities result in no net effect on the climate system. Achieving such a state would require balancing of residual emissions with emission (carbon dioxide) removal as well as accounting for regional or local, biogeophysical effects of human activities that, for example, affect surface albedo or local climate. (Source IPCC Glossary)

CLP	Regulation (EC) No 1272/2008 of the European Parliament and of the Council on classification, labelling and packaging of substances and mixtures.
Coatings	Coatings are layers of a material applied to the surface of an object for protection, decoration, or functional purposes, such as enhancing durability, appearance, or performance.
Cocktail effect	effects or potential effects (synergistic or antagonistic) of exposure caused by interaction of several (hazardous) chemicals. Usually, cocktail effects are unknown or not well studied.
Composite materials	engineered materials that are formed by combining two or more different constituents to achieve specific performance characteristics. These constituents can include natural raw materials, synthetic materials, or a combination of both.
Compound	a chemical compound is a substance, which consists of molecules made of at least two different elements and that are chemically bound.
Construction product regulation (CPR)	Regulation (EU) No 305/2011 of the European Parliament and of the Council laying down harmonised conditions for the marketing of construction products.
Curing agents	a curing agent is a substance that makes surfaces or materials, like polymers, harden by promoting molecular bonding. There are three types: those reacting with the surface, catalytic agents not reacting with the material, and initiator agents kickstarting hardening reactions without continuous involvement.
Declaration of conformity/compliance (DOC)	a signed document by which a manufacturer (or his authorised representative) claims responsibility for the accuracy of the provided information about a particular product and its compliance with relevant legal requirements or standards. Optionally, a proof for the claim can be included.
Declaration of performance (DoP)	a documentation of the performances of construction products in relation to their essential characteristics required in the Construction product regulation. With the DoP the manufacturer assumes responsibility for the conformity of the construction product with the declared performance. So far environmental characteristics have not been included.
Ecodesign	means the integration of environmental sustainability considerations into the characteristics of a product and the processes taking place throughout the product's value chain.
Ecolabel	a voluntary method of environmental performance certification and with a label that identifies products that are proven to be environmentally preferable. A certified ecolabel is the most reliable way to inform consumers about the environmental and chemical safety aspects of a product.
Element	a substance which consists of only one type of molecules. Elements are listed in the periodic table of the elements.
Emerging pollutants	chemical compounds that are already widely used or present in the environment, that have recently been identified as hazardous to human health or the environment with an increasing concern.
Endocrine disruptors	chemicals that can change the function of the hormone system, such as, for example, the reproductive system, or the immune system and cause harmful effects on human health or the environment. Such chemicals may be effective at very low doses and may cause long-term damage to humans or animals.
Environmental Product Declarations (EPDs)	document providing declarations based on life cycle assessment of the respective product. In addition to LCA information technical and functional properties of the product are included. EPDs are intended for communication within the supplier industry.
ECHA	European Chemical Agency.
Exposure	Contact of an organism with a chemical.
Finishing materials	Surface treatments applied to a material for example in forms of paints, stain, varnishes, lacquers, waxes and oils. They can be synthetic or natural.
Forever chemicals	persistent or very persistent chemical substances that are not easily biodegradable and have long lifetimes in the environment. Usualy poly- / perfluorinated chemicals are referred to as "forever chemicals".
GHS	The globally harmonised system of classification and labelling of chemicals is a voluntary international agreement on a standardised approach to identify chemical hazards and communicate on them. The GHS defines what type of hazards there are and gives guidance on the process of analysing if a chemical has a hazardous property. In addition, it suggests standard phrases to inform chemical users of these hazards. The GHS is implemented in many, but not all countries at global level. In the EU it is implemented through the CLP regulation (see CLP).
GPP vs SPP	Green Product Procurement vs Sustainable product procurement. Sustainable procurement takes a broader approach, considering social, environmental, and economic factors of products, while green procurement primarily focuses on the environmental aspects of products.
Green building standards	Green building standards are guidelines promoting environmentally friendly and energy-efficient practices in construction, focusing on factors like energy efficiency, water conservation, and the use of sustainable materials to reduce environmental impact.
Harmonised standards	mean standards as defined in Article 2(1), point (c), of Regulation (EU) No 1025/2012 of the European Parliament and of the Council of 25 October 2012 on European standardisation.

Hazard refers to any situation, condition, or substance that has the potential to cause harm, injury, damage to property, or adverse health effects. Hazards in construction can include a wide range of factors, such as unsafe working conditions, hazardous materials, equipment malfunctions, and other risks that may compromise the safety of workers, occupants, or the construction site.

Hazard category (GHS) describes the division of criteria within each hazard class, e.g. oral acute toxicity includes five hazard categories [Category 1, 2, 3, 4, 5] and flammable liquids includes four hazard categories.

Hazard class (GHS) describes the nature of the physical, health or environmental hazard, e.g. flammable solid, carcinogen, oral acute toxicity. Hazard class and should not be taken as a comparison of hazard categories more generally.

Hazard statement (GHS) "means a statement assigned to a hazard class and category that describes the nature of the hazards of a hazardous product, including, where appropriate, the degree of hazard." For example: a chemical substance with an assigned hazard class "Carcinogenicity" and a hazard category "Category 1A" will have a hazard statement "May cause cancer".

Hazardous properties in the context of construction and building, hazardous properties refer to characteristics of materials or substances used in construction that may pose risks to the health and safety of construction workers, occupants, and the environment. These properties can include toxicity, flammability, corrosiveness and therefore it is important to handle these properties carefully to minimize potential dangers.

Heavy metal defined as metallic elements that have a relatively high density compared to water. With the assumption that heaviness and toxicity are inter-related, heavy metals also include metalloids, such as arsenic, that can induce toxicity at low level of exposure.

Hot spot a location of the building of pronounced exposure or emissions of hazardous chemical substances.

Insulation materials create a building's thermal envelope, reducing heat transfer. They come in various forms, compositions, and functions, resisting heat transfer through conduction, radiation, or convection.

Label (from GHS) means an appropriate group of written, printed or graphic information elements concerning a hazardous product, selected as relevant to the target sector(s), that is affixed to, printed on, or attached to the immediate container of a hazardous product, or to the outside packaging of a hazardous product.

Life cycle assessment (LCA) a method for assessing the environmental effects of product (systems). The assessment is based on material and energy flows, including all stages of a products life. The classification and characterisation of the recorded substances in terms of their environmental effects (impact assessment) and the subsequent evaluation are also included.

Load bearing refers to elements such as walls and columns engineered to bear the weight of a structure, ensuring stability. These elements withstand various loads, like occupants and environmental forces. Non-load-bearing components, such as interior walls, lack the responsibility of bearing structural loads but contribute to space division. Recognizing load-bearing elements is vital for safety in construction and renovation endeavours.

Logbook a list where construction projects document and list the products and materials they use, mainly with focus on the products that are built in. The aim is to keep the list during the whole lifecycle of the building and provide traceability, to know where products and certain substances are used. This will facilitate recycling and waste management during renovation and demolition.

Low-dose effect refer to claimed biological effects occurring at doses below those traditionally tested in standard toxicology studies. The term is often used for doses below the No Observable Adverse Effect Level (NOAEL) or levels relevant to human environmental exposure. Some scientists argue that certain chemicals, even at low doses, can mimic hormones and cause effects not observed at higher doses in standard toxicology studies.

Membrane in engineering and construction, membranes can act as barriers or separators. Waterproof or weatherproof membranes are commonly used in roofing to prevent water infiltration.

Migration describes a phenomenon that substances can move within matrices. For example, softeners which are diluted in polymers migrate through the material and eventually reach the surface from which they can evaporate or leach. The "migration rate" is the speed with which the migration takes place.

Mixture the term addresses any intentionally produced mixture of more than two substances or compounds. Other words for mixture are preparation or formulation. Examples are lacquers or "additive packages", e.g. mixtures of additives ready made for formulating them into polymers.

Non hazardous materials are safe substances used in building projects that do not pose risks to health or the environment.

Non-hazardous refers to safe materials that pose no risks to health or the environment during normal use, handling, and disposal.

Poly and (residual) monomers is a term used in the chemical or manufacturing industry to describe a combination of polymers and unreacted monomers that remain in the product. Polymers are large molecules that are formed by linking smaller units called monomers. Residual monomers refer to those monomers that have not fully participated in the polymerization process and still exist in the final product. It is important to monitor the presence of residual monomers as they can affect the properties and safety of the final polymer product.

Polymer are large molecules that are formed by linking smaller units called monomers

POP Persistent Organic Pollutant. An initial list of POPs was compiled under Stockholm convention on Persistent Organic Pollutants, which is an international treaty signed in 2001 aiming to restrict production and use of POPs. Initially 13 chemicals were in the list, including notorious pesticide DDT and other organochlorine compounds. Now the list is being supplemented with additional chemical substances.

Preservative a chemical substance or a mixture, a biocide, that is added to a chemical composition with an aim to extend its' lifetime and prevent microbiological degradation.

Product this term is used for any object, which is not considered a chemical. In general, a product has got a physical form and shape that is relevant for its function, while the function of chemicals is mainly determined by their composition.

Raw material not processed or little processed material, close to its' original state.

REACH Candidate List list of substances of very high concern (SVHC) from which the substances to be included in Annex XIV of the REACH Regulation (list of substances subject to authorisation) are selected. The candidate list is established in accordance with Article 59 of the REACH Regulation.

Residues chemical substances present in a chemical product or material, usually at trace levels, but not required for its function or application. They can be contaminants, reaction byproducts, unreacted precursors or breakdown products, etc.

Risk (health and environment) relates to the potential for harm to health and the environment, including hazardous substances, unsafe conditions, accidents, and environmental damage.

Safe means free from hazards or risks that could cause harm to workers, the environment, or the people who live in or around the houses.

Safe by design means incorporating safety features and considerations at the design phase of a project. This proactive approach aims to identify and address potential hazards, ensuring the construction process and the finished structure are inherently safe for workers, occupants, and the environment.

Safe and sustainable by design a voluntary approach to guide the innovation process for chemicals and materials recommended by the European Commission, which aims to

- steer the innovation process towards the green and sustainable industrial transition,
- substitute or minimise the production and use of substances of concern, in line with, and beyond existing and upcoming regulatory obligations,
- minimise the impact on health, climate and the environment during sourcing, production, use and end-of-life of chemicals, materials and products.

Safety data sheet (SDS) a safety data sheet is a compilation of information needed to safely handle a hazardous substance or mixture. In countries and regions where safety data sheets are legally required, such as the European Union or China, they usually have a clear structure with different subsections. Safety data sheets are sometimes also called material safety data sheets (MSDS)

Sealants are materials used to fill gaps and joints, preventing the penetration of air, water, dust, or other environmental elements.

Substance (GHS) means chemical elements and their compounds in the natural state or obtained by any production process, including any additive necessary to preserve the stability of the product and any impurities deriving from the process used, but excluding any solvent which may be separated without affecting the stability of the substance or changing its composition.

Sunda Hus One of three assessment systems in Sweden that assess construction material/products.

Sustainable In construction, "sustainable" means adopting practices that minimize environmental impact, prioritize resource efficiency, and consider long-term ecological, social, and economic well-being.

Sustainable construction materials are eco-friendly building materials designed to reduce environmental impact and are resource-efficient. These materials are not only good for the environment but also promote the health and comfort of the people who live in the buildings.

Sustainably managed forests (SFM) is the responsible oversight of forests, guided by principles of sustainable development. It seeks a balance between ecological, economic, and socio-cultural aspects, allowing the utilization of trees while preserving natural patterns of disturbance and regeneration. SFM contributes to climate change mitigation by increasing carbon storage in trees and soils while ensuring a lasting supply of renewable raw materials through responsible forest management.

SVHC Substances of Very High Concern, in the context of the REACH Regulation, are substances that are included in the REACH Candidate list for Authorisation due to their hazardous properties.

Three-pillar perspective The concept of "three pillars of sustainable development" refers to three interconnected areas of focus that are crucial for achieving long-term sustainability. The first pillar is ecological sustainability, which is concerned with ensuring the health and well-being of ecosystems. The second pillar is economic sustainability, which aims to promote long-term prosperity and economic growth without compromising the environment. The third pillar is social sustainability, which prioritizes equity and well-being for all members of society. These three pillars are interdependent and must be balanced to achieve sustainable development that benefits both present and future generations.

Tox-free also, zero pollution ambition, refers to materials and practices free from harmful toxins or pollutants, promoting a safer built environment.

Tox-free construction construction is a construction that avoids hazardous substances in materials or finishes and therefore reduces the impact buildings have on human health and environment (especially the aquatic environment).

Toxic refers to materials, substances, or practices that contain harmful or poisonous components, posing potential health risks to construction workers, occupants, or the environment.

Trace components refer to minimal amounts of specific materials or substances that are present in a mixture or construction material. These components are typically present

	in tiny quantities but can play a significant role in influencing the properties or characteristics of the overall material.
Varnishes	are liquid coatings that are applied to surfaces, particularly wood, to enhance appearance and provide protection. They create a transparent, glossy, or satin finish that improves aesthetics and durability while protecting against moisture and UV rays.
VOC	volatile organic compound. Usually, a light molecular weight chemical that has a tendency to evaporate into the environment from its source. E.g. formaldehyde released from the resins in furniture.
Water directive	The Water Framework Directive (Wasserrichtlinie) 2000/60/EC is a European Union mandate that requires member states to ensure good quality and quantity of water in all water bodies by 2015. The directive evaluates the ecological and chemical status of water bodies by examining factors such as biological quality, hydromorphological quality, and physical-chemical quality. The groundwater must attain "good quantitative status" and "good chemical status" by 2015, using criteria such as the Ecological Quality Ratio. The directive stresses the active participation of stakeholders in its implementation, aligning with the Aarhus Convention.
Zero pollution ambition	action plan set out in the European Green Deal to protect Europe's citizens and ecosystems. The zero-pollution vision for 2050 is for air, water and soil pollution to be reduced to levels no longer considered harmful to health and natural ecosystems, that respect the boundaries with which our planet can cope, thereby creating a toxic-free environment.

AO	Associated organisation
BSR	Baltic Sea Region
BVB	Sv Byggvarubedömningen, Eng Building product assessment
CMR	carcinogenic, mutagenic and reprotoxic
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen
EDC	Endocrinedisrupting chemical
EPD	Environmental Product Declaration
GoA	Group of Activity
HS	Hazardous Substances
LCA	Life Cycle Assessment
LP	Lead Partner
NHC3	NonHazCity3
PBT	Persistent, bioaccumulative and toxic
PMT	Persistent, mobile and toxic
PP	Project Partner
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals (Legislation)
vPvB	very persistent and very bioaccumulative
vPvM	very persistent and very mobile
WP	Work Package

3 Materials and intermediates

While we aspire to provide a holistic overview, please note that this catalogue does not include technical specifications of specific brands or in-depth manufacturing processes. Our focus is on offering insights into the types of sustainable materials available, encouraging you to explore and integrate them within your design and construction projects.

The upcoming chapters, provide insights into each material category, accompanied by visual references and comprehensive lists of what to keep in mind when choosing a product from the respective category. We invite you to utilize this catalogue as a valuable resource to create spaces that prioritize human and ecological well-being and contribute to a sustainable and healthy built environment.

As a material in this literature review is considered substances or mixtures of substances used in construction, meanwhile products in general are combinations of two or more materials. Both the materials and the products are assessed based on three aspects of environmental sustainability (CCC): chemicals (toxicity), climate (contribution to greenhouse gas, GHG, emissions) and circularity.

The toxicity is assessed based on the material's or product's content of toxic substances and likelihood of emissions to the indoor environment, to the natural environment both over time and during their application i.e., as a workers health issue. This also includes whether production and end of life of the material or product requires use of toxic substances and/or leads to emissions of toxic substances.

The impact on climate change is assessed based on the materials' or product's GHG emissions and total global warming potential (GWP), focusing on the product stage, A1-A3. As described in the standard EN15804+A1 (Sustainability of construction works- Environmental product declarations- Core rules for the product category of construction products) A1-A3 stages include the following:

- A1 Raw material extraction, including processing of secondary material input.
- A2 Transport of raw material and secondary material to the manufacturer.
- A3 Manufacturing of the construction products, and upstream processes from cradle to gate.

The circularity of the material or product is assessed based on the potential for reuse, remanufacturing, and material recycling as well as recycled content of raw materials. This includes reviewing the durability, quality, availability of recycling processes and the potential of GHG emission savings during material recycling. Infrastructure for recycling is described when applicable.

Untreated wood

Fig. 2
Construction timber. Image generated with Midjourney 6.0

Timber is a natural material that comes from tree trunks, roots, or branches. It is used for load bearing and non-load bearing elements.

Raw timber is processed in limited amounts and is mainly common in products such as– full logs, sawn beams, or planks.

Toxicity

Generally, timber is considered to be a safe material and untreated timber does not pose any toxicity risk to the natural environment. Attention must be paid to the levels of formaldehyde. Moreover, installation of timber elements does not pose any toxicity risk and does not require any extra protective measures other than typical work safety. Lastly, timber does not pose any risk at the end-of-life stage.

Climate

Untreated timber has typically a low climate impact resulting from the product stages A1-A3 (raw material extraction, manufacturing, and transportation). due to low processing of the material and a regional supply chain with low transportation distances. During its growth, a tree sequesters carbon, timber products may therefore be viewed as a carbon sink when used as a high value building material and products with considerably long lifetime. The climate impact of the material varies between countries and the level of processing, for example, in Sweden sawn timber has a total GWP of ca 0.08 kg CO_2e/kg (Boverket, 2023). The indirect impacts on climate resulting from land system change and reduced carbon sequestration in soil is however difficult to quantify and models regarding the climate impact are continuously improving. Opting for PEFC or FSC- certified timber helps in assuring a sustainable value chain, which reduces the indirect GHG emissions.

Circularity

Most typical end-of-life treatment is energy recovery by incineration. However, to increase the circularity of construction materials and reduce raw material consumption, a preference should be given for reuse and recycling of the material- both are possible with untreated timber (Hafner et al., 2013). As a raw material, it cannot have any content of recycled material, however, it can be recycled and used in other processed timber products typically done by chipping the material and using it in the production of timber-based boards. Low quality and contaminated waste timber may be processed by pyrolysis with material and energy recovery in the form of pyrolysis oil, biochar and heat. However, the possibility for recycling highly depends on the quality of the timber and the local infrastructure for recycling.

If installed correctly, timber as a material can be very durable. Some of the oldest buildings using timber can be found in in Norway such as the Stålekleivloftet (storehouse) which has been dated between 12th and 14th century. Even older timber structures can be found in Japan in the Horyu-ji Area where these have been dated late 7th and 8th century (UNESCO, n.d.).

Timber as a material is highly adaptable as it allows for easy handling, fixing as well as cutting and sanding to renew the appearance or repurpose. The main barrier for adapting timber materials for new uses are wet connections (glue) or extensive use of fixtures which require time for disassembly.

Untreated timber can be used in all types of construction, from load bearing elements to insulation and finishes – both interior and exterior.

Literature

Boverket. (June 16, 2023). Sawn timber, u 16 %, coniferous. Climate database from Boverket. Retrieved November 15, 2023, from https://www.boverket.se/en/start/building-in-sweden/developer/rfq-documentation/climate-declaration/climate-database/GetResourceByCategoryID/

Hafner, A., Ott, S. J., & Winter, S. (2013). Recycling and End-of-Life Scenarios for Timber Structures. In S. Aicher, H.-W. Reinhardt, & H. Garrecht (Eds.), Materials and Joints in Timber Structures: Recent Developments of Technology (pp. 89-98). Springer Netherlands. https://www.researchgate.net/publication/271135321_Recycling_and_End-of-Life_Scenarios_for_Timber_Structures

UNESCO. (n.d.). Buddhist Monuments in the Horyu-ji Area. UNESCO World Heritage Centre. Retrieved November 1, 2023, from https://whc.unesco.org/en/list/660/

Seaweed

Fig. 3
Construction seaweed. Image generated with Midjourney 6.0

Seaweed, also known as macroalgae, is categorised as a multicellular macroscopic alga. It appears to have a similar appearance to non-woody land plants but lacks the latter's complex structures. Seaweed comes in various shapes, sizes, and colours, the most known one probably being Kelp.

All sorts of seaweed have been used as a traditional raw material with many purposes. It is available in many regions of the world, including the BSR and easy to collect at the shores. Often seaweed is collected in an organised manner on tourist beaches (Pedersena & Ransby, 2007). Seaweed has the ability to absorb and give off water, regulating humidity parameters indoors (Widera, 2014; Pedersena & Ransby, 2007). It also has insulating properties.

Toxicity

Toxicity in seaweed products is generally low when properly processed and stored, as they are non-toxic and fire-resistant, partly due to their salt content, which also protects against bacteria, molds, and insects. However, if washed, the seaweed's salt content decreases, necessitating treatment against microorganisms, and reducing concerns about salt leaching into adjacent metal constructions. Trace levels of heavy metals like arsenic, lead, and cadmium may be present but rarely pose health or environmental risks. Dust inhalation during processing and exposure to allergenic compounds are potential risks, depending on application and processing methods. It's important to be aware that seaweed products may be treated with hazardous chemicals.

In sustainable harvesting, seaweed is manually collected, cleaned, and sun-dried, requiring no additives. However, cultivated seaweed using electricity, synthetic fertilizers, pesticides, or equipment like HDPE for raft systems can lead to environmental emissions. Avoiding these practices enhances sustainability.

At its end-of-life, seaweed can be composted, enriching the soil, or used for biomass energy generation, although hazardous substances in the final product may impair this process.

Climate

Seaweed has a promising role in mitigating climate change due to its ability to sequester carbon dioxide from the atmosphere and its relatively low energy use within the production and harvesting. The carbon sequestration potential depends on the species and growth conditions.

Circularity

Natural seaweed previously used in construction may be reused in various ways, e.g. in industrial processes and as a raw material for various products. Thermal recovery is another option for energy generation. However, if the material has been in contact with potentially hazardous substances because it was further processed to a specific product or because hazardous substances may have migrated into the material, it is recommended to test the seaweed before re-using, recycling or composting. Untreated seaweed derived from construction can be re-used without a risk of emitting hazardous substances. The infrastructure for recycling seaweed materials is not yet common. However, as the demand for sustainable alternatives grows, it's likely that the recycling and reprocessing infrastructure will improve.

For construction materials, it is feasible to also use waste or by products from cultivated algae, e.g. parts of algae attached to substrate (not edible).

Once dry, seaweed will last a very long time. It may be boxed e.g. into wooden cassettes, for protection against excess moisture and subsequent leaching of salt into neighbouring materials (Widera, 2014). Keeping the salt content high, reduces flammability and susceptibility to decay via microbes, insects, and mold. Subsequently, washing of seaweed materials reduces its durability.

Literature

Nakhate, P., & van der meer, Y. (2021). Systematic Review on Seaweed Functionality: A Sustainable Bio-Based Material. Sustainability.

Pedersena, C., & Ransby, E. (2007). Production and Properties of Insulation Mats Made from Sea Grass. Proc. of the 3rd IASME/WSEAS Int. Conf. on Energy, Environment, Ecosystems and Sustainable Development, Agios Nikolaos, Greece, July 24-26, 2007.

Widera, B. (2014). Possible Application of Seaweed as Building Material in the Modern Seaweed House on Læsø. Wroclaw University of Technology, Faculty of Architecture: 30th international plea conference, researchgate.net.

Straw

Fig. 4
Construction straw. Image generated with Midjourney 6.0

Straw is a plant material that refers to the dried stems or stalks of plants, typically cereal, such as wheat, barley, rice, oats, and rye, among others. However, also other types of grasses (Poaceae) may be used (Biorefine cluseter europe, 2023). It is the remaining, hollow part of the plant after the grains or seeds have been harvested. The stalks are often dry, rigid, and durable, making them useful for various purposes, including the use as construction material.

Toxicity

Straw is generally low in toxic substances. However, it is vital to ensure that it is free from contaminants, such as mold and pesticide residues, which can lead to indoor air quality issues. Untreated straw naturally decomposes without releasing toxic substances into the natural environment. During application, workers may face potential health risks due to dust and allergenic reactions. Chemically treated straw may cause other health problems during application, this strongly depends on the treatment. Proper protective equipment and handling procedures might mitigate some of these risks. Straw production typically does not require the use of toxic substances. However, conventional farming practices, like synthetic pesticide or fertilizer use, can result in emissions of toxic substances into the environment. Sustainable farming practices are encouraged to minimize these impacts. Straw is biodegradable and can be composted at the end-of-life stage. It does not contribute to long-term environmental pollution and can even enrich the soil as compost.

Climate

Straw as a construction material tends to have a low carbon footprint. It stores carbon during growth and retains this carbon when used in construction, effectively removing carbon dioxide from the atmosphere. The main contribution to GHG emissions results from the use of synthetic fertilizers and pesticides. Sustainable farming practices and local sourcing of straw as a by-product, further reduces emissions from pesticide and synthetic fertilizer production as well as transportation. Straw can also have a climate change mitigating effect when treated with pyrolysis for energy recovery and biochar production, resulting in further carbon sequestration when the biochar is used as soil amendment (Azzi et al., 2022).

Circularity

Straw is often obtained as a by-product of cereal production and utilizing it for construction purposes instead of energy production, soil amendment and animal bedding, will increase its circularity by increasing the lifetime of the material and implementing multi-functional use throughout different life stages. Straw can often be recycled or repurposed at the end-of-life stage. It can either be used as compost if untreated or be used for thermal recovery, as it can be burned for energy generation or used as a feedstock to produce biochar and heat.

Exact repurposing or recycling potential depends on the specific product and the local systems for recycling. The infrastructure for recycling straw materials is still evolving, similar to many other emerging sustainable building materials. It is possible to reuse, compost or thermally treat straw after ISO (Bauen und Wohnen Fachagentur Nachwachsende Rohstoffe e. V., 2023). Quality issues may arise if contaminants are present in the recycled materials. Proper processing and quality control are therefore essential.

The type of straw used can influence durability, with wheat straw, rice straw, and other varieties differing in resistance to decay and pests. Proper processing and treatment can significantly impact the longevity. Straw used in construction should have a moisture content no higher than 15% (Bauen und Wohnen Fachagentur Nachwachsende Rohstoffe e. V., 2023). It is adaptable for various construction applications, including insulation and parts of load-bearing elements.

In renders and plasters, straw can be combined with clay, sand, and fibres to create environmentally friendly and cost-effective materials. Additionally, hempcrete and straw bale elements, when coated with earthen plaster, provide an eco-friendly building envelope with water permeability properties, promoting healthier indoor environments. In load bearing elements straw is traditionally mixed with clay to form walls.

Literature:

Bauen und Wohnen Fachagentur Nachwachsende Rohstoffe e. V. (November 1, 2023). Dämmstoffe Stroh. Von https://baustoffe.fnr.de/daemmstoffe/materialien/stroh/abgerufen

Biorefine cluseter europe, l. p. (November 1, 2023). Gramitherm – Insulation panels made out of grass! Von https://www.biorefine.eu/news/gramitherm-insulation-panels-made-out-of-grass/abgerufen

Azzi, E. S., Jungefeldt, L., Karan, S., Sundberg, C. (2022). Mistra Food Futures Report #4. Biochar in Swedish agriculture – straw pyrolysis as a first step towards net-zero.

3 Natural organic materials

Cork

Fig. 5
Construction cork blocks. Image generated with Midjourney 6.0

Cork for construction material is harvested from the bark of cork oak trees, without harming or cutting down the trees themselves. The bark regenerates and can be harvested again after approximately nine years. This renewable process allows cork construction materials to be a relatively sustainable choice. However, as bark harvest reduces the vigour of Quercus suber L. trees (Costa, Catela Nunes, Spiecker, & Garca, 2015), attention should be paid to truly sustainable growing and harvesting practices in order to avoid overexploitation of the valuable and biodiverse cork ecosystems. The trees typically grow in the Mediterranean area and North Africa (GBIF Secreteriat. , 2023).

Toxicity

Cork is a naturally non-toxic material. It does not contain or emit harmful chemicals, making it a safe and healthy choice for the indoor environment. It does not off-gas volatile organic compounds (VOCs), contributing to improved indoor air quality as its own binders (suberin) may be used to glue the flour or granulates together (Brandhorst, Spritzendorfer, & Gildhorn, 2012) in most construction products.

Cork's natural composition, free from synthetic additives, ensures it does not release toxic substances into the natural environment either. During application, the health concerns for workers are related to standard construction safety practices and not specifically to cork. The production of cork granules from cork bark involves peeling and grinding using expansion processes including steam. This involves energy consumption, but it does not typically involve toxic emissions (Brandhorst, Spritzendorfer, & Gildhorn, 2012).Cork is biodegradable and can be disposed of by depositing or thermally recycling it. At the end of its life, it does not contribute to long-term environmental pollution if untreated. Cork is biodegradable and can be disposed of by depositing or thermally recycling it. At the end of its life, it does not contribute to long-term environmental pollution if untreated.

Climate

Cork materials tend to have a low climate impact, particularly during the A1-A3 stages (raw material extraction, manufacturing, and transportation). This is due to the use of renewable cork bark and relatively low energy consumption during production. One of the drawbacks are however the distance cork needs to be transported from where it grows in the Mediterranean area and North Africa (GBIF Secreteriat. , 2023) and potential indirect impacts on climate from land use.

Circularity

Cork construction material can often be made from recycled cork, particularly from bottle corks. At the end-of-life stage, it can be reused, repurposed, or recycled.

Availability and quality of recycled cork materials may vary depending on local demand and recycling facilities. The quality of recycled cork is generally high, as it tends to retain its properties.

Cork is known for its durability and adaptability. It resists decay, moisture, and pests, ensuring it maintains its properties over time. It is also capillary active and vapour permeable (Brandhorst, Spritzendorfer, & Gildhorn, 2012), which increases the durability of the product using cork material as it helps regulate the humidity of the building.

As a natural and sustainably harvested material, the act of recycling cork can be used to balance the negative impacts of bark harvest on individual trees and eventually ecosystems. Hence, ecosystems can be given additional time to reproduce cork in a sustainable manner and serve as true sources of biodiversity.

While the infrastructure for recycling cork materials may not be as developed as some other materials like metals, its increasing popularity is likely to lead to improved recycling facilities over time.

Its sound and thermal insulation characteristics make it suitable for various applications, including floorings and ceilings (Brandhorst, Spritzendorfer, & Gildhorn, 2012). Additionally, it is suitable for condensation insulation purposes.

Literature:

Brandhorst, J., Spritzendorfer, J., & Gildhorn, K. (2012). Dämmstoffe aus nachwachsenden Rohstoffen. Gülzow-Prüzen.

Costa, A., Catela Nunes, L., Spiecker, H., & Garca, J. (2015). Insights into the Responsiveness of Cork Oak (Quercus suber L.) to Bark Harvesting. Economic Botany, Vol. 69, No. 2 pp. 171-184.

GBIF Secreteriat. (3. November 2023). Quercus suber L in GBIF Secreteriat. GBIF Backbone Taxonomy. Checklist dataset https://doi.org/10.15468/39omei . Von www.GBIF.org abgerufen

Reed

Fig. 6
Reed bound for use in construction. Image generated with Midjourney 6.0

Reed is a tall, slender, grass-like plant that typically grows in wetland areas, such as marshes, swamps, riverbanks, and the shores of lakes or ponds in middle Europe. Reed is characterized by its hollow stems or stalks and can reach significant heights, often several meters or more.

Toxicity

Reed is a non-toxic construction material. It allows for the passage of vapour, preventing the buildup of condensation within walls or structures. This natural breathability enhances indoor air quality, promotes comfort, and minimizes the risk of mold growth. Reed is capillary active in its natural surroundings, regulating moisture. It does not contain or emit harmful substances, making it safe for both indoor and outdoor use.

Often it is bound together by wires to hold the stems together. Also, the production and application of these reed panels do not typically involve toxic emissions into the natural environment.

During application of untreated reed (panels), workers' health is not a major concern.

Reed is a natural wetland plant that grows without the need for pesticides or fertilizers, reducing the use of toxic substances in its cultivation. The raw material extraction process typically does not involve the use of toxic substances.

Untreated reed can be reused, repurposed or composted after removing potential wire bindings during the end-of-life stage. Thermal recycling is also possible.

Climate

Reed has a low climate impact during the A1-A3 stages (raw material extraction, manufacturing, and transportation). Its sustainable cultivation and harvesting practices, including annual mowing to preserve wetland ecosystems, align with environmental stewardship principles. The material captures greenhouse gases while maintaining wetland ecosystem services (Karstens, Inácio, & G, 2019).

Circularity

Natural reed products can be reused, repurposed, or recycled after their useful life. They are designed to have a minimal impact on the environment during disposal.

The availability of recycled reed materials depends on local demand and recycling facilities. If they are handled with care during deconstruction, the quality of reused or repurposed reed panels can be high (e.g after indoor use) and they can be reused for various elements. Weathered reed panels on the other hand may have comparably low quality and is more suited for energy recovery through composition or material recovery through composting and biogas production.

Reed is known for its resistance to decay, moisture, and pests. This ensures that it maintains its properties over time (life span of e.g. a thatched roof is up to 100 years). It is adaptable for various construction applications, including thermal and sound insulation (Brandhorst, Spritzendorfer, & Gildhorn, 2012) and wall construction.

The sustainability and low climate impact contribute to significant GHG emissions savings when considered in circular building practices. Re-using reed helps reduce the potential impact on the ecosystem, similar to cork products.

While the infrastructure for recycling reed materials is not as developed as for some other materials like metals, the growing popularity of sustainable construction practices is likely to lead to improved recycling facilities over time.

Literature

Brandhorst, J., Spritzendorfer, J., & Gildhorn, K. (2012). Dämmstoffe aus nachwachsenden Rohstoffen. Gülzow-Prüzen.

Karstens, S., Inácio, M., & G, S. (2019). Evaluation of Ecosystem Service Provision in Coastal Reed Wetlands Under Different Management Regimes. Frontiers in Environmental Science, Vol 7, Article 63.

3 Natural organic materials

Hemp

Fig. 7
Hemp fibres. Image generated with Midjourney 6.0

Hemp is generally considered a sustainable raw material. The hemp plant ***(Cannabis sp.)*** is easily cultivated, sequestering carbon within short time. Pesticide and fertiliser input as well as transport is usually not needed or kept to a minimum (Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen, 2023; Brandhorst, Spritzendorfer, & Gildhorn, 2012). Usually, the short bast fibres from the stalks are used for construction materials (Crini, Lichtfouse, Chanet, & Morin-Crini, 2020).

Toxicity

Hemp is a non-toxic construction material. It does not contain or emit harmful substances, making it safe for both indoor and outdoor use. Untreated hemp-based materials do not pose health risks in the indoor environment.

The production and application of hemp-based materials typically do not involve toxic emissions into the natural environment.

During application, workers' health is not a significant concern, as untreated hemp-based materials are generally safe to handle.

Hemp is grown with minimal pesticide and fertilizer inputs, reducing the need for toxic substances in its cultivation. The raw material extraction process does not typically involve the use of toxic substances or emissions.

Untreated hemp materials are environmentally friendly at the end of their life cycle. They can be recycled or repurposed, contributing to minimal environmental impact during disposal. Whenever hemp is part of a composite, their composition needs to be considered.

Climate

Hemp materials have a low carbon footprint during the A1-A3 stages (raw material extraction, manufacturing, and transportation). The sustainable and regional growth of hemp plants helps sequester carbon dioxide from the atmosphere. The hemp can be utilized wholly: fibres, foliage, seeds. Fibers used in the production of most construction materials require minimal processing, further reducing embodied GHG emissions.

Circularity

Natural and untreated hemp fibres can generally be reused, repurposed or recycled (Reinhardt, et al., 2019). Attention should be paid to composites as well as chemical treatments.

Availability and quality of recycled hemp-based materials may depend on local demand and recycling facilities (Reinhardt, et al., 2019). The quality of recycled materials is generally high, as they can be repurposed into various construction applications.

Hemp(-based) materials, are known for their durability and adaptability. As the plant itself minimally processed hemp materials tend to resist decay, moisture, and pests, ensuring that they maintain properties such as thermal and sound insulation as well as breathability and structural strength over time.

Like for most plant based and natural raw materials enlarging the reused, repurposed or recycled proportion of the material used for a specific construction element will have a balancing effect on the cultivation or harvest form its ecosystems. If more material is reused, cultivation can be less intense. Whether this reduces GHG emissions depend on the exact system the hemp is harvested from as well as the elements that the recycled material needs to be separated from, as well as the process of doing so.

While the infrastructure for recycling hemp-based materials can be improved, hemp material reuse and repurposing have some potential. Currently the most common scenario is thermal recovery in cement plants, as a renewable alternative to hard coal (Reinhardt, et al., 2019).

Hemp is used in various industries including construction material, food and textile production (Crini, Lichtfouse, Chanet, & Morin-Crini, 2020). For more specific information on building elements made from hemp see also hempcrete, hemp insulation.

Literature

Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen. (August 15, 2023). WECOBIS. Abgerufen am 1. September 2023 von Flachs/Hanf-Dämmstoffe - Rohstoffe / Ausgangsstoffe: https://www.wecobis.de/bauproduktgruppen/daemmstoffe/aus-nachwachsenden-rohstoffen/flachs-daemmstoffe.html

Brandhorst, J., Spritzendorfer, J., & Gildhorn, K. (2012). Dämmstoffe aus nachwachsenden Rohstoffen. Gülzow-Prüzen.

Crini, G., Lichtfouse, E., Chanet, G., & Morin-Crini, N. (2020). Applications of hemp in textiles, paper industry, insulation and building materials, horticulture, animal nutrition, food and beverages, nutraceuticals, cosmetics and hygiene, medicine, agrochemistry, energy production and environment: a review. Environmental Chemistry Letters, Vol 18, issue 1, pages 1451- 1476.

Reinhardt, J., Veith, C., Lempik, J., Knappe, F., Mellwig, P., Giegrich, J., .Voß, I. (2019). Ganzheitliche Bewertung von verschiedenen Dämmstoffalternativen. Heidelberg / Neckargemünd,.

Flax

Fig. 8
Flax panels for construction. Image generated with Midjourney 6.0

Flax *(Linum usitatissimum)* is a herbaceous plant that has been used for many purposes of thousands of years already. It is native to the eastern Mediterranean and western Asian region, preferring N-rich habitats.

Construction material made from flax tends to be vapor permeable and capillary active offering optimal buffering of humidity.

Toxicity

Natural untreated flax materials are non-toxic, safe for indoor and outdoor use, and contribute to a healthy environment. Their production involves minimal toxic emissions, making flax a sustainable choice. Easily cultivated locally, it requires little or no pesticides and fertilizers (Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen, 2023).

Handling flax-based materials poses low health risks for workers, eliminating the need for special protective measures. Flax cultivation is low-impact, with minimal chemical inputs. The traditional extraction process, involving water immersion and microorganism-induced pectin digestion, has evolved. Today, maceration methods, which may involve water, enzymes, ash, and surfactants, are used based on desired outcomes (Minol, 2023).

End-of-life for untreated flax materials involves composting, ensuring minimal environmental disposal impact. It's important to verify the sustainability of specific products, as applications and finishings are typically added post-production.

Climate

Flax materials have a low carbon footprint during the A1-A3 stages (raw material extraction, manufacturing and transportation). The sustainable cultivation of flax and the proximity of production to the source reduce transportation emissions. As a photosynthesizing organism flax also sequester carbon dioxide from the atmosphere. Extracting its fibres used in most construction materials requires minimal processing, further reducing embodied GHG emissions.

Circularity

Flax-based materials are inherently compostable and can be reused, repurposed, or recycled, provided they're free from hazardous processing substances. Their high quality makes them suitable for reuse, especially if untreated with harmful chemicals (Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen, 2023).

Known for durability and adaptability, flax materials possess stretchiness and high tensile strength. Their water absorption capacity ensures consistent insulation properties. Flax fibers also contain natural substances that repel insects and rodents (Brandhorst, Spritzendorfer, & Gildhorn, 2012).

Increasing the reuse or recycling of flax materials in construction can reduce the intensity of cultivation, potentially impacting greenhouse gas emissions. This depends on the harvesting system, the separation process, and the materials involved.

While recycling infrastructure could improve, there's potential in reusing and repurposing flax in building elements, particularly if they remain free from hazardous substances.

Flax is versatile, used in insulation and as pipe sealants. Natural linoleum includes linseed oils, and varnishes can be linseed oil-based.

Literature

Brandhorst, J., Spritzendorfer, J., & Gildhorn, K. (2012). Dämmstoffe aus nachwachsenden Rohstoffen. Gülzow-Prüzen.

Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen. (15. August 2023). WECOBIS. Abgerufen am 1. September 2023 von Flachs/Hanf-Dämmstoffe - Rohstoffe / Ausgangsstoffe: https://www.wecobis.de/bauproduktgruppen/daemmstoffe/aus-nachwachsenden-rohstoffen/flachs-daemmstoffe.html

Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen. (17. August 2023). WECOBIS. Abgerufen am 1. September 2023 von Flachs/Hanf-Dämmstoffe - Nachnutzung: https://www.wecobis.de/bauproduktgruppen/daemmstoffe/aus-nachwachsenden-rohstoffen/flachs-daemmstoffe.html

Sisal

Fig. 9
Strands of sissal. Image generated with Midjourney 6.0

Sisal fibres are obtained from the long hawthorn-like leaves of the cactus Agave, a plant that is native to southern Mexico. The fibre is extracted from the leaves dried and brushed. The resulting product can be woven into for example carpets and geotextiles. Carpets made from sisal have long been a favourite for interiors thanks to their earthy, rustic texture. The high durability makes them a good option for wall-to-wall carpets in high traffic areas such as hallways and living rooms.

Toxicity

Sisal is non-toxic and do not contain any harmful substances and does not pose any health risk.

Climate

Sisal carpeting is environmentally friendly because of its sustainable growth. It is important to note though that the cactus Agave typically only grows in specific climates. This presents transport of the material from the manufacturer to the intended site of use as an additional environmental concern. No generic data on the climate impact of Sisal has been found in the used databases.

Circularity

At its end-of-life stage, sisal is commonly incinerated for energy recovery. However, it can be recycled and easily biodegrades. However, systems for recycling are not yet in place. The circularity of the material is therefore currently considered as low although may be improved over time.

Sisal fibers are also used in PP composites or as fibre reinforcement in concrete.

Literature

dos Santos, G. Z. B., Caldas, L. R., Melo Filho, J. de A., Monteiro, N. B. R., Rafael, S. I. M., & da Silva, N. M. (2022). Circular alternatives in the construction industry: An environmental performance assessment of sisal fiber-reinforced composites. Journal of Building Engineering, 54, 104603. https://doi.org/10.1016/j.jobe.2022.104603

Coconut

Fig. 10
Coconut fibres. Image generated with Midjourney 6.0

Coconut materials are made from mature coconut trees that no longer bear fruit. The wood of old coconut trees is dense, and therefore acts as a suitable material for example flooring materials. Coconut trees grow rapidly, and the trees can be considered a renewable resource. Products made from coconut trees can be regarded as sustainable products. Additionally, the shells of coconuts can also be used for materials. The fibre from the husks of the coconut is called coir, and these long fibres can be formed into yarn. These, in turn, can be used to produce carpets. The fibres can withstand great wear and tear and makes a good flooring material. The resilience is advantageous compared to other carpeting types. Coir flooring is a durable alternative to traditional carpets and rugs. It is environmentally friendly, non-toxic, and well suitable for people with allergies. It also has significant insulating and noise-cancelling properties, which are particularly useful in airy rooms or those with a lot of foot traffic.

Toxicity

Coconut wood and coconut husk are non-toxic and do not contain any harmful substances. There is therefore no likelihood of emissions of toxic substances to the indoor or natural environment. However, during the retting process used for extracting and refining the fibres, emissions of organic matter and chemicals to nearby water streams can cause harmful effects on the local ecosystem (Abraham et al., 2013).

Climate

The climate impact from coconut production mainly results from the use of pesticides and fertilizers during the A1-A3 stages (raw material extraction, manufacturing, and transportation). Moreover, indirect GHG emissions may occur from deforestation and loss of biodiversity as the pressures on nature increases due to increasing demand for coconut. As coir is a by-product, the total environmental impact may not be attributed to the material, but as the global demand increases for organic and renewable materials the environmental effects need to be considered and a sustainable value chain needs to be assured. Coconut trees typically only grow in specific climates and therefore, transport of the material from the manufacturer to the intended site of use also result in GHG emissions. No generic data on the climate impact of coconut has been found in the used databases.

Circularity

Coconut is often obtained as a by-product of agricultural production and utilizing it for construction purposes instead of consumer products, energy production or soil amendment is preferable and result in increased valorisation. Coconut fibres can either be used as compost if untreated or be used for thermal recovery, as it can be incinerated for energy generation. Systems for recycling of coconut fibres at the end-of-life stage are not yet widely in place.

Literature

Abraham, E., Deepa, B., Pothen, L. A., Cintil, J., Thomas, S., John, M. J., Anandjiwala, R., & Narine, S. S. (2013). Environmental friendly method for the extraction of coir fibre and isolation of nanofibre. Carbohydrate Polymers, 92(2), 1477-1483.

Ali, B., Hawreen, A., Ben Kahla, N., Amir, M. T., Azab, M., & Raza, A. (2022). A critical review on the utilization of coir (coconut fiber) in cementitious materials. Construction and Building Materials, 351, 128957. https://doi.org/10.1016/j.conbuildmat.2022.128957

Reddy, N. (2019). Sustainable applications of coir and other coconut by-products. Cham: Springer International Publishing.

3 Natural organic materials

Natural rubber

Fig. 11
Sheets of natural rubber. Image generated with Midjourney 6.0

Natural rubber is produced through extraction of latex from the 'Amazionian rubber tree', also known as ***Hevea brasiliensis***. Refining of the latex produced by the tree gives natural rubber that can be used for commercial purposes. Products made from natural rubber are generally sturdier and more durable compared to synthetic rubber.

Toxicity

Natural rubber is non-toxic and does not contain any harmful substances. There is therefore no likelihood of emissions of toxic substances to the indoor or natural environment.

Climate

Natural rubber is an organic substance and a renewable source. The climate impact during the A1-A3 stages (raw material extraction, manufacturing, and transportation) mainly results from use of machinery, transport, processing and use of pesticides and herbicides. Indirect GHG emissions occur from deforestation and loss of biodiversity due to change in land use.

Circularity

Natural rubber is biodegradable and will decompose over time. End-of-life treatment is commonly incineration with energy recovery. The recycling infrastructure for natural rubber is generally not well-developed.

Literature

Ansari, A. H., Jakarni, F. M., Muniandy, R., Hassim, S., & Elahi, Z. (2021). Natural rubber as a renewable and sustainable bio-modifier for pavement applications: A review. Journal of Cleaner Production, 289, 125727.

Sheep wool

Fig. 12
Sheep wool insulation. Image generated with Midjourney 6.0

Sheep wool construction materials commonly use wool from the regional sheep populations. It is worth looking into the conditions under which the respective sheep were held and choose wholly sustainable ones. In many countries sheep herds are held for maintaining landscapes.

Toxicity

Untreated natural sheep wool insulation is free from hazardous substances and has the unique ability to neutralize formaldehydes, contributing to healthier indoor environments (Sweredjuk, Wortmann, & Zwiener; Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen, 2023). It's also vapor-permeable and capillary active, capable of absorbing up to 30% of its own weight in water without losing thermal insulation properties. This makes it effective in regulating indoor humidity and preventing mould growth.

The processing of sheep wool may involve detergents and dyes, but if left untreated, sheep wool construction materials are generally safe to handle and do not emit harmful substances.

Sustainable wool production can support valuable biomes. After shearing, wool is washed, and lanolin may be removed for certain uses. For insulation, lanolin is retained, and the wool is often combined with stabilizing synthetic fibers like polyester or corn-based polylactide to form flexible mats (Brandhorst, Spritzendorfer, & Gildhorn, 2012).

Sheep wool materials can be reused, repurposed, and recycled. However, older materials used for insulation might contain brominated flame retardants or moth protection formulations with hazardous substances like boron salts. Recycling options include processing into reusable fibers for industries like automotive. Composting is possible for untreated materials, but common keratin-consuming insect protection can hinder this. Energy recovery is another disposal option (Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen, 2023).

Climate

Depending on the circumstances under which the sheep are held and region, the climate impact from the production of wool may vary. However, extensive and sustainably managed herding of sheep have the potential to maintain and rebuild cultural and semi-natural valuable landscapes, especially grassland and heath ecosystems. Cleaning and further processing of the wool can be regarded to consume relatively little energy when compared to synthetic or mineral materials. Opting for wool of lower quality rejected by the textile industry may also result in lower GHG emissions.

Circularity

Untreated sheep wool, useful for construction, is often repurposed or recycled, offering a high degree of circularity depending on local recycling systems. Currently, construction mainly utilizes lower quality wool, unsuitable for the textile industry (Bosia, et al., 2015). Recycled wool, if integrated effectively, can reduce sheep numbers, alleviating ecosystem pressure.

The quality of wool in construction materials generally remains high post-recycling, but this depends on regional availability (Bosia, et al., 2015). Sheep wool can be processed into flexible materials enduring 20,000 flex cycles at 180°C (Brandhorst, Spritzendorfer, & Gildhorn, 2012) or into rigid panels. However, treatments for keratin-consuming insects, using chemicals like permethrin, can introduce hazardous substances.

Sheep wool's natural thermal and acoustic insulation properties make it ideal for building insulation. It's also used in geotextiles, felted wool panels, and composites, expanding its application in sustainable construction.

Literature

Bosia, D., Savio, L., Thiebat, F., Patrucco, A., Fantucci, S., Piccablotto, G., & Marino, D. (2015). Sheep wool for sustainable architecture. Energy Procedia, Vol 78 pages 315 – 320.

Brandhorst, J., Spritzendorfer, J., & Gildhorn, K. (2012). Dämmstoffe aus nachwachsenden Rohstoffen. Gülzow-Prüzen.

Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen. (2023). WECOBIS. Abgerufen am 1. September 2023 von Schafwolle-Dämmstoffe -Nachnutzung: https://www.wecobis.de/bauproduktgruppen/daemmstoffe/aus-nachwachsenden-rohstoffen/schafwolle-daemmstoffe.html

Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen. (2023). WECOBIS. Abgerufen am 1. September 2023 von Schafwolle-Dämmstoffe-Produktgruppeninformation: https://www.wecobis.de/bauproduktgruppen/daemmstoffe/aus-nachwachsenden-rohstoffen/schafwolle-daemmstoffe.html

Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen. (2023). WECOBIS. Abgerufen am 1. September 2023 von Schafwolle-Dämmstoffe - Rohstoffe / Ausgangsstoffe: https://www.wecobis.de/bauproduktgruppen/daemmstoffe/aus-nachwachsenden-rohstoffen/schafwolle-daemmstoffe.html

Sweredjuk, R., Wortmann, G., & Zwiener, G. (kein Datum). SCHAFWOLLE ALS REAKTIVES SORBENS FÜR LUFTSCHADSTOFFE IM INNENRAUM. Aachen, Köln, Kempten.

Wood fibres

Fig. 13
Wood fibre insulation. Image generated with Midjourney 6.0

Wood fibre materials are derived from natural wood. Some wood fibre is produced from wood waste, sawdust, or wood chips. Depending on the size of the wooden particles a range of building elements including boards and insulation elements, can be made. Different production processes use different process chemicals as well as treatments. What combines most of them are binders or glues. These may contain hazardous substances emitting VOCs such as formaldehyde.

Toxicity

Materials made from wood fibres are not necessarily toxic. However, depending on how these fibres are attached to each other in the final building element (Reinhardt, et al., 2019), they may emit harmful substances, VOCs, that reduce indoor air quality, especially in poorly ventilated spaces. These compounds can contribute to indoor air pollution, which may cause health issues like headaches, respiratory problems, and irritation of the eyes, nose, and throat.

When released into the atmosphere, VOCs can contribute to the formation of ground-level ozone (smog). This can have detrimental effects on air quality and may lead to health issues in both humans (Halios, et al., 2022) and animals. Additionally, some VOCs can react with other compounds in the atmosphere, contributing to the formation of secondary pollutants (Atkinson, 2000) that can affect ecosystems, water quality, and contribute to the greenhouse effect.

Installing wood fibre materials does not have any additional effects to human health; those of the installed product remain.

During the manufacturing process, the use of chemicals such as adhesives, finishes, or treatments can potentially lead to pollution. These hazardous substances are still found in the product, while concentrations during the production will be much higher. Improper disposal of waste containing these substances could contaminate ecosystems and affect the health of people working in the production process.

Wood fibre materials free of hazardous substances (brought in by adhesives, treatments or plastic reinforcements) can be re-used, re-purposed, recycled, composted, or used as biofuel after their useful life.

Climate

Wood fibre materials have a low carbon footprint during the A1-A3 stages (raw material extraction, manufacturing, and transportation) of an LCA (Ökobaudat, oekobaudat.de, 2023). The carbon sequestration potential of wood fibres contributes to their climate neutrality. Using old untreated wood fibre additionally reduces waste and keeps the carbon sequestered over time.

Circularity

Wood fibre materials are often made from wood industry residues and byproducts, diverting waste from landfills and utilizing a renewable resource for a preferred material use instead of energy usage. Additionally, these materials can often be reused, repurposed, or recycled after their useful life, contributing to their circularity. Availability and quality of the materials at the end of their life for the former purpose vary and depend on local demand and recycling facilities. Wood fibres that are connected by adhesives cannot be recycled without recycling the hazardous substances contained in the binding agents. The infrastructure for recycling wood into wood fibre materials is in place. Further recycling of these products can be further developed.

Many wood fibre-based products commonly use waste or leftover wood fibre material, while binders and adhesives cannot be sourced this way.

Wood fibre materials can be formed into various products with varying functions. Durability and adaptability strongly depend on the way materials are combined in the product.

Natural wood fibre materials may contribute to GHG emissions savings when considered in circular building practices. Their low embodied GHG emissions and climate neutrality generally make them the preferred choice.

The infrastructure for recycling wood into wood fibre materials is in place. Further recycling of these products can be further developed.

Literature

Atkinson, R. (2000). Atmospheric chemistry of VOCs and NOx. Atmospheric Environment , Vol 4 pages 2063-2101.

Halios, C. H., Landeg-Cox, C., Lowther, S. D., Middleton, A., Marczylo, T., & Dimitroulopoulou, S. (2022). Chemicals in European residences – Part I: A review of emissions, concentrations and health effects of volatile organic compounds (VOCs). Science of the Total Environment.

Reinhardt, J., Veith, C., Lempik, J., Knappe, F., Mellwig, P., Giegrich, J., . . . Voß, I. (2019). Ganzheitliche Bewertung von verschiedenen Dämmstoffalternativen. Heidelberg / Neckargemünd,.

Paper/cellulose

Fig. 14
Cellulose insulation wool. Image generated with Midjourney 6.0

Paper and cellulose are closely related materials, primarily derived from plants, and are fundamental to a wide range of products and applications. Cellulose is an organic polysaccharide consisting of a linear chain of several hundred to many thousands of linked D-glucose units. It is the primary structural component of the cell walls in green plants and algae and is the most abundant organic polymer on Earth. Cellulose is mainly extracted from wood and cotton and is used to produce paper, cardboard, and other material.

Toxicity

Paper and cellulose materials are generally non-toxic, but it's crucial to keep raw materials untreated to avoid hazardous substances, including pesticides and biocides. When recycled, attention should be given to inks, bleaching agents, deinking agents, dyes, and fixing agents, which might contain harmful chemicals.

Volatile organic compounds (VOCs) emitted from residual chemicals in paper products, such as from bleaching agents or inks, can affect indoor air quality (Alam & Sharma, 2023). Traditional chlorine-based bleaching, associated with the production of toxic chlorinated organic compounds like dioxins, has been largely replaced by safer alternatives in modern processes. However, older paper materials might still pose risks.

Direct skin contact with paper materials containing hazardous substances, such as brominated flame retardants in insulation, should be avoided. The recycling of paper, while beneficial in reducing the need for new raw materials, can introduce contaminants if not managed properly. The use of water-based inks and adhesives is preferred due to their lower likelihood of emitting harmful substances.

Virgin paper and cellulose materials can be composted or used as biofuel after their useful life. Their disposal generally doesn't significantly impact the environment. However, if these materials are treated or made from contaminated recycled paper, careful consideration of hazardous compounds is necessary at their end-of-life stage. Recycling processes must prevent the leaching of harmful substances into the environment and indoor air.

Climate

Paper and cellulose materials have a relatively low carbon footprint during the A1-A3 stages (Ökobaudat, Prozessdatensatz Kraftpapier, 2023). Their production typically involves relatively low energy consumption, contributing to their low global warming potential. The indirect impact on the climate resulting from land system change caused by unsustainable forestry practices in the supply chain is however difficult to quantify. Opting for PEFC or FSC- certified paper helps in assuring a sustainable value chain.

Circularity

Virgin, untreated paper and cellulose materials, often suitable for recycling or energy recovery through incineration, have good end-of-life options. Recycled paper with sustainable inks and dyes enhances circularity and recycling potential.

The infrastructure for recycling these materials is well-established, but the recycled content in products varies, and repeated recycling may affect paper quality. These materials are versatile, used in products that offer vapor barriers and insulation, though they can be sensitive to moisture (Brandhorst, Spritzendorfer, & Gildhorn, 2012).

Their circular use can lead to greenhouse gas (GHG) emission savings, particularly when sourced sustainably and kept untreated. Paper and cellulose materials' low embodied GHG emissions and recycling potential make them environmentally favourable.

Literature

Alam, I., & Sharma, C. (2023). Degradation of paper products due to volatile organic compounds. Scientific Reports , Vol 13 article number 6426 https://doi.org/10.1038/s41598-022-23898-z.

Brandhorst, J., Spritzendorfer, J., & Gildhorn, K. (2012). Dämmstoffe aus nachwachsenden Rohstoffen. Gülzow-Prüzen.

Ökobaudat. (29. November 2023). Prozessdatensatz Kraftpapier. Von https://oekobaudat.de/OEKOBAU.DAT/datasetdetail/process.xhtml?uuid=03f8e9cd-16ee-4ece-93bc-b68441d34afe&version=20.23.050&stock=OBD_2023_I&lang=deabgerufen

Treated wood

Fig. 15
Impregnated construction timber. Image generated with Midjourney 6.0

Wood preservatives contain chemical substances to prevent the wood from fungi, mold or pests. Wood can be treated with preservatives on the surface, by forcing preservatives into the wood (so called pressure-treated) or they can be heat treated. Itis possible to prevent exposure to unnecessary moisture by choosing the right construction solutions and locations, but in some exposed locations pressure-treated wood may be the only option.

Leaching to the environment may occur. A less toxic alternative to chemically treated wood is instead heat-treated wood and there are also wood preservatives on the market that are not classified as hazardous. Heat treated wood is only treated with heat and contain no hazardous substances.

Common products made by treated wood are facades and decking. A framework made by wood is also common in single-family homes and in apartment buildings as it is a way to decrease the climate impact of the building.

Additionally, wood can be treated to receive flame retarding properties (Fu et al 2017).

Toxicity

Wood itself is considered a safe material in both the indoor, the outdoor environment, during application, production and after demolition. Treated wood can contain substances that are not hazardous to the environment, it can be only heat treated or it can contain substances hazardous to the environment. Commonly used today are different copper salts (Westin, 2020). When leaching to the environment copper is hazardous to aquatic life, about 10-20% of copper is assumed to leach from the wood the first year after treatment (Lihammar et al, 2021). If possible, it is preferable to use heat treated wood, a non-hazardous preservative or untreated wood that is painted with e.g. linseed oil. Hazardous substances used as flame retardants can possibly leak to both natural- and indoor environment throughout the life cycle of the material.

Climate

Wood has a relatively low climate impact compared to other materials (Andersson, 2020). The generic climate impact for pine wood or spruce is <0,4 kg CO_2 eq./kg for the phases A1-A3 (Boverket). Wood stores carbon, so called carbon sequestration which makes it suitable for products with a long service life. Opting for PEFC or FSC- certified OSB helps to assure a sustainable value chain, which reduces the indirect GHG emissions from land use.

Circularity

Wood is considered a renewable resource and is possible to reuse and recycle. The wood lifespan can be increased by using different treatments, it can be heat, copper salts or different oils. Pressure treated wood is generally incinerated with energy recovery (depending on region). Treated wood should be reused if possible and only pressure treated wood should only be used when it is necessary in certain exposed locations.

Overall, treated wood is a sustainable material to use in construction, e.g. for decking or facades. It has a relatively low climate impact, is a renewable material that can be reused and depending on the treatment the toxicity can be considered as low. It is preferable to use heat or silica impregnation or paint the wood with linseed oil.

Literature

Andersson, J. (2020) A climate impact comparison between four facade materials for an apartment building (in Swedish). Bachelor thesis p. 2 & 18, Umeå univeristy.
Boverket. https://www.boverket.se/en/start/building-in-sweden/developer/rfq-documentation/climate-declaration/climate-database/GetResourcesByCategoryID/ (November 2023)

Fu, F., Lin, L., & Xu, E. (2017). Functional pretreatments of natural raw materials. In M. Fan & F. Fu (Eds.), Advanced High Strength Natural Fibre Composites in Construction (pp. 87-114). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-100411-1.00004-2

Lihammar, R., Edlund, E., Nerentorp, M. (2020) Prestudy – copper leaching from impregnated wood compared with other copper flows in Sweden. Report U 6481. IVL Swedish Environmental Research Institute. https://organowood.com/wp-content/uploads/2022/03/U6481-Forstudie-kopparurlakning-fran-impregnerat-virke-jamfort-med-ovriga-kopparfloden-i-Sverige_vers2.pdf

Westin, F. Träskyddsaktuellt. (2020) Is pressure treated wood bad for the health (in Swedish). https://traskydd.com/2020/04/ar-tryckimpregnerat-tra-en-halsobov/

Natural linoleum

Fig. 16
Rolls of linoleum flooring. Image generated with Midjourney 6.0

Natural linoleum has a simple composition, consisting of linseed oil, jute and cork flour. Limestone, wood flour, natural resins and pigments can be added. Natural linoleum produced from naturally occurring substances is a sustainable product.

Toxicity
Natural linoleum produced from natural materials is a non-toxic product. It does not emit any volatile organic compounds (VOCs), which otherwise may cause harm to human health.

Climate
The raw materials for production of natural linoleum come from renewable resources. Production of natural linoleum (A1-A3) has a total GWP of 4.1 kg CO_2 eq./kg (Ökobaudat, 2023).

Circularity
Natural linoleum is a fully recyclable product and both spill materials from installation as well as used linoleum can be recycled. The ingredients in natural linoleum also does not pose any health risks to humans or animals, which simplifies the recycling process. However, the infrastructure and systems for recycling of used linoleum may vary depending on the region.

Literature
Rosso, F., Pisello, A. L., Pigliautile, I., Cavalaglio, G., & Coccia, V. (2020). Natural, bio-based, colored linoleum: Design, preparation, characteristics and preliminary life cycle assessment. Journal of Cleaner Production, 267, 122202. https://doi.org/10.1016/j.jclepro.2020.122202

Limestone/lime

Fig. 17
Crushed limestone. Image generated with Midjourney 6.0

Limestone or calcium carbonate is a sedimentary rock that is quarried in many places worldwide and around Baltic Sea region. Lime is produced by heating limestone ($CaCO_3$) to give off CO_2 and CaO (quicklime). Quicklime can then be reacted with water to produce hydrated lime ($Ca(OH)_2$) simply referred to as 'lime'. Lime has been used in construction as the main component of durable plasters/ renders/ mortar since the ancient times and continues to be one of the most important building materials today. Lime is also a significant ingredient of concrete. In buildings lime absorbs carbon dioxide from the atmosphere and over time becomes stronger as calcium carbonate crystals form (Van Balen, 2005).

Toxicity

Since lime is alkaline it is irritant and corrosive to skin, eyes and respiratory tract. Inhalation of dust should be avoided.

Climate

Lime production results in CO_2 emissions as it is released from heating limestone and the energy use for processing may also have a high climate impact. However, over time lime in buildings reabsorbs part of this carbon dioxide.

Circularity

Technically lime is "reusable", as by itself it can be fired and hydrated repeatedly. Although it is mainly used as a raw material within other materials used in construction products and is therefore not separable by its end-of-life stage. Building material such as concrete containing lime can be used for pavements and landscaping or as filling material. The degree of circularity is therefore considered as low.

Literature

Van Balen, K. (2005). Carbonation reaction of lime, kinetics at ambient temperature. Cement and concrete research, 35(4), 647-657.

3 Inorganic material

Clay

Fig. 18
Sun-dried clay bricks. Image generated with Midjourney 6.0

Clay is a natural sedimentary material abundant on the Earth's surface and it forms a part of soil. Clay has a vast number of uses and is widely used for construction purposes. It is not a single mineral, but it is composed of various clay minerals (aluminium silicates) and contains various metal ions that influence its colour, plasticity and other properties. Clay differs quite widely from location to location in terms of quality (purity), colour, texture, workability, but most types can be used for construction. Specific clay minerals, such as kaolin, a white clay mineral, can be used for special purposes, such as white wall plaster.

Unfired clay can be used as a structural material to produce cob, straw-bale and "Wattle and doub" wall constructions or shaped into bricks to produce adobe walls. However, unfired clay is prone to water damage. In warm and dry climates clay is a very popular structural material and it is less popular in wet climates due to this reason.

Fired clay materials (bricks and tiles) are often used in modern construction. Clay can also be used as plaster for interior walls and there are even clay paints.

Toxicity

Clay is non-toxic natural material and does not pose risks to the environment or health risks.

Climate

Clay is abundant in most locations, thus, the GHG emissions associated with locally sourced clay is minor. Clay preparation for use is not energy demanding and emissions from transport are considered low.

Circularity

As clay is a natural material, it can be returned to the nature. However, the potential for reuse or recycling will be case specific and depends on factors such as type of product, use of additives, adhesives, etc. Fired clay elements such as bricks and roof tiles may be reused although the local availability and economic feasibility may vary. The infrastructure for reuse of fired clay elements may depend on the region and recycling of the material occur in the form of use in landscaping and as filling materials. The degree of circularity can therefore be considered as fairly low, although it has a large potential due to its high durability.

Literature

Shubbar, A. A., Sadique, M., Kot, P., & Atherton, W. (2019). Future of clay-based construction materials–A review. Construction and Building Materials, 210, 172-187.

3 Inorganic material

Expanded clay

Fig. 19
Expanded clay perals for use in construction. Image generated with Midjourney 6.0

Expanded clay is a natural mineral product made from clay. These are light, porous almost potato or round shape granules of fired clay, produced by processing raw clay at extremely high temperatures (~1200°C). It has excellent thermal and acoustic insulation properties. Expanded clay is water resistant, because it quickly releases moisture. It is also resistant to fire, fungi, mould and harmful insects and rodents. An important feature is high compressive strength.

Expanded clay has several common uses, for example, in insulation and in concrete blocks, concrete slabs, lightweight concrete.

Toxicity

Material is inert, non-toxic in nature, with no hazardous additives. There is no dangerous leaching from expanded clay, even when in contact with soil, water or rain. It does not emit VOCs or any other dangerous substances.

Climate

Energy is used to expand the aggregate. For Expanded clay granulate; grain size 4/16, the total GWP per kg material (stages A1-A3) is 0.3771 kg CO2 eq./kg (Ökobaudat, 2023).

Circularity

Expanded clay is durable, has a long lifetime and requires no maintenance. Expanded clay is 100% recyclable or reusable (due to its high resistance, expanded clay can be used many times.). There are no problems with the disposing of demolition waste. The aggregate can be reused directly in another project if not physically damaged or polluted. It can also be incorporated in new blocks or go back into the production of new lightweight expanded clay aggregates. When expanded clay is used with concrete, it will be recycled as a concrete.

Literature

Agrawal, Y., Gupta, T., Sharma, R., Panwar, N. L., & Siddique, S. (2021). A comprehensive review on the performance of structural lightweight aggregate concrete for sustainable construction. Construction Materials, 1(1), 39-62.

3 Inorganic material

Gypsum

Fig. 20
Chunks of gypsum. Image generated with Midjourney 6.0

Gypsum (hydrated calcium sulphate $CaSO_4 \cdot 2H_2O$) is a naturally occurring abundant soft mineral that is of high commercial importance. It is mainly used in construction industry to produce gypsum plaster boards for drywall. Gypsum is also an ingredient in the composition of cement and in compositions of many different plasters. It is also used to cast various decorative plaster elements for the interior.

Gypsum, when mined, needs to be heated to a certain temperature for it to lose water. Dehydrated gypsum is then processed into plaster boards or added to plaster or other compositions. Dehydrated gypsum reacts with water giving of heat and setting into a solid form.

Toxicity

Gypsum is considered as non-toxic, however inhalation of dust should be avoided.

Climate

Manufacturing processes of gypsum mineral heating and gypsum plasterboard drying have the highest climate impact contribution during the life cycle along with the end-of-life treatment as landfill.

Circularity

Gypsum is technically recyclable and needs to be pulverised and re-heated. However, it is most commonly not recycled due to contaminants, lack of infrastructure for recycling and the low economic value. When not recycled into new gypsum it is instead treated as landfill.

Literature

Lushnikova, N., & Dvorkin, L. (2016). Sustainability of gypsum products as a construction material. In Sustainability of Construction Materials (pp. 643-681). Woodhead Publishing.

Plaster

Fig. 21
Wall plaster. Image generated with Midjourney 6.0

Plaster is a surface layer of mortar mainly used on facades and walls. Common types of plaster are lime plaster, cement plaster, lime cement plaster, clay plaster and gypsum plaster. There are also types of plasters with added polymers, such as synthetic acrylic, PVA, or natural polymers such as cellulose that improve the performance characteristics of the plaster.

Toxicity

Natural, mineral-based plasters usually do not require preservatives and do not contain any hazardous substances and can be considered safe from a toxicity point of view. However, plasters with organic or synthetic additives that are produced as liquid or wet products may require preservatives and may contain other additives with hazardous properties. Additionally, lime plaster tends to have high pH, thus, adequate protection should be used when handling lime plaster. Inhalation of any plaster dust can damage the respiratory tract; thus, appropriate protective measures should be used.

Climate

Different kinds of plaster have different climate impact during the during the A1-A3 stages (raw material extraction, manufacturing, and transportation) depending on production method and variations in raw material input. Clay plaster has the lowest climate impact, gypsum medium high and lime plaster the highest.

- Clay plaster has a GWP of 98.2 kg CO2 eq./kg A1-A3 (Ökobaudat, 2023)
- Gypsum plaster has a GWP of 112.3 kg CO2 eq./kg A1-A3. (Ökobaudat, 2023)
- Gypsum lime plaster has a GWP of 129.1 kg CO2 eq./kg A1-A3. (Ökobaudat, 2023)
- Lime-cement plaster has a GWP of 348.4 kg CO2 eq./kg A1-A3. (Ökobaudat, 2023)
- Lime plaster has a GWP of 397.7 kg CO2 eq./kg A1-A3. (Ökobaudat, 2023)

Circularity

Plaster has a service life of 40-60 years (Berge, p. 307). It's hard to recycle or reuse because it is a chemical product that is cured. However, it may be used for refurbishing of other construction materials such as walls etc. prolonging the lifetime of existing interiors. Generally, no renewable materials are used in the production. However, it is possible to mix lime with hemp, to make a hemp plaster (ECO construction guide, 2023).
Overall, mineral-based plaster is considered safe from a toxicity point of view. Plasters sold as liquid (or wet) products may contain preservatives, while some plasters products may have other additives, thus the safety should be checked on case-by-case basis. Additionally, plasters have quite high climate impact depending on what type of plaster it is. Clay and gypsum plasters have the lowest impact. It is currently not recycled or reused but is typically landfilled.

Literature

Berge, B. (2009) The Ecology of Building Materials. 75-76. Elsevier.

ECO construction guide. Material knowledge (in Swedish). (2023) https://www.ekobygguiden.se/kopia-p%C3%A5-v%C3%A4lja-r%C3%A4tt-material

Ökobaudat. https://www.oekobaudat.de/no_cache/en/database/search.html November 2023)

3 Inorganic material
Stone

Fig. 22
Stacked construction stones. Image generated with Midjourney 6.0

Stone is a natural material that has been used in construction for centuries. It is suited for load bearing and non-load-bearing elements due to not only the structural capability but also durability and aesthetics. Stone can be grouped in three main categories such as igneous, sedimentary and metamorphic rocks. Igneous rocks are the hardest type, an example of these is granite. Sedimentary rocks are such that are combined with organic materials, an example is limestone. Metamorphic rocks are sedimentary rocks that have been transformed in the structure, here an example is quartzite. As for sourcing of the material, two options can be distinguished – field stone and quarry stone. The typical application is in form of blocks, slabs, sheets or crushed parts. (Berge, 2009)

Toxicity

Stone is an inert material, and it does not pose any health risk to the indoor or natural environment during use. However, during extraction, construction, repairs or demolition, the dust particles of the material can cause skin or respiratory irritation. Furthermore, since stone might contain thorium and radium, the quarrying of the stone might emit radon gas and therefore increase the radiation level of the area (Berge, 2009). Attention must be paid also when using coatings, sealers, adhesives and mortars to bind and protect the material. At the end of life, as an inert material, stone alone does not possess any toxicity risk.

Climate

It is hard to pinpoint the climate impact of stone due to high variety of use and type of stone. If field sourced stone is used, the main contribution of GHG emissions is mainly from the transport but varies depending on the level of processing. If quarry is used for sourcing the stone additional emissions for this need to be considered. Local or regional sourcing is preferred to reduce the emissions from transport and assure a sustainable supply chain with minimum impact on local ecosystems.

To give an example, slate sheets that are typically used as cladding or roofing can be taken. The total GWP of slate sheets in Germany in A1-A3 stages have 15.39 kg CO_2 eq./m2 of material or 0.51 kg CO_2e/kg of material (ÖKOBAUDAT, 2023).

Circularity

Stone is very durable material and can usually outstand the lifetime of the building itself (Berge, 2009). However, it is very labour intensive to make changes over time in stone load-bearing construction, therefore, the use of the material should be carefully considered and optimized. On the other side, due to the durability, stone can be very well reused. The only limiting factor is the use of mortars that might complicate or limit the disassembly process. In terms of recycling, there is a well-established infrastructure for crushing stone. This crushed stone can then become a recycled content in other products. For this stage the infrastructure availability varies from country to country.

Stone can be used in all types of construction, from load bearing elements, such as foundation or walls, to finishes, both interior and exterior, and even insulation.

Literature

Berge, B. (2009). The Ecology of Building Materials. Elsevier/Architectural Press.

ÖKOBAUDAT. (March 2, 2023). Schieferplatten. ÖKOBAUDAT-Datensätze. Retrieved December 10, 2023, from https://oekobaudat.de/OEKOBAU.DAT/datasetdetail/process.xhtml?uuid=8847396e-ce82-433d-9f65-8bc144a2a7a4&version=20.23.050&stock=OBD_2023_I&lang=de

3 Inorganic material

Soil

Fig. 23
Fresh soil. Image generated with Midjourney 6.0

Soil is a material that derives from mineral or organic, decomposed products from animals and plants (Berge, 2009). Soil has a very wide possibility to be used in construction processes, it can be used raw in rammed earth constructions or as aggregate in concrete, it is also the primary ingredient of bricks and tiles.

Toxicity

Soil as a raw material typically is not toxic, however, the location of sourcing matters. If the area where it was sourced is polluted, there might be toxicity to the indoor or natural environment. During application the primary concern is dust particles which can cause skin or respiratory irritation. At the end-of-life stage, soil can be returned to nature without any toxicity risk, if there have been no toxic additives used in the construction process.

Climate

Soil extraction is low in energy intensity and often soil can be even used as a waste from other construction processes. No specific data on the climate impact of the material can be stated. It is typically assessed in the stage of building products.

Circularity

Soil as a stand-alone material can be endlessly recycled, this, however, changes when it is used as a content in other building products. The reuse possibility depends on the type of application. The durability and adaptability of soil is hard to define as the raw material is in a loose form and in most cases is used as a content for other materials and products. Soil which is removed during the construction phase may preferably be reused in local areas, to reduce emissions from transports of excavation masses. It is hard to define infrastructure for soil recycling and reuse. In Europe there are several companies that buy in soil that is extracted from construction processes, however, the availability of the service depends on region.

Soil can be found as a content in many mineral-based building products. As such, it is often found in load bearing building elements. But can be found also in finishes.

Literature

Berge, B. (2009). The Ecology of Building Materials. Elsevier/Architectural Press.

Ceramics

Fig. 24
Nordic style ceramic tiles. Image generated with Midjourney 6.0

Ceramic tiles are a suitable choice for many areas of the home. They are resistant to moisture and stains and do not absorb bacteria or odours. Ceramic tiles are made from naturally occurring inorganic materials such as clay. Therefore, ceramic tiles are a non-toxic material, provided that no toxic pigments are added.

Toxicity

Ceramic tile is made from naturally occurring materials and can be produced and maintained without toxic chemicals. Ceramic tiles are inert and do not emit potentially toxic substances to the indoor or natural environment.

Climate

There are GHG emissions associated with the production of ceramic tiles. During the process of heating, several gases are emitted, which include large quantities of GHGs.These gases contribute to ozone layer depletion and air pollution. Additionally, transporting ceramic tiles from the manufacturer to the site of construction results in additional emissions. No generic data on the climate impact of ceramic materials has been found in the used databases.

Circularity

At the end of their life cycle, discarded or removed tiles can be reused or recycled as hardcore for concrete. Recycling and reusing the material reduces the need for fresh raw materials, which lowers their environmental impact. It is important to note though that ceramic tiles placed in a landfill can take thousands of years to degrade, leading to environmental pollution.

Mineral wool

Fig. 25
Mineral wool insulation. Image generated with Midjourney 6.0

Mineral wool is a type of insulation material that is made from minerals, primarily basalt or rock. It is often used as thermal insulation in buildings, industrial applications, and appliances due to its thermal and acoustic insulation properties.

Toxicity

Due to its non-combustible properties (construction product class A1) there is no need of flame retardants. Similarly, the high durability means that there is no need for chemical treatment against mold. Hence, mineral wool generally has a low content of hazardous substances, making it safe for use indoors. However, certain older formulations or products may contain binders such as phenol-formaldehyde resins or isocyanates containing polyurethane resins and additives with potential health and environmental hazards. Newer products, however, use alternatives made from plant-based materials (e.g. soybean oil or starch) or water-based binders using acrylic.

One drawback is the health risk associated to respirable fibres, which one may get into contact with during implementation and dismantling (Sattler, Pomberger, Schimek, & Vollprecht, 2020).

The production process of both stone wool and glass wool involves melting and fiberization of raw materials, which are often recycled glass for glass wool and rocks for stone wool. The process may include binders, which can release volatile organic compounds (VOCs).

Older stone wool insulation materials may contain carcinogenic fibres, classifying them as hazardous waste (Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen, 2023). However, newer products have fewer concerns. Stone wool is non-combustible and cannot be incinerated for energy recovery, which limits end-of-life options.

Climate

The production of mineral wool does involve high-temperature processes, and there are environmental considerations associated with the energy consumption and emissions during manufacturing as this is often still fossil fuel based. Additionally, like any industrial process, there may be localized environmental impacts associated with the extraction of raw materials used in the production of mineral wool, which lead to ecosystem disruption and results in indirect impact on the climate.

Circularity

Theoretically stone wool insulation materials are reuseable. For products produced after year 2000 no general carcinogenic properties are expected. However, many older products and stocked goods produced before year 2000 but implemented thereafter, hold carcinogenic properties due to respirable fibres. It is then classified as hazardous waste (Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen, 2023). As stone wool insulation tends to be durable material, reused material will generally be produced before the 2000s. As stone wool is non-combustible it cannot be used for thermal recycling.

The infrastructure for material recycling of mineral wool materials may vary by region. Both stone wool and glass wool insulation materials often include recycled content, such as recycled glass. The availability and quality of recycled materials may vary.

Technically mineral wool can be recycled. However, this involves the melting down of the old material in order to form a new. This process is energy intensive. Additionally, the products tend to contain binders that may pose hazards to human and environmental health at this stage, especially when produced before the 2000s.

Literature

Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen. (22. August 2023). WECOBIS. Abgerufen am 1. September 2023 von Mineralwolle-Dämmstoffe - Nachnutzung: https://www.wecobis.de/bauproduktgruppen/daemmstoffe/aus-mineralischen-rohstoffen/mineralwolle-daemmstoffe.html

Sattler, T., Pomberger, R., Schimek, J., & Vollprecht, D. (2020). MINERAL WOOL WASTE IN AUSTRIA, ASSOCIATED HEALTH ASPECTS AND RECYCLING OPTIONS. (09, pages 174-180).

Glass foam

Fig. 26
Glass foam insulation panel. Image generated with Midjourney 6.0

Glass foam (porous blown glass) is manufactured by melting glass cullet with a chemical foaming agent, often carbon-black or limestone. Glass foam is produced in various forms: slabs, boards, granules or profiled parts. Its advantages include light weight, high strength, good load-bearing properties, chemical and biological resistance, and thermal and acoustic insulating properties (Adhikary et al., 2021; da Silva, 2021).

Toxicity

Glass foam is non-toxic and does not release harmful or toxic substances into the environment. It does not contain carcinogenic particles and fibres. Fire-resistancy is an advantage of glass foam in itself; also, flame retardants, many of which are toxic, are not necessary.

Glass dust and small amounts of hydrogen sulfide gas may be released during cutting and processing of this material (Wilson, 2016; Pittsburgh Corning Europe NV, 2021).

Climate

Production of glass foam is energy intensive. For expanded glass granulate, the total GWP per kg material (stages A1-A3) is 3.442 kg CO_2 eq./kg (ökobaudat).

Circularity

If bitumen has not been used (sometimes needed for the installation of slabs) and the material has been properly removed without damaging it, it can be reused.

It is a very durable material, significantly reducing maintenance and replacement cycles. Glass foam is sometimes made from recycled glass. Glass can be recycled multiple times without reducing the quality, thus saving energy and avoiding emissions. The waste in production- foam glass powder and scrap can also be used as filler for decorative lightweight concrete and other purposes (da Silva, 2021).

Literature

Adhikary S.K., Ashish D.K., Rudzionis Z. (2021) Expanded glass as light-weight aggregate in concrete – A review. Journal of Cleaner Production, 313, 127848. https://doi.org/10.1016/j.jclepro.2021.127848

da Silva R.C., Puglieri F.N., de Genaro Chiroli D.M, Bartmeyer G. A., Kubaski W. T., Tebcherani S. M. (2021) Recycling of glass waste into foam glass boards: A comparison of cradle-to-gate life cycles of boards with different foaming agents. Science of the Total Environment 771, 145276. https://doi.org/10.1016/j.scitotenv.2021.145276

Wilson A. (2016). Foamglas insulation: a great option for below grade. Building Green, September 29. Reprinted in Building Science, Energy Efficiency, June 26, 2019. https://www.sbcmag.info/news/2019/jun/foamglas-insulation-great-option-below-grade

Pittsburgh Corning Europe NV (2021) Environmental product declaration. Declaration No. EPD-PCE-20200300-IBB1-EN. Product: FOAMGLAS® T3+. www.ibu-epd.com / https://epd-online.com

Gypsum board

Fig. 27
Drywall plasterboard. Image generated with Midjourney 6.0

Gypsum board is the technical product name used by manufacturers for a specific board with a gypsum core and a paper facing. There are two types of gypsum boards:
- Regular Gypsum Board – a gypsum board with naturally occurring fire resistance from the gypsum in the core and
- Type X Gypsum Board – a gypsum board with special core additives to increase the natural fire resistance of regular gypsum board.

Toxicity

The production of gypsum boards, also known as drywall or plasterboard, requires a combination of various materials and additives to achieve specific properties and performance characteristics. Gypsum is the primary ingredient in gypsum board production, and it can be sourced from natural gypsum or synthetic gypsum. The gypsum provides the core structure and strength of the board, and its properties, such as fire resistance and moisture resistance, can be tailored by altering the gypsum's chemical composition or by adding specific additives.

The front and back surfaces of gypsum boards are typically covered with paper facing, which can be made from recycled paper, kraft paper, or cellulose fibre. The paper facing not only protects the gypsum core but also provides additional strength and durability to the board. In some cases, specialty paper facings, such as mold-resistant or fire-resistant paper, can be used to enhance the board's performance. Cellulose fibres are a common reinforcement material used to improve the bending and impact resistance of gypsum boards. These fibres are often added to the gypsum slurry during the mixing process and can be sourced from various plant-based materials, such as wood pulp or recycled paper. Foaming agents are used to create air bubbles in the gypsum slurry, reducing the density of the gypsum board and enhancing its sound insulation and thermal insulation properties. These agents are typically added during the mixing process and can be derived from natural or synthetic sources. Fire retardants, such as glass fibres or expanded gypsum, can be added to gypsum boards to improve their fire resistance. These additives help to slow down the spread of flames and prevent structural damage in the event of a fire. Fungicides are used to inhibit the growth of mold and mildew on the surface of gypsum boards, enhancing their resistance to moisture and humidity. Silicates are commonly used as accelerators to speed up the setting time of the gypsum slurry, increasing production efficiency. While some of these components can be harmful by themselves, the whole product is generally non-toxic during its intended use; certain health risks can arise during cutting and installation phase where fine particles (dust) from the boards can be inhaled. Appropriate personal protective equipment (e.g. respirators) should always be used. Volatile organic components that are typically problematic for some similar types of materials (e.g. glued or laminated boards) are not causing major concerns for gypsum boards that usually have very low emissions.

Climate

The climate impact mainly results from energy and water use during manufacturing. GHG emissions from transport are generally low due to the local production within the Baltic region. The amount of water used directly affects the setting time, strength, and hardness of the board. To optimize these properties, the water-to-gypsum ratio is carefully controlled during the manufacturing process.

Circularity

Gypsum panels incorporate recycled paper and the gypsum itself can be reused for production of new boards if paper facers are removed.

Paper facers have been made from recycled paper for more than 50 years. Using flue gas desulfurization (FGD) gypsum in gypsum panel products is also one of the sustainable directions as FGD gypsum is a non-hazardous secondary material and substitute for natural gypsum. There is high potential for collecting and recycling scrap gypsum board however the infrastructure for material recycling is not yet widely developed. New construction projects generate a significant amount of scrap gypsum board. An estimated 10 percent of the gypsum board necessary for a new building ends up as scrap. These cut-offs can be source separated on the job site to prevent contamination with other materials and sent to processors who remove the paper facers.

Literature

Gypsum Association home page. Information on sustainability of gypsum panels. Available: Recycling – Gypsum Association

Healthy building network. (2022) Embodied Carbon and Material Health in Gypsum Drywall and Flooring. Summary report.

Lau Jack. Key Materials and Additives Used in Gypsum Board Production. (2023) Available: Key Materials and Additives Used in Gypsum Board Production linkedin.com

Fibre cement board

Fig. 28
Fibre cement interior plates. Image generated with Midjourney 6.0

Fibre cement is a very durable building material. It is hard as rock, yet versatile as wood. Fibre-cement combines the advantages of many alternatives in one, making it a worthwhile solution for facades, roofs or terraces. Cement bonded particle boards have treated wood flakes as reinforcement, whereas in cement fibre boards have cellulose fibre, which is a plant extract as reinforcement. Cement acts as binder in both the cases. The fire resistance properties of cement bonded blue particle boards and cement fibre boards are the same.

Toxicity

Certain manufacturers use different ingredients to make fibre cement siding, but most include Portland cement (limestone, clay, and iron), sand or fly ash, water, and cellulose fibres or wood pulp. Some manufacturers add a few proprietary ingredients for binding and durability. Brittle and dusty. It's brittle and prone to cracking; when cut through, it produces fine silica dust, which requires a protective dust mask during installation because fine silica dust is harmful to breathe in.

Climate

Clinker (used in cement) production is energy intensive and produces direct emissions of CO2 when the lime is heated. The ingredients in cement require quarrying, and cement production generates 8% of the world's GHG emissions. For more information see the section on Cement below.

Circularity

Fibre cement boards are not recyclable but could be used as filling material. When it eventually breaks down, it is inert and not toxic.

Some manufacturers have made material substitutions to reduce the environmental impact, like replacing silica with fly ash to make it less of a health concern for installers and replacing ingredients to make their products with locally sourced, recycled materials, using low-volatile organic compounds, and recaptured water during processing.

Literature

Bernard M. 2023. What Is Fiber Cement Siding? Benefits, Disadvantages, and More. The spruce home page. Available: https://www.thespruce.com/green-fiber-cement-board-1821774

Mary Read. 2022. How sustainable is fiber cement siding? Green Building Canada. Article available here: How Sustainable Is Fiber Cement Siding? | Green Building Canada

MDF

Fig. 29
Stacked MDF boards. Image generated with Midjourney 6.0

Medium Density Fibreboard (MDF) is made from wood fibres extracted from wood residues and bonded together with resins and wax at high temperature and pressure. MDF was invented in the 60s in the US and in the 90s became widely adopted worldwide. The largest producer worldwide is China, followed by Germany and the US but manufacturers of MDF can be found in all continents except Africa.

Toxicity

The resins used in the MDF production, such as urea formaldehyde resin or phenolic resin are emitted as dust in the workplace. They contain unhealthy substances like formaldehyde and other VOCs. MDF off gasses some formaldehyde, a carcinogenic gas, when it is new. The emissions are highest during the first year. E0 or formaldehyde-free MDF, as well as E1 MDF, is preferable due to lower emissions to indoor air. Protecting equipment is needed to avoid breathing dangerous dusts in the workplace. Alternative materials to MDF that are considered as not toxic are bamboo panels, bamboo stems, scaffolding wood, soft wood.

Climate

The production of MDF requires high energy and pressure, comparable to particle board, OSB and plywood and the manufacturing is more energy intensive compared to drying of wood. However, the use of waste streams such as wood residues, result in a reduced climate impact. Alternatives that have low embodied energy are reclaimed wood, scaffolding wood, bamboo stems, construction site wood. Opting for PEFC or FSC- certified OSB helps to assure a sustainable value chain, which reduces the indirect GHG emissions from land use.

Circularity

Some contradictions emerge when looking at the circularity aspects. For example, material has a low environmental impact as MDF is mainly made of sawmill byproducts: woodchips and sawdust. Production of it is a low cost because MDF is cheaper than wood and plywood as a panelling material. Negative aspects include short lifespan compared to more durable materials such as wood or plywood. It is not recyclable, however, energy recovery through incineration may be used for end-of-life treatment. It is also not resistant to humidity, although it is possible to find a moisture resistant MDF materials as well.

Literature

Puettmann M., Oneil E., Wilson J. (2013) Cradle to Gate Life Cycle Assessment of U.S. Medium Density Fiberboard Production. Ecocost database of Delft Technical University. Available: Home - Sustainability Impact Metrics (ecocostsvalue.com)

OSB

Fig. 30
Construction OSB sheet. Image generated with Midjourney 6.0

OSB (Oriented Strand Board) is a material produced from large wood shavings glued together with resins and wax applying high heat and pressure. It is becoming more and more popular, especially in constructions to substitute plywood, due to its good strength and lower price.

Toxicity
OSB is usually made with resins that contain less formaldehyde than plywood, MDF and particleboard. Although OSB releases less free formaldehyde than e.g., plywood and MDF, it emits certain amounts of VOCs, out of which higher aldehydes, such as pentanal, hexanal and heptanal are the most problematic. They occur both naturally and as a result of reaction between wooden material and PMDI that is the most commonly used binder for these types of boards. The emissions drop sharply within a month after production and tend to reach equilibrium after 6 months in well-ventilated areas. There is available formaldehyde free OSB in the market.

Climate
OSB needs high heat and pressure to be produced, just like plywood, particleboard and MDF. OSB can come in larger panels than other wood products, and it require less polishing because of its rough appearance. Total GWP for OSB building products constitutes 0,448 kg CO_2 eq./kg (Boverket, 2023).

Circularity
OSB can be made from narrower, faster growing trees than plywood and is considered by many to be a “green” building material because it can be made from smaller-diameter trees, such as fast-growing poplars. OSB panels are cheaper than plywood, it is a low-cost material. The material has a generally short lifespan due to lower durability compared to wood panels. OSB is very vulnerable to swelling or de-lamination if exposed to hot temperatures or humidity and cannot be easily reused. OSB waste can be incinerated with energy recovery or, to some extent, after shredding re-used for PB production.

Literature
Benetto, E., Becker, M., & Welfring, J. (2009). Life cycle assessment of oriented strand boards (OSB): from process innovation to ecodesign. Environmental Science & Technology, 43(15), 6003-6009.

Sugahara, E., Dias, A., Botelho, E., Campos, C., & Dias, A. (2023, June). Life Cycle Assessment of OSB Panels Produced with Alternative Raw Materials. In International Conference on Bio-Based Building Materials (pp. 959-972). Cham: Springer Nature Switzerland.

Plywood

Fig. 31
Plywood sheet with groove. Image generated with Midjourney 6.0

Plywood is an engineered wood product made of thin layers of wood glued together. Rotating the direction of wood grain in each layer gives plywood panels good strength. The environmental profile of plywood depend its ingredients: wood and glue. It is always better to choose for FSC certified and local wood types. Eco plywood is available, using glues with lower VOC and formaldehyde emissions. Outdoor grade plywood should not be used indoor because both the glue and the wood have larger environmental impacts.

Toxicity

Most concerns regarding material is a VOC & formaldehyde content in emissions. Look for E0 or formaldehyde free plywood to minimize off gassing of plywood products. Alternatively make sure you use E1 plywood, that's the minimum legal requirement in many countries.

While OSB does not use urea-formaldehyde-based resins, plywood can be produced with them. Hence, if considering emissions of free formaldehyde, plywood will typically have higher levels than OSB.

Plywood, OSB, and other engineered wood products that contain glue can be stored outdoors for several weeks before construction so that much of the dangerous gasses are vented safely into the outdoors.

Climate

Production of plywood is energy intensive. The manufacturing of plywood uses much more energy than wood however the emissions from the raw material extraction is lower. Choose FSC certified plywood to make sure your plywood does not contribute to unsustainable deforestation which can lead to indirect climate emissions.

Circularity

Plywood is easy to work with because it is uniform and strong. It has a long lifespan and is durable and resistant, that can make long lasting products. Because of its durability, plywood can be easily reused. Infrastructure for material recycling is not yet fully in place and the main end-of-life treatment is incineration with energy recovery.

Literature

Wood guide organization. Online reports. Available: OSB_ECO_EN.indd (woodguide.org)

CLT

Fig. 32
CLT board. Image generated with Midjourney 6.0

CLT (cross laminated timber) panels are made by gluing wooden planks together in crosswise manner, as a result large panels can be made and cutouts for openings like doors and windows can be made in production plant, this approach makes working on site much easier.

Toxicity

it is estimated that larger cuttings have around 2 % of adhesive. Today CLT is mainly produced using urea-formaldehyde (UF) or polymer iso-cyanine adhesives like polyurethane. UF resins cause toxic fumes, hence the use of polyurethane can reduce the negative impact of the final product. In addition, fatty acids in polyurethane production can be replaced by renewable canola oil reducing the negative environmental impact of polyurethane itself.

CLT residues comprise of sawdust from cutting and finger-jointing, and cuttings made from crosswise laminated planks.

Climate

It does not require as much electricity compared to particleboard production because it does not need to be dried, however the emissions from raw material extraction are higher due to the higher quality material. Total GWP for CLT panels constitutes 0,12 kg CO2 eq./kg (Boverket, 2023). The climate impact from transport is generally low due to the local production.

Circularity

With the developed CLT reprocessing technology, around 70 % of the generated cuttings can be reused for new full-size panel production. CLT are incinerable with energy recovery, recyclable for production of other boards e.g., particle board, MDF.

Literature

Vamza Ilze et al., 2021. Complete Circularity in Cross-Laminated Timber Production. Environmental and Climate Technologies. 2021, vol. 25, no. 1, pp. 1101–1113

Particleboard or chipboard

Fig. 33
Stacked chipboards. Image generated with Midjourney 6.0

Particleboard, or chipboard, also known as MFC, is today the most used wood products in furniture. Standard particle board is typically used as surface material indoor. It is an engineered material made of woodchips bound together with resins into panels at high temperature and pressure. Particleboard products are known for problematic off gassing of formaldehyde gas. However, the sustainability profile of particleboard has improved in the past two decades, thanks to stricter regulation. Since recently formaldehyde-free particleboard is also available.

Toxicity

Dust from working with particleboard can be carcinogenic or create respiratory issues, because of the resins contained in the material. Safer alternatives are OSB, bamboo panels, bamboo stems, scaffolding wood, soft wood. When working with particleboard that is not formaldehyde-free, very-low-formaldehyde or E0 there are dangerous dusts in the workplace. Use masks and extraction equipment to avoid breathing them. E0, formaldehyde-free or very-low-formaldehyde particleboard is generally safer. E1 quality, is the minimum legal requirement in the EU and other countries.

Climate

Manufacturing of the resins and the panels themselves require a lot of energy. Depending on where it is produced, it is around the same as MDF or plywood. Alternatives that have low embodied energy are reclaimed wood, construction site wood, used pallets, bamboo stems, scaffolding wood, second hand particle. Since it is produced from the byproduct, sawdust, emissions from extraction of raw material are generally low. Global warming potential for particle boards constitutes 0,488 kg CO_2 eq/kg (Boverket, 2023). The climate impact from transport is generally low due to the local production.

Circularity

Material has a low footprint because particleboard is made of sawmill waste from the production of cut wood. It has a low cost for production. Particle board is popular because it is the cheapest wood board material. It can be recycled into MDF if the original material used to produce it was of good quality.

Literature

–Home - Sustainability Impact Metrics (ecocostsvalue.com)

3 Metals / alloys

Aluminium

Fig. 34
Sheets of aluminium. Image generated with Midjourney 6.0

Aluminium is extensively used in the construction industry due to its strength, light weight, and resistance to corrosion. It Is employed in a variety of applications such as window frames, roofing, cladding, and structural components. The flexibility and the ability to be easily changed into a new shape make aluminium ideal for designing intricate shapes, crucial in modern architecture.

The extraction of aluminium primarily from bauxite ore involves significant environmental implications, including land degradation and habitat loss in mining areas. However, the largest environmental impact comes from the energy-intensive process of converting bauxite into aluminium, especially during the smelting process. This stage contributes notably to the carbon footprint of aluminium used in construction.

Toxicity

Aluminium (the metal) is not considered as toxic to neither humans nor nature. However, the extraction can have negative impact. Aluminium is primarily extracted from bauxite ore and the process places a significant burden on the natural environment, leading to deforestation, soil erosion, and a loss of biodiversity in mining areas. Aluminium mining and refining also contribute to water pollution whereas aluminium as such is generally not toxic to aquatic life. Aluminium compounds in high concentrations can be harmful to plants and animals. In terms of human use, aluminium is widely used in food packaging, cooking utensils, and water treatment processes. While there is some concern about its leaching into food and water, the levels are typically well below those considered harmful.

Climate

The production of aluminium, particularly primary aluminium, is associated with high GHG emissions due to the high energy use. However, the industry is moving towards more sustainable practices, including the use of renewable energy sources in production processes. The use of recycled aluminium in construction significantly lowers the overall climate impactof the material.

Circularity

Aluminium's recyclability is a key factor in its use in construction. Recycling aluminium requires only about 5% of the energy needed to produce primary aluminium, substantially reducing its environmental impact. The construction industry benefits from this, as recycled aluminium retains its properties and can be reused in various applications, reducing the need for new material extraction. The high recyclability of aluminium adds to its economic viability in the construction sector. With a large percentage of aluminium being recycled, the demand for primary aluminium is reduced, leading to lower environmental impacts. The longevity and low maintenance requirements make it a cost-effective material over the long term.

In construction, aluminium contributes to energy efficiency, especially in modern building designs. Aluminium frames in windows and facades, for example, enable advanced glazing techniques that improve insulation. Its durability means that aluminium structures can last for decades with minimal maintenance, further enhancing its sustainability credentials.

While the initial environmental impact of aluminium production is considerable, its advantages in the construction industry, particularly regarding circularity, toxicity, and climate impact through energy efficiency, make it a favourable material in many aspects. However, due to the current high demand for aluminium and scarcity of recycled aluminium, use of the material should be carefully considered to assure an optimized use of aluminium from a system perspective. Continued efforts in increasing the use of recycled aluminium and renewable energy in production processes are essential for minimizing its environmental impact.

Anodized aluminium

Fig. 35
Anodized aluminium material samples. Image generated with Midjourney 6.0

Anodised aluminium is aluminium that has undergone an electrochemical process to create a durable, corrosion-resistant, aesthetically pleasing surface with low maintenance requirements. Anodised aluminium can be dyed in a wide variety of colours, making it a popular choice for decorative applications. It can serve as a substitute for copper, zinc, and other metal sheets in outdoor applications.

Toxicity

Anodised aluminium does not contain or release any hazardous substances into the environment.

Climate

Anodised aluminium consists of aluminium metal and alloys. The anodising process itself does produce some indirect greenhouse gases. The primary indirect greenhouse gas emitted is sulphur dioxide (SO_2), released during the reduction of sulfuric acid, the primary electrolyte used in anodizing. The source of electricity used to power the anodising process is also a significant factor. Anodising aluminium process has a total GWP per 2 sqrm metal sheet (modules A1-A3) 6.119 CO_2 eq./ kg (Ökobaudat, 2023).

Circularity

Anodised aluminium can be recycled in the same manner as standard aluminium. However, note that any surface treatments may introduce contaminants and affect the recyclability.

Literature

Aluminum anodizers council. Aluminum Anodizing and the Environment- AAC, retrieved 14 dec 2023.

3 Metals / alloys

Copper

Fig. 36
Copper sheets. Image generated with Midjourney 6.0

Globally copper is extracted mainly in Congo, Zimbabwe, Canada, USA and Chile. Copper entails a heavy burden on the natural environment and reserves are very limited. It is toxic to aquatic life and even though a big amount is recycled the use of copper will increase the leaching to the environment (Berge, 2009). Copper is used e.g. as facade and roof-material, copper pipes, cables and in plumbing and sanitary installations.

Toxicity

Copper is an essential nutrient but in free form it is toxic to aquatic organisms and when exposed to heavy rain copper leaches to the environment, especially if the rain is acid (Berge, 2009). This makes copper a less suitable material in the outdoor environment from a toxicity and environmental point of view. In the indoor environment copper does not contribute to leaching to the environment but copper pipes can leach to drinking water or water treatment sludge.

Climate

In copper production most of the energy is consumed in the melting process in the smelter. The copper production contributes to 0.2-0.3% of the global emission of CO2 (Mensell, 2023). Exact amount of energy needed varies because of the ore content and the climate impact also varies depending on what energy source that is used. In primary copper production much more energy is needed than in secondary copper production, recycling copper saves up to 85% of the energy needed in primary production (Jingjing et al. 2019). It is best to choose copper with a high content of recycled post-consumer stage material from a manufacturer that uses mainly renewable energy sources. Even though much copper is recycled, the use of copper continues to expose organisms to its toxicity.

The generic global warming potential for copper sheets depends on the content of recycled material and as seen below the difference in climate impact is big between 50% recycled copper and 97% recycled copper in a product.

Copper sheets with 51% recycled content has a total GWP of 2,5 CO2 eq./kg according to the Boverket climate database (Boverket, 2023). Copper sheets with 97% recycled content has a total GWP of 0,6 CO2 eq./kg (Boverket, 2023).

Circularity

Copper has a very high durability and can be recycled and remelted an indefinite number of times. It also retains up to 95% of the original value (Copper alliance, 2023). Most copper, about 60%, in Western Europe is recycled and within construction and infrastructure it is even more (Ciassi et al. 2020). Globally about 40% of copper is recycled (Copper alliance, 2021). However, there are potential for improvement regarding the recycled proportion of copper. There are limited reserves of copper and even if a lot of copper is recycled it will always be a finite resource. Use of the material should therefore carefully be considered to assure an optimized use from a system perspective.

Overall, copper is not a sustainable construction material because of the toxicity, potential of leaching to the environment when in contact with water and the high climate impact. On the plus side most copper is recycled.

Literature

Berge, B., (2009) The Ecology of Building Materials. 75-76. Elsevier.

Boverket. 51% recycled copper. https://www.boverket.se/en/start/building-in-sweden/developer/rfq-documentation/climate-declaration/climate-database/GetResourceByCategoryID/ (November 2023)

Boverket. 97% recycled copper. https://www.boverket.se/en/start/building-in-sweden/developer/rfq-documentation/climate-declaration/climate-database/GetResourceByCategoryID/ (November 2023)

Ciassi, L., Fishman, T., Elshkaki, A., Graedel, T.E., Vassura, I. et al, (202) Exploring future copper demand, recycling and associated greenhouse gas emissions in the EU-28. Global Environmental Change 63. https://www.sciencedirect.com/science/article/abs/pii/S0959378019313251

Copper alliance. (2021) Circular Copper: Building a Culture of Sustainability. https://copperalliance.org/resource/circular-copper-building-a-culture-of-sustainability/

Copper alliance. (2023) Copper - the World's Most Reusable Resource. https://www.copper.org/environment/lifecycle/g_recycl.html

Jingjing, C., Zhaohui, W., Yufeng, W., Liquan, L., Bin, B., et al. (2019) Environmental benefits of secondary copper from primary copper based on life cycle assessment in China. Resources, Conservation and Recycling 146, 35-44.

Mansell, G. (2023) Understand your copper emissions. https://www.carbonchain.com/blog/understand-your-copper-emissions

3 Metals / alloys

Steel

Fig. 37
Slightly rusted steel sheets. Image generated with Midjourney 6.0

Steel is a material of mineral origin and derives from iron ore. Steel is a widely used construction material and is well known for its durability and strength. It is an alloy, made of iron and varying amounts of carbon. Upon the type of steel, other alloys might be added.

Toxicity

Steel can be considered a safe material as it does not release any harmful substances during the construction and use stage of a building. However, the production of steel releases substances into air and water which are not good for the environment or people. For example, the coking process in steel production produces highly toxic wastewater with cyanide, sulphides, ammonium and ammonia, while naphthalene is released into the air (The World Counts, n.d.)- all of these having the potential to cause cancer. Whereas the smelting process releases arsenic (Berge, 2009). Since steel is inert, it does not leak any substances to the environment if dumped at the end of life (Berge, 2009).

Climate

The extraction of iron ore used in steel production is done in open quarries, this affects the groundwater and local ecosystem (Berge, 2009). Furthermore, production of iron and steel is one of the most energy-consuming industrial activities and as such contribute to large amounts of GHG emissions(OECD, 2010).

The climate impact varies depending on the recycled content. If the material is primary and the steel is produced in Sweden the total GWP for stages A1-A3 it is 3.15 kg CO_2e/kg (Boverket, 2023). Recycled steel (post-consumer stage) has ca 30-50% lower climate emissions depending on alloy and production region.

Circularity

Steel is a fully circular material as it can be 100% recycled without any loss of quality. Although surface treatments may contaminate the material and complicate the recycling process. As such it is highly relevant for achieving circular economy in construction sector (European Economic and Social Committee, 2023). The availability of steel with recycled content is also rather well established, although it varies depending on type of steel. Furthermore, the durability of steel, use of standardised dimensions and the typical manner of steel element assembly in a building potentially enables not only recycling but also direct reuse of the elements. This also has the highest impact of emission reductions. However, for such practices the legislative framework for element safety still needs to be developed along with improvements in infrastructure forreuse of building products

Typically, steel is used for high-rise constructions but can be found also in other types of buildings as main load bearing or integrated as a hybrid construction. It is used both in vertical and horizontal structures above and underground.

Literature

Berge, B., (2009) The Ecology of Building Materials. 75-76. Elsevier.

Boverket. (March 2, 2023). Structural steel, primary material. Boverket climate database. Retrieved December 10, 2023, from https://www.boverket.se/en/start/building-in-sweden/developer/rfq-documentation/climate-declaration/climate-database/GetResourceByCategoryID/

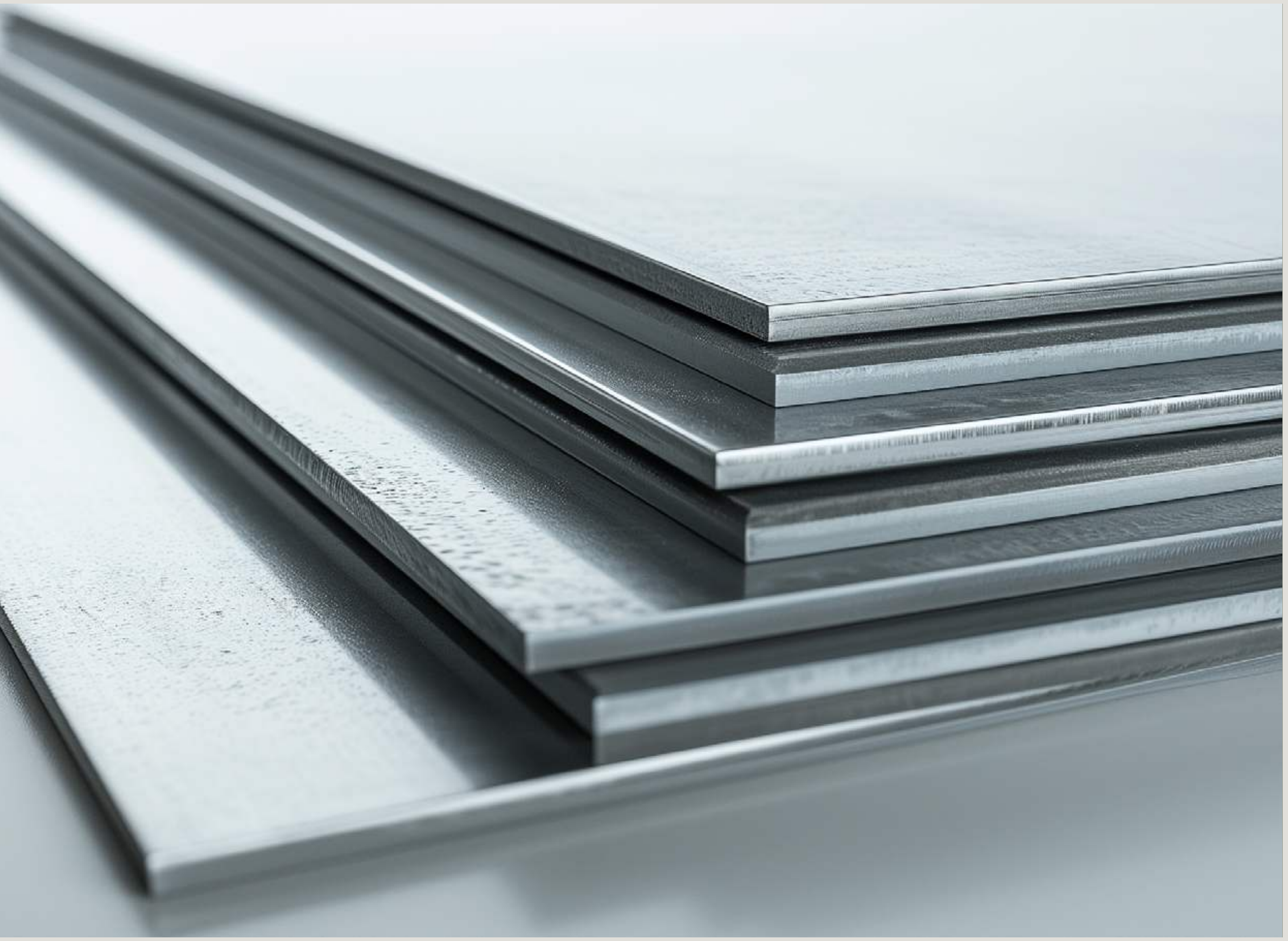
European Economic and Social Committee. (January 24, 2023). Sustainable recycling, use of secondary raw materials and Just Transition in the European ferrous and nonferrous metal industry. European Economic and Social Committee |. Retrieved September 7, 2023, from https://www.eesc.europa.eu/en/our-work/opinions-information-reports/opinions/sustainable-recycling-use-secondary-raw-materials-and-just-transition-european-ferrous-and-nonferrous-metal-industry

OECD. (2010). Eco-Innovation in Industry: Enabling Green Growth. OECD Publishing.

The World Counts. (n.d.). Environmental Impact of Steel. The World Counts. Retrieved September 8, 2023, from https://www.theworldcounts.com/challenges/planet-earth/mining/environmental-impact-of-steel-production

Galvanised steel

Fig. 38
Galvanised steel sheets. Image generated with Midjourney 6.0



Galvanization is a coating with a thin layer of zinc and it extends the life of steel structures by preventing corrosion (Berge, page 80). More than 50% of the zinc consumed in the world every year is used for galvanization (American galvanizers association, 2023). The galvanisation has a function of anti-corrosion and is used on steel when it needs to have a protection against oxygen and corrosion. This means that it is used very much in the outdoor environment on roofs, drainage, poles etc.

Toxicity

Zinc is considered toxic to organisms living in water. Zinc from galvanised steel products in the outdoor environment can leach to stormwater, rivers and lakes when exposed to precipitation (Berge, 2009, p. 80). This makes galvanised steel a less suitable material from a toxicity and environmental point of view.

Climate

Metal production is energy intensive, both in the mining phase and in refining processes. Much energy is consumed in the melting process in the smelter.

The zinc is a very small part of galvanised steel, hence the climate impact of steel is suiting to use instead. The generic value for the total GWP of light weight steel profiles for phase A1-A3 is 3 CO2 eq./kg according to the Boverket climate database. It is the same GWP for zinc coated steel plates according to (Ökobaudat, 2023), 3.1 kg CO2 eq./kg.

Circularity

A large amount of steel is recycled because of the high value of secondary raw material. In ordinary air conditions, one can assume a lifespan of up to 70 years for galvanized steel compared to other types of steel. From a circularity perspective galvanised steel can be considered a good alternative to use when it is risk of corrosion to prolong the lifetime. The frequency of reuse may depend on the installation and type of product.

Overall, galvanised steel is not a sustainable choice for facades because of the toxicity, potential of leaching to the environment when in contact with rain and the high climate impact.

Literature

Berge, B., (2009) The Ecology of Building Materials. 75-76. Elsevier.

Boverket.https://www.boverket.se/en/start/building-in-sweden/developer/rfq-documentation/climate-declaration/climate-database/GetResourceByCategoryID/ (November 2023)

American Galvanizers Association. Zinc: The healthy metal. https://galvanizeit.org/galvanize-it-online-seminar/structural-steel-reliable-resilient-recyclable/zinc-healthy-metal (2023)

Ökobaudat.https://www.boverket.se/en/start/building-in-sweden/developer/rfq-documentation/climate-declaration/climate-database/GetResourceByCategoryID/ (November 2023)

Stainless steel

Fig. 39
Stainles steel poles. Image generated with Midjourney 6.0

Stainless steel is an iron alloy that contains mainly iron, more than 12% chromium and more than 7% of nickel. It is used as corrosion protection, since the chromium with the help of oxygen, the chromium forms a layer of chromium oxide that protects the steel from corrosion.

Toxicity

The material itself is considered safe from a toxicological point of view but chromium and nickel used in the production are hazardous substances.

Climate

Metal production is energy intensive, both in the mining phase and in refining processes. Much energy is consumed in the melting process in the smelter. Raw material extraction of chromium and nickel also results in higher climate impact compared to low-alloyed steel.

The climate impact of steel depends on the content of recycled material.

Primary light weight steel profile has a total GWP of 3 $CO2$ eq./kg for phase A1-A3 according to the Boverket climate database (Boverket, 2023). Stainless steel sheets has about the same GWP , 3.62 $CO2$ eq./kg for phase A1-A3 (Ökobaudat, 2023).

Circularity

Stainless steel is a highly recyclable material and a large amount is recycled because of the high value of secondary raw material. For more information see the section on Steel above.

3 Metals / alloys

Zinc

Fig. 40
Zinc coated roofing sheets. Image generated with Midjourney 6.0

The biggest producers of zinc are China, Peru and Australia (Government of Canada, 2023). The construction and infrastructure industries are the biggest users of zinc. Zinc sheets can be used as e.g. roof material, facade material and as pigment in paints and corrosion protection. Zinc has a function that is anti-corrosion.

Toxicity

Zinc is considered toxic to organisms living in water. Zinc from products in the outdoor environment can leach to stormwater, rivers and lakes when exposed to precipitation (Berge, 2009 p. 80). This makes zinc a less suitable material from a toxicity and environmental point of view.

Climate

Metal production is energy intensive, both in the mining phase and in refining processes. Energy is consumed in the melting process in the smelter and the climate impact is high, especially in primary raw material. From a climate perspective, zinc materials with a high content of secondary raw material are preferred.

Circularity

There are limited reserves of zinc, and it is a finite resource (Berge, 2009 p. 80). About 25% of all zinc is recycled, this means that out of 13 million tonnes used globally in production every year about 4 million tonnes are recovered and recycled (Government of Canada, 2023). Zinc used as surface treatment for e.g. steel may prolong the lifespan of the material.

Overall, zinc is not a sustainable construction material because of the toxicity, potential of leaching to the environment when in contact with water and the high climate impact. On the plus side a lot of zinc is recycled.

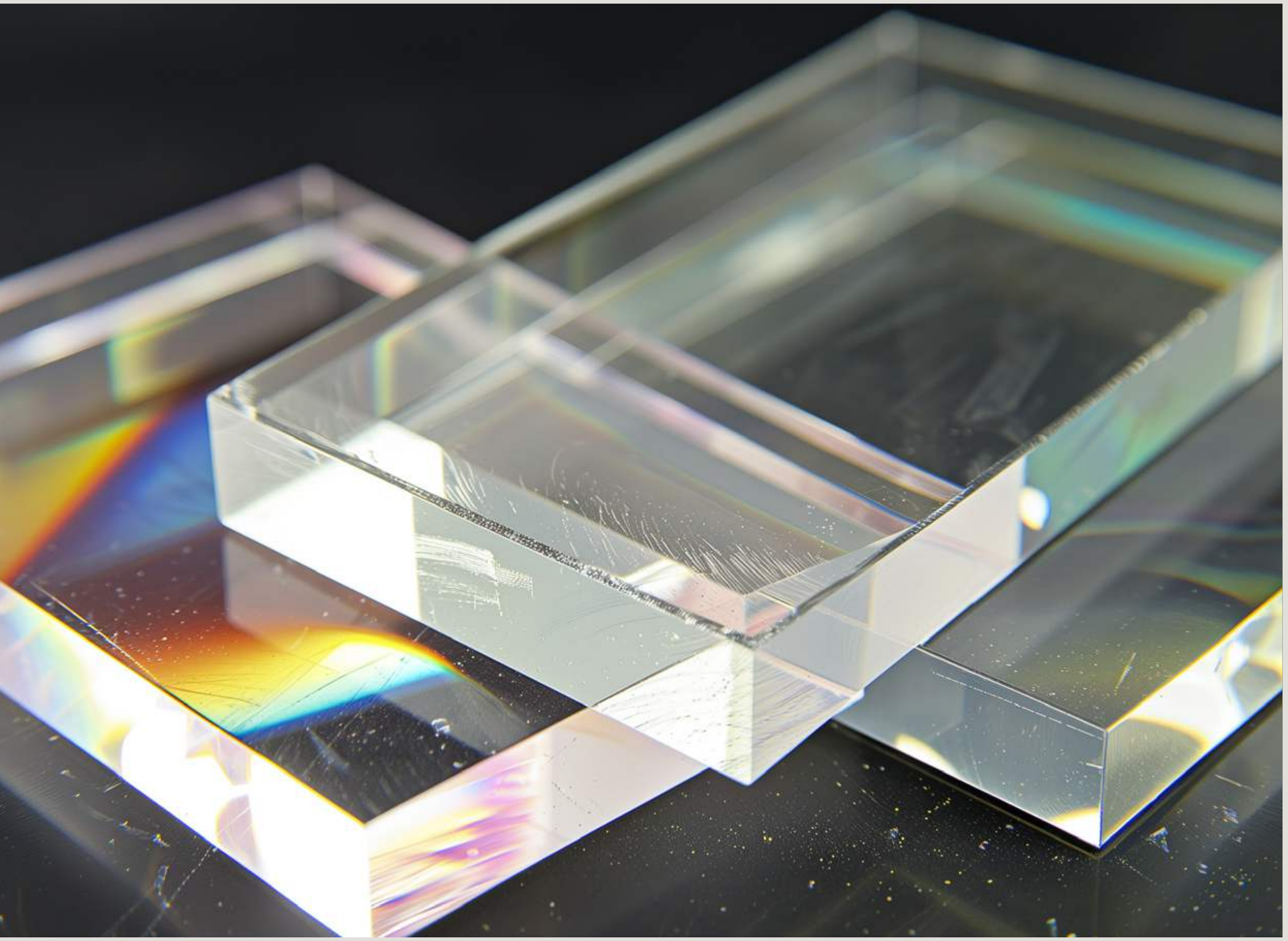
Literature

Berge, B. (2009) The Ecology of Building Materials. 75-76. Elsevier.

Government of Canada, Zinc facts. https://natural-resources.canada.ca/our-natural-resources/minerals-mining/minerals-metals-facts/zinc-facts/20534#L6 (2023)

Acrylic

Fig. 41
Acrylic material samples. Image generated with Midjourney 6.0



Acrylic refers to polymers synthesized from a combination of monomers, usually Acrylonitryil combined with MMA (metyl-metacrylate) and its derivatives. Acrylics are offered for a huge variety of applications and purposes in construction. It can also be blended in materials that seem natural at first glance, such as mortar or clay.

Toxicity

During the synthesis of the monomers mentioned above, a number of toxics are formed as by-products, including acrylonitril and the highly toxic hydrogencyanide (HCN). Unfortunately, the purity of the product is rarely indicated.

Climate

The monomers used to create acrylics are themselves produced from crude-oil as their ultimate feedstock, and on also require further energy to produce. The climate impact needs to be evaluated from case to case and viewed as relative to other material options with suitable properties.

Circularity

Even when disassembled into “pure” acrylic parts, there is currently no recycling technique which handle acrylics, because energy used for any such process exceeds the energy spent for initial production. It is therefore not viable- both from ecologic and economic perspectives. Therefore, unless reuse or repurposing is established for a specific component, acrylics are usually incinerated with energy recovery.

Literature

Irfan, M.H. (1998). Acrylics in the construction industry. In: Chemistry and Technology of Thermosetting Polymers in Construction Applications. Springer, Dordrecht. https://doi.org/10.1007/978-94-011-4954-9_5

https://prozesstechnik.industrie.de/news-chemie/thermisches-recycling-von-polymethylmethacrylat-pmma-im-extruder/

Epoxy

Fig. 42
Epoxy flooring. Image generated with Midjourney 6.0

Epoxy is the family of basic components or cured end products of epoxy resins. Epoxy resins, also known as polyepoxides. Epoxy resins are a class of prepolymers and polymers that, when reacted with hardeners or curing agents, form a strong, durable substance used in a variety of commercial and industrial applications.

Epoxy has a wide range of applications, including metal coatings, composites, use in electronics, electrical components (e.g., for chips on board), LEDs, high-tension electrical insulators, paint brush manufacturing, fibre-reinforced plastic materials, and adhesives for structural and other purposes. Epoxy resins used in building and construction applications can help increase the lifespan of buildings by improving the durability of the structural parts, engineering adhesives and paints.

Toxicity

The health risks associated with exposure to epoxy resin compounds include contact dermatitis and allergic reactions, as well as respiratory problems from breathing vapor and sanding dust, especially when not fully cured.

Liquid epoxy resins (LER) in their uncured state are mostly irritant to the eyes and skin, as well as toxic to aquatic organisms. Solid epoxy resins are generally safer than liquid epoxy resins, and many are classified non-hazardous materials. One particular risk associated with epoxy resins is sensitization. The risk has been shown to be more pronounced in epoxy resins containing low molecular weight epoxy diluents. Exposure to epoxy resins can, over time, induce an allergic reaction. Sensitization generally occurs due to repeated exposure (e.g., through poor working hygiene or lack of protective equipment) over a long period of time. Allergic reactions sometimes occur at a time which is delayed several days from the exposure. Allergic reactions are often visible in the form of dermatitis, particularly in areas where the exposure has been highest (commonly hands and forearms). Epoxy use is a main source of occupational asthma among users of plastics. Safe disposal also needs considering but usually involves deliberate curing to produce solid rather than liquid waste. Epoxy systems can be handled safely by taking basic precautions and following specific safety instructions. Epoxy resins are primarily used in building and construction applications. Workers may be exposed to uncured epoxy resins if they are inappropriately protected or are not handling epoxies resins with appropriate tools. Contact can occur when transporting containers of epoxy resins; when mixing, spreading, spraying or rolling epoxy components; or when disposing of empty containers and waste materials. Wearing PPE while working with epoxy resins can help minimize exposure and associated health effects.

Climate

Epoxy requires a lot of fossil energy in production phase. Global warming potential for epoxies varies between 4,6 – 6,7 kg CO_2 eq./kg (University of Plymouth, 2023), bit less for bio-based epoxies. Global warming potential for bio-based epoxies are 4.079 kg CO_2 eq./ kg.

Circularity

Waterborne epoxy paints have been around since the 1970s and research for recycling is ongoing. The most common end-of-life treatment of epoxy consists of incineration. There are possibilities to use recycled raw materials. Research is being done on innovative solutions such as using waste granite powders in epoxy resins and designing binders for coatings based on this. Other work is ongoing to produce epoxy and epoxy-based coatings from recycled raw materials including PET bottles.

Literature

https://www.chemicalsafetyfacts.org/chemicals/epoxy-resins/

https://www.epoxy-europe.eu/wp-content/uploads/2016/09/EPOXY_SafetyBrochure_2017.pdf

May, Clayton (2018). Epoxy Resins: Chemistry and Technology (2nd ed.). CRC Press. p. 65. ISBN 978-1-351-44995-3.

Health Effects from Overexposure to Epoxy WEST SYSTEM. WEST SYSTEM. Retrieved October 2023.

Disposal of 2-part epoxy". (April 2013, Retrieved October 2023). Available: https://www.lion.com/lion-news/april-2013/how-to-dispose-of-2-part-epoxy-solutions

Bal, Kevser; Ünlü, Kerim Can; Acar, Işıl; Güçlü, Gamze (May 1, 2017). Epoxy-based paints from glycolysis products of postconsumer PET bottles: synthesis, wet paint properties and film properties. Journal of Coatings Technology and Research. 14 (3): 747–753.

Kampa, Łukasz; Chowaniec, Agnieszka; Królicka, Aleksandra; Sadowski, Łukasz (September 1, 2022). Adhesive properties of an epoxy resin bonding agent modified with waste granite powder. Journal of Coatings Technology and Research. 19 (5): 1303–1316.

University of Plymouth, 2023. Available: https://ecm-academics.plymouth.ac.uk/jsummerscales/mats347/LCA_quantified_environmental_impacts.htm

PS (and EPS)

Fig. 43
EPS insulation boards. Image generated with Midjourney 6.0

Polystyrene (PS) is a polymer made from the monomer styrene, which is manufactured from petroleum. Polystyrene foam is commercially available in two forms: expanded polystyrene (EPS) and extruded polystyrene (XPS). EPS is commonly made by evaporating pentane into polystyrene particles. In the extrusion process, through which XPS is made, polystyrene particles are melted in an extruder and mixed with key additives, and the mixture then expands when cooling. While XPS has similar insulating qualities to EPS, it absorbs less moisture and poses a higher specific heat.

Both EPS and XPS are among the most widely used insulation materials. The uniqueness of the composition lies in the fact that only 2% of the product composition consists of polystyrene, and the remaining 98% is air. Polystyrene is flammable.

Toxicity

Styrene, which is used in the production, has various negative health effects, including neurotoxicity, suspected carcinogenicity. The blowing agent pentane (used in EPS production) creates hazardous earth-level smog.

To meet fire safety regulations, a flame retardant is added. HBCDD was the most common flame retardant since 1980s but was classified as persistent organic pollutant (POP) under the UN Stockholm Convention in 2013, and it is in the list as a restricted chemical. 90% of the use of HBCDD was with polystyrene insulation, which is the probable primary source of the global contamination. Nowadays other flame retardants are used instead; alternatively, foam plastics are required to be separated from the interior of a building by a "thermal barrier," e.g. gypsum wallboard (Babrauskas et al., 2014).

Burning polystyrene releases large amounts of carbon monoxide, along with styrene and other toxic chemicals.

EPS materials are extremely brittle. The small pieces scatter in the wind and contaminate the environment. PS is non-biodegradable foam. But it is sensitive to sunlight in a process called photodegradation. PS-foam fragments into smaller pieces without degrading, creating microplastics and causing harm to aquatic and soil organisms and ecosystems (Gupra et al., 2022).

Climate

Polystyrene requires a lot of fossil fuel to manufacture. XPS is usually made with hydrofluorocarbons (HFC-134a), which has a high global warming potential. The climate impact from the production (phase A1-A3) of 1 m3 material is the following (Ökobaudat, 2023):

- EPS Foam Insulation (density 15 — 30 kg/m³): 46.99 – 87.74 kg CO2 eq.;
- EPS Foam Insulation (grey; density 15 — 25 kg/m³): 58.61 – 76.73 kg CO2 eq.;
- XPS, 30 kg/m³: 94.03 kg CO2 eq.

As polystyrene provides excellent insulation, this reduces the need for heating and cooling, leading to energy savings. Still, the occurring claims that the reduction of GHG emissions during the use phase offsets the GHG emissions from the production of polystyrene, should be viewed with great caution. The climate impact needs to be evaluated from case to case and viewed as relative to other material options with suitable properties.

Circularity

EPS manufacturing usually does not produce residual solid waste. Process waste, off-cuts etc., are recycled back into the production process. Theoretically all uncontaminated polystyrene could be recycled: technology exists in some countries. During recycling, polystyrene is crushed into pellets and returned to the production process. Nevertheless, the collection of polystyrene waste is problematic. Polystyrene is very light, but its volume is large: the collection and transportation of its waste is not economical. Even more, insulating panels are usually inseparably fixed in the structure, they cannot be removed and reused. As a result, a lot of PS-foam is incinerated or ends up in landfill. Inside a landfill shielded from light virtually no breakdown of PS-foam takes place.

Presence of additives further complicates the process of recycling. Although technologies exist, recycling systems for polystyrene is not widely in place in the Baltic Sea region.

Literature

Babrauskas V., Fuoco R., Blum A. (2014). Flame Retardant Additives in Polymers: When do the Fire Safety Benefits Outweigh the Toxicity Risks? In "Polymer Green Flame Retardants", p. 87-118.

CEFIC (n.d.) PolyStyreneLoop Cooperative Offers an Efficient Recycling System to Recover Old Polystyrene Foam. Available at: https://cefic.org/a-solution-provider-for-sustainability/chemical-recycling-making-plastics-circular/chemical-recycling-via-dissolution-to-plastic/polystyreneloop-cooperative-offers-an-efficient-recycling-system-to-recover-old-polystyrene-foam

Gupta C., Kaushik S., Himanshu, Jain S., Dhanwani I., Mansi, Garg S., Paul A., Pant P., Gupta N. (2022). Bioaccumulation and toxicity of polystyrene nanoplastics on marine and terrestrial organisms with possible remediation strategies: A review. Environmental Advances 8, 100227.

PE (and PEX, HDPE, LDPE) and PP (and EPP)

Fig. 44
PE pipes. Image generated with Midjourney 6.0

Polyethylene and polypropylene each have a limited temperature-range within which they are functional. They become brittle when exposed to frost (or slightly deeper temperatures when modified), and they start melting at above 100 degrees or some above 140 degrees. Each is produced in a variety of densities resulting in different properties, each needing different catalysts and/or additives and processing requirements. Both types LDPE and HDPE are used to insulate power cables, can be foamed and used in insulation or as barriers in different foil-types. LDPE has a low density and is used for pipings while HDPE has a higher density rendering is suitable for packaging materials such as fibres and geo-foils and -membranes and even bottles and tanks for chemicals, because it is well resistant to many substances. It is however permeable to oxygen which is why it is also used for the piping in drinking-water supply, as drinking-water is already saturated with oxygen. Without an additional barrier, it cannot be used in systems where it must not absorb further oxygen, like floor-heating. With an additional barrier layer to prevent the passage of oxygen and its absorption it is also used in floor-heating systems PEX comprises a number of important PE cross-linking modifications, the most common ones (https://www.chemie.de/lexikon/polyethylen.html) being:

- cross-linking involving peroxide (PE-Xa)
- cross-linking involving silane-compounds (PE-Xb)
- crosslinking using radiation techniques (PE-Xc), used rarely in construction
- and crosslinkings creating azo-bonds, i.e. using urea etc. (PE-Xd)

Toxicity

In their purest form, both plastics PE and PP are considered low toxic plastic materials and are used in food-contact materials such as zip-lock bags and food containers. However, for construction material this is theoretical since modifications do require the addition of catalysts and/or other additive, the very first catalysts include metal compounds such as CrO_3, silica and $TiCl_4$. Depending on the pH-value, Chromium compounds can easily morph into carcinogenic forms and silane is rather toxic, too (Choudhury et al 2021). Chlorinated compounds can generally not be recommended due to poor degradation properties and their potential persistence (for-ever chemicals properties) and accumulation potential of degradation products. Titaniumtetrachlorid is liquid and hydrolyses very rapidly in the presence of water and its final hydrolysis product may be persistent and even accumulate.

While neither their photodegradation nor pyrolysis of the pure forms would usually result in toxics, any catalytic chemical degradation could still result in the formation of (undesirable) benzene, toluenes, xylenes etc.

Climate

Both plastics are ultimately produced from crude-oil and require further energy during production and thus do contribute to CO2 emissions. However, if there is an urge to use plastics, then these two plastics belong to the better options. Although they are not as energy efficient as natural materials, their carbon-footprint may be improved when used in a way that provides for clean dismantling and recycling at the end-of-life.

Circularity

Both plastics are thermoplastic and can undergo true material recycling by shredding and re-molding, which requires far less energy compared to chemical recycling which is not recommended. Depending on the exact use, this material may come with a good reparability as sometimes faults can be patched using heat. However currently the challenge is still to have systems in place that provide for different kinds of PE and PP to be collected separately and as pure as possible.

Literature

Bala, A., Arfelis, S., Oliver-Ortega, H., & Méndez, J. A. (2022). Life cycle assessment of PE and PP multi film compared with PLA and PLA reinforced with nanoclays film. Journal of Cleaner Production, 380, 134891.

Banerjee, R., & Ray, S. S. (2022). Sustainability and life cycle assessment of thermoplastic polymers for packaging: a review on fundamental principles and applications. Macromolecular Materials and Engineering, 307(6), 2100794.

Choudhury, S., Kumar, A., & Kumar, N. (2021). Silane: Risk assessment, environmental, and health hazard. In Hazardous Gases (pp. 353-362). Academic Press.

Kristensen, H. S., & Mosgaard, M. A. (2020). A review of micro level indicators for a circular economy–moving away from the three dimensions of sustainability? Journal of Cleaner Production, 243, 118531.

PUR

Fig. 45
PUR insulation boards. Image generated with Midjourney 6.0

Polyurethane (PUR) is a type of polymer created by combining isocyanate and polyol. These chemicals are derived from crude oil refinement. Depending on usage, additives (e.g. flame retardants) and catalysts are needed. PUR may be rigid or soft, made in factory or be sprayed/ poured onto/ into the desired surface in situ. It is durable, water resistant, thermal insulator. However, it is flammable (de Souza et al., 2021).

Polyurethanes are used in insulators, foams (for sealing doors and windows, and filling voids and spaces), elastomers, synthetic skins, coatings, adhesives, etc.

Toxicity

Fully reacted polyurethane polymer is chemically inert. Exposure to chemicals may occur during or after PU spray foam application, when chemicals may be emitted. Exposure may occur also during the production process. The most commonly used isocyanates are toluene diisocyanate (TDI) and methylene diisocyanate (MDI). Isocyanates can cause respiratory disorders, especially asthma, if inhaled. In addition to being respiratory and skin sensitizers, both MDI and TDI are suspected of causing cancer (ECHA, 2023).

Because of the flammability of the material, it has to be treated with flame retardants, almost all of which are considered harmful. PU board often contains tris (1-chloro-2-propyl) phosphate (TCPP). While its toxicity in mammals and the effects of long-term exposure are unknown, it is toxic in aquatic environments (Babrauskas et al., 2014). When a PU foam fire breaks out, various thermal decomposition products and toxic gases can be generated.

Production involves blowing agents, e.g., pentane, which creates hazardous earth-level smog.

Climate

PUR derives from oil, and that in itself causes a lot of concern. There are some efforts to replace oil-based precursors with new precursors derived from renewable resources, such as bio-based isocyanates and polyols (Hai et al., 2021), as well as polyols based on CO2. The climate impact needs to be evaluated from case to case and viewed as relative to other material options with suitable properties. PUR materials have the following global warming potential in the production (phase A1-A3) (Ökobaudat, 2023):
- Elastomer joint tape, polyurethane: 3.862 CO2 eq. per 1 kg material.
- Polyurethane rigid foam (pipe insulation); hard foam: 153 CO2 eq. per 1 m3 material.

Circularity

After dismantling or demolishing the building, rigid polyurethane foam (RPUF) insulation materials can be re-used. Clean RPUF waste can be crushed and made into new materials, e.g., pressed boards, be used as oil binders or in combination with cement as insulating mortar. However, RPUF waste with impurities, or with the remains of other building materials still attached, can only go to landfilling or incineration. Polyurethane produces toxic gases when incinerated. It is classified as special waste in the EU, thus difficult to recycle. Some recycling solutions for RPUF exist, but they poorly address the issue of huge waste streams generated by the disposal of end-of-life PU products. The structural diversity of PURs makes it difficult to develop a universal recycling process (Fonseca et al., 2023).

Regarding other issues and other PUR products, e.g., polyurethane glue, it has a limited shelf life (not longer than 1 year).

Literature

Babrauskas V., Fuoco R., Blum A. (2014). Flame Retardant Additives in Polymers: When do the Fire Safety Benefits Outweigh the Toxicity Risks? In "Polymer Green Flame Retardants", p. 87-118. https://www.sciencedirect.com/science/article/abs/pii/B9780444538086000032?via%3Dihub

ECHA (European Chemicals Agency) (2023). Information on chemicals. Available at: https://echa.europa.eu/information-on-chemicals

de Souza F. M., Kahol P.K., Gupta R.K. (2021). Introduction to Polyurethane Chemistry. In Polyurethane Chemistry: Renewable Polyols and Isocyanates. ACS Symposium Series, Vol. 1380. DOI: 10.1021/bk-2021-1380.ch001

Fonseca L.P., Duval A., Luna E., Ximenis M., De Meester S., Avérous L., Sardon H. (2023) Reducing the carbon footprint of polyurethanes by chemical and biological depolymerization: Fact or fiction? Current Opinion in Green and Sustainable Chemistry 41:100802. https://doi.org/10.1016/j.cogsc.2023.100802

Hai T. A. P., Tessman M., Neelakantan N. et al (2021) Renewable polyurethanes from sustainable biological precursors. Biomacromolecules 22 (5): 1770–1794.

https://doi.org/10.1021/acs.biomac.0c01610

PVC

Fig. 46
PVC pipes. Image generated with Midjourney 6.0

PVC is a common plastic material used e.g. as plastic facade cladding, in windows and flooring. It is considered a low maintenance material with good characteristics, but fossil fuels are used in the production, and it often contains hazardous additives. There are two types of PVC; soft PVC and rigid PVC. Soft PVC always contain a softener to make it flexible and soft, and rigid PVC is harder and used for e.g. plastic pipes.

Toxicity

The monomer vinyl chloride used in the production of PVC is classified as a carcinogen. Though the polymer is not hazardous, there are findings that show that some residual monomers may be found in PVC materials (Huang et al., 2022). PVC also contains additives that can be hazardous to both health and the environment, e.g. phthalates, flame retardants and heavy metals. Many of these additives can affect our hormones, reproduction, and the aquatic life. When burned toxic dioxins can be formed (Health Care Without Harm Europe, 2021). Phthalates and other additives can migrate from the material to water and dust and cause adverse health effects both for humans and the environment. For these reasons PVC is not a good material from a toxicity point of view. If soft PVC is needed, choose one without phthalates.

Climate

The monomer vinyl chloride is made from fossil fuels (ethylene) and salts (chloride) which means that it contributes to the loss of fossil fuels (Health Care Without Harm Europe, 2021). The climate impact of PVC products ranges from 2-8 kg CO2 eq./kg for phase A1-A3. A PVC sewer pipe has a total GWP of 2.6 kg CO2 eq./kg for phase A1-A3, a PVC roofing membrane has a total GWP of 5.82 kg CO2 eq./kg and a
PVC floor covering has a total GWP of 7.6 kg CO2 eq./kg (Ökobaudat, 2023).

If a project has a need for PVC materials, choose bio-attributed PVC that use more biobased raw materials and preferably less fossil based energy in the production. Construction spill may preferably be collected and returned to the producer for direct material recycling. The climate impact needs to be carefully evaluated from case to case and viewed as relative to other material options with suitable properties.

Circularity

PVC can be recycled, e.g. there are examples of suppliers who recycle phthalate free plastic flooring, after being cleaned from glue and patty. Today most PVC is incinerated and one of the challenges is contamination by additives. It is preferred to use PVC products that can be recycled by the producer.

In conclusion, PVC is made from a toxic monomer and often contain hazardous additives. It has a relatively low climate impact and can be recycled, even though most PVC is not recycled today. Is PVC material needed in a project, try to find products that can be recycled and request information from the supplier what additives it contains.

Literature

https://www.oekobaudat.de/no_cache/en/database/search.html (nov 2023)

Health Care Without Harm Europe, The polyvinyl chloride debate: Why PVC remains a problematic materia. https://noharm-europe.org/sites/default/files/documents-files/6807/2021-06-23-PVC-briefing-FINAL.pdf (2021)

Huang L., Fantke P., Ritscher A. and Jolliet O. (2022) Chemicals of concern in building materials: A high-throughput screening. Journal of Hazardous Materials 424.

Ökobaudat.

SBR

Fig. 47
A roll of SBR. Image generated with Midjourney 6.0

Styrene-butadiene rubber is a synthetic rubber created through the polymerisation of styrene and butadiene. SBR is a versatile material that, when blended with other substances (additives or polymers), enhances its performance for specific applications.

Toxicity

SBR itself does not contain any hazardous substances, but the additives may have hazardous properties. Examples of additives include plasticisers, fillers, and/or antioxidative agents. These additives can consist of phthalates, HA-oils, zinc oxide, BHT, and BHA.

Climate

The production of SBR emits greenhouse gases from the refining of petroleum oil, as well as the extraction of monomers used for building blocks and subsequent polymer processing, all result in carbon dioxide emissions. If SBR is not reused or recycled, the material will also produce greenhouse gases when incinerated during the end-of-life treatment. For SBR plastic profile, the total GWP per kg material (modules A1-A3) is 4.30kg CO_2 eq./kg (Ökobaudat, 2023).

Circularity

SBR is a material that can be recycled and reused. However, the variation between materials and presence of contaminants in the form of additives can complicate the recycling of SBR rubber.

Recycled SBR from tires

Fig. 48
Granules of recycled SBR. Image generated with Midjourney 6.0

Reusing materials from old tires has served as a circular alternative, rather than incinerating the material (Armada et al., 2022). For instance, it is common to employ granules crafted from recycled tires for soccer fields (crumb rubber infill) or playground surfaces.

Toxicity

Recycled SBR may contain substances potentially harmful to health and the environment, including, for example, PAHs, volatile organic pollutants (VOCs), semi-volatile organic pollutants (SVOCs), phthalates, vulcanizers, heavy metals, and more. Ensuring the source of the recycled tyres used is challenging, leading to significant variations in the composition of recycled tire granules. Granules from recycled tyres employed in soccer fields are subject to Reach regulations, with a limit of not exceeding 20 µg/g for eight PAHs (ECHA, 2021).

Climate

Recycled SBR does not emit greenhouse gases, as it is a recycled material that can also undergo further recycling. The climate impact results from energy use for processing into rubber granules, transportation and incineration during its end-of-life treatment. For recycled SBR no generic climate data is found. The climate impact needs to be evaluated in relation to other environmental impacts from for instance release of granules into the environment.

Circularity

Recycled SBR can undergo additional recycling owing to its durability and versatility. However, the presence of hazardous substances limits its range of applications, as the material should not be near humans or the environment due to the potential risk of exposure to toxins.

TPE

Fig. 49
Profilated TPE strands. Image generated with Midjourney 6.0

TPE, or Thermoplastic Elastomers, is a collective term encompassing polymers of two types:
- Thermoplastic Polymers: These have long chains of plastic polymers, either with or without branching, that tightly pack together when the temperature falls below the glass transition temperature. Generally, they melt when heated and can be reshaped into new objects. Examples of thermoplastics include PS, PVC, and PET.
- Elastomeric Polymers: These exhibit rubber-like elasticity, as seen in materials such as PUR and SBR.

TPE also incorporates additives such as plasticizers, fillers, and antioxidative agents. Numerous varieties of TPE exist, each requiring assessment based on the specific combination of polymer and additives employed. Thera are many types of TPE:s namely TPS, TPE-O, TPE-PVC, TPE-PUR, described elsewhere (Whelan, 2017).

Toxicity

TPEs typically contain low levels of hazardous substances due to the polymer design and elastomer proportion. Nonetheless, the additives may have hazardous characteristics, necessitating individual assessment for each TPE.

Climate

The production process of TPE generates greenhouse gases, as refining petroleum oil and extracting monomers for the building blocks, along with the polymer processing, all result in carbon dioxide emissions. Ongoing research focuses on developing biobased and renewable TPE, which can have a reduced climate impact. Although limitations such as mechanical properties, cost efficiency and degradability remain (Jeon, Jung and Choi, 2023).

Circularity

TPE is a material that can be recycled and reused. It can also be melted and reconfigured for a specific application. However, products composed of mixed materials and the presence of additives can pose challenges for recycling TPE.

Literature

Whelan, D. (2017). Thermoplastic elastomers. In Brydson's Plastics Materials (pp. 653-703). Butterworth-Heinemann.

Jeon, J. H. Jung, J. H. and Choi, C. (2023). Toward a greener future: Exploring sustainable thermoplastic elastomers. Journal of Polymer Science.

3 Plastics (Synthetic / fossil fuel based polymers)

EPDM

Fig. 50
Slices of EPDM. Image generated with Midjourney 6.0

EPDM (Ethylene Propylene Diene Monomer) is a vulcanised synthetic rubber. The properties of the final polymer are determined by the design of the polymer backbone, including the number of cross-bindings, among other factors. The vulcanisation process renders the rubber consistent, robust, and versatile, allowing for reuse with the same design but precluding recyclability, as it cannot be melted to create a new structure.

Toxicity

EPDM typically does not contain hazardous substances. However, vulcanisation agents or residues typically persist in the material.

Climate

The production process of EPDM generates greenhouse gases, as refining petroleum oil and extracting monomers for the building blocks, along with polymer processing, all result in GHG emissions. If EPDM is not reused, the material will also produce greenhouse gases when incinerated. For EPDM foil, the GWP per kg material (modules A1-A3) is 4.30 kg CO_2 eq./kg. (Ökobaudat, 2023).

Circularity

EPDM is a material that can be reused but not recycled. It cannot be melted or reconfigured for another specific application. End-of-life treatment is therefore commonly incineration with energy recovery.

NBR

Fig. 51
NBR tubes. Image generated with Midjourney 6.0

NBR (Nitrile Butadiene Rubber) is a synthetic vulcanised rubber made from acrylonitrile and butadiene. It is a versatile material that, when combined with other substances (additives or polymers), enhances its performance for specific applications.

Toxicity

NBR itself does not contain any hazardous substances, but the additives and residues from the vulcanisation process may have hazardous properties. Examples of additives include plasticisers, fillers, antioxidative agents, flame retardants, and vulcanisation accelerators. Some specific examples are phthalates, chlorinated paraffins, brominated flame retardants, thiurams, and dithiocarbamates (ref).

Climate

The production processes of NBR such as refining petroleum oil and extracting monomers used for building blocks, along with polymer processing, all result in GHG emissions. If NBR is not reused or recycled, the material will also produce greenhouse gases when incinerated. For NBR no generic climate data is found.

Circularity

NBR is a material that is difficult to recycle and in places where infrastructure for material recycling is not in place, end-of-life treatment is therefore often incineration. Products composed of mixed materials which requires material separation and presence of additives can complicate the recycling of NBR rubber. However, as the material is vulcanised, it must be vulcanised anew to be suitable for other applications (Ghowsi and Jahmshidi, 2023).

Rubber

Fig. 52
Profilated rubber seal. Image generated with Midjourney 6.0

Synthetic rubber is an artificial polymer that is synthesized from petroleum by-products. It can also be made from recycled materials such as tires, sport equipment, and even shoes.

Toxicity

Rubber materials made from synthetic materials can release volatile organic compounds (VOCs) to the air, resulting in an unpleasant odour and high toxicity. Synthetic rubber can contain residues of carcinogenic or endocrine disrupting chemicals that are used during the production of the material.

Climate

Synthetic rubber is made from petroleum, a non-renewable resource, which leads to a significant climate impact. One of them is that the production of artificial rubber contributes to air pollution. When heating manmade rubber, the toxic residues are released into the atmosphere.

Circularity

Synthetic rubber can theoretically be recycled to produce other rubber products, and therefore reduce landfill and its overall environmental impact. The biggest obstacles in the recycling process of synthetic rubber are the toxic chemicals in the material.

3 Composite material
Mycelium

Fig. 53
Mycelium construction blocks. Image generated with Midjourney 6.0

In the production process of a mycelium composite material, fungal hyphae of white rot-fungi grow on by-products from agriculture or forestry e.g. spelt husks and beechwood chips. A transdisciplinary project from Germany (Berkau, et al., 2019) grew Ganoderma lucidum (the glossy bracket fungus) on spelt husks and beechwood chips. This fungus uses a complex symposium of enzymes to be able to externally digest the organic material, including lignin. For this it first needs to bind the organic constituents, producing a composite material. The feeding of the fungus is stopped by dehydration of the composite.

Toxicity

All essential ingredients in mycelium composite materials do not tend to release toxic substances to the indoor environment. As the plant materials used is already dead, immune reactions including the production of potentially toxic secondary phytochemicals are ruled out.

The materials used for this composite are all fully degradable under natural conditions, as you find them in real-life ecosystems. They do not release toxic substances to the natural environment, as long as the raw materials themselves were not grown using such.

Hence, also the application of this composite is harmless to those working with it.

Biocide input during the growth of the plant biomass used to feed the fungal species is recommended. Depending on the type of biocide, this may help the growth rate of the fungal species and prevent the production of potentially harmful metabolites. Fungi are known to accumulate potentially hazardous substances including heavy metals. However, the contamination always occurs through the feeding on contaminated material. Hence, if the plant material is free of hazardous substances so will the mycelium composite be.

Naturally grown, untreated mycelium composite material will not release toxic substances at the end of its life.

Climate

The global warming potential of mycelium composite materials is very low. The raw material includes plant biomass, which sequesters carbon during its growth. The mycelium attaches to it binding it together. It will release small parts of the sequestered carbon under cell respiratory processes. However, as the plant material will not be fully digested by the fungi most carbon will stay trapped within the composite. The climate impact from raw material impact is low since the material is produced from byproducts of the wood industry. The possibility of local production results in low GHG emissions from transport.

Circularity

Reuse, repurpose, recycle and compositing are all possible end-of-life treatments for natural mycelium composites. There is no system in place for mycelium composite recycling today. Manufacturers and other secondary companies may fill the gap in the future when significant amounts of these composites are in use. Energy recovery through incineration or composting is therefore likely the most common end-of-life treatment.

Natural mycelium composite materials can be circular. The technical recycling into new composites of the same sort, however, will only work when there is enough plant material left to feed the fungi. There is therefore a limited potential for circular mycelium composites.

Under appropriate conditions mycelium composite material can be long lasting. The composite is water repellent to some extent. It should be protected from prolonged moisture exposure. It would take up a substantial amount of water promoting further natural degradation by microorganisms.

Literature

Berkau, A. J., Nuzum, A.-K., Schritt, H., Krause, I., Lüdemann, J., Senn, J., . . . Eger, Y. (2019). Die Entwicklung, Nutzung und Verbreitung von pilzbasierten Materialien nach Cradle to Cradle Prinzipien als transdisziplinäre Forschung. Leuphana University Lüneburg.

3 Composite material

Polymer concrete

Fig. 54
Polymer concrete tiles. Image generated with Midjourney 6.0

Polymer concrete, also called epoxy granite, is a type of concrete that uses a polymer binder instead of a traditional cement binder. Polymer binders are made from synthetic resins, such as epoxy, polyester, or acrylic. Polymer concrete is also made with aggregates, such as sand, gravel, and crushed stone.

Toxicity

The polymer binder itself may contain residual monomers from the curing process, such as bisphenol A (epoxy). These residues can potentially leach from the material during its lifecycle (ref).

Climate

The manufacturing process of synthetic organic polymers generates greenhouse gases as it involves the refining of petroleum oil, extracting monomers used as building blocks, and the subsequent polymerization process, all of which result in GHG emissions.

Circularity

Polymer concrete is typically challenging to recycle, except for specific applications.

In construction sector polymer concrete is often used to repair already existing concrete structures. It is also resistant to corrosion, therfore it is commonly used in constructions that have the likelyhood of being under humid conditions, such as swimming pools.

3 Composite material

Tar paper

Fig. 55
Roll of tar paper. Image generated with Midjourney 6.0

Tar paper or as it is today known, bitumen paper or bituminous lining paper, is a strong paper coated with bitumen. Tar has been replaced by bitumen and actual tar paper is used only rarely, for example in historical renovations.

Toxicity

Bitumen paper consists of strong paper, kraft liner, bitumen and minerals, often fine sand. Chemical consistency of bitumen paper and its' main component bitumen is accurately controlled, and it does not release harmful substances during its normal use. However, bitumen paper may cause contamination to natural and indoor environment if the bitumen layer is heated, and it liquefies. Exposure to bitumen is possible by breathing in fumes or skin absorption.

Bitumen is basically an inert material that must be heated or diluted to a point where it becomes workable to produce materials for paving, roofing, and other applications. High temperature affects occupational exposure and the potential bioavailable carcinogenic hazard/risk of the bitumen emissions. International Agency for Research on Cancer (IARC) has classified paving asphalt fumes as a Class 2B, possible carcinogen, indicating inadequate evidence of carcinogenicity in humans. (IARC, 2013). Also, during production, construction, repairs or demolition of bituminous lining paper, the dust particles of the materials can cause skin or respiratory irritation. (RoofKeen, 2022) In the USA The National Institute for Occupational Safety and Health (NIOSH) has set a recommended exposure limit of 5 mg/m3 over a 15-minute period. (NIOSH, 2015) In Finland recommended exposure limit is 10 mg/m3 over a 15-minute period or 5 mg/m3 per 8-hour period. (HTP-ARVOT 2020)

Bitumen paper is not generally used as construction paper inside buildings because of the bitumen contained in the product and the characteristic smell coming from it. (Tectis, 2023)

Attention must be paid when demolishing old tar or bitumen paper. Old tar or bitumen paper may include harmful substances such as PAH compounds (polycyclic aromatic hydrocarbons) or asbestos. (Työterveyslaitos, 2016) When investigating or demolishing hazardous construction materials, national legislation shall be followed.

Climate

The manufacturing process of bitumen generates greenhouse gases as it involves the refining of petroleum oil. Information on the GHG emissions from production of bitumen paper specifically are limited, for more detail see the section below on Bitumen membranes.

Circularity

Bitumen paper is considered as non-reusable and non-recyclable material. It can be incinerated with energy recovery. (Ympäristöhallinto, 2022)

Bitumen paper is used to protect structures from rain and wind. It is permeable to water vapor, but waterproof. Thanks to its permeability i.e., its breathability, it is used in wall and floor structures, usually as a wind protection outside the thermal insulation (Tectis, 2023) or for moisture insulation especially in wooden walls and upper and lower floors (Ympäristöhallinto, 2022).

Bitumen paper is produced as a net-like material and is usually delivered rolled up. Both sides of the paper are usually covered with minerals such as fine sand. The sand coating prevents bitumen from running off if the paper is exposed to heat. It also prevents the paper from sticking together in the roll. (Tectis, 2023).

Literature

International Agency for Research on Cancer, IARC (2013). Bitumens and Bitumen Emissions, and Some N- and S-Heterocyclic Polycyclic Aromatic Hydrocarbons. Vol. 103. Lyon, France https://publications.iarc.fr/127

Cavallari, J. M., Zwack, L. M., Lange, C. R., Herrick, R. F., & McClean, M. D. (2012). Temperature-Dependent Emission Concentrations of Polycyclic Aromatic Hydrocarbons in Paving and Built-Up Roofing Asphalts. Annals of Occupational Hygiene, 56(2), 148–160. https://doi.org/10.1093/annhyg/mer098

RoofKeen, (2022) What Is the Difference Between Roofing Felt and Tar Paper? (2022) https://roofkeen.com/what-is-the-difference-between-roofing-felt-and-tar-paper/

HTP-arvot (2020) Haitalliseksi tunnetut pitoisuudet, Sosiaali- ja terveysministeriön julkaisuja 24, https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/162457/STM_2020_24_J.pdf)

Tectis Oy, (2023) Tuulensuojat ja vuoraus, Bitumivuorauspaperi Arvo, https://tectis.fi/tuotteet/tuulensuojat-ja-vuoraus/ei-alakategoriaa/bitumivuorauspaperi-arvo/

Työterveyslaitos, (2016) Asbestirakennusmateriaaleissa.

Ympäristöhallinto, (2022) Bitumipaperi, tervapaperi, https://www.ymparisto.fi/fi/rakennettu-ymparisto/ekotehokas-rakentaminen/kiinteistojen-yllapito-ja-korjaaminen/rakennusmateriaalien-tietopankki/bitumipaperi-tervapaperi

Bituminous membrane

Fig. 56
A roll of bituminous membrane. Image generated with Midjourney 6.0

Today the primary use (more than 70 %) of bitumen is in road construction, where it is used as glue or binder mixed with aggregate particles to create asphalt concrete. (MPA, 2022) Its other main uses are for bituminous waterproofing products and for sealing flat roofs.

Bitumen is versatile, durable, cost effective and above all highly waterproof, making it an ideal system for both new build and refurbishment roofing projects. It can be modified with several other materials to provide different membrane characteristics: limestone, sand and polymers. (BMI Group, 2023)

There are two main types of polymer modification:
• SBS (Styrene Butadiene Styrene)
• APP (Atactic Polypropylene)

Toxicity

Bituminous membranes consist of bitumen and different materials to provide different membrane characteristics. Toxicity of bituminous membranes is comparable to toxicity of bitumen paper. Chemical consistency of bituminous membranes is accurately controlled, and it does not release harmful substances during its normal use. However, bituminous membranes may cause contamination to natural and indoor environment if the bitumen layer is heated, and it liquefies. Exposure to bitumen is possible by breathing in fumes or skin absorption.

Climate

For bituminous membranes, GWP per kg material depends on the density and other characteristics of the membrane (Ökobaudat, 2018):
• bitumen sheets V 60, density 5,0 kg/m2, for A1-A3 stage have GWP of 2,323 kg CO2 eq./ kg;
• bitumen sheets PYE-PV 200 S5 ns (slated), density 6,2 kg/m2, for A1-A3 stage have GWP of 4,985 kg CO2 eq./ kg

Most of the emissions of bitumen come from the manufacturing of raw materials. As SBS has a large share of emissions, using alternative copolymers to modify the bitumen would also change the carbon footprint. (Bionova Ltd, 2022)

Circularity

Landfill disposal of bituminous membranes is banned in European Union (EU) countries. At the moment the asphalt industry is the only recycling method that works on an industrial scale for bituminous membranes. (Peltoniemi, 2022) The recycling process of bituminous membranes requires the same stages as production of virgin bitumen. The process is energy intensive and therefore results in high emissions. High temperature also affects occupational exposure and the potential carcinogenic hazard/risk of bitumen emissions. (IARC, 2013)

Bituminous membranes in construction are suitable for moisture insulation and as roofing material (IKO, 2020). They are typically attached by welding.

Literature

BMI Group, What is Bitumen Roofing?, (2023) https://www.bmigroup.com/uk/bmi-from-the-rooftop-blog/what-is-bitumen-roofing/

Mineral Products Association (2022). MPA, Asphalt Applications, 22 January 2022 https://www.mineralproducts.org/search-resultsaspx?searchtext=Asphalt+Applications&searchmode=anyword

International Agency for Research on Cancer. (2013). Bitumens and Bitumen Emissions, and Some N- and S-Heterocyclic Polycyclic Aromatic Hydrocarbons. (Vol. 103). Lyon, France: International Agency for Research on Cancer. Retrieved from https://publications.iarc.fr/127

HTP-arvot 2020, Haitalliseksi tunnetut pitoisuudet, Sosiaali- ja terveysministeriön julkaisuja 2020:24, https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/162457/STM_2020_24_J.pdf)

Bionova Ltd, (2022) Generic data for bitumen roofing – modified bitumen sheets, https://www.co2data.fi/reports/Bitumen-roofing-revised-January-2022.pdf)

Peltoniemi, Joona, Kattohuovan kierrätys, (2022) Tampere University, Bachelor's Programme in Engineering and Natural Sciences, 2022, https://trepo.tuni.fi/handle/10024/140498

Ökobaudat, Sustainable Construction Information Portal, the Federal Ministry for Housing, Urban Development and Building (Germany), 2018 https://www.oekobaudat.de/en.html

IKO, (2020) What is the difference between bitumen roofing and EPDM roofing?, 2020 https://be.iko.com/en/what-is-the-difference-between-bitumen-roofing-and-epdm-roofing/

3 Composite material

Fiberglass

Fig. 57
Strands of fiberglass. Image generated with Midjourney 6.0

Fiberglass is a type of fibre-reinforced plastic where glass fibre is reinforcing plastic. That is why it is sometimes called glass fibre reinforced plastic or glass reinforced plastic. (Tencom Ltd., 2022)

Glass fibres can be comprised of different types of glass. Flattened into a sheet, the glass fibre is randomly arranged or woven into a fabric. Fiberglass is lightweight, strong, and less brittle. One of the most appealing features of fiberglass is that it can be moulded into different shapes.

Fiberglass behaves like regular glass (Tencom Ltd., 2022):

- It does not absorb moisture.
- It does not mold nor mildew.
- It is non-conductive.
- It does not rust, shrink, expand, or burn.

Toxicity

The silica fibres used in fiberglass are generally not considered as hazardous. Reinforcing fibres and most fillers have a particle size of more than 5 µm and thus cannot be transported to the alveoli. However, in the mechanical processing of products containing them, e.g., sanding, dust smaller than the particle size can be generated, which must be avoided to be inhaled. Although the fibres themselves are not suspected of causing health harm to humans, it is still possible to be exposed to respiratory irritation and mechanical skin, eye, and pharynx irritation due to fibre dust during handling and processing. Based on some research the safety of glass fibre has been called into question, as research shows that the composition of glass fibres (asbestos and glass fibres are both silicate fibres) can cause similar toxicity as asbestos. (Fuller, 2008, YU, 2010) When exposed to heat, fiberglass does not emit smoke or give off toxic chemicals (Tencom Ltd., 2022).

Climate

The climate impact from continuous filament glass fibre products (CFGF) mainly results from the melting of glass. The climate impact of the production is on average 1.44 kg CO2 eq./kg CGFG. Direct emissions on site stand for ca 37% of the total GHG emissions in the stage A1-A2, due to combustion of natural gas Glass Fibre Europe Rue Belliard (2023).

Circularity

Fiberglass is not commonly recycled, as grinding and crushing destroys most of the glass which affects the fibres.ts strength, durability, size, and usefulness in future applications are significantly reduced. Because of this, there is very little demand for recycled fiberglass. Another problem with fiberglass recycling is that the equipment required for recycling is very expensive and not available at every recycling facility. (Goncalves et al., 2022)

Even though fiberglass is hard to reuse, manufacturers of glass fibre insulation can use recycled glass. Glass fibre may contain up to 40% recycled glass. (NAIMA, 2005)

Fiberglass is widely used in construction in facade panels, window frames, doors, wetroom equipment etc. (Saarela, O. et. al., 2019). It does not corrode when used in harsh environments and is lightweight. (Tencom Ltd., 2022)

Literature:

Tencom Ltd., (2022) The Different Types and Forms of Fiberglass and How They Are Used, 2022, https://www.tencom.com/blog/the-different-types-and-forms-of-fiberglass-and-how-they-are-used

Fuller, John, (2008) Fiberglass and Asbestos. Is insulation dangerous?, Retrieved 27 August 2010 https://web.archive.org/web/20110720122709/http://www.einstein.yu.edu/ehs/Industrial%20Hygiene/Fs_Fibergls.htm

Glass Fibre Europe Rue Belliard (2023). Life cycle assessment of CFGF – Continuous Filament Glass Fibre Products. 199, B-1040 Brussels

Gonçalves, R.M., Martinho, A., Oliveira J.P., (2022) Recycling of Reinforced Glass Fibers Waste: Current Status. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8876600/

North American Insulation Manufacturers Association (NAIMA), FAQs About Fiber Glass Insulation, (2005) http://www.naima.org/pages/resources/faq/faq_fiber.html

Saarela Olli, Airasmaa Ilkka, Kokko Juha, Skrifvars Mikael, Komppa Veikko, (2019) Komposiittirakenteet https://www.lujitemuovi.fi/

3 Composite material

Timber / plastic composite

Fig. 58
Timber/plastic terrace boards. Image generated with Midjourney 6.0

Wood-plastic composites (WPC) are made of wood fibres and plastics such as polyethylene, polypropylene, polylactic acid or polyvinyl chloride. WPCs are relatively new materials and are used as alternatives to pure wooden products. A recycled plastic component reduces the GHG emissions of the material production in comparison to using virgin plastic.

Toxicity

Pure wood is a material that does not contain any toxic chemicals. Provided that the recycled plastic component does not contain any harmful additives, WPCs are a non-toxic choice of material. If the wood in the WPC is untreated wood and the plastic does not contain any harmful additives, the material will not leach chemicals to the environment.

Climate

Information on the GHG emissions from production of wood-plastic composites are limited and no generic data on the climate impact of production of WPCs has been found in the used databases.

Circularity

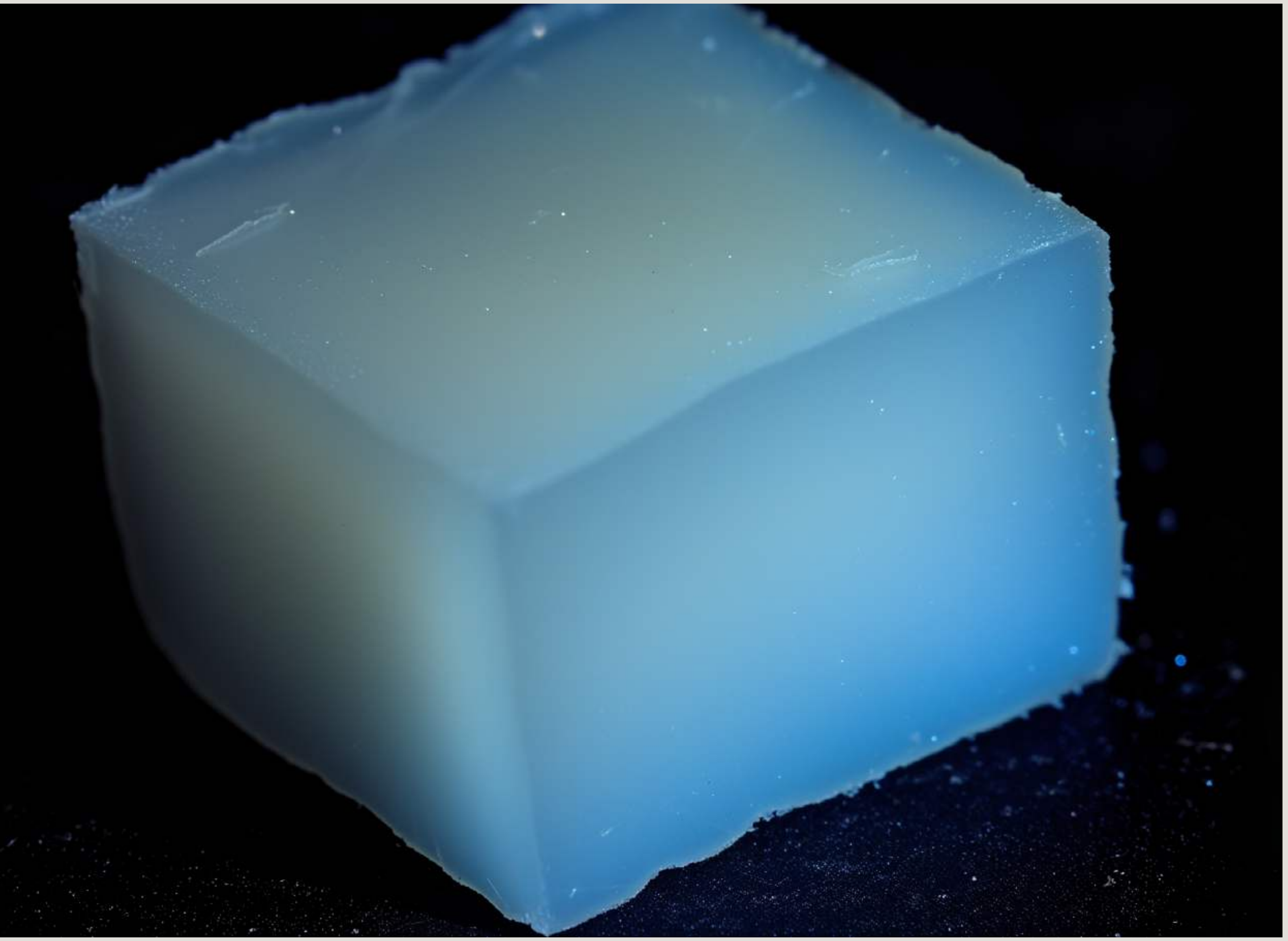
WPCs in theory can be remanufactured into new composite products. However, the wood and the plastic component cannot be recycled themselves respectively. The most common end-of-life treatment is energy recovery through incineration or disposal to landfill.

Literature

Khan, M. M. H., Deviatkin, I., Havukainen, J., & Horttanainen, M. (2021). Environmental impacts of wooden, plastic, and wood-polymer composite pallet: a life cycle assessment approach. The International Journal of Life Cycle Assessment, 26, 1607-1622.

Aerogels

Fig. 59
Aerogel material sample. Image generated with Midjourney 6.0



Aerogels are exceptionally porous nanostructured solids. More than 80% of this material is air. Material has a potential for increasing use in the construction sector both for internal insulation and as an additive to external plaster systems because of remarkable good thermal insulating characteristics. Aerogel is a very light, low-density solid material from which the extracted liquid has been replaced by gas. Some sources compare its weight to air: aerogel weighs about 1.2 mg/cm3 and is only three times heavier than air.

Toxicity
Since aerogel is composed only of silica and air, the product is not toxic. Moreover, the production process involves precursor siloxanes, which pose relatively insignificant hazards. During the exploitation stage, aerogel insulation sheets generate dust consisting of complete amorphous silica. However, amorphous silica is not classified as carcinogenic, and no evidence regarding silicosis has been found (Baetens, 2011).

Climate
Thanks to its hydrophobic properties, aerogel will not age, mold, or mildew. This longevity translates to minimized GHG emissions throughout the entire life cycle of the product (Thermablok, 2023). When considering only the A1-A3 production stage, the total GWP of aerogels in these stages is 114 kg per 0.11 m³ of aerogel board (AEROCOINs, 2015).

Circularity
Because aerogels are resistant to natural decay, their lifespan expands, thereby reducing waste generation and the need for recycling. Moreover, producers of aerogels claim that the material is recyclable since it is composed only of silica and air, without any hazardous substances that might hinder circularity (Thermablok, 2023). However, sufficient systems for recycling are currently not in place.

Super insulation material (SIM) such as types of vacuum insulation panels (VIP), gas filled panels (GFPs) and aerogel based products (ABPs) are investigated in the IEA-EBC Programme Annex || IEA EBC (iea-ebc.org). Research is on-going but besides offering excellent insulation performance, these materials are relatively expensive and there has been a lack of information on their durability under different thermo-hygric conditions.

Literature
EBC. Long-Term Performance of Super-Insulating Materials in Building Components and Systems (2023). https://iea-ebc.org/Data/publications/EBC_Annex_65_Factsheet.pdf

Baetens, R., Jelle, B. P., & Gustavsen, A. (2011). Aerogel insulation for building applications: A state-of-the-art review. Energy and buildings, 43(4), 761-769.

Thermablok® Aerogel Insulation. Retrieved November 8, 2023 https://www.thermablok.com/

AEROCOINs (2015). Aerogel-based Composite/Hybrid Nanomaterials for Cost-effective Building Superinsulation systems. Retrieved November 8, 2023 https://cordis.europa.eu/docs/results/260/260141/final1-aerocoins-_final-report.pdf

Schiavoni, S., D'Alessandro, F., Bianchi, F., Asdrubali, F. (2016) Insulation materials for the building sector: A review and comparative analysis. Renewable and Sustainable Energy Reviews, 62: 988-1011. https://doi.org/10.1016/j.rser.2016.05.045

Vacuum insulation panels

Fig. 60
Vacuum insulation panel. Image generated with Midjourney 6.0

The Vacuum Insulation Panel, commonly referred to as VIP, are a type of thermal insulation which is comprised of a low-density core material (e.g. rigid fumed silica) wrapped in an airtight high barrier envelope. This structure results in an innovative insulation solution with a lambda value below 0.0045 W/mK (Božiček, 2023).

Toxicity

Although fumed silica in VIPs was considered to be safe, some studies reveal that during production of fumed silica, toxic chemical groups are formed. However, recent animal studies show that ingestion of small quantities is not harmful (Maynard, 2014). Silicon tetrachloride is the raw material fumed silica is produced from, but this substance does not pose any risks of cancer or reproductive hazards. Nevertheless, it was found to be a sensitizing material (HS fact sheet, 2010).

Climate

The climate impact of VIPs is primarily influenced by fumed silica, with over 90% of the GWP attributed to its production. Interestingly, economic and GHG emissions payback time of such VIPs (3.7–8.6 years) is shorter than for aerogel (Božiček, 2023). Regarding GWPs of VIPs in the A1-A3 stages, a few suppliers state that GWP of their VIPs is around 41 kg CO2 eq. (INNOVIP, 2020). However, the GHG emissions from manufacturing varies depending on the raw material used and use of recycled materials and development of less energy intensive production methods may lower the emissions (Resalati et. al. 2020). VIP can be produced from recycled materials which may reduce the GHG emissions from raw material extraction.

Circularity

Undamaged panels may be easily reused. Researchers have developed recycling methods for VIP (INNOVIP, 2020). Moreover, the expected service life of VIPs is more than 25 years which reduces the need for recycling in general (Božiček, 2023).

Super insulation material (SIM) such as types of vacuum insulation panels (VIP), gas filled panels (GFPs) and aerogel based products (ABPs) are investigated in the IEA-EBC Programme Annex || IEA EBC (iea-ebc.org). Research is on-going but besides offering excellent insulation performance, these materials are relatively expensive and there has been a lack of information on their durability under different thermo-hygric conditions.

Literature

Božiček, D., Peterková, J., Zach, J., & Košir, M. (2024). Vacuum insulation panels: An overview of research Literature: with an emphasis on environmental and economic studies for building applications. Renewable and Sustainable Energy Reviews, 189, 113849.

INNOVIP (2020). Innovative multifunctional VacuumInsulation-Panels (VIPs) for use in the building sector. Retrieved December 7, 2023 https://ec.europa.eu/research/participants/documents/

Schiavoni, S., D'Alessandro, F., Bianchi, F., Asdrubali, F. (2016) Insulation materials for the building sector: A review and comparative analysis. Renewable and Sustainable Energy Reviews, 62: 988-1011. https://doi.org/10.1016/j.rser.2016.05.045

Gas filled panels

Fig. 61
Gas filled insulation panel. Image generated with Midjourney 6.0

Gas-filled panels (GFPs) comprise a barrier envelope and a gas located between reflective layers, acting as a baffle. The gas may be air or a denser alternative, aimed at reducing thermal advection and conduction (Baetens, 2010).

Toxicity

GFPs are a relatively simple construction material consisting of an aluminium baffle and gas. The employed gas may be sulphur hexafluoride, refrigerants, or inert gases. In general, these gases are not hazardous, but in some cases, they or their decomposition products may be sensitizing (Baetens, 2010).

Climate

Since gas-filled panels have been found to be less promising than vacuum insulation panels, data regarding the climate impact of GFPs is not available. However, the GWP for GFPs can vary significantly because the gas employed might be inert or, on the contrary, have a high GWP like freons. GFPs configured with freons would potentially have an enormous GWP compared to vacuum insulation panels if the gas leaks. (Baetens, 2010).

Circularity

Aluminium foil combusts during high temperatures which makes the aluminium envelope difficult to recycle. The collection and reuse of different gases might not be cost-effective. Additionally, damages to the envelope would result in the loss of gases to the environment, making recycling impossible.

Super insulation material (SIM) such as types of vacuum insulation panels (VIP), gas filled panels (GFPs) and aerogel based products (ABPs) are investigated in the IEA-EBC Programme Annex || IEA EBC (iea-ebc.org). Research is on-going but besides offering excellent insulation performance, these materials are relatively expensive and there has been a lack of information on their durability under different thermo-hygric conditions.

Literature:

Baetens, R., Jelle, B. P., Gustavsen, A., & Grynning, S. (2010). Gas-filled panels for building applications: A state-of-the-art review. Energy and Buildings, 42(11), 1969-1975.

Schiavoni, S., D'Alessandro, F., Bianchi, F., Asdrubali, F. (2016) Insulation materials for the building sector: A review and comparative analysis. Renewable and Sustainable Energy Reviews, 62: 988-1011. https://doi.org/10.1016/j.rser.2016.05.045

Oils

Fig. 62
Oiled timber surface. Image generated with Midjourney 6.0

In the construction sector oils are mainly used as decorative finishes for wood or plaster or to even seal concrete surfaces. Linseed oil, tung oil, “Danish oil” or “Teak oil” are commonly used for these purposes as oils polymerising and forming a hard film after application. Other kinds of natural oils could also work for wood protection (such as olive oil, refined hemp oil or even walnut oil). In some cases, petroleum based mineral oil is used.

Linseed oil is one of the more popular raw materials used to manufacture varnishesand it is even used to manufacture linoleum. Linseed oil can be processed by double boiling to improve its’ qualities and drying rate. After application linseed oil polymerises over a period a time until it completely hardens and becomes dry.

Toxicity

Natural oils are generally hazard free. There may be hazards associated with additives, such as solvents, pigments, dryers, etc. Processed oils such as double boiled linseed oil or mineral oil are harmful if entered digestive tract or airways.

Climate

Biobased oils often have a considerably lowimpact on climate change. However, this varies depending on production region, type of oil, use of synthetic fertilizers in agricultural practices and energy usage during extraction and processing. Indirect impacts on climate change may also occur due to changes in land and water use affecting the local ecosystems.

Circularity

The coating increases the durability and prolongs the service life of products, and the long-lasting coating can be renewed if needed. As the oil is consumed during use, no recycling or reuse is relevan

Waxes

Fig. 63
Waxed timber floor. Image generated with Midjourney 6.0

Natural waxes such as soy wax, carnauba (Brazilian palm wax) or bees wax can be used to produce varnishes for wood or other materials. Waxes are typically long chain aliphatic chemical compounds that are solid at room temperature with a relatively low melting point of 40-50° C.

Waxes can also be of fossil fuel origin, such as those acquired from petroleum distillation and referred to as paraffin waxes. Waxes are also chemically synthetised at an industrial scale, for example by polymerisation of ethylene to obtain polyethylene wax. These synthetic or fossil fuel derived waxes can be used in various coating products.

Toxicity

Natural waxes are not known to be hazardous. Polyethylene wax is considered non-toxic also. Petroleum-derived paraffin waxes may contain hazardous residues, such as Polyaromatic hydrocarbons (PAHs). (Shubik, 1962)

Climate

Synthetic waxes and petroleum derived waxes are produced through numerous steps of processing, thus the GHG emissions are significant. GHG emissions may vary depending on type of wax and energy and material input used in the production.

Circularity

The coating prolongs the service life of products, and the long-lasting coating can be renewed if needed. As the oil is consumed during use, no recycling or reuse is relevant.

Literature

Shubik, P., Saffiotti, U., Lijinsky, W., Pietra, G., Rappaport, H., Toth, B., ... & Ramahi, H. (1962). Studies on the toxicity of petroleum waxes. Toxicology and applied pharmacology, 4, 1-62. https://doi.org/10.1016/0041-008X(62)90112-6

Cement

Fig. 64
Cement powder. Image generated with Midjourney 6.0

There are many different cement compositions used for various applications. The most widely used type is “Portland cement”. Usually, the main ingredients of cement are lime, silica (sand), alumina (aluminium oxide), magnesia (magnesium oxide), iron oxide, gypsum, sulphur and other minor ingredients. This is a simplified description as usually more complex mineral ingredients or industrial byproducts are used to compose cement in a multi-step manufacture process.

Toxicity

Cement compositions such as concrete, renders, plasters, or mortar are alkaline and when wet are irritant or even corrosive to skin, eyes, thus care should be taken when handling. When cured it is relatively inert and have no hazardous properties. Inhalation of dry cement dust, which occurs mainly during construction and demolition stages, can damage the respiratory tract and should be avoided.

Climate

Cement that is used in many masonry materials or biding mortars releases high CO2 emissions during production (IEA, 2023) and accounts for around 8% of the global emissions (Nature, 2021). The emissions occur mainly due to the energy intensive processing of lime during production.

Circularity

Cement-based products (such as cement plasters, renders, tiles, cladding and boards can be crushed and repurposed as filling materials, for pavement and road construction, landscaping or as an aggregate for “recycled concrete”. However, this allows to only reduce the use of new aggregates in the concrete but does not substitute the use of new cement.

Cement is an important building material today. It is used to make concrete. Cement in a combination with sand and water is used to produce mortar for masonry and it is also an ingredient in many construction render and plaster compositions, where it functions as the main binding agent. A wide range of cement-based plaster and render products exist that are suitable for various applications. Cement is also manufactured into roofing tiles, exterior wall cladding of various types, such as fibre cement, lightweight concrete boards or construction blocks.

Literature

IEA. (2023, July 11). Cement - IEA. International Energy Agency. Retrieved September 7, 2023, from https://www.iea.org/energy-system/industry/cement

Nature. (2021, September 28). Concrete needs to lose its colossal carbon footprint. Nature, (597), 593-594. https://doi.org/10.1038/d41586-021-02612-5

Cement-based concrete

Fig. 65
Precast concrete panel. Image generated with Midjourney 6.0

Concrete is an inert material that is composed of aggregates (sand, gravel, crushed stones), cement and water. The mixture forms a paste that hardens over time. Concrete is the most used material in the construction industry (European Commission, 2019).

Toxicity

Concrete, when cured is relatively inert and has no hazardous properties. Wet concrete can be irritant or corrosive to skin as it is alkaline. To speed-up the curing process of concrete, various additives might be used in the mixture which can release substances during the curing process (Johansson, I. et al, 2016). Alkylphenols may be used as additives to certain types of concrete (Lamprea, 2018). When cured and being cut, crushed or smoothed, the dust particles of concrete can cause skin or respiratory irritation.

Climate

Concrete production has a significant role in increased amounts of CO2 emissions in the atmosphere. The cement used in concrete is responsible for around 8% of global CO2 emissions (Nature, 2021). Although, concrete in the interior of a building can act as thermal mass and balance temperature fluctuations, resulting in lower energy consumption for heating and cooling, these do not balance out the large environmental impact from production. There have been various concrete products developed that partially substitute cement with fly ash or slag and reduce the embodied emissions, however, these tend to be more expensive (Berndt, M. L, 2009).

The climate impact of the material varies between countries, based of the strength class and product type, for example, in Sweden ready mix concrete with class C25/C30 has a total GWP of ca 0.129 kg CO_2e/kg for A1-A3 stages (Boverket, 2023).

Circularity

Concrete can be reused or recycled; however, the process is rather complex and therefore in most cases concrete is downcycled. To reuse concrete elements, these should be either easy to disassemble or cut in new elements, where the latter is often time consuming and costly. As per most building regulations, structural elements should fit to certain norms, meaning that reused concrete elements should undergo testing or can be used in non-load bearing elements only. Recycling process for concrete follows crushing the existing concrete elements and using these as aggregate in new concrete mixtures. Although it is possible, not many concrete producers offer this as a product and same as for reused elements, such product in most cases must undergo testing to be allowed for use in new load-bearing elements. As a result, concrete is often downcycled and used in crushed form as underlay in road construction.

Concrete forms pavements, building slabs, roofs, walls, columns etc. It can also be used to produce blocks and roof tiles for construction. Lightweight concrete blocks can be made from aerated concrete or by adding lightweight aggregates such as clinker, pumice rock or perlite.

Literature

Berndt, M. L. (2009, July). Properties of sustainable concrete containing fly ash, slag and recycled concrete aggregate. Construction and Building Materials, 23(7), 2606-2613. https://doi.org/10.1016/j.conbuildmat.2009.02.011

European Commission. (2019, April). EU construction sector: in transition towards a circular economy. European Construction Sector Observatory, 12. https://ec.europa.eu/docsroom/documents/34904

Johansson, I., Carlsson, P., Sandberg, M., & Kumlin, A. (2016). Emissions from concrete an indoor air quality issue? Retrieved September 7, 2023, from https://www.semanticscholar.org/paper/Emissions-from-concrete-an-indoor-air-quality-issue-Johansson-Carlsson/35502fbea775805408c8266b2bc9132ea960a588

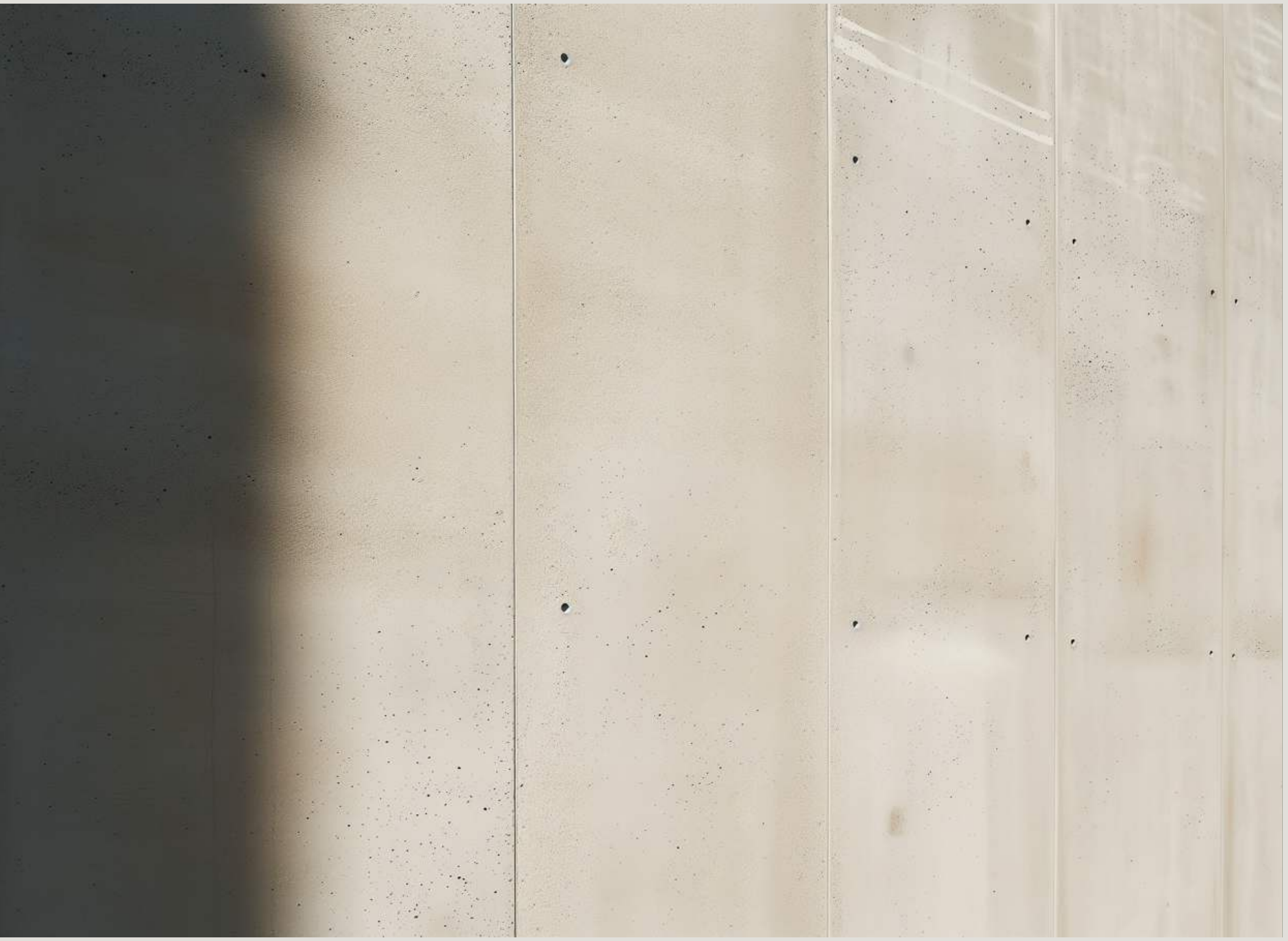
Lamprea, K., Bressy, A., Mirande-Bret, C., Caupos, E., & Gromaire, M. C. (2018). Alkylphenol and bisphenol A contamination of urban runoff: an evaluation of the emission potentials of various construction materials and automotive supplies. Environmental Science and Pollution Research, 25, 21887-21900. https://doi.org/10.1007/s11356-018-2272-z

Nature. (2021, September 28). Concrete needs to lose its colossal carbon footprint. Nature, (597), 593-594. https://doi.org/10.1038/d41586-021-02612-5

Boverket. (2023, October 30). Ready-mix made concrete, buildings C25/30. Boverket climate database. Retrieved from https://www.boverket.se/en/start/building-in-sweden/developer/rfq-documentation/climate-declaration/climate-database/GetResourceByCategoryID/

Lime-based concrete

Fig. 66
Precast lime-based concrete panels. Image generated with Midjourney 6.0



Lime based concrete, also called limecrete, has been used since the ancient times and was an important building material before the emergence of Portland cement. Lime concrete is produced by mixing lime with sand or other aggregates in a certain proportion. Lime combined with sand can be used as mortar for masonry walls. Certain mixtures of lime can be used to composed “hydraulic cement”, which sets even under water.

Toxicity

Lime concrete is non-toxic. The solution is irritant or corrosive, thus appropriate care should be taken when handling. Moreover, lime dust is corrosive to respiratory tract.

Climate

Production of lime used in concrete is generally less energy intensive than production of Portland cement. The material however requires longer setting times.

Circularity

Concrete can be crushed and repurposed as filling materials, for pavement and road construction, landscaping or as an aggregate for “recycled concrete”.

Recycled concrete

Fig. 67
Crushed brick and concrete for use as aggregate in concrete mix. Image generated with Midjourney 6.0

Concrete rubble (demolition waste) can be collected, crushed and ground up to be used as an aggregate for new concrete. This helps to save resources. However, it is necessary to ensure, the source concrete has not been contaminated during its lifetime (e.g. in various chemical product manufacturing industry buildings, floor in automobile repair workshops (oil leaks), chemical or hazardous waste storage buildings). Concrete rubble can be also used as a resource for road pavement. (Nixon, 1978; Oikonomou, 2005).

Toxicity

Recycled concrete can be a source of pollution if contaminated concrete waste was used. Otherwise, concrete is an inert material.

Climate

The impact on climate change is generally lower compared to the case where crushed rock aggregate is used, due to lower energy usage for processing and transportation. (Collins, 2010). However, the use of recycled aggregate does not eliminate the need of new cement.

Circularity

Recycled content concrete increases the circularity of the building sector and reduces concrete waste. Overall, the use of recycled aggregate in new concrete reduces the need of such finite resources as sand. The only two downsides of concrete recycling is the lack of established infrastructure and lack of legislation and testing that would allow to use recycled concrete in load-bearing constructions.

Literature

Collins, F. (2010). Inclusion of carbonation during the life cycle of built and recycled concrete: influence on their carbon footprint. The International Journal of Life Cycle Assessment, 15, 549-556. https://doi.org/10.1007/s11367-010-0191-4

Nixon, P. J. (1978). Recycled concrete as an aggregate for concrete—a review. Matériaux et Construction, 11, 371-378. https://doi.org/10.1007/BF02473878

Oikonomou, N. D. (2005). Recycled concrete aggregates. Cement and concrete composites, 27(2), 315-318. https://doi.org/10.1016/j.cemconcomp.2004.02.020

Paints

Fig. 68
Wall paint. Image generated with Midjourney 6.0

Paints are used to coat various surfaces in construction, such as plastered walls or ceiling, wooden surfaces, facades, other surfaces. Paints are either water-based or solvent-based.

Solvent based paints (such as oil paints or alkyd enamel paints) are usually suite for outdoor applications, typically when higher performance is necessary to protect surfaces from weathering and water damage, corrosion, Sun's UV and other environmental or biological effects. The downside is the large quantities of VOCs that are emitted during the application.

Water based paints are used in less demanding environments and typically water-based paints have less hazardous compositions. However, there are also many water-based high-performance paints developed that can match the durability and other qualities of the solvent-based paints.

The compositions of paints differ for each category, but the main ingredient types are the following: binders (usually synthetic polymers, for example acrylic, vinyl acrylic, PVA); pigments; solvent (water and low amounts of other organic solvents); fillers (calcium carbonate or others); additives such as anti-foaming agents, thickeners, stabilisers, preservatives. Water-based paints are typically sold as liquid in-can products and preservatives are necessary in their compositions to prevent degradation by microorganisms that can ruin the coating product or produce harmful mycotoxins. Other co-formulants that have hazardous properties may also be present (check according to case-by-case basis) (Hirsch, 2023).

Still there are tox-free natural material-based options, such as clay-based paints or lime wash that are most environmentally and human health friendly.

Oil-based paints. These coatings contain natural oils such as linseed, tung or other oils that are dissolved in petroleum or other solvents. Additional ingredients include pigments, dryers, fillers and other additives. When applied, large concentrations of VOCs are emitted. It is possible to use oils, such as linseed without any solvents at all (see section on varnishes).

Alkyd paints or alkyd enamel paints are an upgrade of oil-based paints that are made of alkyd resins, solvents and other additives. Alkyd paints are known for their good durability and versatility. However, they still contain high concentrations of VOCs.

Epoxy resin-based paints are usually 2 component products comprised of resins and their hardeners. Epoxy coatings are usually very durable, resistant to environmental and chemical effects and long-lasting. These are solvent based and, when used, emit large quantities of VOCs. Additionally, bisphenol A residue (small quantities of unreacted monomer used in resin production) may leach into the environment or contaminate indoor space. BPA is a known to be toxic to reproduction and disrupt endocrine system. (ECHA, 2023)

Polyurethane (PU) paints can be 2 component or a 1 component products and can be cured by different means in different conditions depending on the formulation. Polyurethane is a polymer that forms in a reaction of isocyanates and polyol – a crucial components of PU paints. Isocyanates can cause damage to respiratory tract and are suspected of causing cancer. Additionally, PU paints contain VOCs and possibly other hazardous components. (SpecialChem, 2023)

Wood preservative coatings are designed for treatment of exterior wooden surfaces to protect them from weathering and degradation by environmental factors and microorganisms. These coatings usually have high concentrations of biocides that may leach into the environment (Paijens, 2020). Some of these chemicals may be persistent in the environment.

Water based low/zero-VOC paints. There are several categories of water-based paints, such as acrylic, latex, waterborne enamel, water-based emulsion, and others. Water-based paints are not entirely hazardous chemical-free, as small percentage of organic VOCs may be present in the compositions, but after application large proportion of VOCs content dissipates relatively quickly (Chang, 2011). Zero-VOC paints are entirely VOC free. However, the preservatives used for in-can preservation such as isothiazolinones are less volatile, thus they evaporate over a longer time period and may become an important indoor pollutant (Lundov, 2014). Hazardous heavy metal-based pigments are no longer used, but they may be contained in old paints that should not be used but properly disposed of.

Clay based paints can be completely free from VOCs, synthetic binders and preservatives making it one of the most sustainable coating solutions.

They can be sold in liquid or in powder form. Clay paints are not widely commercially available but are gaining interest in the sustainable construction sector and the niche market is expanding.

Lime wash is a simple coating solution for interior or exterior walls. Suitable for DIY application, as limewash only consists of lime and water. Additional ingredients can be added to improve its properties. Lime wash coating is an environmentally friendly solution, but PPE should be used during its preparation and application as lime and lime solution is corrosive and can burn skin or eyes.

Natural pigments are extracted from plants, animals or earthen pigments. Commercially available pigments can be used for DIY application and are generally safe materials to work with if the inhalation of their dust is avoided and provided, they are not heavy metal compounds.

Toxicity

Water-based paints can contain small amounts of VOCs, solvent-based paints have high amounts of VOCs. Some of the VOCs may be cancerogenic, cause respiratory or other irritation, headaches, or other adverse health effects.

Nearly all water-based paints contain preservatives, such as isothiazolinones, but possibly other kinds. Preservatives can leach into the environment and cause negative effects or contaminate the indoor environment. Wood treatment coatings contain high concentration of biocides that pose risk to the environment (Paijiens, 2020).

Paints may contain other additives, such as resins, dispersants, preservatives, defoamers, surfactants, plasticisers some of which may have hazardous properties (Healthy Building Network, 2023; IARC, 2012)

Climate

The GHG emissions of paints highly depends on the type of paint and the raw material and energy input.

Circularity

Synthetic binders used in paints take a very long time to degrade and at the end of life are a potential source of microplastics (Gaylarde, 2021). High quality paint may increase the durability and prolong the service life of products.

Literature

Chang, Y. M., Hu, W. H., Fang, W. B., Chen, S. S., Chang, C. T., & Ching, H. W. (2011). A study on dynamic volatile organic compound emission characterization of water-based paints. Journal of the Air & Waste Management Association, 61(1), 35-45. https://doi.org/10.3155/1047-3289.61.1.35

ECHA (European Chemicals Agency). (2023). Information on chemicals. https://echa.europa.eu/substance-information/-/substanceinfo/100.001.133

Gaylarde, C. C., Neto, J. A. B., & da Fonseca, E. M. (2021). Paint fragments as polluting microplastics: A brief review. Marine Pollution Bulletin, 162, 111847. https://doi.org/10.1016/j.marpolbul.2020.111847

Healthy Building Network. (2023). Interior Paint Product Guidance. https://homefree.healthybuilding.net/products/3-paint

IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. (2012). "Occupational exposure as a painter". Chemical agents and related occupations. IARC monographs on the evaluation of carcinogenic risks to humans, 100(PT F), 9. https://www.ncbi.nlm.nih.gov/books/NBK304433/

Lundov, M. D., Kolarik, B., Bossi, R., Gunnarsen, L., & Johansen, J. D. (2014). Emission of isothiazolinones from water-based paints. Environmental science & technology, 48(12), 6989-6994. https://doi.org/10.1021/es500236m

Paijens, C., Bressy, A., Frère, B., & Moilleron, R. (2020). Biocide emissions from building materials during wet weather: identification of substances, mechanism of release and transfer to the aquatic environment. Environmental Science and Pollution Research, 27, 3768-3791. https://doi.org/10.1007/s11356-019-06608-7

Hirsch, M., Petrie, E. M. (2023). Biocide Selection: In-can Preservation, Dry Film Protection, Anti-fouling. SpecialChem. https://coatings.specialchem.com/selection-guide/biocides-selection-for-in-can-and-dry-film-protection

SpecialChem. (2023). Polyurethane Coatings: A Comprehensive Guide. https://coatings.specialchem.com/selection-guide/polyurethane-coatings

Varnishes

Fig. 69
Varnished timber surface. Image generated with Midjourney 6.0

Varnishes are applied to various surfaces such as wood, plaster or other materials to give a glossy appearance, seal and provide protection from water and dirt, increase durability and extend the lifetime of the material. Natural varnishes are made from plant oils, waxes and/or resins (for example, rosin from conifer trees). Waxes or resins need to be dissolved in solvents such as turpentine, or petroleum-based solvents, while oils can be used as a single ingredient varnish or in simple compositions. Varnishes are also often made of synthetic components (polymers). Additionally, there are water-based varnishes where oils or synthetic polymers are emulsified in water. (Segura, 2021)

Natural oils such as linseed oil, tung oil, refined hemp oil or walnut oil can be used as a single ingredient varnish. Single ingredient plant oil varnishes without solvents, such as linseed oil, are among the safest choices.

Natural waxes such as soy wax, carnauba or bees wax are used in some varnish compositions. Such compositions may contain plant oils, solvents (turpentine or others) and other additives (pigments, UV stabilisers, dryers, etc.).

Water-based polymer varnishes contain synthetic polymers functioning as film coating agents. Acrylic is among the safest options, while the use of products with polyurethane, for example, should be carefully considered due to their potential toxicity. Acrylic varnishes typically contain low VOC amounts, but may also contain other chemical additives, thus the associated hazards should be checked.

Danish soap finish is an environmentally friendly wood finishing technique that renders the wood surfaces with a soft light matte effect. The only ingredients needed for this finish are soap and water.

Toxicity

Solvent-based products have high amounts of VOCs. Some of the VOCs may be cancerogenic, cause respiratory or other irritation, headaches, or other adverse health effects (IARC, 2012).

Some products may contain preservatives, such as isothiazolinones, but possibly other kinds. Preservatives can leach into the environment and cause negative effects or contaminate the indoor environment.

Climate

Biobased oils often have a considerably low impact on climate change. However, this varies depending on production region, type of oil, use of synthetic fertilizers in agricultural practices and energy usage during extraction and processing. Indirect impacts on climate change may also occur due to changes in land and water use affecting the local ecosystems.

Circularity

The coating increases the durability and prolongs the service life of products, and the long-lasting coating can be renewed if needed. As the oil is consumed during use, no recycling or reuse is relevant. Synthetic polymer binders used in some varnishes at the end of life take a very long time to degrade and are a potential source of microplastics. (Gaylarde, 2021).

Literature

Gaylarde, C. C., Neto, J. A. B., & da Fonseca, E. M. (2021). Paint fragments as polluting microplastics: A brief review. Marine Pollution Bulletin, 162, 111847. https://doi.org/10.1016/j.marpolbul.2020.111847

Halios, C. H., Landeg-Cox, C., Lowther, S. D., Middleton, A., Marczylo, T., & Dimitroulopoulou, S. (2022). Chemicals in European residences–Part I: A review of emissions, concentrations and health effects of volatile organic compounds (VOCs). Science of The Total Environment, 839, 156201. https://doi.org/10.1016/j.scitotenv.2022.156201

IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. (2012). Occupational exposure as a painter. Chemical agents and related occupations. IARC monographs on the evaluation of carcinogenic risks to humans, 100(PT F), 9. https://www.ncbi.nlm.nih.gov/books/NBK304433/

Segura, C. (2021). A Guide to Non-Toxic Sealers, Stains, and Varnishes. My Chemical-Free House Consulting. https://www.mychemicalfreehouse.net/2021/01/natural-finishes.html#vii_Exterior_Wood_Sealers

PU glue

Fig. 70
Expanded PU glue. Image generated with Midjourney 6.0

Polyurethane (PU) glue is often a yellow glue that foams while it cures. It forms a very strong, water-resistant bond. Can be used to fill holes and cracks because it expands a little bit. In addition to wood, PU sticks to a wide range of materials (e.g., paper, textile, metal, glass, plastic). The downside of PU glue is that it is a messy glue, stains are difficult to remove from wood and hands. It is also expensive compared to other wood glues such as PVA. Highly durable and water resistant. Very suitable for outdoor woodworking. Quick to apply and short curing time.

Toxicity

Polyurethanes are formed by combining a variety of chemicals. Polyurethane contains solvents and other toxic compounds, such as isocyanates, that will release gases during application. Isocyanates also have not such an environmentally friendly profile. Extensive exposure can cause skin irritation or allergies.

It is important to note that a new set of restrictions under REACH Regulation have entered into force since August 24, 2023, requiring that the manufacturer of all products that contain diisocyanates in concentrations above 0,1% (which includes PU glue) provide the end users with guidance and training on their safe use. In practice this means that only professional and industrial users with appropriate training and risk assessments are able to legally use these products.

Climate

The embodied energy of polyurethane glue is four times higher than wood glue. The main contribution to GHG emissions results from the energy intensive production of chemicals used in the PU glue.

Circularity

The polyurethane produces toxic gases when incinerated and is classified as special waste in the EU. It is therefore difficult to recycle, and its short shelf life may result in excessive waste.

Silicone glue

Fig. 71
Silicone sealing. Image generated with Midjourney 6.0

Silicone adhesive is a versatile water-resistant polymer whose primary ingredient is silica, a common form of sand found in quartz. The term silicone refers to a group of polymers that have a siloxane bond with organic compounds. Their production begins with the isolation of silicon from silica, also known as silicon oxide. Silicone adhesives are used as a non-toxic alternative to toxic adhesives.

Toxicity

Silicone adhesives and sealants are made from polymerized silicone. When silicone is uncured, it is a highly adhesive gel or liquid. It is a chemically inert substance that is safe for use in a variety of applications and is non-toxic. The final result of the production of silicone adhesives is a flexible heat resistant glue that can be used for electronics, automotive manufacturing, and construction.

Silicone adhesive is a material that resembles ointment, and it cures into a tough rubber-like solid once it contacts moisture in the air. Different solvents are added to achieve the correct consistency of the binder. As the main source of indoor VOCs, silicone adhesives cannot be ignored, especially in newly built buildings. As result study shows there are various VOC emitted to the air when using silicone adhesives. The detected compounds included ketones, alcohols, benzenes, esters and nitrogenous organic compounds. The representative compounds that were identified in studies are butanone oxime, butanone and ethanol, all of which had high chemical concentrations and detection frequencies. Since the ingredients in silicone adhesives are taken from natural elements, it has very little impact on the environment. Silicone adhesives are resistant to most chemicals and are non-chemical reactive, a factor that emphasizes its environmental safety.

Epoxy glue

Fig. 72
Epoxy glue. Image generated with Midjourney 6.0

Epoxy glue is an extremely strong adhesive, used e.g. for building airplanes, automobiles, bicycles, boats, snowboards and other products that require high strength bonds. Commonly available in hardware stores is the 5-minute epoxy glue, a two-component glue that comes in a tube with two different compartments. One is a resin, the other one a curing agent. When the two are mixed, they turn into a strong plastic material.

Toxicity

Cured epoxy poses few health risks, but liquid and partially cured epoxies, as well as dust from sanding introduce numerous health threats that need to be managed as efficiently as possible. Epoxy glues are highly toxic in production. The resins and solvents in the liquid glue produce fumes that can affect the skin and lungs. Another risk is posed by fine dust from sanding (partially) cured epoxy. When epoxies are used outdoor, in big amounts and large surfaces, they can get in contact easily with water and direct sunlight. In that case the depolymerization of hardeners and other toxic chemical compounds can happen. When cured, epoxy is rather safe for the user, it doesn't emit toxic fumes. It may leach small quantities of hardeners and other toxic compounds through hydrolysis (exposure to water) and photolysis (exposure to direct sunlight). The amount of resin used as a connector is normally small and is not directly exposed to water and sunlight (especially when it is indoor).

Liquid and partially cured epoxies introduce numerous health threats that need to be managed as efficiently as possible. Measures to be taken are proper ventilation to extract fumes, wear gloves and a mask with filters. Another risk is formed by sanding (partially) cured epoxy. Epoxy may be hard enough to sand after a couple of hours; however, it may not be completely cured for up to two weeks. The dust increases risk of exposure by skin contact, inhaling or ingesting. When inhaled repetitively this can cause serious harm to the lungs and on the long run can result in sensitization and asthma.

Alternative is bio epoxy resins; they are becoming more commonly available nowadays.

Climate

Two components epoxy has the highest embodied energy of all glues, about five times that of wood glue. Glued wooden constructions cannot be disassembled so they take more space, which increases energy use in transportation.

Moreover, epoxy is expensive and woodworking it is only used for small repairs in high performance products such as boats or snowboards, etc.

Circularity

Both components of 2-parts epoxy glue, epoxy and amine curing agent, are produced with polluting chemical processes. Materials are not recyclable and epoxy components are labelled as hazardous waste. Epoxy also emits toxic fumes during incineration.

PVA glue

Fig. 73
Wood glue. Image generated with Midjourney 6.0

PVA, PVAc glue (Polyvinyl acetate), or white glue, is the most used glue in wood construction nowadays. It is a product of the petrochemical industry. It can be seen as microscopic plastic particles diluted in water with relatively low VOC emissions, however PVA is a potential wastewater pollutant. Overall, it is considered as a safe product to use. Also used for bookbinding and paper crafting, or as a protective coating for cheese.

Toxicity

PVA is nontoxic to humans however it does release toxic fumes if burned. It can have VOC emissions but there is also low VOC wood glue available on the market. The PVA glue has very low offgassing when it is hardened out. Overall, PVA is formaldehyde free.

Most of synthetic glues are slightly hazardous in case of skin contact (irritant), of eye contact (irritant) or of ingestion.

Climate

Natural glues have lower embodied energy than wood glue and other synthetic glues. As glues and adhesives are used in small amounts the overall climate impact can be considered as low and environmental impacts such as human and ecotoxicity and chemical or mechanical properties, should be prioritized when evaluating the choice of material.

Solvent-less adhesives have been shown to emit 75 % less CO2 and use 80 % less energy than solvent-based adhesives.

Circularity

Natural glues are generally not classified as hazardous waste and can be incinerated for energy. Even though it is a synthetic thermoplastic, under the right conditions, it biodegrades, however, the glue does not bidegrade if poured down a drain, therefore attention must be paid to cleaning construction tools.

PVA glue makes strong, durable connections (stronger than the wood itself), enuring the longetivity of the constrcution assembly, however, making the wood parts difficult to reuse through disassembly.

4 Environmental assessment of building elements

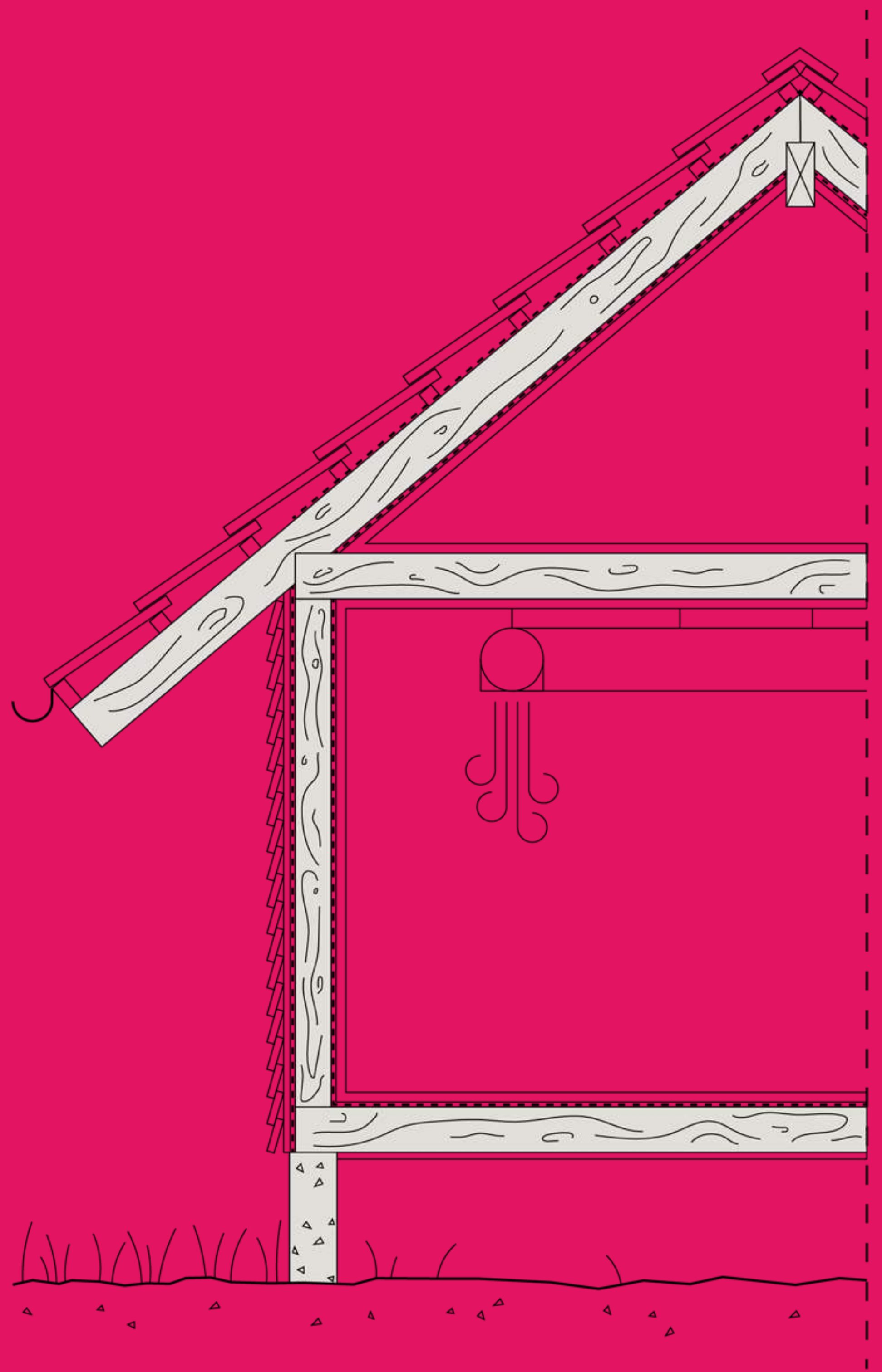
This catalogue aims to be a valuable resource to create buildings that prioritise human and ecological well-being and contribute to a sustainable and healthy built environment. While we aspire to provide a holistic overview, please note that this catalogue does not include technical specifications of specific brands or in-depth manufacturing processes. Our focus is on offering insights into the types of sustainable materials and respective building elements available, encouraging you to explore and integrate them within your design and construction projects.

Chapter three gives information about different materials that can be used in construction projects and buildings. These materials can be used in different building elements. In this chapter the sections are divided into building elements, to show which materials should be preferred, from an environmental sustainability perspective, for each element.

Remember when choosing products:
• Hazardous substances often come with functionality and plastics, but tox-free products are not free of functionality
• Circularity is strongly connected to design. Products designed circular are often but not always tox-free
• The impact the product has on the climate strongly depends on material and processes of the complete supply chain (raw material to finishing). Get to know your products suppliers.

A design that facilitates modularity and disassembly is essential to be able to recycle building materials after demolition. To focus throughout the whole design phase on the possibility to disassemble elements, e.g., the use of mechanical fasteners rather than glues, to reduce the coatings etc.

Walls and slabs



Load bearing elements are used as main construction of a building – these provide the stability and structural support of the building. Materials with load bearing capacity are used in the building's foundation, columns / studs, and beams, as well as walls. These can be light-weight, such as timber construction, or heavy-weight, such as concrete construction. However, there can also be hybrid constructions where the use of lightweight and heavyweight is mixed to increase the efficiency of the particular construction. Overall, one can distinguish 4 most common load bearing material groups such as timber, steel, concrete, and masonry. However, there are far more materials, especially when it comes to sustainable and innovative construction methods.

Walls and slabs

In a typical construction the load bearing elements within walls and slabs are locked in between interior finishes, insulation, vapour barriers and further layers. Therefore, these do not directly affect the indoor air quality and in exterior are protected from the impacts of weather. As such, these elements tend to have protection treatment against fire, mould, and further aspects. However, sustainable construction requires more simple and honest construction methods that reduce the overall impacts on environment while at the same time increase the quality of the built environment for the society, following the principles of New European Bauhaus. Within sustainable construction all layers of a building are either easy to see or access for easy maintenance, repairs, transformation, and demounting. While this has high benefits for building circularity, it does bring concerns when it comes to material toxicity. Firstly, due to the typical treatments of these elements and secondly, in case of reuse, where such elements that were not intended for exposure indoors or outdoors, change their location in the building and are in direct contact with weather or indoor air.

Timber, sourced from sustainably managed forests, embodies circularity by being both a renewable resource and amenable to easy disassembly for reuse or recycling. It is used for walls, slabs and roof constructions. In its raw or engineered forms, such as CLT or glulam, timber's adaptability allows for reduced waste and increased structural properties. While generally considered safe, the presence of formaldehyde in glued timber products and general tendency to use coatings ad treatments necessitates attention to mitigate health risks. The circularity of timber extends to its climate neutrality, as harvested trees sequester CO2, and timber materials act as carbon sinks if used for the building's lifespan. However, careful consideration of treatments as well as assembly methods is vital to ensure sustainability across multiple cycles.

Masonry, encompassing materials like stone and brick, often bound by mortar, offers durability and benefits for a building's thermal mass, contributing to a comfortable indoor climate. Masonry is mostly used for foundations and walls. Inherently inert, masonry materials typically pose minimal toxicity risks, though attention is required during production and application of coatings, sealants, adhesives, and mortars. Masonry materials are deemed reusable and recyclable, but challenges arise due to construction methods, particularly with hard cement-based mortar limiting disassembly possibilities, often leading to downcycling.

The climate neutrality of masonry materials various, for bricks this involves energy-intensive production and significant CO2 emissions, especially in brick firing and cooling. On the contrary, stone production is less energy intensive. These materials, when in contact with the indoor environment, exhibit thermal storage capabilities, reducing the heating or cooling demand of a building. Notably, historic methods like sun-dried bricks present a low-energy alternative. For a circular approach, select disassembly-friendly mortars or explore alternative joinery with dry connections, along with minimizing unnecessary coatings.

Steel, renowned for its durability and strength, is a widely used construction material, finding applications in diverse structures, including high-rises and hybrid constructions. It is used for foundations, columns and beams. While it is inert and safe during construction and use, the environmental toll of steel production must be noted. Steel's climate impact stems from the extraction of iron ore, affecting groundwater and ecosystems, and its energy-intensive production, contributing to substantial CO2 emissions. The potential of steel can be expressed through its 100% recyclability without quality loss, contributing significantly to the circular economy in construction. However, realizing its full circular potential demands the development of legislative frameworks for ensuring the safety of reused steel elements. To mitigate the negative impacts, responsible sourcing with high recycled content is crucial, and construction practices should facilitate easy demounting for reuse while minimizing surface treatments to enhance recyclability.

Concrete, a prevalent construction material valued for its durability and strength, consists of aggregates, cement, and water. Widely used in various building elements, it often incorporates steel reinforcement for enhanced tensile strength. It is generally inert and non-toxic. In terms of circularity, concrete faces complexities in reuse or recycling, often leading to downcycling due to disassembly challenges and testing requirements for structural elements. Despite its potential to act as thermal mass for energy efficiency in building interiors, concrete production significantly contributes to global CO_2 emissions, with cement alone responsible for around 8%. Efforts to reduce embodied emissions by substituting cement with fly ash or slag exist but come with higher costs.

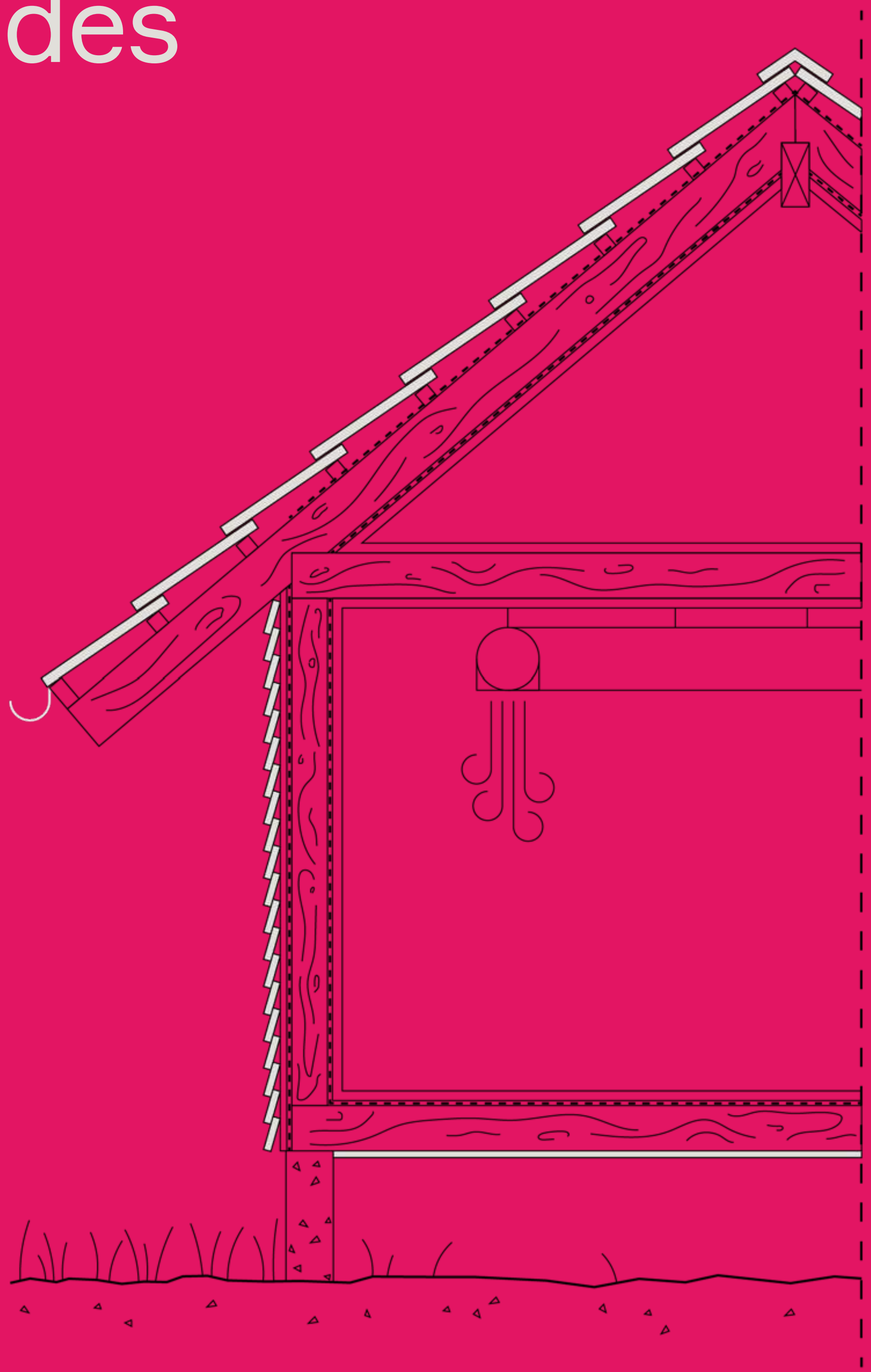
In the realm of load-bearing construction materials also local traditional options have to be addressed. For the European context, rammed earth emerges as a notable choice, if used in weather-protected constructions. It is used to form walls. Comprising layers of rammed soil, this material is considered non-toxic, with attention directed towards sourcing uncontaminated soils. Rammed earth exhibits circularity, offering options for on-site or prefabricated off-site use, with the potential for reuse in new constructions or natural return to nature at the end of a building's life. With low embodied carbon and energy-efficient characteristics, particularly in balancing indoor humidity and acting as thermal mass, rammed earth is deemed a good material from all three perspectives.

Another historic method is where straw and/or flax is mixed with clay to form load bearing walls. This method, similar as rammed earth, can be seen as circular and with low embodied carbon. The toxicity of such construction elements is only an issue if straw is sourced from fields that have been treated with chemicals.

Lastly, a less known material that can be used in lightweight load-bearing constructions as a building block is cork. Cork, harvested from cork oak trees in a renewable process that preserves the trees, emerges as a sustainable construction material. The non-toxic nature of cork makes it safe for both indoor use and disposal, contributing to improved indoor air quality. In terms of circularity, cork exhibits recyclability, particularly from bottle corks, offering potential reuse, repurposing, or recycling at the end of its life. Though transportation distances may impact its carbon footprint, cork's low energy demand during production contributes to a relatively low carbon footprint. With inherent durability, adaptability, and resistance to decay, moisture, and pests, cork stands as a resilient load-bearing material.

The choice of the material for load-bearing constructions depends on the particular application and environmental concerns that are prioritized. If circularity is strictly ensured, also energy intensive materials such as steel and concrete can be used where needed. However, the safest way to go is by using timber and other methods that have derived from vernacular construction, if buildings with the lowest environmental impact are desired. However, these often require more care and maintenance and, therefore, should be already planned for that during the design stage.

Roofs
Windows
Facades



Exterior non-loadbearing elements refer to construction materials on the outer surface of a building that do not contribute to its structural support. These elements encompass components such as roofs, facades, and windows, serving a pivotal role in shielding the building from rain and wind. This chapter furnishes information regarding some of the prevalent materials utilized in a building's envelope.

Roofs

There are numerous roofing materials to choose from, and distinctions exist between urban and residential areas, including small houses. Metal sheets and brick tiles are commonly used, as are elastomeric membranes (PVC, EPDM, TPE and SBR). The use of organic materials represents a more traditional approach to roofing materials but has become increasingly common, even in urban areas. Examples of organic materials include green roofs or roofs constructed from straw, reed, or seaweed.

It is crucial to bear in mind that the roofing material should be free from harmful substances, as these can leach into the environment during rainfall. When it rains, the water from the roof is directed through gutters and downpipes into the stormwater system, which ultimately discharges into the environment or, alternatively, flows through stormwater wells and pipes to a municipal treatment facility. Neither of these options is ideal. In water bodies, these substances have a detrimental impact on the aquatic environment. In a treatment plant, harmful substances can disrupt the treatment process or pass through to the environment via the treated water or sludge, which may be reused in agriculture.

Green roofs offer several benefits. Firstly, they aid in climate adaptation within urban environments by mitigating water runoff. Additionally, they can enhance biodiversity. However, there are also drawbacks associated with green roofs. To safeguard against moisture, they necessitate the use of a plastic membrane. During dry periods, irrigation may be required, and in more severe cases, the use of fertilizers or herbicides may become necessary, especially if issues with invasive species arise.

Metal and metal alloys frequently boast a long service life, yet their production can result in a significant GHG emissions. Certain metals and alloys can also release oxidized ions, which may enter stormwater, leading to pollution (as discussed in the introduction to this chapter).

Several types of plastics (PVC, TPE, EPDM, SBR) and bitumen roofing felt are commonly employed as roofing materials. Detailed descriptions of these materials can be found in chapter about material. While these materials offer functional advantages, their environmental impact is less favourable. They have the potential to leach harmful substances, rely on fossil raw materials, and face challenges in terms of recycling within existing systems.

Clay and concrete roof tiles offer several advantages as they typically contain minimal harmful substances and are highly reusable. However, in terms of their environmental impact, it's worth noting that GHG is emitted during their production. Additionally, brick and concrete roof tiles can be equipped with a surface layer that can alter their properties. The composition of this surface layer, including the presence of potentially harmful substances, can affect the tile's characteristics.

Choosing organic materials like straw, seaweed, or reed for roofing has environmental benefits. They are renewable and have a low environmental impact, reducing energy-intensive processes and emissions. Organic materials are biodegradable, reducing waste and supporting carbon sequestration. Their local sourcing encourages biodiversity and supports local economies. However, proper maintenance is essential, and their suitability may vary with climate and building requirements.

The choice of roofing material should depend on your specific priorities and the environmental concerns you prioritize. Green roofs are beneficial for climate adaptation and biodiversity but require ongoing maintenance, including the potential use of plastic membranes and irrigation. Metal and metal alloys offer durability but have a significant carbon footprint and the risk of releasing oxidized ions. Plastics and bitumen roofing felt are functionally advantageous but pose environmental challenges due to potential substance leaching and reliance on fossil raw materials. Brick and concrete tiles are relatively low in harmful substances but emit carbon dioxide during production. Organic materials like straw, seaweed, or reed are environmentally friendly, renewable, and support biodiversity, but they require proper maintenance and may be climate dependent. Ultimately, your choice should align with your environmental priorities and the specific conditions of your project.

Windows

Windows are an integral aspect of any building's design and functionality, providing not only light and ventilation but also significantly contributing to the energy efficiency and aesthetics of a structure. Various types of windows, such as Casement, Double-Hung, Tilt and Turn, Sliding, Fixed, as well as Bay and Bow Windows, are available. Additionally, different glazing options include Single Glazing, Double Glazing, and Triple Glazing.

Energy efficiency is a crucial consideration in Central Europe and Scandinavia, given the cold winter climate and high energy costs. Similarly, in Southern Europe, where high summer temperatures prevail, windows must balance elevated inner temperatures. The energy efficiency of a window is measured by its U-value, indicating the rate of heat loss; lower U-values signify better insulation. In Scandinavia, windows with a U-value of 1.0 W/m^{2}K or lower are often mandated.

However, tight building sealing, while conserving heat, can impede necessary air flow. Therefore, proper ventilation is essential to prevent condensation and mould growth. In Scandinavia, where buildings are often tightly sealed, windows with ventilation features, such as trickle vents, are common.

When selecting windows, awareness of national regulations is crucial. Europe and Scandinavia enforce strict regulations on the energy efficiency, safety, and installation of windows. For instance, in some countries, windows must be installed by a FENSA registered installer or approved by the local building control department.

The aesthetics of windows are also vital, particularly in historic buildings or conservation areas. In Europe, stringent regulations often dictate the types of windows allowable in such areas. Window design can also impact circularity; windows designed for easy disassembly and recycling are considered more circular.

Window Frames

There is a growing trend towards utilising sustainable materials and energy-efficient windows in Europe and Scandinavia. Smart windows, which can be remotely controlled or programmed, are gaining popularity.

Wood: Traditional and widely used in Central Europe and Scandinavia, prized for its natural look and insulating properties. Regular maintenance is required to prevent rot and decay. Wooden windows are recyclable and biodegradable, but coatings may contain harmful VOCs.
uPVC: A durable, energy-efficient plastic, popular in Europe. Concerns about the toxicity of PVC production and disposal exist. Efforts, like the VinylPlus program, aim to address these concerns. uPVC windows are durable and low maintenance but face challenges in recyclability.
Aluminium: Lightweight and durable, often used in modern designs. Less common in Scandinavia and Central Europe due to lower insulation properties. Aluminium windows are highly recyclable, but production can have a high environmental impact.
Composite: Combining materials like wood and aluminium or wood and uPVC, offering the best properties of each. Adhesives and sealants used may contribute to toxicity. The recyclability and environmental impact depend on design elements.

Windows play a crucial role in the energy efficiency, ventilation, and aesthetics of buildings in Central Europe and Scandinavia. The choice of window type, material, and glazing depends on factors such as climate, regulations, and personal preferences. Consider the entire life cycle, from production to disposal, when assessing the climate impact of windows. Each material has advantages and challenges, and ongoing efforts aim to address concerns through improvements in materials, design, and production processes.

Reflect on aspects such as using recycled raw materials for aluminium, ensuring PVC windows are free of hazardous additives, and maintaining wooden windows regularly with non-toxic coatings. Additionally, windows should be designed for disassembly, favouring mechanical fasteners over glues.

Facades

There are several possible facade materials, some of the most common are plaster, bricks, wood, PVC, galvanized steel and copper or zinc metal sheets.

Regarding the overall assessment of materials used for facades, treated wood is one of the most sustainable choices, especially if the treatment doesn't contain hazardous substances. There are alternatives of wood treated with e.g., heat or silica. Wood is a renewable material with a low climate impact. Recommendations are to choose heat or silica treated wood, a non-hazardous preservative or untreated wood that is painted with e.g., linseed oil.

Regarding toxicity bricks are generally considered safe. They have a long lifespan, but sand lime bricks have a high climate impact. In comparison, the CO2 release per m2 from bricks are 3-8 times higher than plaster, fibre cement or heat-treated wood (pine). Bricks are also possible to reuse, if possible, try to reuse bricks from older buildings.

Plaster is not possible to recycle, but it can be used for refurbishing of other construction materials. It is considered safe from a toxicity point of view. Lime plaster has a relatively high climate impact compared to clay or gypsum plaster that have a lower climate impact. Overall, clay or gypsum plaster is one of the better choices for facade material.

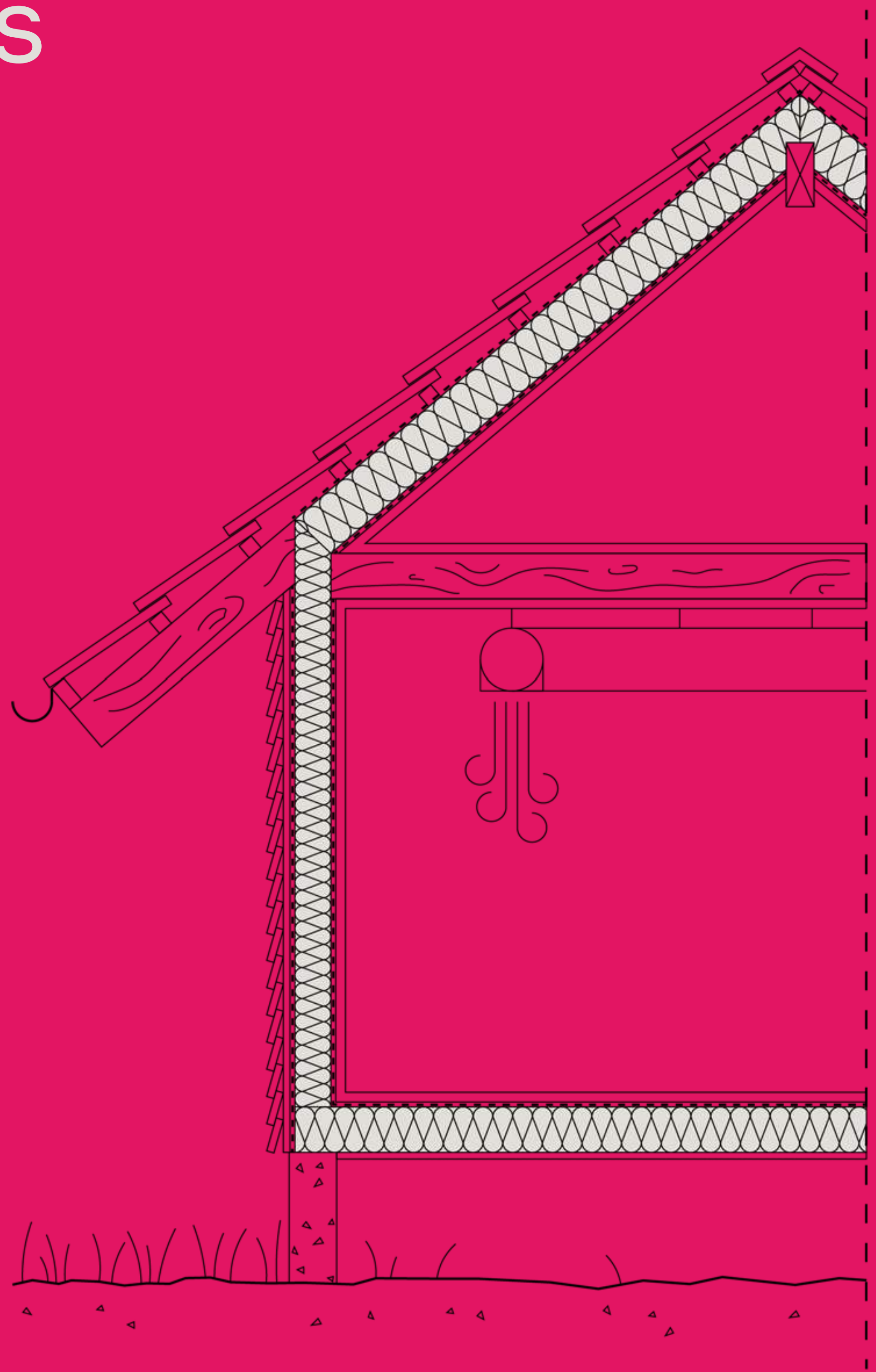
Copper sheets, zinc sheets and galvanised steel are not a sustainable choice for facades because of the toxicity, potential of leaching to the environment when in contact with rain and the high climate impact. In a project where copper or zinc sheets are required, choose a product with a high content of secondary material. Also, painting metal sheets can decrease the leaching to the environment.

PVC has many good functions, but it is produced from a hazardous monomer and often contains hazardous additives. It is possible to recycle but it is mostly incinerated. If PVC is required in a project, choose a phthalate free PVC from a company that can recycle the material.

Wood-plastic composite is a material that can be used, but it's better to use a homogenic material such as wood for circularity reasons, also the plastic can contain hazardous substances.

The most sustainable facade materials are wood without hazardous impregnations or treatments. Also clay plaster or gypsum plaster are good choices, but they are not easy to recycle. PVC can contain hazardous additives and metal sheets are not renewable and contain both toxic substances and have a high climate impact. Bricks have a high climate impact but are considered safe regarding toxicity.

Basement
Non-basement
Pipes



Insulation aims to create barriers for transmission of some kind of energy or materials. In case of buildings reduction of heat transfer is the most common but not the only need (other needs are moisture, sound, etc.). Several materials may be chosen for their insulation properties, however other properties of the respective material often restrict the implementation in specific areas such as basements. The variety of insulation materials can be grouped according to different criteria, e.g. organic vs inorganic, natural vs synthetic. Insulation may come as foam boards (or rigid panels), rolls blanket, loose fill or liquids (spray foams).

Basement

When choosing insulation materials for basements, materials are needed, which are able to block heat transfer, do not accumulate moisture, and prevent mould growth.

Polystyrene offers excellent insulation properties but comes with significant environmental and health concerns, as well as challenges in recycling and disposal. One disadvantage of insulating materials of fossil fuel origin are related to their origin: they are produced from oil, a finite resource.

Polyurethane is a versatile material with both advantages, related to contribution to energy efficiency, and properties of concern, related to toxicity of raw materials, limited recycling possibilities, fossil fuel origin.

Glass foam has great technological characteristics, although thermal insulation properties are somewhat worse compared to fossil-based foams, such as XPS. Glass foam is an environmentally friendly material: it is non-toxic, it has circularity potential through recycling. However, its production is energy-intensive.

Expanded clay can be considered a sustainable solution, because it does not have toxicity, is suitable for reuse and recycling, contributes to reduction of CO_2 footprint even if its production consumes energy, but the use phase allows to achieve substantial energy savings.

ETICS is a great technology to conserve energy in housing with positive carbon balance when considering production and exploitation stages. However, circularity is hardly possible due to ETICS multicomponent nature and potential microbial overgrowth resulting in impeded reusability. In regard to toxicity, ETICS may contain a range of hazardous substances depending on constituents used.

Non-basement insulation

Thermal insulation materials for non-basement use come in diverse forms, such as rigid panels and mats, utilizing synthetic, mineral, or renewable resources, each with distinct properties and environmental impacts. Various insulation materials, such as wood fibre, wool, hemp, stone wool, glass wool, seaweed, sheep's wool, flax, straw, hempcrete, mycelium composite, cork, and reed, can be used for non-basement insulation.

In the overall assessment of non-basement insulation materials, hemp, seaweed, sheep's wool, hempcrete, mycelium composite, cork, reed, and wood fibers (if free from synthetic additives and binders, and in loose-fill form) are favourable choices.

In terms of toxicity, hempcrete, mycelium composite, cork, and reed are considered safe. While wood fibre can be a good choice, it's crucial to select variants free from synthetic additives and binders, as they are often treated with fire-retardant additives. Seaweed, another potential option, may be treated with biocides and potentially flame retardants. Similarly, straw, though generally a good choice, may sometimes require flame retardant treatment. Thus, ensuring that non-basement insulation materials are entirely free of hazardous substances is essential.

In terms of circularity, all materials are generally favourable, but specific details must be considered. Wood fibre insulation is best when loose and not attached to neighbouring materials. Wood and paper wool may pose challenges due to treatments hindering composting, favouring incineration, though reuse is feasible. Flax insulation has circularity challenges due to boron salts, making panels non-compostable. Treated mats, containing hazardous substances, need special disposal, but reuse is possible for the same purpose. Straw is a good circular choice when toxin-free and untreated with flame retardants.

Considering climate aspects, all materials, except stone wool and glass wool, are considered environmentally friendly, as the production of stone wool and glass wool involves high energy consumption.

In conclusion, hemp, seaweed, sheep's wool, hempcrete, mycelium composite, cork, reed, and untreated wood fibers are recommended for insulation. These materials have varying toxicity considerations and circularity challenges. Environmentally, they are preferable to stone wool and glass wool due to lower energy consumption in production.

Pipes

Condensation insulation materials are designed to counteract the adverse effects of condensation, which occurs when moist air contacts cooler surfaces such as water pipes or ventilation systems. The collection of moisture on the surface of the piping system could result in mold growth, corrosion, and deterioration of building materials. Additionally, condensation insulation materials, such as pipe jackets/ blankets, play a pivotal role in preventing undesired temperature exchange to and from the pipes, thus conserving energy and providing energy savings.

There are many types of material used for condensation insulation, but the most notable types are: mineral wool, elastomer foam insulation, polyethylene foam and natural fibre-based insulations (such as cork, flax, hemp wool, coconut husks).

Mineral- based insulation, such as rock wool, glass wool/ fibre are natural material-based and as these materials are non-biodegradable and non-combustible the may not require hazardous chemicals additives. However, certain types of binders and additives, particularly in older formulations, could include substances with properties that are hazardous for health and the environment. Mineral wool's hydrophobic nature makes it resistant to moisture, reducing the risk of condensation-related issues like mold growth. Their production is energy demanding, but the materials are long lived and can even be reused if they are intact and free from contamination, but the recycling may be more difficult as these materials are often multilayer (e.g. with reflective foil).

Synthetic elastomers particularly closed-cell elastomeric rubber insulation, are commonly used in HVAC systems. Synthetic elastomers have low thermal conductivity, which helps maintain temperature differentials and prevents moisture build-up on surfaces. They also provide a moisture-resistant barrier that helps prevent condensation. They also offer durability, flexibility and ease of installation, ensuring a proper fit around pipes and ducts. These materials (can be different synthetic rubbers, such as styrene-butadiene rubbers (SBR), polyisoprene, neoprene, nitrile and EPDM rubbers), are usually made from petroleum-derived chemicals and have a high carbon footprint. Synthetic elastomeric foam insulation materials may not be hazardous themselves, but their manufacture may have high environmental and occupational hazards. Additionally, elastomeric foams are flammable, they may contain hazardous chemicals additives such as hazardous flame retardants or hazardous chemical residues (for example, EPDM may have PAH residues). But it really depends on the polymer type and the composition, as different compositions are produced for different uses.

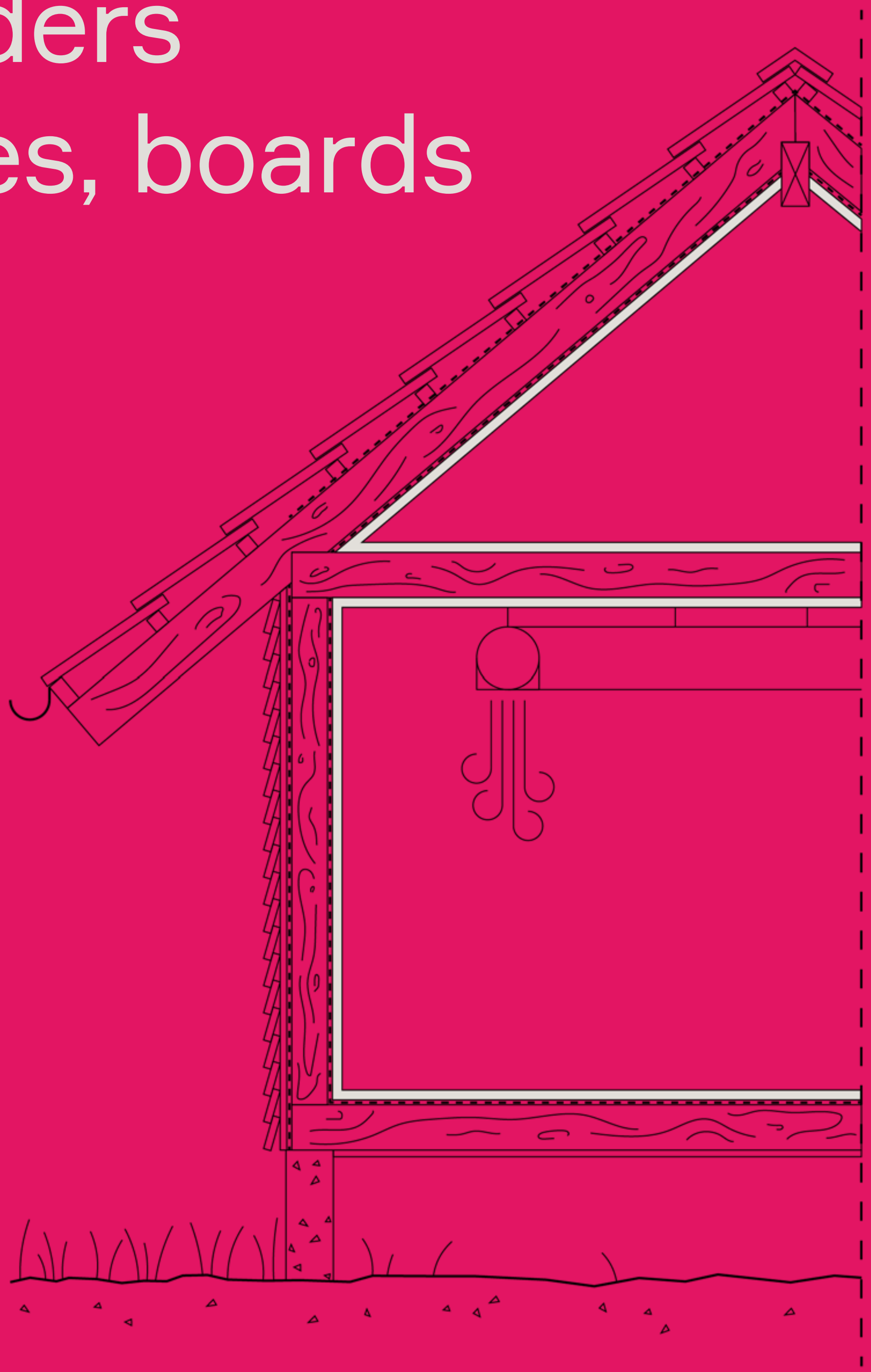
Meanwhile polyethylene foam is one of the most common pipe insulation types. It is relatively tox-free and durable, unless it is treated with flame retardants to reduce flammability. PE is easily recyclable, provided the PE pipe insulation is not multi-layered. Its' carbon footprint is comparable to that of stone wool, and it has similar thermal resistance qualities. As with many plastics, these synthetic materials pose circularity challenges, such as microplastic generation risk during waste stage, recycling challenges due to hazardous chemicals additives, etc. While if these materials are glued multi-layer materials, they should be avoided with the circularity perspective in mind and more sustainable options should be chosen such as single material recycled PE insulation.

There is also an option of natural organic material-based insulation, such as cork, flax, hemp wool, coconut husks or cellulose. These materials offer a combination of thermal and moisture-regulating properties. They possess inherent breathability, allowing them to absorb and release moisture from the surrounding environment, thus reducing the risk of condensation. These materials are tox-free (provided there is no flame-retardant treatment), have low embodied energy and are carbon neutral (as they are plant material based (carbon sequestration)). They exemplify circularity by being renewable, biodegradable and at the end of the service life if not reused, the materials could be composted or used as fuel. However, such pipe insulation types are less available in the market.

There are also rare, more exotic materials such as types of vacuum insulation panels (VIP), gas filled panels (GFPs) and aerogel-based products (ABPs). Research is on-going but besides offering excellent insulation performance, these materials are relatively expensive and there has been a lack of information on their durability under different thermo-hygric conditions.

Toxicity of the condensation insulation materials in this case really much depend on whether there are additives in the product composition or not. Mineral wool, polyethylene foam or natural material insulation would be the safest options if no hazardous additives are used. From the circularity perspective single-material options are the best, as multilayer materials hinder recycling. Plastics are a potential source of microplastic at the end of their service life, if they are not recycled. PE plastic is usually recycled, while rarer types, such as those that are used to make flexible elastomeric foams are usually not. From the carbon footprint perspective, natural material-based insulation is the most sustainable option, while the production of mineral wool and polyethylene have a notable footprint, the other types of elastomers have the highest. Overall, the most sustainable options are mineral wool insulation and insulation made of natural materials.

Floors
Coatings
Renders
Plates, boards



Floors

Flooring can be done using different materials such as wood, concrete, rammed earth, epoxy resin, rubber, coconut, cork, sisal etc. All of these materials have different properties. The selection of flooring material could depend on various factors such as durability, appearance, slipperiness, hardness etc., but should depend also on sustainability and toxicity. It is important to consider the composition of materials when considering a product from the aspect of sustainable flooring. Hazardous chemicals are common in various flooring products and can be released from products, exposing installers and residents. The greater presence of synthetic materials and toxic substances impacts the recyclability of the product.

Sustainable from all three aspects (toxicity, climate, circularity) floors and floor coverings are made from natural, renewable and biodegradable raw materials that come from plants, such as wood, cork, sisal, coconut, natural rubber or natural linoleum. Natural linoleum is composed of linseed oil (obtained from flax seeds, tree resins), and of various natural materials such as jute, cork etc. The raw materials for each of these materials are produced by growing plants which, using sunlight as a source of energy, capturing carbon dioxide and releasing oxygen during the growth process, and storing captured carbon within the plant material formed. The detailed descriptions of these materials can be found in the material's chapter.

Ceramic tiles are made from naturally occurring inorganic materials (clay). Therefore, ceramic tiles are a non-toxic material, provided that no toxic pigments are added. Rammed earth is a sustainable material from all three aspects. Main attention should be paid to sourcing the soil – are there possibilities to reuse soil from nearby construction works and has the soil been contaminated.

Carpets which made with synthetic materials can contain PFAS (Per-and polyfluoroalkyl substances) in the case of their treatment for stain, soil, water resistance. PFAS are persistent in the environment and cause toxic effects on people.

Epoxy floor coverings cause a variety of health problems due to the release of volatile organic compounds (VOCs). Uncured liquid epoxy resins mostly irritate the eyes and skin, solid epoxy resins are generally safer. Epoxy flooring is safer if it is made from high-quality, low-VOC products and if it is properly installed and maintained.

Wood flooring requires finishes for protection and longevity. The water-based finishes have lower levels of volatile organic compounds (VOCs). Better to have the flooring that can be installed without an adhesive. Engineered wood flooring (thin veneer, plywood) has good properties due to its sustainability and durability. This flooring type consists of multiple layers of wood, with a top layer of real hardwood veneer and an inner core made from fast-growing and renewable materials. The sustainable practice is to use natural waxes rather than toxic chemicals for staining and finishing the plywood panels.

The PVC linoleum is not eco-friendly. It can emit VOCs after installation, it can't be recycled, it's not biodegradable, and like all plastic, it is not sustainable. It contains hazardous additives (phthalates) and fossil fuels are used in the production. More information on PVC can be found in the material's chapter.

Floorings from natural, renewable and biodegradable raw materials such as wood, cork, sisal, coconut, rammed earth or natural linoleum and with no stain or waterproofing treatments or with low-VOC adhesive are sustainable and good options to consider. Prefer non-vinyl flooring (no PVC). If you choose a PVC floor, choose a phthalate free PVC. Avoid PFAS-based stain or water repellents in the flooring materials.

Coatings

Paints and pigments

As there is an overwhelming diversity of paint compositions developed, the choice of paint is not straightforward, especially when designing or building with sustainability in mind. First, there is the engineering side – will the considered coating product fit the required performance characteristics? Then there is the aspect of aesthetics – which coating will fulfil the envisioned building appearance idea? And then there are sustainability challenges – which materials are tox-free, produced sustainably and posing no harm for the environment? Which have the lowest carbon footprint?

"Water-based" title is often thought of as meaning "environmentally friendly", but by no means all water-based paints are completely safe, thus checking each individual product composition is important. Probably the most notorious paint options are the so called "oil paints" that are based on oils diluted with organic solvents and produce a vile smell when applied as VOCs evaporate. They were extensively used in the past, but fortunately, nowadays as paint technology is constantly improving, they can be replaced by high performance water-based options. Another environmentally threatening coating option is wood preservative paints that may often be seen as necessary for exterior wooden elements of the buildings, but in reality, by no means they are the only option to protect wooden exterior. But there are also natural material-based coatings, such as lime wash, clay-based paints and natural pigments, that offer significant sustainability advantages, at the cost of some performance limitations.

Solvent based paints are hazardous to human health. Additionally, solvents in the solvent-based coatings are most likely derived from fossil fuels, thus their environmental impact will be significant and carbon footprint relatively high. Similarly, alkyd paints are also based on solvents. In contrast, water-based paints have only a tiny fraction of VOC or even zero VOC depending on the composition, but as they are liquid and the constituents are synthetic polymers, they are subject to microbial degradation, thus preservative use is necessary. The range of preservatives used in water-based paints is very wide, but almost all are toxic to the environment and many are harmful to human health, may cause allergenic reactions. But there are safer options containing more benign preservatives, thus such paints should be judged on case-by-case basis. Water based paints are usually made with synthetic polymers, whose manufacture have a notable carbon footprint. Meanwhile, clay-based, lime-based coatings and natural pigments are relatively tox-free. It is essential to avoid the use of solvent based paints in the interior in order not to be exposed to high concentrations of VOCs. Wood preservatives use in the interior pose significant health risks and is completely impractical, thus should be avoided.

When it comes to circularity and paint, it is hard to expect paint to be recyclable, as paint is only applied as a thin layer on top of surfaces to which they adhere or are absorbed. But in the case of paints, sound circularity demands could be that no harmful substances are emitted or microplastics do not form at the end of life and the material does not contaminate the neighbouring construction materials or render them impossible to reuse/ recycle otherwise. From this perspective the most sustainable options would be polymer-free paints such as clay-based paints, lime wash, natural pigments as they are not sources of microplastics and leave to hazardous residues on the materials they are applied to. Water based paints, solvent-based and alkyd paints may all eventually produce microplastics, while wood preservatives essentially make the wood a hazardous waste that should be disposed properly. But circularity may also mean, can out-of-date or old paint be regenerated or recycled, as there is always unused quantities of paints after a construction project is finished. Unfortunately, this question is not easy if not impossible to answer, as it depends on the individual paint compositions, not coating types. However, for primitive coating materials such as clay-based paints, lime wash and pigments the answer would be – yes, just add water.

There are actually many more coating types, but their use is reserved to certain applications where specific performance requirements are necessary. The most notable options are polyurethane coatings, epoxy-based coatings, specific acrylic coatings or enamel types.

The most primitive paint options tend to be the most sustainable, these are clay-based paints, lime wash, and natural pigments. However, their use has limitations, for example, clay- based paints use in the exterior is prone to water damage. Water based paints seem to be the most practical option for many applications as they have a wide range of compositions. The safest zero VOC and hazardous preservative free options should be sought for and a general guidance could be to look for eco-labeled products. In cases where high performance is necessary, it is best to look for high-performance water-based paint products and only as a second option choose oil or alkyd paints. In general, it is advisable to choose higher quality paints, that will have a longer service life and will not fade away or deteriorate in any other way so quickly. From a chemical's safety standpoint, it would avoid the use of wood preservatives, would be to use heat treated wood or rot-resistant hardwood species. An engineering option when designing a building could be more protruded roof eaves that prevent rain dripping onto walls.

Varnishes

Similarly to paints, numerous varnish compositions exist with slightly different qualities and based on different materials. The base materials of varnishes can be plant oils, resins, waxes or certain synthetic polymers. Varnishes are typically used to protect wood, plaster or other surfaces from, ageing, provide aesthetic finishes or seal the surfaces from the effects of water or dirt or even to protect from mechanical damage.

Oils (such as linseed, tung oil, hemp, walnut) are used on their own or in combination with other oils or diluted with solvents. Waxes and resins need to be dissolved in oils and/ or solvents to be usable while polymer-based varnishes offer an easily applicable, quick drying water-based solution.

From the chemical safety standpoint, solvent free plant oil varnishes are mostly safe, but in some products oils are "diluted" with solvents (e.g. "Danish oil" or "Teak oil"), to aid applicability, penetration and drying. These are a source of VOC and are in most cases hazardous to human health, especially during the application. Similarly hazardous are wax (soy wax, carnauba wax or bee's wax) or resin-based varnishes and they should be used outdoors or in a very well-ventilated rooms allowing some time for VOCs to dissipate before occupying the building. Water-based acrylic varnish is solvent free, but may contain other chemical additives, thus associated hazards should be checked for specific products. There are also water-based polyurethane varnishes that are claimed to be much more human health friendly than conventional PU systems. Special attention should be paid when choosing waterborne PU varnishes and compositions should be checked for chemical safety, as the typical constituents isocyanates or isocyanate intermediates are known to be hazardous to human health. Meanwhile the Danish soap finish is one of the safest varnishes from the chemical standpoint as it requires the use of only soap and water.

From the circularity standpoint, good varnishes should have long service life and have good performance characteristics. Additionally, they should not produce microplastics or contaminate the underlying material with hazardous chemicals or render them unusable at the end of their service life. Synthetic polymer-based varnishes (acrylic, PU) may produce microplastics at the end of their services life. But if the polymer-based products are high quality, they will produce a coating that is reliable and will have a long service life. In comparison, natural oil-based varnishes will need to be re-applied every several years or so.

From the carbon emissions perspective, synthetic or petroleum-based products, such as those containing high proportions of solvent or synthetic polymers will have the highest carbon footprint. Natural materials such as natural oils will have a carbon footprint close to neutral or even negative (carbon storage).

While the natural oils, such as flax, hemp, tung, walnut is the safest, most climate neutral option, at the downside that the surfaces may need to be recoated after some time. Similarly, "Danish soap" finish may need re-coating occasionally. Solvent based options have some advantages related to their applicability, drying, at the downside of health risks (VOCs) and associated carbon emissions. Water based acrylic varnishes are durable and reliable, but it is recommended to check individual compositions to avoid hazardous chemicals and to select the highest quality products for better service life. A good idea would be to look for eco-labelled products. While the use of water-based polyurethane varnish needs to be carefully weighted, as the polyurethane manufacture is a polluting industry the product compositions most often are hazardous to human health and the environmental.

Renders/Plasters/Mortar

Renders are mineral-based wall coating/cover? used for the exterior walls of the buildings. It protects the wall constituents, such as insulation, or can be used only for decorative purposes (e.g. to coat brick wall). When dried-out renders form a stable exterior layer that is resistant to environmental effects and can provide aesthetic qualities. In the interior renders are coated onto walls as a first rough layer to hide the wall sub-structure (e.g. insulation) or to even-out the walls and then to be followed by finer and smoother plaster coat. Plasters are also mineral-based and can be composed of different kinds of materials in different compositions to provide desired aesthetic qualities for the interior. Meanwhile, mortar is used for masonry and is limited solely for functional use. Mortar is typically made from cement, sand and water, but another option is a lime-based mortar, where lime is mixed with sand and water.

However, circularity and carbon footprint should be thought through when choosing the plaster or render materials. Keeping this in mind a good practice would be to choose local materials, whose production has low energy demands. Additionally, polymer-composite plasters may have higher performance, but there are associated circularity challenges.

Plaster, render and mortar materials are mineral-based materials available in a powder form and usually do not contain hazardous chemical additives. The only health concerns are related to occupational exposure, such as respiratory irritation due to inhalation of dust and skin irritation/corrosion, since lime and cement are alkaline. But these challenges are easily overcome with the use of PPE and sound work practices. The only hazardous chemical challenge here is related to polymer composite renders/ plasters. In this category of renders/ plasters polymers are included in the composition with a goal of improving its' performance. In association with the polymer particles undesired chemical additives may be present, thus the chemical composition of these plasters/ renders should be carefully checked.

Each kind of plaster can be repurposed at the end of their service life. Uncontaminated clay plasters/ renders can be "returned to soil" or even re-used, lime, gypsum can be used as agricultural amendments or for landscaping, or crushed and repurposed for similar use, while cement-based plasters/renders can be used for landscaping or crushed and used as an aggregate for concrete. At the end-of-life, mineral composite renders should be judged based on their composition, but to the least, it should be possible to use it for landscaping or agricultural purposes. Thus, from the circularity standpoint, all of these materials line up more or less equally, except polymer composites. Polymer composite renders/ plasters contain polymer additives, such as acrylic, PVA or plant derived cellulose. Acrylic polymer additives may cause microplastic pollution at the waste stage. Meanwhile, PVA and plant derived cellulose are acceptable from the circularity perspective as they readily degrade in the environment, but they may hinder reuse as the material may become difficult to crush and then to repurpose, especially PVA.

The real "Recycling" is more difficult than repurposing for plasters/ renders. Clay plaster is easily recyclable – just add water. Lime tends to absorb carbon dioxide from the atmosphere, so real recycling would involve firing it to produce quicklime again. Gypsum absorbs water, so it would need to be reheated in order to recycle it. On the other hand, composite render/ plaster recycling is much more challenging.

Regarding mortars, lime-based mortar has an advantage over cement-based, as it can easily be removed from masonry material at the end-of-life allowing reusing of bricks or other masonry materials. Lime mortar waste can be used as an agricultural amendment, for landscaping purposes or even recycled. Clay can also be used as mortar material, but it is rarely done in colder climates due to the possibility of rain damage.

One thing to note, when considering how to reuse the renders/ plaster/ mortar at the end of their service life, is the importance of avoiding their contamination. Here contamination can be primers, paints, varnishes. If they are based on synthetic materials, such as polymer-based paints, then there could be challenges related to microplastics. If circularity is pursued, ideally, the coatings should be compatible with the underlying render/ plaster so it would not hinder the reuse/ recycling. E.g. lime-wash for lime plaster, earthen pigments for clay-based plaster, etc.

From the carbon footprint perspective, the renders/ plasters/ mortar with the lowest carbon footprint are clay and lime. Even though lime production is energy intensive, but when curing, lime-reabsorbs CO_2 back into its composition. Gypsum and concrete have a higher carbon footprint due to energy intensive manufacture process, while mineral composite and polymer composite plasters/ renders should be judged on case-by-case basis. It is worth noting the environmental benefits of reusing cement/ concrete. Crushing of cement-based renders/plasters for reuse exposes the surface of cement to the air and CO_2 is absorbed, reducing the footprint from cement manufacture and relieving the pressure on resource extraction.

The most sustainable materials are clay and lime, provided they are locally sourced. These are abundant almost everywhere in the world, they are tox-free, can be reused and even recycled in some cases and have a low associated carbon footprint.

Plates and Boards

Wood based boards are various types of construction and refurbishment materials that are based on various sized wood particles that are bound together by chemical resin and application of heat. Most widely used boards that can be found on the consumer market are OSB (oriented strand board), MDF (medium density fibreboard), plywood and CLT (cross-laminated timber). Each board type has different visual appearance and physical-mechanical characteristics, hence also different area of application. OSB, CLT and certain types of plywood usually are seen as construction materials and used in load-bearing applications (e.g., under roofs, floors, walls), while MDF and some plywood types are more often used in indoor refurbishment where it is not intended to put increased loads on them.

The most concerning health aspect with these types of boards have always been emissions of formaldehyde into indoor air after their application. Formaldehyde is a very volatile carcinogenic compound that occurs both naturally from wood and from resins that are typically used to produce wood-based boards. Formaldehyde emissions from construction materials have been under strict restrictions and now maximum allowable limits are extremely low. Still, many producers strive to reach even lower emission limits. So, when considering purchase, choose brands that declare at least E1 emission class or better yet E0,5.

Other volatile organic compounds (VOCs) besides formaldehyde can also pose health risks if inhaled constantly from indoor air, so several independently verified labels exist to help identify products that have lower overall impact on indoor air quality. Among them are A+, M1, Eurofins Indoor Air Gold and others. Choose products with this labelling.

Production of wood-base boards is very energy-intensive. However, some board types can utilize recycled wood in the production process and most types can be recycled to produce new wooden boards after their life cycle has ended.

When consider using gypsum board it is better to use regular gypsum board because it doesn't contain additional additives. The whole product is generally non-toxic during it's intended use; certain health risks can arise during cutting and installation phase where fine particles (dust) from the boards can be inhaled. Appropriate personal protective equipment (e.g. respirators) should always be used.

Volatile organic components that are typically problematic for some similar types of materials (e.g. glued or laminated boards) are not causing major concerns for gypsum boards that usually have very low emissions.

Production of gypsum boards is rather resource-consuming, especially with regards to energy and water use. On the other hand, the boards can incorporate recycled materials and the gypsum itself can be reused for production of new boards if paper facers are removed.

Fibre cement is a very durable building material. Fibre-cement combines the advantages of many alternatives in one, making it a worthwhile solution for facade, roof or terrace. Cement bonded particle boards have treated wood flakes as reinforcement, whereas cement fibre boards have cellulose fibre, which is a plant extract as reinforcement. Cement acts as binder in both the cases. The fire resistance properties of cement bonded blue particle boards and cement fibre boards are the same.

Always use protective dust mask during installation because fine silica dust is harmful to breathe in.

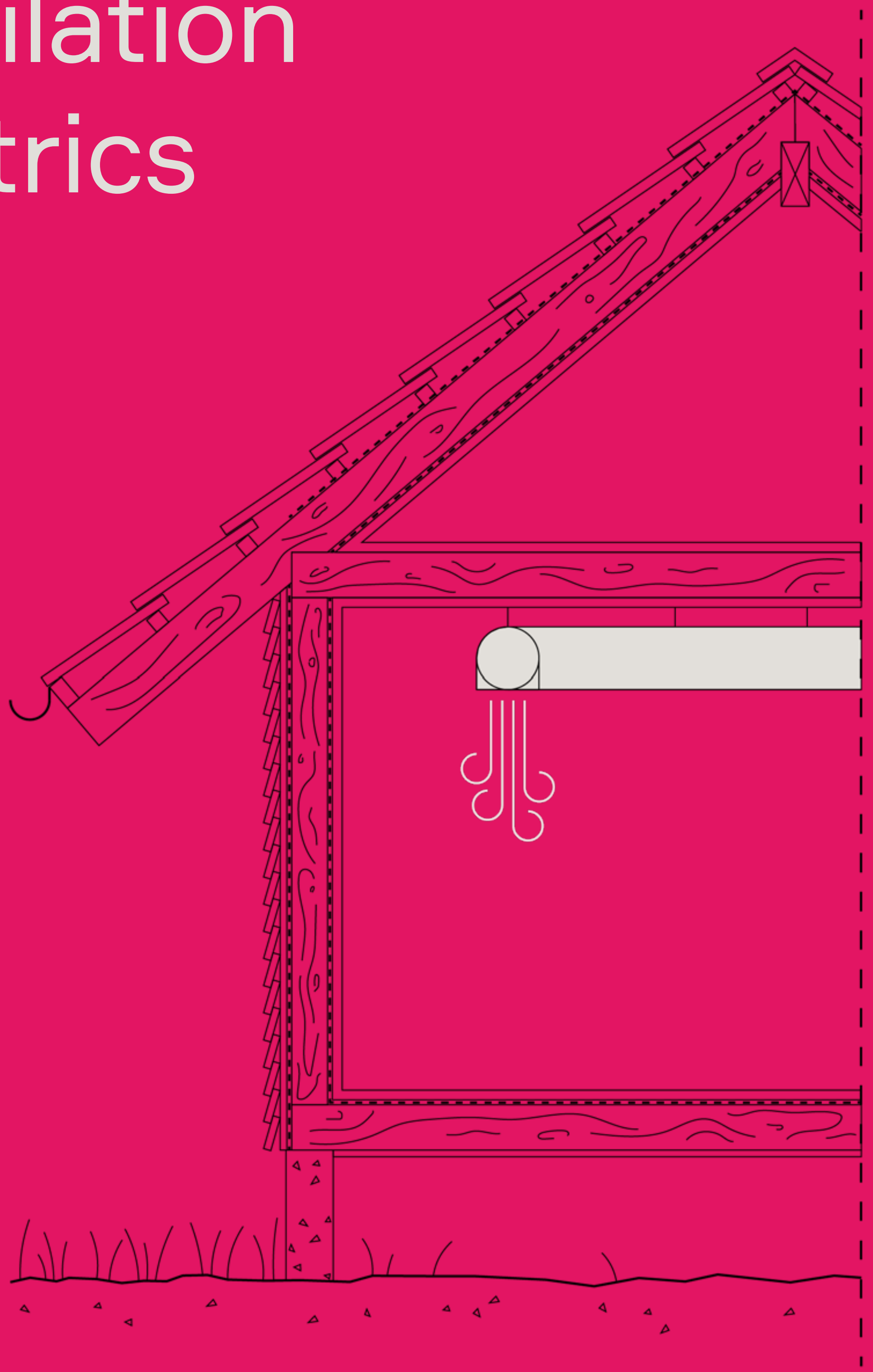
Fibre-cement is not entirely eco-friendly since it contains energy-intensive cement. Cement production is energy- and water-intensive. The ingredients in cement require quarrying, and cement production generates 8% of the world's CO_2 emissions.

Fibre-cement is not recyclable, but when it eventually breaks down, it's inert and non-toxic.

Some manufacturers have made eco-friendly changes, like replacing silica with fly ash to make it less of a health concern for installers and replacing ingredients to make their products with locally sourced, recycled materials, using low-volatile organic compounds, and recaptured water during processing.

In conclusion, the choice between wood-based boards, gypsum boards, and fibre cement depends on specific project needs and environmental priorities. Wood-based boards offer the advantages of renewable resources, recyclability, and controlled emissions, making them versatile for various applications. Gypsum boards, while suitable for non-toxic indoor use, come with the trade-off of resource-intensive production and limited recyclability. Fibre cement, known for its durability, raises concerns due to energy-intensive cement production and non-recyclability, though some manufacturers are making strides with eco-friendly alternatives. The decision should consider the project's requirements and a balance between functionality, sustainability, and health considerations during installation, with a preference for manufacturers embracing eco-friendly practices.

Fire barriers
Underfloor heating
Ventilation
Electrics



Fire barriers

Fire protection is one of the most important requirements for construction projects. The larger the buildings, the more people live or stay in them, the stricter the requirements.

Building codes define building classes and the protection requirements according with the classes. e.g. how long a wall or a ceiling must remain without damage in the fire. Here it is important that a fire is confined to a small part of the building and cannot spread unhindered.

For example, construction elements that separate two units (for example two flats) from each other must be planned and executed with particular care. They must not contain any weak points through which fire or smoke could come into the neighbouring unit.

Unavoidable passages of cables and wires must therefore be sealed off by a fire barrier.

Which chemicals are in use to seal the penetration of the wall? There are requirements how long they resisted the fire, but the factsheets don't tell about toxicity.

It's important to note that firestop sealants are typically subject to rigorous testing and certification to ensure they meet fire safety standards, which include considerations for toxicity and smoke production. Therefore, when selecting firestop sealants, it's advisable to look for products that have undergone third-party testing and certification by recognized organizations, such as UL (Underwriters Laboratories) or other relevant certification bodies. These certifications often include information about the fire resistance, smoke production, and toxicity of the product.

Always consult the manufacturer's technical data sheets and product documentation for detailed information on the specific sealant you intend to use, including its fire performance characteristics and safety considerations. Additionally, local building codes and regulations may specify requirements for firestop materials, so compliance with these regulations is essential.

Intumescent Compounds: These compounds expand when exposed to heat and form an insulating char that seals gaps and penetrations. They are often used in fire-resistant coatings and sealants. Ammonium Polyphosphate (APP) is a common intumescent ingredient that releases non-combustible gases to form a protective char. Pentaerythritol is an organic compound that contributes to char formation and expansion.

Intumescent compounds themselves are typically non-toxic. However, the breakdown products generated during combustion (e.g., ammonia from ammonium polyphosphate) can be irritating to the respiratory system in high concentrations.

Silicone Sealants: Silicone-based sealants are known for their high-temperature resistance and flexibility. They are commonly used in firestop applications. Silicone sealants are known for their low toxicity. When exposed to high temperatures, they typically release minimal smoke and non-toxic combustion byproducts.

Graphite-Based Materials: Graphite is often used in firestop products due to its ability to expand at high temperatures and create a barrier against fire and smoke. Expanded Graphite is used in firestop products due to its ability to expand and provide a fire-resistant barrier. Graphene is an advanced material that may be incorporated for enhanced fire resistance.

Graphite is generally considered non-toxic. However, in the event of a fire, graphite-based materials may produce some carbonaceous smoke, which can be an irritant.

Fire-Resistant Fillers: These can include various types of fillers, such as mineral fillers, that enhance the fire resistance of the sealant.

Mineral fillers materials like vermiculite or perlite can be used to enhance fire resistance. Clay fillers fillers may also be utilized. Mineral fillers like vermiculite and perlite are naturally occurring minerals and are not toxic.

Clay fillers are also non-toxic.

Low Smoke and Low Toxicity Formulations. Manufacturers of firestop sealants often design their products to emit minimal smoke and low levels of toxic gases when exposed to fire. This is a critical safety consideration. Inorganic compounds formulations incorporate inorganic compounds to reduce smoke and toxicity. Flame retardants- chemicals like antimony trioxide may be added to achieve low smoke and low toxicity properties but with flame retardants need to be careful. Toxicity depends on flame retardant type (check the previous summary – Flame retardants).

Adhesion Promoters: Chemicals that improve the adhesion of the sealant to different surfaces, ensuring a secure seal. Silane Compounds like silane adhesion promoters can be used to enhance bonding to various surfaces. Amino silanes are a subgroup of silane compounds that can improve adhesion. Silane adhesion promoters are generally low in toxicity.

Polymers and Binders: These provide the structural integrity of the sealant. Polyurethane is used in some firestop sealants for its flexibility and adhesion. But acrylic polymers can provide structural integrity. Polymers like polyurethane and acrylics used in firestop sealants are typically low in toxicity. However, combustion of these materials can produce carbonaceous smoke.

Underfloor heating systems and components

Underfloor heating is a method of heating indoor spaces by installing a heating system underneath the floor surface. This system generates heat that rises from the floor and warms up the room, providing a comfortable and even distribution of heat. There are two main types of underfloor heating systems – electric underfloor heating system (e.g., copper based electric cables) and water underfloor heating system.

Copper based electric cables are widely used and have high thermal and electrical conductivity. Copper is the preferred wiring over e.g., aluminium because its more durable, and have better conductivity than aluminium. Copper when leaching to the environment is toxic to aquatic organisms, thus plastic coating of wires serves as a protective layer and protects leaching. Copper based electrical cables are highly recyclable. Copper production is highly energy intensive.

Water underfloor heating is composed by pipes or tubes installed beneath the floor, through which warm water is circulated. Water underfloor heating is often used as a primary heating system in new energy efficient constructions or as a retrofit solution for existing buildings. Such system can be installed under various flooring types e.g., tile, wood, carpet. Pipes are typically made of polyethylene or metal-reinforced plastic. Metal-reinforced plastic pipes consists of several layers - cross-linked polyethylene inside, then metallized (aluminium) foil, and a polymer coating on the outside, it protects against mechanical damage. As the result corrosion does not form and proper installation, the pipeline will last for several decades. In addition, aluminium inclusion adds increasing resistance of the pipe to water hammer, provides higher operating parameters and makes faster and more efficient heating of the room.

Polyethylene (PE) pipes (especially high-density polyethylene (HDPE), cross-linked polyethylene pipes), are strong, highly elastic, durable, inert to chemical and biological influences and have very good insulating properties which help to reduce energy loss during operation. Polyethylene is considered as non-toxic material. Polyethylene is durable and water-resistant, making it last longer when exposed to the elements compared to other polymers. Polyethylene is recyclable. Production of polyethylene is highly energy consuming process.

Metal-reinforced plastic pipes are resistant to corrosion, chemically neutral. They have high durability, firmness, temperature and chemical resistance. The added aluminium layer e.g., placed in the middle of the pipe wall increases the durability and serves as a diffusion layer protecting from penetration of oxygen and thus preventing the pipes from corrosion. Aluminium is infinitely recyclable, as well as polyethylene coating. The extraction of aluminium is extremely energy intensive.

Ventilation system

The aim of ventilation is to ensure a constant supply of fresh air, remove carbon dioxide (CO_2), lower the concentrations of indoor air pollutants or contaminants. Ventilation helps to remove the excess amount of moisture that can cause mould growth and shall create healthy and comfortable living and working environment. In buildings where a natural ventilation through gaps between the window frame and the window itself or by opening the windows and vents is not possible, or in energy efficient buildings, where natural air flow is significantly reduced, it must be compensated and mechanical ventilation systems (exhaust, supply, balanced, demand-control, energy recovery, etc.) are required. Ventilation systems generally consist of fans, ductwork, air filters and air inlets. Being responsible for transporting air throughout the home and ensuring appropriate air quality level and temperature in each room, air ducts play a major role in every ventilation system. Thus, materials that are used in the duct system may impact the performance of the system. Most used materials for ductwork are sheet metal, fiberglass, and plastic.

Sheet metal air ducts are made of galvanized steel or aluminium. Such ducts are lightweight and durable. In their finished form, galvanized steel products do not present toxic risk. The galvanizing process creates a coating to the metal that prohibits rust. This coating contains zinc, which can be toxic only when consumed. Galvanised steel sheets show high average elution rates. Aluminium metal is light in weight. Exposure to aluminium is usually not harmful, but exposure to high levels can affect human health. Galvanized steel can be recycled easily with other steel scrap. Zinc volatilises early in the process and is collected in dust that is then recycled in specialist facilities and often returns to refined zinc production. Aluminium is well suited to recycling as 100% can be recovered in the recycling process. Re-melting used aluminium saves up to 95% of the energy needed to produce the primary product and reduces the environmental impacts of bauxite mining. Metal production requires high energy consumption. Aluminium production requires 8 times more energy per kilogram than steel production because the production process of aluminium is much more complicated and involves more steps than steel production. Thus, when selecting sheet metal ventilation ducts, preference should be given to recycled material.

Fiber glass ducts are easy to work with, can be installed in tight spaces and are widely available. Fiberglass has an inner coating that prevents the air moving through the channels from coming into direct contact with the fibers themselves, which could be dangerous if they came loose. It is very resistant to mould and mildew, which makes it an ideal option for homes in warmer climates where this moisture might pose a problem. Fiberglass ducts do require cleaning, due to their fiberglass lining. Fibrous glass is a synthetic fibre made from tiny particles of glass. Fiberglass is an irritant. Skin irritation is generally associated with thick fibers which can be found in construction materials. Fiberglass may also cause irritation of the eyes and throat. If this material is inhaled, it can also be dangerous and worsen asthma. Long-term exposure to fiberglass is associated with lung disease. Fiberglass products are durable and have very long-life cycles. Fiber glass cannot be recycled because grinding and shredding will destroy most of the glass fibers, thus the strength, durability, size, and usefulness of the fiberglass for future applications is reduced drastically. Therefore, it can be used as a filler in artificial wood, cement, or asphalt. Fiberglass has good thermal and sound insulating properties. However, the production of glass fibre consumes high levels of energy.

Ventilation systems made of plastics (PVC - polyvinyl chloride, EPP - expanded polypropylene) are widely used. Plastic ducting has good thermal insulation, energy efficiency, easy installation, airtightness, and leaking prevention, lightweight, versatility, mould prevention properties. PVC is not toxic. However, PVC contains chemical additives e.g., phthalates, lead, cadmium which can be toxic. Toxic additives can leach out or evaporate into the indoor air over time as well as to the environment if PVC is landfilled. EPP is relatively stable and generally considered a safer plastic. Both PVC and EPP are fully recyclable. When recycled, it is significantly reducing the carbon footprint in comparison to the production of material. Most PVC can be recycled up to 6 or 7 times. Nevertheless, even if PVC is recycled, the problem of harmful additives still remains, and it interferes with the recycling of other plastics. PVC has higher energy consumption and CO_2 gas emission than other plastics thus contributing significantly to the global warning. In summary, when selecting plastic ventilation duct systems, preference should be given to expanded polypropylene.

Electric systems

The electric system at home consists of various components e.g., wiring, lights, and appliances. Lighting is one of the major sources of energy demand in buildings. Development of energy efficient technologies allow reaching energy savings and reduce the impact of energy consumption on the environment. Coupling energy smart home systems - smart control and sensors with efficient light bulbs allow significantly reduce energy consumption in home or office. The three most common energy efficient lighting options available are compact fluorescent lamps (CFLs), halogen incandescent bulbs, and light-emitting diodes (LEDs).

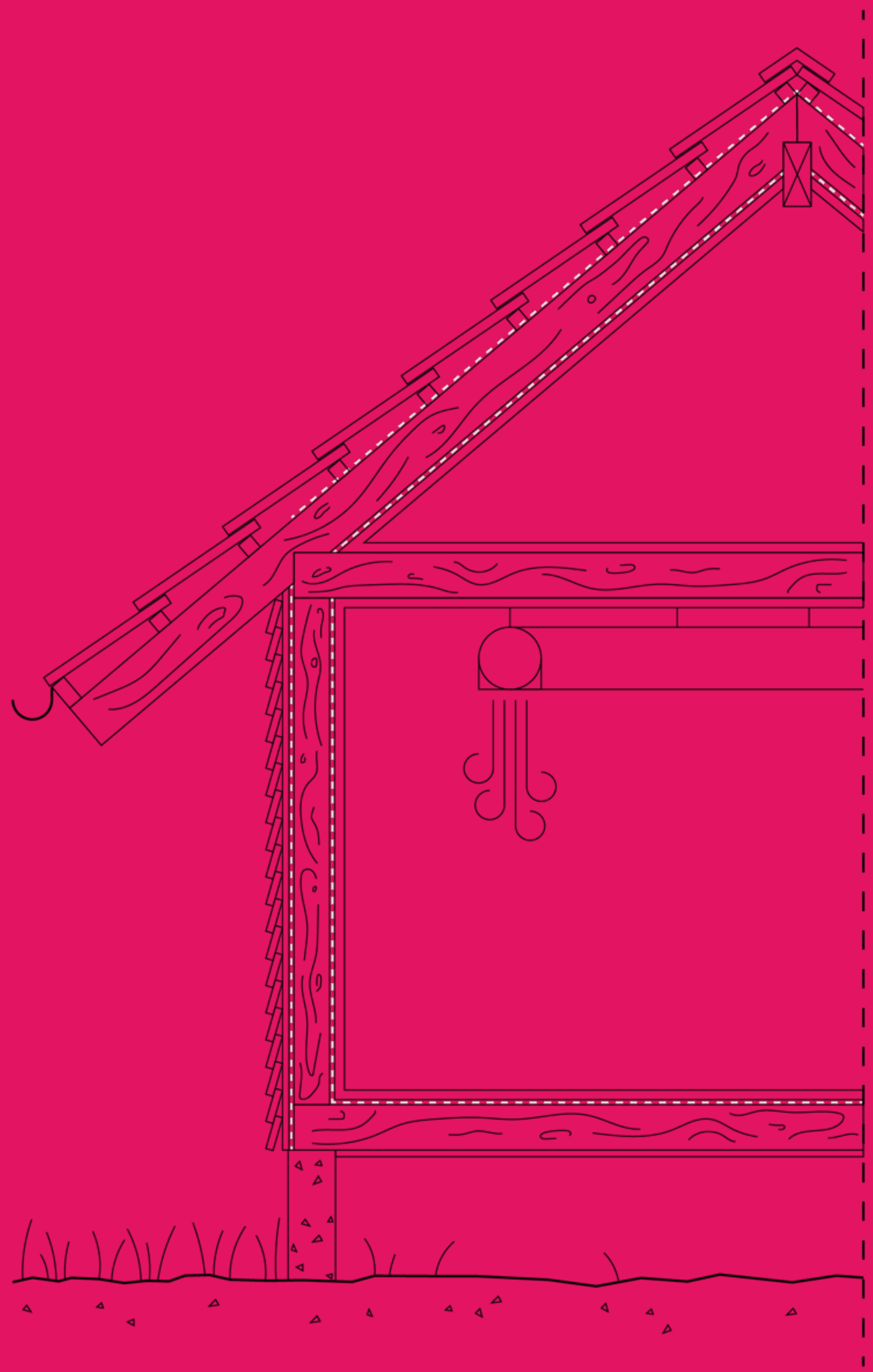
Compact fluorescent lamps can have 4 to 5 milligrams of mercury present in each of them. Thus, if a fluorescent lamp is broken, a small amount of toxic mercury can be released as a gas, contaminating the surrounding environment. Fluorescent lamps can be recycled by special machines to extract mercury, break down the aluminium caps and glass casing. Mercury can be reused in new bulbs or products e.g., thermostats.

Halogen bulbs do not contain toxic substances and can be recycled. However, they consume more energy than CFLs and LED lights, leading to higher greenhouse gas emissions and have a shorter lifespan which results in more frequent replacements.

LEDs are free of any chemical which can be hazardous for the environment or public health. LEDs are efficient, long-lasting and require low maintenance. Because of their long service life, the replacement rate and disposal rate are lower, while fewer luminaires need to be produced. They contain many valuable elements e.g., gallium. LEDs can be recycled, although like other highly integrated electronics products recycling is not a simple task. Because of their energy efficiency, greenhouse gas emissions associated with the LED lights are considerably lower (ca. 80%) than conventional incandescent or compact fluorescent lights.

In summary, considering toxicity, circularity, and climate neutrality aspects, installing electric systems by using LED lighting should be a preferred option.

Air and vapour barrieres



Membranes have a function as vapor barriers for walls, roofing felt, and drainage plans and they are used for preventing or limiting the passage of moisture, gases, or particles through a surface or a structure. Vapor barriers can be crucial to ensuring the durability and the safety of the building.

Depending on the specific purpose and the area of use, various materials are used as vapor barriers. Vapor barriers are often installed on the warm side of insulation to prevent moisture migrating into the insulation and causing reduced effectiveness. Buildings with tightly sealed construction methods, such as well-insulated and airtight structures, might benefit from vapor barriers to ensure that indoor moisture does not become trapped and cause problems.

Adequate ventilation can sometimes reduce the need for vapor barriers by allowing moisture to escape the building envelope. Proper ventilation strategies can work in conjunction with or in place of vapor barriers. In warm and humid climates, where the primary concern is preventing moisture from entering the building, vapor retarders (materials that allow some moisture transmission) might be more appropriate than traditional vapor barriers.

Plastic film is a thin continuous polymeric material. Thicker plastic material is often called a sheet. Plastic films or sheets, such as polyethylene or polypropylene, are common materials used as moisture barriers under concrete slabs or as vapor barriers in walls or roofs. They are also used as a protective wrap to protect building materials, insulation, and other components during the construction process. The use on plastic films and sheets as moisture or vapor barriers reduces the amount of energy needed to heat and cool a building, resulting in cost savings for the building owner.

Production of plastic films and sheets is energy efficient and leads to large greenhouse gas (GHG) emissions. Plastic films and sheets also contain chemicals and substances that might harm human health and natural environment (micro plastics). Recycling of plastic films and sheets is difficult due to huge variety of plastic types. Recycled plastic can replace virgin plastic raw materials, which are made from oil. Plastics unsuitable for recycling are diverted to energy recovery.

Bituminous membranes are suitable construction materials for moisture insulation especially in wooden walls and upper and lower floors. Bitumen and bituminous membranes have a long lifetime making them the most sustainable choice for the roofing. Bitumen and bituminous membranes also have a good climate resistance and can be installed without problem in all climates and seasons.

Bituminous membranes do not release harmful substances during their normal use. However, they may cause contamination to natural and indoor environment if the membrane is heated, and bitumen liquefies. The manufacturing process of bituminous membranes generates greenhouse gases as it involves the refining of petroleum oil. The recycling process of bituminous membranes requires the same stages as production of virgin bitumen i.e., the ground membrane needs to be heated or diluted before it becomes workable. At the moment the asphalt industry is the only recycling method that works on an industrial scale for bituminous membranes.

Vapor barrier paper is used to prevent moist vapor from penetrating insulation or constructions. It is often used in roof and wall constructions. Vapor barrier papers are made out of strong paper, kraft paper and suitable coating. The coating can be plastic, metal or bitumen based.

Vapor barrier papers do not release harmful substances during their normal use. Only if bitumen or plastic coated paper is heated and the bitumen or the plastic liquefies or burns, contamination to natural and indoor environment may occur. Production of vapor barrier papers is energy efficient and generates GHGs. Ways of recycling of vapor barrier papers depends strongly on the used coating. Plastic coated vapor barrier papers can be recycled as a material of paper or carboard. Metal and bitumen coated vapor barrier papers are nor recyclable and they are typically used as energy production.

Rubber membranes are used as waterproof layers, especially in wet areas like bathrooms and basements. Synthetic rubber is also widely used as a roofing membrane. Natural rubber is non-toxic and does not contain any harmful substances, when synthetic rubber is a mixture of ingredients that are derived from oil and natural gas.

The climate impact of the natura rubber mainly results from the use of machinery, transport, processing and use of pesticides and herbicides. Refining of synthetic rubber requires a lot of energy and produces GHGs. Natural rubber is biodegradable and will decompose over time. End-of-life treatment is commonly incineration with energy recovery. Synthetic waste rubber materials can be converted into sweet crude oil and char materials, which are essential in producing fuel and coal energy. Grinding and grounding into a power-like substance and re-production is another option for reusing synthetic rubber membranes.

Special moisture-resistant paints can be applied to surfaces exposed to humidity, such as basement walls or bathrooms. Moisture-resistant paints can come in a range of forms, from primers that are designed to be applied underneath paint to emulsions that have added ingredients that provide the protection against moisture. Moisture-resistant paints should not include chemical substances that may harm human life or natural environment. Production of moisture-resistant paints does not require large energy resources. Recycling of waste moisture-resistant paints (as fresh, liquid form) is not well organised, and they need to be disposed as hazardous waste.

Bitumen is used as a waterproof and moisture-resistant material in roof constructions and as a membrane in foundation applications. Primary use (more than 70 %) of bitumen is in road construction, where it is used as a glue or binder mixed with aggregate particles to create asphalt concrete. Bitumen may be found in natural deposits or may be a refined product.

Bitumen is a petroleum compound that is separated from lighter compounds by distillation. Distillation is energy efficient and leads to emissions of toxic and hazardous fumes and gases. During the use bitumen must be heated or diluted again to a point where it becomes workable, which needs energy. High temperature also affects occupational exposure and the potential of bitumen emissions.

Bitumen is a commonly recycled material and most of the existing asphalt and bituminous materials can be recycled. Recycling of bitumen and bituminous materials reduces the need to use non-renewable resources and for example reducing the emissions created through processing plants. However, the quality of the recycled bitumen can vary depending on the original bitumen quality and the process used to recycle it. Attention must be paid when demolishing old bitumen or bitumen-based products. They may include harmful substances such as PAH compounds (polycyclic aromatic hydrocarbons) or asbestos. When investigating or demolishing hazardous construction materials, national legislation shall be followed.

5 Substances in building materials

This chapter lists substances that can be found in various building materials, as well as the related health and environmental concerns.

Phthalates

Phthalates are a group of chemicals commonly used as plasticizers. They are added to polymer compositions (plastics) or other chemical mixtures to provide desired properties such as flexibility, elasticity, and durability. Phthalates are primarily used to plasticize PVC plastics. Phthalates do not bond to the materials they are added to. Thus, over time they leach into the environment and can cause adverse effects.

Found in materials and products
PVC flooring materials (synthetic linoleum, PVC boards), PVC roofing materials (flat roofs), PVC cables, PVC carpets, PVC windows and doors, PVC gutters, coatings, sealants, and many others.

Typical chemical compounds in the group
DEHP (Di(2-ethylhexyl) phthalate), DiNP (Di-isononyl phthalate), DiDP (Di-isodecyl phthalate), DiBP (Di-isobutyl phthalate), DNOP (Di-n-octyl phthalate), etc. Lower molecular weight phthalates: BBP (Benzyl butyl phthalate), DBP (Di-butyl phthalate), DEP (Di-ethyl phthalate), etc.

Many of these compounds have been extensively used in the past but are presently being replaced with alternatives. Some of the commonly used alternatives: DINCH (Di(isononyl) cyclohexane-1,2-dicarboxylate), ATBC (Acetyl tributyl citrate), etc.

Health and environmental concerns
Although phthalates are easily degraded in the environment, their occurrence is high. According to several literature sources, most of the commonly used phthalate compounds are known/suspected to be toxic to reproduction, endocrine disrupting and may have other negative effects. For example, DEHP is classified as toxic to reproduction category 1B, according to the harmonized classification of ECHA. The phthalates BBP, DEHP and DBP are toxic to fish and other aquatic invertebrates (immunotoxicity, neurotoxicity, genotoxicity, endocrine, metabolic, and developmental toxicities).

More information about phthalates and their health effects can be found in the European Human Biomonitoring Initiative HBM4EUR project:
https://www.hbm4eu.eu/wp-content/uploads/2021/12/Factsheet_Phthalates.pdf

PFAS

Per- and polyfluoroalkyl substances are polymeric and non-polymeric chemicals consisting of more than 10,000 of individual compounds. The group can be categorised into the following sub-groups:

- F-gases: fluorinated gases that have a high global warming potential,
- Fluoropolymers: polymers made of fluorinated monomers (plastics),
- "Classic" PFAS and their precursors (similar to PFOA and PFOS): substances that cause the main environmental and health concerns and are discussed below.

As PFAS have several useful properties, they are widely used for various industrial and engineering applications or manufacture of consumer goods. PFAS are resistant to heat, radiation, and weathering, they are chemically inert and repel stains. Due to these properties, they are commonly used for surface treatments, industrial processes, and numerous other applications.

Found in materials and products
Textile materials including carpets and upholstery, wood boards, OSB and chipboards, wooden insulation, electrical and electronic equipment, resilient linoleum, laminated plastic floor covering, plastic piping, insulation materials, insulation aluminium foil, mounting foams, indoor and outdoor paints, plaster, coatings, sealants, architectural foil. Contaminants of PFAS can also be found in recycled materials.

Typical chemical compounds in the group
Perfluoroalkyl carboxylic acids (PFOA, PFHxA, PFHpA, PFPA, etc), perfluoroalkyl sulfonic acids (PFOS, PFHxS, PFHpS, PFBS), perfluoroalkane sulfonamides (FASA), fluorotelomer alcohols (FTOH), fluorotelomer carboxylic acids (FTCA), fluorotelomer sulfonic acids (FTSA), perfluoroalkane sulfonamido substances, per- and polyfluoroalkyl ether acids (PFEAs), Per-/ polyfluoroalkyl phosphate compounds, etc.

Presently, the production and use of PFOS, PFOA and PFHxS are globally prohibited via the Stockholm's convention. A proposal to ban all PFAS in the EU is under discussion:
https://substitution-perfluores.ineris.fr/sites/substitution-perfluores/files/documents/fact_cards_of_major_groups_of_per-_and_polyfluoroalkyl_substances_pfass_ocde_2022.pdf

Health and environmental concerns
Due to the very strong carbon-fluorine bond, PFAS are extremely resistant to degradation. Therefore, they are also known as "Forever chemicals".

Due to this, PFAS concentrations in the environment continue to increase. Additionally, PFAS are mobile substances. They are transported and distributed across the globe and can even reach groundwater. Some PFAS are bioaccumulative, meaning that the concentration of PFAS increases in organisms over time, and therefore contaminate food chains. Many PFAS are also toxic, causing negative health and environmental effects.

Some PFAS (perfluoralkyl carboxylic acids and perfluoroalkyl sulfonic acids) have been thoroughly investigated and have been shown to have one or more of the following effects: endocrine disruptive, toxic to reproduction, carcinogenic, and other chronic effects. The toxicological profile of many other PFAS have not been as investigated, but many are suspected to have similar adverse effects. In any case, the core concern of persistence is applicable to the entire group of PFAS.

More information about flame retardants and their health effects can be found in the European Human Biomonitoring Initiative HBM4EUR project:
https://enveurope.springeropen.com/articles/10.1186/s12302-023-00721-8https://www.sciencedirect.com/science/article/abs/pii/S004565351631147Xhttps://hbm4eu.eu/wp-content/uploads/2021/11/Factsheet_Flame-retardants.pdf

Brominated flame retardants

Brominated flame retardants (BFRs) are a group of organic compounds with at least one bromine atom. They are added to various products and materials to reduce the products' flammability and to slow down the spread of a fire. Many BFRs have bioaccumulative and toxic properties, which has led to bans and restrictions of the most harmful compounds.

Found in materials and products
Polystyrene, expanded polystyrene, extruded polystyrene, elastomeric foams,

insulation materials, linoleum, laminate flooring, polyacrylate, wood and chip wood, OSB wood, sealants, paints, drywall, plaster, carpets and textiles, foils, insulation foils, architectural foils, air conditioning foils, adhesives and sealants. BFRs that are restricted could be found in recycled materials.

Typical chemical compounds in the group
Historically, the most used BFRs were polybrominated diphenyl ethers (PBDEs) and hexabromocyclododecane (HBCDD). However, their use has been banned under the EU POP regulation. While banned BFRs have been largely replaced by organophosphate flame retardants (OPFRs), other non-restricted BFRs still remain on the market. BFRs currently in use include for example tetrabromobisphenol-A (TBBPA), brominated phthalates and brominated alcohols.

Health and environmental concerns
PBDEs and HBCDDs are persistent, mobile, and toxic chemicals with bioaccumulative properties. Many BRFs currently available on the market have shown to be or are suspected carcinogenic, mutagenic and/or endocrine disruptive properties. Aromatic BFRs, such as TBBPA and brominated phthalates, have been listed as candidate substances in the EU due to their suspected health hazards.

BFRs can be released from building materials, for example through abrasion. Major routes of exposure for humans are dust and air inhalation. Due to their persistency as well as the high volumes used, elevated concentrations are found globally in the environment, despite restrictions on the production and use of the compounds. PBDEs have the potential for long-range atmospheric transport and have been detected in the Arctic and other remote areas.

More information about PFAS and their health effects can be found in the European Human Biomonitoring Initiative HBM4EUR project:
https://www.hbm4eu.eu/infographics/flame-retardants/

Organophosphate flame retardants (OPFRs)

OPFRs have flame retardant properties and are increasingly being used as substitutes for restricted brominated flame retardants. They are added to various materials, including building materials, to reduce the materials' flammability and combustibility as required by legal acts and building standards. OPFRs are also often used as plasticizers. However, OPFRs do not form a chemical bond with the products that they are added to. Thus, they end up in the environment. OPFRs are of emerging concern as they are found in the indoor environment as well as in the surface of water bodies. Some OPFRs have also been found in humans.

Found in materials and products
PVC plastics, polyurethane (PUR) and polyisocyanourate (PIR) materials, polyurethane foams/spray PU foams, furniture, textiles, electronic equipment. OPFRs are also used as plasticizers in floor polishes, coatings, engineering thermoplastics and epoxy resins.

Typical chemical compounds in the group
OPFRs are either alkyl or aryl organic esters of phosphoric acid., They can be halogenated or non-halogenated. There are several OPFR compounds, and they can be divided into five major groups:

- Aliphatic,
- Brominated aliphatic,
- Chlorinated aliphatic,
- Aromatic-aliphatic, and
- Aromatic phosphates.

The most common individual compounds are: TCEP, TCIPP, TDCIPP, TMP, TEP, TPP, TIBP, TNBP, TBOEP, TEHP, EHDPP, TPHP, TMPP.

Health and environmental concerns
Different OPFRs have different negative effects. Overall, there are large gaps in the available data for many of the compounds. OPFRs have been associated with the following adverse effects: neurotoxicity, developmental toxicity to humans and animals, damage to the reproductive function, endocrine disruption, carcinogenicity, as well as bioaccumulation and persistence in the environment. OPFRs are generally less persistent and less bioaccumulative than PBDEs, but due to their widespread use, OPFRs are often found at even higher concentrations in the environment than PBDEs. OPFRs are ubiquitous pollutants commonly detected in a variety of environmental matrices, including the atmosphere, surface water, indoor air, dust, sediments, soil, and a variety of biological matrices.

Humans are widely exposed to OPFRs through routes such as skin contact, ingestion, and inhalation. Some OPFRs have been frequently detected in human urine. Non-intentional ingestion of dust particles and dermal absorption was indicated as a significant human exposure route.

More information about flame retardants and their health effects can be found in the European Human Biomonitoring Initiative HBM4EUR project:
https://enveurope.springeropen.com/articles/10.1186/s12302-023-00721-8https://www.sciencedirect.com/science/article/abs/pii/S004565351631147Xhttps://hbm4eu.eu/wp-content/uploads/2021/11/Factsheet_Flame-retardants.pdf

Bisphenols

Bisphenols are a group of chemicals of which Bisphenol A (BPA) is the most widely known. BPA and similar bisphenols which are used to replace BPA (e.g. BPS, BPF), are monomers of polycarbonate plastics and are used in reaction to produce epoxy resin components. They are also used in thermal paper and as additives to other plastics. Even though bisphenols are mainly used as reagents, unreacted molecules remain in the final product and may end up in the environment, both indoors and outdoors. Very large volumes of bisphenols compound are produced annually.

Found in materials and products
Polycarbonate plastic materials (clear roofing sheets, porch/veranda and conservatory, greenhouse glazing), epoxy resins (composite floor coatings, metal coatings, other composites, reinforced concrete, high performance coatings), PVC plastic (and its products), layers in plastic products, sealing membranes.

Typical chemical compounds in the group
Bisphenol A, bisphenol S, bisphenol F and others. In 2017, the Swedish Chemicals Agency (Kemi) identified 37 bisphenol compounds suspected of having endocrine disrupting properties. In 2021, ECHA identified 148 bisphenols and bisphenol derivatives with potential ED properties.

Health and environmental concerns
Bisphenol A is a proven endocrine disruptor. It is toxic to reproduction and causes negative developmental and neurological effects in humans. Similarly, the health concern of many bisphenols in the group is endocrine disruption, reproductive toxicity, and skin sensitisation, as well as ED for the environment and PBT/vPvB properties. BPA is also toxic to aquatic life. BPA readily degrades in the environment but since it is used and emitted in such a high amounts, it occurs in many environmental matrices. It is commonly found in household dust and even in human blood and tissues. Although many bisphenols are poorly studied, it is expected that the currently used alternative bisphenols (BPS, BPF, BPB etc.) have a similar toxicological profile to BPA and can therefore not be considered as safer substitutes.

More information about bisphenols and their health effects can be found in the European Human Biomonitoring Initiative HBM4EUR project: https://www.hbm4eu.eu/factsheets/bisphenols/

Metals
Metals are naturally occurring elements widely used in different building materials, including exterior and indoor finishings and supportive structures. Metals are durable, malleable and recyclable. Some metal salts or other metal compounds are used as additives in chemical products, such as coatings.

Found in materials and products
Metal roofing, gutters and rain pipes, window frames, construction beams, piping foils, sheets and finishings, concrete and cement, and coatings.

Typical metals in the group
Aluminium (Al), copper (Cu), chromium (Cr), cadmium (Cd), iron (Fe), nickel (Ni), lead (Pb) and zinc (Zn) are commonly found in construction products. Metals in construction materials often occur as alloys, such as steel and brass. These alloys can contain metals such as lead (Pb) and cadmium (Cd) as additives or impurities.

Health and environmental concerns
Non-essential metals, such as lead and cadmium, may cause toxic effects even when present in trace amounts. Also, essential metals such as zinc are toxic in high concentrations. Common health effects of metals are for example damage to lungs, liver, kidneys and other internal organs, carcinogenicity, reproductive problems, damage to fish gills and acute toxicity. Main concerns related to heavy metals in construction and building materials are related to leaching to the environment and toxicity to especially aquatic biota.

Humans can be exposed to metals in construction materials mainly through dust and fumes. Workers are especially at risk of harmful exposure to metals through dust inhalation and contaminated air. Also, metals can leach into the environment, for example from metal roofs during heavy rain. This leads to that the metals end up in soil and aquatic environments.

More information about metals and their health effects can be found in the European Human Biomonitoring Initiative HBM4EUR project:
Cadmium (https://www.hbm4eu.eu/infographics/cadmium/)
Lead (https://www.hbm4eu.eu/infographics/lead/)
Chromium (https://www.hbm4eu.eu/infographics/chromium/)

Chlorinated paraffins (CPs)
CPs have a wide range of industrial applications and are usually used as plasticizers, flame retardants as well as additives to various chemical products such as paints, sealants, adhesives, and many other products. CPs are a large group of thousands of different chemical compounds with varying toxic properties. Overall, they are of high concern due to their toxic properties and persistence in the environment. Chlorinated paraffins mixtures of hundreds of different compounds are produced with varying toxic properties. This makes it hard to analyse CPs and determine their hazardous properties more precisely.

Found in materials and products
PVC plastic, PVC wood panels, PVC flooring, various plastics, rubber tracks/playgrounds, rubber granules, , rubber products, adhesives, sealants, paints, spray polyurethane foams, chloroprene rubber (neoprene), chloroprene joint insulations, chloroprene elastomeric membranes used as roof waterproofing.

Typical chemical compounds in the group
CPs are divided into 3 groups according to their chain lengths: SCCPs – short chain chlorinated paraffins, MCCPs – medium chain CPs, LCCPs – long chain CPs.

SCCPs are banned under the Stockholm Convention and the EU POPs regulation and should therefore not be found in newly produced construction materials. MCCPs are included in ECHA's candidate list for authorisation. However, it is worth noting that SCCP residues occur and are permitted in MCCP and LCCP mixtures by the EU regulation.

Health and environmental concerns
SCCPs are carcinogenic as well as persistent, bioaccumulative and toxic to aquatic life. MCCPs are used as alternatives to SCCPs, but they are also persistent and toxic to aquatic organisms. They are much more common in the environment due to high production volumes.

CPs are commonly found in indoor dust as they are released, sometimes in high concentrations, from various articles and construction materials. Inhaling dust is one of the main pathways of human exposure to CPs.

Biocides
European Biocidal Product Regulation (BPR) defines a biocidal product as a chemical substance or a mixture that is used "with the intention of destroying, deterring, rendering harmless, preventing the action of, or otherwise exerting a controlling effect on, any harmful organism by any means other than mere physical or mechanical action".

Biocides that prevent microbiological degradation are usually referred to as preservatives. They are added to construction products or applied materials to prevent their decomposition/degradation, or to impede the growth of microorganisms (mosses, fungi, bacteria, algae and lichens) on the building surfaces. Among the 22 types of biocidal products defined by the EU Biocidal Product Regulation, five types are currently used in building materials: in-can preservatives (type 6), film preservatives (type 7), wood preservatives (type 8), fibre, leather and polymerised materials preservatives (type 9) and masonry preservatives (type 10).

Most biocides are of concern to humans and the environment as they are designed to have an effect on the biota. Whether or not humans or the environment are actually exposed depends on the type of product and where it is used.

There are many biocidal chemicals which have been restricted due to their toxic properties. New, more benign preservatives are being developed as well as other non-chemical means to prevent bacterial degradation of a product. For example, paints could be sold as a set of ingredients for mixing before immediate use.

Found in materials and products
Water-containing construction products such as paints, coatings, sealants, adhesives (in-can preservation) as well as products that can be easily biodegraded after absorbing moisture (dry film preservation), such as paints, coatings, materials made from wood, natural fibre insulation, other natural or semi-natural materials.

Outdoor materials
Facade paints/renders/other coatings, wooden facades, other outdoor wooden elements, wood coatings/preservatives, roof paints, flat roof coating, bitumen sheets, flat roof bitumen sheets, roofing tile post-treatment, insulation made from natural biomass.

Indoor materials
Water-based paints and varnishes, pre-mixed (water-containing) renders and plasters, water-based adhesives, sealants, others.

Typical biocide classes and individual chemical compounds
Isothiazolinones:
• 5-chloro-2-methyl-2H-isothiazol-3-one (CIT),
• 2-methyl-2H-isothiazol-3-one (MIT),
• 1,2-benzisothiazol-3-one (BIT),
• 2-octyl-2H-isothiazol-3-one (OIT),
• 4,5-dichloro-2-octyl-2H-isothiazol-3-one (DCOIT)
Carbamates:
• carbendazim,
• iodopropynyl butyl carbamate (IPBC).
Phenylureas:
• diuron,
• isoproturon.
Triazines:
• terbutryn,
• cybutryne.
Triazoles:
• propiconazole,
• tebuconazole,
• thiabendazole.
Pyrethroid compounds:
• permethrin.
Quaternary ammonium compounds:
• benzalkonium chloride,
• didecyldimethylammonium chloride.
Other biocides:
• mecoprop,
• tolylfluanid,
• dichlofluanid,
• zinc pyrithione,
• silver nanoparticles,
• boron,
• various cooper-based compounds.

Health and environmental concerns
• Isothiazolinones are skin sensitizing and acute toxic to varying degree, depending on the chemical compound.
• Carbendazim is skin sensitising, acute toxic, mutagenic and toxic to reproduction.
• 3-iodo-2-propynyl butylcarbamate (IPBC) is skin sensitising, acute toxic and is under assessment as an endocrine disruptor by ECHA.
• Diuron and Isoproturon are both suspected of causing cancer. Diuron is acute toxic.
• Terbutryn and Cybutryn are skin sensitising, Terbutryn is under assessment as an endocrine disruptor by ECHA, and is also acute toxic.
• Propiconazole is acute toxic, skin sensitising, toxic to reproduction and is under assessment as an endocrine disruptor by ECHA.
• Tebuconazole is suspected of being toxic to reproduction and is acute toxic.
• Thiabendazole is hazardous to the aquatic environment with long lasting effects.
• Permethrin is skin sensitising and acute toxic.
• Benzalkonium chloride and Didecyldimethylammonium chloride are corrosive to skin and are acute toxic.
• Mecoprop is a skin irritant and acute toxic.
• Tolylfluanid is skin sensitising and acute toxic.
• Dichlofluanid is skin sensitising and acute toxic.
• Zinc pyrithione is toxic to reproduction and acute toxic.
• Copper-based compounds are very potent biocides and are of concern due to their environmental toxicity.

All of the abovementioned biocides are hazardous to the aquatic environment.

• Silver nanoparticles- the properties depend on the particle size. They are known to exhibit various forms of toxicity and there is evidence about toxic effects for several organs (Ferdous et al., 2020). They are also hazardous to the aquatic environment (Fabrega, 2011).
• Boron compounds are of concern mainly due to their reproductive toxicity.

Occupational exposure during the application of biocide-containing materials is of high concern. In the indoor environment, semi-volatile biocidal compounds used for in-can preservation are released during and for some time after indoor application of paints (e.g. light molecular weight isothiazolinones). Biocides used for in-film preservation of paints (e.g. 2-octyl-2H-isothiazol-3-one (OIT)) can also be released into indoor environment but causes a slower degree of exposure. Biocidal materials present in exterior building materials end up in building runoff water after rain and contribute to the contamination of surface waters (Paijens et al., 2020).

Formaldehyde
Formaldehyde is a volatile organic compound (VOC) with a characteristic odour. Formaldehyde has broad industrial applications. One of them is for synthetic resin production used in the manufacture of fibreboards. Formaldehyde is one of the most common occurring indoor air pollutants and is thought to be one of the contributing factors to "Sick building syndrome".

Found in materials and products
Plywood, wood (or other material) fibreboards made with phenol-formaldehyde, melamine-formaldehyde, urea-formaldehyde and other cross-linked resins, laminates, other fibre boards or panels. Formaldehyde is also emitted from chemical products, e.g. paints, with formaldehyde releasing preservatives.

Health and environmental concerns
Formaldehyde is classified as carcinogenic, suspected mutagenic and a skin sensitiser. Besides occupational exposure, people are mainly exposed to it through inhaling the indoor air. Symptoms of exposure include eye, nose, and respiratory system irritation, as well as other symptoms.

Polyaromatic hydrocarbons (PAHs)

PAHs are a large group of chemicals that are ubiquitous and persistent in the environment and are of concern due to their carcinogenic properties. Polycyclic aromatic hydrocarbons are not intentionally produced but are typically associated with fossil resources such as coal or crude oil, as well as the products made from them such as bitumen. PAHs also form during the combustion of organic matter, for example combustion of coal, petroleum products, wood, garden and domestic waste or from forest fires. In the past, creosote (containing around 85% of PAHs) was used as a wood preservative treatment. Currently, it's use is restricted in Europe.

Found in materials and products
Refined coal-tar-pitch-based emulsions, asphalt-based emulsions, coal tar/asphalt binders, asphalt-rubber, recycled tyres, pavement, asphalt boards, bitumen roofing, asphalt roofing shingles, bitumen roofing felt, EPDM roofing materials, bitumen containing roofing membranes, tar paper, bitumen paint, bitumen waterproofing products for foundations, creosote impregnated wood (old reused construction lumber, utility poles, wooden railroad ties).

Typical chemical compounds in the group
Acenaphthene, Acenaphthylene, Anthracene, Benzo[a]anthracene, Benzo[a]pyrene, Benzo[b]fluoranthene, Benzo[e]pyrene, Benzo[ghi]perylene, Benzo[j]fluoranthene, Benzo[k]fluoranthene, Chrysene, Dibenzo[a,h]anthracene, Fluoranthene, Fluorene, Indeno[1,2,3cd]pyrene, Naphthalene, Phenanthrene, Pyrene

Health and environmental concerns
Most PAHs are cancerogenic and/or mutagenic and/or reprotoxic. Some PAHs are persistent, bioaccumulative and toxic (PBT). Exposure to PAHs can also cause skin, eye, and mucous membrane irritation. Benzo[e]pyrene poses the highest cancer risk compared to the other PAHs. PAHs are known to be lipophilic, hence they accumulate in biota. PAHs also have a tendency to adsorb on organic particulate matter (e.g. dust).

PAHs can be found in urban stormwater runoff. Several studies have shown that trace concentrations of PAHs are leached from fossil fuel derived construction materials (such as bitumen roofing sheets) by rain and may contaminate the environment. Additionally, PAHs have also been detected in the indoor environment, as they are emitted from several sources.

More information about bisphenols and their health effects can be found in the European Human Biomonitoring Initiative HBM4EUR project:
https://www.hbm4eu.eu/infographics/phas/

Polychlorinated biphenyls (PCBs)

PCBs are a large group of highly toxic organochlorine chemicals that have been widely used in the past in electrical and other industrial equipment. Examples of use are dielectric oils, heat transfer fluids, lubricants, etc. PCBs have also been used as plasticizers in paints, plastics, rubber and for other purposes in the construction materials sector.

In Europe, PCB production and use of the substances was heavily restricted in the mid-1980s due to PCBs toxic properties. Since 2001, production and use of PCBs are banned under the Convention on Persistent Organic Pollutants (POPs).

Found in materials and products
In old buildings and products such as joint sealants (caulk) between masonry/concrete/door/window joints, paints (exterior/interior), adhesives, slip-resistant flooring, plastic flooring, rubber, legacy electric and electronic equipment, light ballasts, capacitors, double-glazed windows, slip-resistant floors, concrete.

Additionally, PCBs present in joint sealants may migrate into porous adjoining materials, such as wood, concrete, mortar, and other types of masonry.

Typical chemical compounds in the group
PCBs is a group of chemical compounds comprised of 209 individual compounds. Certain compounds (congeners) have a higher toxicity than others. These are known as dioxin-like PCBs and comprise of 12 congeners: PCB 77, PCB 81, PCB 126, PCB 169, PCB 105, PCB 114, PCB 118, PCB 123, PCB 156, PCB 157, PCB 167, PCB 189. Additionally, the indicator PCBs (or non-dioxin like PCBs) are often measured to determine the total PCB content. These are PCBs 28, 52, 101, 138, 153 and 180.

Health and environmental concerns
PCBs is a widespread group of pollutants that are persistent in the environment, meaning that they resist degradation (thermal, chemical and biological). They tend to bioaccumulate in the biota and biomagnify in the food chains. Some of the PCB congeners are associated with endocrine disruption and reproductive effects in animals. Further observed effects include developmental toxicity, neurological damage, immune dysfunction, and liver diseases. The dioxin-like PCBs (cf. list above) are (suspected) carcinogens.

The main exposure pathway for PCBs is the ingestion of contaminated food, especially fish, which can be a problem in the Baltic Sea. The other important pathway is inhalation of contaminated dust in old PCB-containing buildings. Even today, due to their persistency, PCBs are significant legacy pollutants that are found in many environmental matrices.

Volatile organic compounds (VOCs)

VOCs are not a group of closely related chemicals, but they are similar in their physical properties of being volatile at room temperature. VOCs are of concern in the context of the construction material sector as they may be present in construction products (e.g. as solvents or some other co-formulants) and materials.

VOCs are gradually released from many kinds of materials and will thus continuously contaminate indoor air. This results in a possible health risks for inhabitants or visitors. Only after long periods of time (from several months to years) the "source materials" are exhausted from VOCs and can no longer cause any harm.

Found in materials and products
Coatings, adhesives, sealants, finishing plaster, wood stains, stone and masonry treatments, thermal insulation, furniture, wood products, chipboards, fibreboards, gypsum boards, plywood, Oriented Strand Board (OSB), Medium Density Fibreboards, materials used in ceilings and flooring (e.g. tiles, PVC, wood), polymer materials, electronic equipment, and others.

Overall, VOCs can be solvent residues emitted from products and materials, formaldehyde emitted from wood fibreboards, chemical compounds emitted from electronic devices, from plastic articles, from textiles, etc.

Typical chemical compounds in the group
A study of VOCs in European residences identified 65 individual VOCs that are of concern. They belonged to the following chemical groups: aromatic hydrocarbons, alkane hydrocarbons, aldehydes, aliphatic hydrocarbons, terpenes, chlorinated hydrocarbons, glycol and glycol ethers, esters and others. Of the identified VOCs, 52 substances were from sources associated with building and construction materials. Eight chemicals (ethanol, formaldehyde, toluene, limonene, hexaldehyde, α-pinene, butane, acetone) were found to be the most abundant in residences.

The 13 most health relevant and commonly measured VOCs released from construction products are listed in the table in the appendix 5. This list includes their source materials as well.

Health and environmental concerns
Among the 13 most common VOCs in residences' indoor air, almost all adversely affect the respiratory system, including sensitisation. Some VOCs can damage the cardiovascular and the nervous systems and are also carcinogenic. A more detailed health effect table of individual VOCs is provided in the appendix 5.

The worse the ventilation in buildings, the higher the VOC concentrations and the more likely the health effects of VOCs are to occur in residences.

Alkylphenols/alkylphenol ethoxylates (APs/ APEOs)

Alkylphenols are mainly used as surfactants, emulsifiers, dispersants, wetting agents, and other kinds of additives for several industrial applications including construction products manufacture. Alkylphenols are often used as processing chemicals, but their residues may remain in the final products that may be released and cause health risks, especially indoors.

Found in materials and products
Concrete, bitumen roofing felt, bitumen roofing shingles, PVC roofing membranes, lacquered steel, PVC gutters, bitumen emulsions, elastomeric bitumen sealing membranes, layers in polystyrene, layers in polypropylene, lacquers, varnishes, paints (water- and oil-based), resins, PVC roller blinds, residues in various polymers, various plastic products.

Typical chemical compounds in the group
4-octyphenol, 4-nonylphenol, 4-tert-octylphenol, 4-tert-nonylphenol, 4-n-nonylphenol, octylphenol mono-/di-/tri-ethoxylates, nonylphenol mono-/di-/tri-ethoxylates.

Health and environmental concerns
Alkylphenols are of high concern to human health due to their endocrine disrupting properties and potential reproductive toxicity, as well as potential to damage the nervous and immune systems. Alkylphenol compounds have been detected in human breast milk.

In the environment, alkylphenols cause endocrine disrupting effects and reproductive toxicity not only in mammals and fish, but also in other species. As alkylphenols have many isomers that can have varying estrogenic effects, the overall effects of these chemicals are very complex. Alkylphenols also exhibit chronic or acute toxicity depending on their concentration.

In the environment, alkylphenol ethoxylates degrade to alkylphenols that are moderately persistent (more in the sediment than in the water column), tend bioaccumulate and have estrogenic properties causing a risk of ecosystem degradation. Alkylphenols have been found in the effluent of sewage treatment plants and have also been detected in the surface waters in various parts of the world. Stormwater runoff from the building surfaces is also known as a major source of alkylphenols.

Humans are exposed to alkylphenols mainly in the indoor environment through inhalation of air and dust contaminated with alkylphenols from various consumer goods and plastic products, including some construction materials.

Chlorofluorohydrocarbon gases (CFCs), as well as Hydrochlorofluorocarbon gases (HCFCs)

These are a group of potent ozone-depleting inert chemical compounds that have been used for refrigeration, air conditioning and other industrial applications. Some specific CFCs also have a high Global Warming Potential. In the construction material sector, CFCs/HCFCs have been used as blowing agents for insulation foam expansion for use in buildings, thermal insulation of appliances (freezers, refrigerators) and industrial devices. It has been estimated that great amounts of CFCs are present in the construction and demolition waste as well as buildings. Even though the use of the most potent ozone-depleting CFCs has been greatly reduced globally since the Montreal protocol signed in 1987, the reservoir of CFCs in insulation foams is significant. CFCs will slowly be released into the atmosphere from materials. Currently, HFCs (Hydrofluorocarbons) are mainly used as a substitute for CFCs. They do not have the same high ozone depletion potential as CFCs or HCFCs. However, the use of HFCs with a high Global Warming Potential (over 150) are restricted from use in, for example foam products such as XPS or EPS, or as refrigerants.

Found in materials and products
Insulating boards, foamed plastics, cooling, and fire prevention systems, building insulation materials – polyurethane (PU)/polyisocyanourethane (PIR) foam, extruded polystyrene (XPS)/expanded polystyrene (EPS), phenolic foam (PF).

Typical chemical compounds in the group
CFC-11, CFC-12, HCFC-141b, HCFC-142b, HCFC-22, HCFC-134a

Health and environmental concerns
Due to their inertness, the members of this group of chemicals are not (eco-)toxic. However, there are significant concerns regarding the ozone depleting properties of CFCs/ HCFCs and for some of them, regarding the high GWP (Global Warming Potential).

Literature

Abou-Donia, M. B., Salama, M., Elgamal, M., Elkholi, I., & Wang, Q. (2016). Organophosphorus Flame Retardants (OPFR): Neurotoxicity. 2, 1-29. doi:https://doi.org/10.15436/2378-6841.16.0221.16.022

Acir, I.-H., & Guenter, K. (2018). Endocrine-disrupting metabolites of alkylphenol ethoxylates – A critical review of analytical methods, environmental occurrences, toxicity, and regulation. 635, 1530-1546. doi:https://doi.org/10.1016/j.scitotenv.2018.04.079

Agency for Toxic Substances and Disease Registry. (2021). Toxicological Profile of Perfluoroalkyls. U.S. Department of Health and Human Services.

Asikainen, A., Carrer, P., Kephalopoulos, S., E, d. O., Wargocki, P., & Hänninen, O. (2016). Reducing burden of disease from residential indoor air exposures in Europe (HEALTHVENT project). 15. doi:https://doi.org/10.1186/s12940-016-0101-8

Baloyi, N. D., Tekere, M., Maphangwa, K. W., & V, M. (2021). Insights Into the Prevalence and Impacts of Phthalate Esters in Aquatic Ecosystems. Frontiers in Environmental Science, 9, 684190. doi:https://doi.org/10.3389/fenvs.2021.684190

Bečanová, J., Melymuk, L., Š, V., Komprdová, K., & J, K. (2016). Screening for perfluoroalkyl acids in consumer products, building materials and wastes. 164, 322-329. doi:https://doi.org/10.1016/j.chemosphere.2016.08.112

Blum, A., Behl, M., Birnbaum, L. S., Diamond, M. L., Phillips, A., Singla, V., . . . M, V. (2019). Organophosphate Ester Flame Retardants: Are They a Regrettable Substitution for Polybrominated Diphenyl Ethers? 6(11), 638-649. doi:https://doi.org/10.1021/acs.estlett.9b00582

Bornehag, C.-G., Lundgren, B., Weschler, C. J., Sigsgaard, T., Hagerberg-Engman, L., & Sundell, J. (2005). Phthalates in Indoor Dust and Their Association with Building Characteristics. 113(10), 1399-1404. doi:https://doi.org/10.1289/ehp.7809

Brandt, H. C., & de Groot, P. C. (2001). Aqueous leaching of polycyclic aromatic hydrocarbons from bitumen and asphalt. 35(17), 4200-4207. doi:https://doi.org/10.1016/S0043-1354(01)00216-0

Bringezu, S., Fischer-Kowalski, M., Kleijn, R., & Palm, V. (1997). Regional and National Material Flow Accounting: From Paradigm to Practice of Sustainability. Leiden, Netherlands: Wuppertal Institute for Climate, Environment, Energy.

Brunn, H., Arnold, G., Körner, W., Rippen, G., Steinhäuser, K. G., & I, V. (2023). PFAS: forever chemicals—persistent, bioaccumulative and mobile. Reviewing the status and the need for their phase out and remediation of contaminated sites. 35, 20. doi:https://doi.org/10.1186/s12302-023-00721-8

Burkhard, L. P. (2021). Evaluation of Published Bioconcentration Factor (BCF) and Bioaccumulation Factor (BAF) Data for Per- and Polyfluoroalkyl Substances Across Aquatic Species. 40(6), 1530-1543. doi:https://doi.org/10.1002/etc.5010

Canesi, L., & Fabbri, E. (2015). Environmental Effects of BPA. 13(3), 1559325815598304. doi:https://doi.org/10.1177%2F1559325815598304

Carlstedt, F., G, J. B., & C-G, B. (2012). PVC flooring is related to human uptake of phthalates in infants. 23(1), 32-39. doi:https://doi.org/10.1111/j.1600-0668.2012.00788.x

Chupeau, Z., Bonvallot, N., Mercier, F., Le Bot, B., Chevrier, C., & Glorennec, P. (2020). Organophosphorus Flame Retardants: A Global Review of Indoor Contamination and Human Exposure in Europe and Epidemiological Evidence. 17, 6713. doi:https://doi.org/10.3390/ijerph17186713

De Buyck, P.-J., Olha, M., Dumoulin, A., Rosseau, D. P., & Van Hulle, S. W. (n.d.). Roof runoff contamination: Establishing material-pollutant relationships and material benchmarking based on laboratory leaching tests. 283, 131112. doi:https://doi.org/10.1016/j.chemosphere.2021.131112

van Der Schyff, V., Kalina, J., Govarts, E., Gilles, L., Schoeters, G., Castaño, A., ... & Melymuk, L. (2023). Exposure to flame retardants in European children—Results from the HBM4EU aligned studies. International journal of hygiene and environmental health, 247, 114070. https://doi.org/10.1016/j.ijheh.2022.114070

European Chemicals Agency, (2021). Assessment of regulatory needs (bisphenols). https://echa.europa.eu/documents/10162/3448017/GMT_109_Bisphenols_Report_public_23502_en.pdf/1bd5525c-432c-495d-9dab-d7806bf34312?t=1647590013566

European Chemicals Agency. (2023). Regulatory strategy for flame retardants. Helsinki. doi:DOI: 10.2823/854233

Fabrega, J., Luoma, S. N., Tyler, C. R., Galloway, T. S., & Lead, J. R. (2011). Silver nanoparticles: behaviour and effects in the aquatic environment. Environment international, 37(2), 517-531.

Ferdous, Z., & Nemmar, A. (2020). Health impact of silver nanoparticles: a review of the biodistribution and toxicity following various routes of exposure. International journal of molecular sciences, 21(7), 2375.

Finnish Safety and Chemicals Agency. Use and disposal of creosote-treated wood. [online] [Accessed 4.9.2023] Available from: https://tukes.fi/en/chemicals/biocides/restrictions-on-the-use-of-creosote

Gasperi, J., Sebastian, C., Ruban, V., Delamain, M., Percot, S., Wiest, L., . . . Gromaire, M. C. (2013). Micropollutants in urban stormwater: occurrence, concentrations, and atmospheric contributions for a wide range of contaminants in three French catchments. 21, 5267-5281. doi:https://doi.org/10.1007/s11356-013-2396-0

Gautam, G. J., & R, C. (2021). Toxic Impact of Alkylphenols on the Fish Reproduction and Endocrine Disruption. 74, 648-659. doi:https://doi.org/10.1007/s12595-021-00416-z

Gupta, K. C., Ulsamer, A. G., & Preuss, P. W. (1982). Formaldehyde in indoor air: Sources and toxicity. 8(1-6), 349-358. doi:https://doi.org/10.1016/0160-4120(82)90049-6

Halios, C. H., Landeg-Cox, C., Lowther, S. D., Middleotn, A., T, M., & S, D. (2022). Chemicals in European residences – Part I: A review of emissions, concentrations and health effects of volatile organic compounds (VOCs). 839, 156201. doi:https://doi.org/10.1016/j.scitotenv.2022.156201

Horn, W., Jann, O., & Wilke, O. (2003). Suitability of small environmental chambers to test the emission of biocides from treated materials into the air. Atmospheric environment, 37(39-40), 5477-5483. https://doi.org/10.1016/j.atmosenv.2003.09.024

Janousek, R. M., Lebertz, S., & Knepper, T. P. (n.d.). Previously unidentified sources of perfluoroalkyl and polyfluoroalkyl substances from building materials and industrial fabrics. 21, 1936-1945. doi:https://doi.org/10.1039/C9EM00091G

Jones, D., & Brischke, C. (2017). Performance of bio-based building materials. Woodhead Publishing.

Khamphaya, T., Pouyfung, P., Kuraeiad, S., Vattanasit, U., & Yimthiang, S. (2021). Current Aspect of Bisphenol A Toxicology and Its Health Effects. 18(21), 408. doi:https://doi.org/10.48048/tis.2021.408

Kjeldsen, P. (2013). Management of C&D waste from generation to final sink- do w forget the volatile harmful substances. Espoo, Finland: 2nd International Conference on Final Sinks.

Kohler, M. T., Zennegg, M., Seiler, C., Minder-Kohler, S., Beck, M., Lienemann, P., . . . Schmid, P. (2005). Joint Sealants: An Overlooked Diffuse Sources of Polychlorinated Biphenyls in Buildings. 39(7), 1967-1973. doi:https://doi.org/10.1021/es048632z

Lamprea, K., Bressy, A., Mirande-Bret, C., E, C., & Gromaire, M.-C. (2018). Alkylphenol and bisphenol A contamination of urban runoff: an evaluation of the emission potentials of various construction materials and automotive supplies. 25, 21887-21900. doi:https://doi.org/10.1007/s11356-018-2272-z

Lin, W.-T., C-Y, C., Lee, C.-C., Chen, C.-C., & Lo, S.-C. (2021). Air Phthalate Emitted from Flooring Building Material by the Micro-Chamber Method: Two-Stage Emission Evaluation and Comparison. 9(9), 216. doi:https://doi.org/10.3390/toxics9090216

Mahler, B. J., Van Metre, P. C., Bashara, T. J., Wilson, J. T., & Johns, D. A. (2005). Parking lot sealcoat: an unrecognized source of urban polycyclic aromatic hydrocarbons. 39(15), 5560-5566. doi:https://doi.org/10.1021/es0501565

McGrath, T. J., Poma, G., Matsukami, H., Malarvannan, G., Kajiwara, N., & Covaci, A. (2021). Short-and medium-chain chlorinated paraffins in polyvinylchloride and rubber consumer products and toys purchased on the Belgian market. International journal of environmental research and public health, 18(3), 1069. https://doi.org/10.3390%2Fijerph18031069

Montano, L., Pironti, C., Pinto, G., Ricciardi, M., Buono, A., Brogna, C., . . . O, M. (2022). Polychlorinated Biphenyls (PCBs) in the Environment: Occupational and Exposure Events, Effects on Human Health and Fertility. 10(7), 365. doi:https://doi.org/10.3390/toxics10070365

Muir, D., Stern, G., & Tomy, G. (2000). Chlorinated paraffins. In O. Hutzinger, & J. Paasivirta, The Handbook of Environmental Chemistry Volume 3K. Berlin, Heidelberg: Springer. doi:https://doi.org/10.1007/3-540-48915-0_8

Müller, A.; Schmahl, V.; Gschrei, St. (2020). Survey on alternatives for in-can preservatives for varnishes, paints and adhesives. Federal Institute for Occupational Safety and Health. Dortmund, Germany. https://www.baua.de/DE/Angebote/Publikationen/Berichte/Gd103.pdf?__blob=publicationFile&v=4

Müller, A., Österlund, H., Marsalek, J., & Viklander, M. (2020). The pollution conveyed by urban runoff: A review of sources. 709(20), 136125. doi:https://doi.org/10.1016/j.scitotenv.2019.136125

Müller, A., Österlund, H., Nordqvist, K., Marsalek, J., & Viklander, M. (2019). Building surface materials as sources of micropollutants in building runoff: A pilot study. 680, 190-197. doi:https://doi.org/10.1016/j.scitotenv.2019.05.088

Möller, A., Xie, Z., Strum, R., & Ebinghaus, R. (2011). Polybrominated diphenyl ethers (PBDEs) and alternative brominated flame retardants in air and seawater of the European Arctic. 159(6), 1577-1583. doi:https://doi.org/10.1016/j.envpol.2011.02.054

Oliveira, M., Slezakova, K., Delerue-Matos, C., Pereira, M. C., & Morais, S. (2019). Children environmental exposure to particulate matter and polycyclic aromatic hydrocarbons and biomonitoring in school environments: A review on indoor and outdoor exposure levels, major sources and health impacts. Environment international, 124, 180-204. https://doi.org/10.1016/j.envint.2018.12.052

Paijens, C., Bressy, A., Frère, B., & Moilleron, R. (2020). Biocide emissions from building materials during wet weather: identification of substances, mechanism of release and transfer to the aquatic environment. Environmental Science and Pollution Research, 27, 3768-3791.

Pantelaki, I., & Voutsa, D. (2019). Organophosphate flame retardants (OPFRs): A review on analytical methods and occurrence in wastewater and aquatic environment. 649, 247-263. doi:https://doi.org/10.1016/j.scitotenv.2018.08.286

Rudel, R. A., E, C. D., Spengler, J. D., Korn, L. R., & Brody, J. G. (2003). Phthalates, Alkylphenols, Pesticides, Polybrominated Diphenyl Ethers, and Other Endocrine-Disrupting Compounds in Indoor Air and Dust. 37(20), 4543-4553. doi:https://doi.org/10.1021/es0264596

Saito, I., Onuki, A., & H, S. (2004). Indoor air pollution by alkylphenols in Tokyo. 14(5), 325-332. doi:https://doi.org/10.1111/j.1600-0668.2004.00250.x

Salhberg, B., Gunnbjörnsdottir, M., Soon, A., Jogi, R., Gislason, T., Wieslander, G., . . . Norback, D. (2013). Airborne molds and bacteria, microbial volatile organic compounds (MVOC), plasticizers and formaldehyde in dwellings in three North European cities in relation to sick building syndrome (SBS). 444(1), 433-440. doi:https://doi.org/10.1016/j.scitotenv.2012.10.114

Salis, S., Testa, C., Roncada, P., Armorini, S., Rubattu, N., Ferrari, A., ... & Brambilla, G.

(2017). Occurrence of imidacloprid, carbendazim, and other biocides in Italian house dust: potential relevance for intakes in children and pets. Journal of Environmental Science and Health, Part B, 52(9), 699-709. https://doi.org/10.1080/03601234.2017.1331675

Schettler, T. (2006). Human exposure to phthalates via consumer products. 29(11), 134-139. doi:https://doi.org/10.1111/j.1365-2605.2005.00567.x

Sharkey, M., Harrad, S., Abdallah, M. A.-E., Drage, D. S., & Berredheim, H. (2020). Phasing-out of legacy brominated flame retardants: The UNEP Stockholm Convention and other legislative action worldwide. 144, 106041. doi:https://doi.org/10.1016/j.envint.2020.106041

Sharma, V. K., Anquandah, G. A., Yngard, R. A., H, K., J, F., Bouzek, K. B., . . . D, G. (2009). Nonylphenol, octylphenol, and bisphenol-A in the aquatic environment: A review on occurrence, fate, and treatment. 44, 423-442. doi:https://doi.org/10.1080/10934520902719704

Sinclair, G. M., Long, S. M., & Jones, O. A. (2020). What are the effects of PFAS exposure at evnrionementally relevant concentrations? 258, 127340. doi:https://doi.org/10.1016/j.chemosphere.2020.127340

US EPA. (2015). PCBs in Building Materials- Questions & Answers. Retrieved from https://www.epa.gov/sites/default/files/2016-03/documents/pcbs_in_building_materials_questions_and_answers.pdf

US EPA. (2021). Multi-Industry Per- and Polyfluoroalkyl Substances (PFAS) Study - 2021 Preliminary Report. Washington D.C.

van Mourik, L. M., Gaus, C., Leonards, P. E., & de Boer, J. (2016). Chlorinated paraffins in the environment: A review on their production, fate, levels and trends between 2010 and 2015. 155, 415-428. doi:https://doi.org/10.1016/j.chemosphere.2016.04.037

Wang, M., S, J., Lee, S. H., Chow, A., & Fang, M. (2021). Polycyclic aromatic hydrocarbons (PAHs) in indoor environments are still imposing carcinogenic risk. 409, 124531. doi:https://doi.org/10.1016/j.jhazmat.2020.124531

Wicke, D., Tatis-Muvdi, R., Rouault, P., Zerball-van Baar, P., Dünnbier, U., Rohr, M., & Burkhardt. (2022). Emissions from Building Materials—A Threat to the Environment? 14(3), 303. doi:https://doi.org/10.3390/w14030303

World Health Organization. (2010). WHO guidelines for indoor air quality: selected pollutants. Chapter 3 – Formaldehyde. https://www.ncbi.nlm.nih.gov/books/NBK138711/

WWF. (n.d.). Factsheet: Alkylphenols (octylphenol and nonylphenol isomers). Retrieved 09 04, 2023, from https://wwfeu.awsassets.panda.org/downloads/fact_sheet___alkylphenols_food.pdf

Yang, J., Zhao, Y., Li, M., Du, M., Li, X., & Li, Y. (2019). A Review of a Class of Emerging Contaminants: The Classification, Distribution, Intensity of Consumption, Synthesis Routes, Environmental Effects and Expectation of Pollution Abatement to Organophosphate Flame Retardants (OPFRs). 20(12), 2874. doi:https://doi.org/10.3390/ijms20122874

Yang, Y., Chen, P., Ma, S., Lu, S., Yu, Y., & An, T. (2022). A critical review of human internal exposure and the health risks of organophosphate ester flame retardants and their metabolites. Critical Reviews in Environmental Science and Technology, 52(9), 1528-1560. https://www.tandfonline.com/doi/abs/10.1080/10643389.2020.1859307

Yang, S., Arcanjo, R. B., & A, N. R. (2021). The effects of the phthalate DiNP on reproduction. 104(2), 305-306. doi:https://doi.org/10.1093/biolre/ioaa201

Ying, G.-G., Williams, B., & Kookana, R. (2002). Environmental fate of alkylphenols and alkylphenol ethoxylates—a review. 28(3), 215-226. doi:https://doi.org/10.1016/S0160-4120(02)00017-X

Yu, C., Crump, D., & Brown, V. (2009). Exposure risk assessment of the emissions of wood preservative chemicals in indoor environments. CLEAN–Soil, Air, Water, 37(6), 466-474. https://doi.org/10.1002/clen.200900046

Yuan, B., Tay, J. H., Padilla-Sánchez, J. P., & Småstuen Haug, L. d. (2021). Human Exposure to Chlorinated Paraffins via Inhalation and Dust Ingestion in a Norwegian Cohort. 55(2), 1145-1154. doi:https://doi.org/10.1021/acs.est.0c05891

Zhao, J. R., R, Z., Tang, J., J, S. H., & Wang, J. (2022). A mini-review on building insulation materials from perspective of plastic pollution: Current issues and natural fibres as a possible solution. 438, 129449. doi:https://doi.org/10.1016/j.jhazmat.2022.129449

Zhao, J. Y., Zhan, Z. X., Lu, M. J., Tao, F. B., Wu, D., & Gao, H. (2022). A systematic scoping review of epidemiological studies on the association between organophosphate flame retardants and neurotoxicity. Ecotoxicology and Environmental Safety, 243, 113973. https://doi.org/10.1016/j.ecoenv.2022.113973

Zuiderveen, E. A., Slootweg, J. C., & de Boer, J. (2020). Novel brominated flame retardants - A review of their occurrence in indoor air, dust, consumer goods and food. 255, 126816. doi:https://doi.org/10.1016/j.chemosphere.2020.126816

Sweden has a long history of controlling chemicals used in the construction sector, both via regulations such as classification and labelling, through assessment systems and through chemical requirements in procurement. To get information on which product groups within the construction sector that can contain hazardous substances, data was extracted from the Swedish assessment system Byggvarubedömningen. Byggvarubedömningen consists of a database of construction products assessed on chemical content and lifecycle aspects, and a logbook tool. Assessments of chemical content is based on content declared by suppliers/producers. The data extraction was done in June 2023 and shows what substances and products were present in the database at that time. The aim of the data extraction was to give examples of the content of products, with focus on the substance groups mentioned earlier in this chapter.

In the database of Byggvarubedömningen, a search for 370 chosen hazardous substances was performed. More than 200 of the substances came from a study on chemicals of concern in the construction sector (Huang et al, 2022). Additional substances of interest were added by Non Hazard City-project members with focus on the product groups mentioned in this chapter. This means that the search was made on a selection of hazardous substances, and that the results of the search provide examples of what product groups that could contain these substances. There are more substances in the product groups than these results show, and there can be more product groups containing the substances than shown in these results. Since products are assessed and archived in the Byggvarubedömningen system continuously, and the search provides a snapshot, the number of products found in the search is presented as intervals.

It is voluntary for suppliers to assess their products in Byggvarubedömningen, and the database contains almost 30 000 construction products (in August 2023). Suppliers are both Swedish and international companies and Byggvarubedömningen makes the assessments of products using the documentation that the suppliers submit. It is important to note that the products assessed in the database are many, but they do not fully cover what is present on the Swedish or the European market.

Results from the search

In the search, 230 of the 370 chosen substances were found in the Byggvarubedömningen system. Of these 230 substances, about 70 substances are on the Candidate List of substances of very high concern or on the REACH annex XVII restriction list.

Phthalates

Among the substances found in products in the search, 10 were phthalates. The most common product groups containing phthalates in the search were lighting, ventilation, and sealant products. Most common of the phthalates was DINP, which is a frequently used substitute for the restricted phthalate DEHP. DINP was found in approximately 400 products, for example in lighting products, sanitary products, sealants, adhesives, sun protection and some plastic flooring products. For most products, the phthalate concentration was <0,1%. However, in some chemical products, it could be up to 20%. To read more about phthalates, see section above.

PFAS

There were 11 types of PFAS found in about 1000 products. The most common substance was Teflon (found in about 700 products), followed by fluorinated ethylene propylene and Viton. The products that contain PFAS include heating and sanitation, ventilation and lighting or other electrical products. For all PFAS, the concentrations in the products were generally low, <1%. To read more about PFAS, see chapter above.

Brominated flame retardants

All electronics, including FR4 circuit boards, are assumed to contain brominated flame retardants. This concerns about 3000 products in Byggvarubedömningen. The most common brominated flame retardant in the search was Tetrabromobisphenol A (TBBPA). The brominated flame retardants found in the search were often found in lighting and ventilation products. Several flame retardants among the substances searched for were not found in any products in the system. To read more about brominated flame retardants, see chapter above.

Organophosphate flame retardants

In the search, 8 organophosphate flame retardants were found, however only in a maximum of 50 products each. The product types vary between lighting, insulation, fire security products and chemical products. In some insulation products the amount was high, and in the other product groups the amount was low. To read more about organophosphate flame retardants, see chapter above.

Bisphenols

The two substances bisphenol A and bisphenol A diglycidyl ether were found in about 100 products. These are mostly chemical products, and the concentrations vary between 0,01% to 70%. Bisphenol S, Bisphenol F and Bisphenol AF was not found in any products in the search. To read more about bisphenols, see chapter above.

Heavy metals

The metals lead, chromium, nickel, zinc, and cadmium are often present in alloys. In the search, these were found in mostly electrical products, sanitary systems, ventilation, and fittings. Cadmium was often present as an alloy element in very low concentrations (<0,001%). A few lead compounds were present in explosives.

Copper was present in up to 10 000 products. These were mostly products containing brass alloys used in lighting products (50% of the products were lightning), in sanitary products, ventilation or floor heating. In the search copper compounds were also found in approximately 150 treated wood products since copper is also used as biocides in wood preservatives. In the wood products copper concentration mainly were below 0,5%. To read more about metals, see chapter above.

Chlorinated paraffins

Medium-chained and long-chain chlorinated paraffins were found in about 100 products. These are mostly lighting products, sealants, chemical products, and products related to fire security. No short-chain chlorinated paraffins were declared in any products. To read more about chlorinated paraffins, see section above.

Biocides

In the search, 23 biocides were found in products. The most common of the biocides, excluding the isothiazolinones, was iodopropynyl butylcarbamate. It was found in approximately 400 products. These are mainly in paint products, board and panel materials, outdoor furniture, and playground products. Most biocides were found in chemical products such as paint and in wood products, and predominantly in low concentrations (<0,1%). To read more about biocides, see chapter above.

Isothiazolinones

The preservative substance group isothiazolinones was common in paint products since water-based paint need preservatives. Isothiazolinones can also be found in for example sealants and adhesives. The substances BIT and MIT were the most common ones, found in up to 2000 products each. Both BIT and MIT are assigned specific concentration limits according to CLP and are mostly present in products below their thresholds. To read more about isothiazolinones, see chapter above.

Triazoles
Triazoles such as propiconazole and tebuconazole are often used as preservatives in wood products. Both were found in about 200 products combined, with propiconazole being the most common one. Both were present in concentrations below 0,01%. The triazole cyproconazole is no longer used in Sweden and was found in only a couple of products. To read more about triazoles, see chapter above.

Volatile organic compounds (VOC)
Of the 230 substances found in the search, 45 belonged to the group of volatile organic compounds (VOC). The most common VOCs were ethylene glycol and xylene. These were found in approximately 400 products. The majority were lighting products for ethylene glycol and chemical products such as adhesives, primers, or paint for xylene. In total VOC substances were mostly found in chemical products and lightning. However, some were also found in insulation, impregnated wood, and panel materials.

Formaldehyde is one of the most common VOC. It was found in about 150 products, and often in concentrations below 0,01%. Formaldehyde was as expected present in products such as panel materials, doors and adhesives. To read more about VOCs, see chapter above.

Polyaromatic hydrocarbons (PAHs) and Creosote
PAHs as a group of substances were found in approximately 400 products, mostly in waterproofing products and sealing layers. A few of the restricted PAHs were not found in any products in the system. Creosote is closely related to PAHs in its composition and, as expected since it is very regulated, no products containing creosote were found in the search. To read more about PAHs, see chapter above.

Polychlorinated biphenyls (PCBs)
Polychlorinated biphenyls (PCBs) have been restricted from use for over 40 years in Sweden and were therefore not found in any products in the search. To read more about PCBs, see chapter above.

Alkylphenols
One nonylphenol was found, which was present in less than 10 chemical products. To read more about alkylphenols, see chapter above.

Fluorinated gases (F-gases)
Two types of F-gases were found in less than 20 products in total. These were mostly sealants, refrigerants and heating and sanitation products. To read more about F-gases, see chapter above.

Isocyanates
Isocyanates are mainly used in the manufacture of polyurethane plastic (PUR), which is used as a plastic material and in for example varnish, paint, foam plastics and adhesives. The handling is regulated since exposure of small amounts can cause health problems. Isocyanates were in the search found in around 150 products, mostly in waterproofing products, adhesives, or other chemical products. The most common isocyanate was methylene diphenyl diisocyanate (MDI).

Other substances
There were 67 substances found that could not be assigned to above categories. These are for example silanes, alternative plasticizers, and various amines.

Literature

Byggvarubedömningen. 2023. At <https://byggvarubedomningen.com/>
Huang, L., Fantke, P., Ritscher, A., Jolliet, O. Journal of Hazardous Materials 424, 2022, At <https://www.sciencedirect.com/science/article/pii/S0304389421025425>

Huang L., Fantke P., Ritscher A. and Jolliet O. Chemicals of concern in building materials: A high-throughput screening. Journal of Hazardous Materials 424 (2022).

VOC occurrence in construction materials	
Chemical compound	Found in construction materials
Acetaldehyde	Concrete screed with and without PVC covering, wooden flooring and battens, composite board MDF, chipboard , plywood, skirting board, expanding foam, finishing plaster, ceiling tiles, gypsum, plaster, vinyl and ingrain wallpaper, polyurethane adhesive mastic, wallpaper paste, latex and dispersion paints, carpet nylon with PVC backing .
Acetone	Solid wood pine, oak, beech , plywood, composite board MDF, chipboard, OSB , glue for wallpaper, finishing plaster, linoleum, silicone, expanding foam, ceiling tile, gypsum board, veneered particle board UV curing lacquer , surface sprays, glues.
Benzene	Gypsum board, commercially available floor coverings made of PVC or with polypropylene or polyamide fibers , low density polyethylene, polyurethane foam, carpet glue, scatter rugs, solvent-based cleaning and painting products acrylic and water-based paints, matt emulsion .
Ethylbenzene	Materials for floor coverings PVC, linoleum, rubber, polyolefin , gypsum board, Carpet, plywood, polyurethane foam and adhesive mastic, solvent-based cleaning and painting products, solvent and water based interior coating, carpet glue.
Formaldehyde	Composite board MDF, particleboard , plywood, gypsum board, ceiling tiles, sound insulators, polyurethane adhesive mastic, vinyl and ingrain wallpaper, expanding foam, glue for wallpaper, sealing plaster, finishing plaster, wallpaper paste, latex and dispersion paint, machine wash liquids detergents, paints and coating, adhesives, furniture and carpets. Used in adhesives and sealants, coating products, fillers, putties, plasters.
Limonene including d-limonene	MDF, particle boards veneered and unveneered , adhesive for flooring installation, paints, multipurpose coating products, solvents, and water-based interior coatings polishes and waxes .
m p-Xylene	Wooden flooring, furfurylated solvent-based cleaning and painting product solvent-based and water-based interior coating , polyurethane foam, medium density board, commercially available candles, machine wash liquids detergents, paints and coating, adhesives. Used in lubricants and greases, polishes and waxes, adhesives, and sealants.
Naphthalene	Wooden flooring, furfurylated solvent-based cleaning and painting product solvent-based and water-based interior coating .
o-Xylene	Wooden flooring, furfurylated solvent-based cleaning and painting product solvent-based and water-based interior coating .
Styrene	Wooden flooring, materials for floor coverings PVC, linoleum, rubber, polyolefin , polyurethane foam and adhesive mastic, rubber and epoxy adhesives, medium density board, carpet Nylon and polypropylene w SBR adhesive , polystyrene foam, solvent-based cleaning and painting products, solvents, and water-based interior coatings.
Toluene	Materials for floor coverings PVC, linoleum, rubber, polyolefin , carpet backing, polyurethane foam, vinyl flooring, carpet backing, gypsum board, medium density board, paints, adhesives, sealants, carpet backing, vinyl flooring, non-metal surface treatment products, carpets, general furnishing.
Trimethylbenzene 1,2,4-Trimethylbenzene and 1,3,5-Trimethylbenzene	Materials for flooring coverings PVC, linoleum, rubber, polyolefin
a Pinene	MDF, chipboard both veneered and unveneered , adhesives for flooring installation, nylon carpet PVC, solvent-based interior coatings.

VOC health effects summary table					
	Respiratory	Cardiovascular	Neurotoxic	Carcinogenic	Irritant
Acetaldehyde	Y	N	N	Y	Y
Acetone	Y	Y	Y	N	Y
Benzene	N	Y	Y	Y	Y
Ethylbenzene	Y	N	Y	Y	Y
Formaldehyde	Y	N	N	Y	Y
Limonene including d-limonene	N	N	N	N	Y
m p-Xylene	Y	Y	Y	N	Y
Naphthalene	Y	N	Y	Y	N
o-Xylene	Y	Y	Y	N	Y
Styrene	Y	ND	Y	Y	Y
Toluene	Y	Y	Y	N	Y
Trimethylbenzene 1,2,4-Trimethylbenzene and 1,3,5-Trimethylbenzene	Y	N	Y	ND	Y
a- Pinene	N	N	N	N	Y

6 Legislation in the BSR related to chemicals and construction

Consumers as well as professionals in the construction sector have the expectation that they can use and install all materials available on the market in any form without hesitation. Materials should be free from hazardous chemicals, i.e. do not contribute to chemical risks to human health and the environment. This should be ensured meanwhile by the legislation. This statement is often heard when talking about the necessity of a project like NHC3.

Is this expectation realistic? It is indeed not always fully ensured, in particular with a view to mixture effect in such complex situations as buildings with different materials, coverings, claddings and so on. What about the three pillars climate-neutrality, circularity and tox-free construction? Consumers know or get to know about the climate issue, latest if they pass an official permission process. The legal frame in principle is organized and well-established from EU to national level, see Energy Performance of Buildings Directive, EPBD. Therefore, the legislation concerning climate protection requirements is not the one in focus of the catalogue and this chapter.

Circularity only truly makes sense when toxic substances are not dispersedly distributed from one product to the entire material stream during the recycling process as there is no possibility to track contaminants in the products made from recycled materials. Legislation effectively preventing the use of toxic substances is therefore a key to circularity. Hence the focus of this chapter on legislation lies on the selection of materials that are free from toxic substances.

In order to assess whether the existing legal norms effectively protect consumers and professionals in this sense, an attempt is made to give a structured overview to the relevant regulations on EU level and the BSR States.

First, a brief outline of what is happening on the EU level.

Europe has one of the most advanced chemical regulations in the world. It is called REACH (registration, evaluation, authorisation and restriction of chemical substances) and CLP (classification, labelling, packaging) that aims to protect human health and the environment.

The CLP-regulation lays down the rules on how to identify if a chemical has got hazardous properties (classification). It also defines how classified substances must be labelled and packaged.

The REACH regulation requires the manufacturers and importers of chemicals to register them. This includes providing data on the substances' hazards as well as an assessment of potential risks for those substances, which are classified.

ECHA, the European chemicals agency is of the main institution responsible for the management of the implementation of REACH. Amongst others, it manages substance registration and provides a database of registered chemical substances[1], evaluates a certain share of the registration dossiers, coordinates the substance evaluation by the member states and operates the authorisation procedure under REACH. You may use ECHA's database for information on chemical substances. English web page: Homepage - ECHA (europa.eu) (ref. 26 in the excel file).

Each Member state has responsible institutions for implementing (and enforcing) EU's chemicals policy at the national level.

Although REACH is considered to be one of the most advanced chemical regulations in the world, it cannot prevent that risks from chemicals (and chemical cocktails) exist or that the indoor air quality in buildings is partly rather low.

[1] Please note that the information provided in the database is based on the industry's registration dossier and not generally quality assured or checked by the authorities.

Fig. 74
Synopsis on legislation related to chemicals and construction

National laws							
FI	EE	LV	LT	SE	DE	DK	PL
Environmental protection decree 713/2014	Environmental Code		Law on environmental protection	Swedish Environmental Code (1998:808)		The Environmental Protection Act	Environmental Law
Land use and building act 132/1999	Building Code	Construction Law	Law on construction	Swedish Building Regulation		Byggeloven-Construction Law	Building Law
Chemicals act 599/2013	Chemicals act		Chemical substances and preparations law	Swedish Chemicals Agency's regulations	Chemicals act		
Health protection act 763/1994	Occupational Health and Safety act		Law on safety and health on work	Work Environment Authority's regulations		Health and Safety at Work act	
Waste act 646/2011	Product Complience act	Law on the Safety of Goods and Services	Basic requirements of fire safety	Waste Regulation (2020:614)	Closed substance cycle management act		Water Law / Revitalisition Law
				Federal level	MBauO		
				Federal level	HMauO		

Following, a short overview, what is happening in the BSR States.

It can be assumed that the EU laws are implemented in all BSR states. The aim was to find out, if there are regulations going beyond.

When asked which laws and regulations are important in the construction sector to avoid damage caused by toxic substances, in the construction activity, while using the building or when it has been demolished, partners reported that there are rules in different categories in all BSR States. The Legislation is related to:

- **environment,**
- **construction in general,**
- **chemicals (see REACH regulation),**
- **health and safety aspect,**
- **and other, like waste or water management.**

Rules related to construction in general like building codes may include more or less stringent regulations on chemicals in construction. Originally building codes served to typical danger defense like fire protection or to guarantee stability of buildings. However, it is unclear whether chemicals are also classified as an actual hazard in all countries.

Relevant can also be chemical legislation and concern health and safety regulations on construction sites. But environmental codes or regulations can be the most important, if they are effective to set standards that the construction sector must follow.

Figure 74 shows examples of regulations of the different categories from the BSR countries. There are for example countless technical rules for dealing with hazardous substances on construction sites. Therefore, here is given only an exemplary overview, to understand the main directions and unfortunately gaps in current legislation. A more expanded list of regulation in BSR States you will find in the attachment.

Even the simplified presentation with exemplary regulations still makes too little statement about which rules or combinations of rules meet the consumer's expectation on tox free construction materials.

Which country goes effective beyond the REACH regulation?

Unfortunately, what remains, at the moment, is that the legislation legislation does not prevent that hazardous substances are contained in construction materials.

The importance of filling the gap between the consumers expectations and the occurrence of hazardous substance in materials, dealt with by this catalogue, remains.

7 Databases, Platforms, Information sites

In this chapter, you will find yourself on a journey through various information resources, databases, and platforms dedicated to aiding different stakeholders in the construction sector. Our focus is on sustainable building practices, selecting sustainable construction materials and adhering to environmental standards.

The chapter addresses three levels of detail:

- You want to simply find sustainable construction products for your purpose? Consider the section of (labelled) product-databases or platforms, that provides simple, aggregated information. These resources are designed to guide purchasing decisions, making eco-friendly choices accessible to all.
- You are a professional and need to comply with sustainability requirements, but do not have extensive background knowledge on this topic? Consider the introduction to databases with features such as interactive project-logbooks, project databases, networking platforms. These platforms offer straightforward information and assist in meeting documentation standards for building quality.
- You are deeply committed to understanding and implementing sustainable practices? Explore scientific databases using datasets and databases utilizing these datasets (e.g., EPD database). These resources require a certain level of expertise for interpretation and offer in-depth insights into sustainable building.

Information sources described were selected when at least one of the following is true:
• Partner municipalities use them
• They are considered a common source of information for sustainable construction

When sources are privately owned for-profit organisations they were included if:
• They are considered being commonly used by partners
• They are the only resource of their kind in a respective country

The table below indicates in which section you are most likely to find the information you need. The databases, platforms and other information sources are then grouped into sections (for specific target groups), pinpointing which resource focusses on which aspect of the NHC 3 pillars and which target group is likely to find it beneficial in tables at the beginning of each section.

Fig. 75
A table indicating the structure of the chapter and its target audience.

Section	Goal	Target group
(1) Product databases or platforms	You want to simply find sustainable construction products for your purpose	Everyone interested in sustainable construction, with and without background knowledge
(2) Databases and platforms with management functions (logbooks, projects, product assessments, networking)	You need to comply with sustainability requirements, but do not have extensive background knowledge on this topic	Professionals of the construction sector, with or without background knowledge on aspects of chemicals, circularity, climate impact or overall sustainability
(3) Databases and other information sources using data(sets) that require comparison and interpretation by the reader	You are deeply committed to understanding and implementing sustainable practices	Professionals with background knowledge on aspects of chemicals, circularity, climate impact or overall sustainability and scientists

In this section (labelled) product-databases in the BSR are described. These are easy-to-use databases with familiar products already assessed or labelled. Using this kind of resources requires little background knowledge about the construction materials or about the NHC 3-pillar approach aspects (Chemicals, Circularity, Climate). These resources are designed to guide purchasing decisions, making eco-friendly choices accessible to all.

The list below gives an overview intended for swiftly identifying the most suitable tool for the respective situation. Once the right resource is found, it is possible to dive deeper to better understand how it works and how it can best serve the respective needs.

Link:
https://ccbuild.se/en/marketplace/products

https://www.loopfront.com/about

Circularity platforms CCBuild and Loopfront (SE)

Section (target group):
1 (1,2)
Solution for:
Circular aspect integrated with climate aspect (CO2 savings from circular purchasing)
General description:
In Sweden there are also some digital platforms that focus on circularity (reuse) in the construction sector. Loopfront and CCBuilds marketplace are two of them.
In Loopfront a company needs an account at a cost to register and search for products. In the system they can register products, search for products, show financial and environmental savings such as CO2 and waste.

In CCBuilds marketplace sellers need an account to register products but anyone can search for products. You can find all sorts of second-hand construction materials such as windows, bricks, kitchens, radiators, flooring, lightning and much more. Regarding toxicity it can be hard to know the exact content of reused products. Also overall information on material can vary between products.

Link:
https://www.dgnb-navigator.de/produktdatenbank

DGNB Navigator (DE)

Section (target group):
1 (1,2)
Solution for:
Overall environmental sustainability
General description:
The DGNB Navigator is an online platform provided by the German Sustainable Building Council. It aims to promote sustainable building practices e.g. by offering a comprehensive product-database and evaluating construction products. In this section only the product database is described. For more information on the platform and its uses see section 2.

Should a manufacturer want to let a product be assessed, the relevant data is provided and maintained by them. The DGNB provides a standardised mask for the uptake of products, checks plausibility and completeness of the entered data during evaluation and includes a comparison between products regarding sustainability aspects. Here

pollutant or hazardous substance content, CO_2 emissions during manufacturing and ease of recycling are important topics. The products published in the DGNB Navigator will not show first or second level certifications, as these do not consider the situation of installation. Promoting transparency, the DGNB highlights products with especially high standards on transparency and data quality. For such products all data have been made publicly available and a product specific EPD is available.

Product search is possible via material, cost group, manufacturer or via the general search. As the manufacturer decides which information is available on the product-page detail varies between products. The connection to the DGNB building certification criteria is shown directly and colourfully under the product description. If manufacturers provide this information, it is here where chemical content may be found.

Finland's environmental administration (FI)

Link:
https://www.ymparisto.fi/en

Section (target group):

1 (1)

Solution for:

Chemical and circularity aspect

General description:

Ymparisto.fi is a website of Finland's environmental administration. The main themes are a safe living environment, the preservation of biodiversity and the prevention of environmental damage.

The website is jointly produced and run by the following authorities, which together make up Finland's environmental administration: The Ministry of the Environment, The Finnish Environment Institute (Syke), 13 Centres for Economic Development, Transport and the Environment (ELY Centres), and Regional State Administrative Agencies (AVI).

In 2017 the Finnish environmental administration released a database / data bank (available only in Finnish) about old construction materials.

Link:
https://www.ymparisto.fi/fi/rakennettu-ymparisto/rakentaminen/kiinteistojen-yllapito-ja-korjaaminen/rakennusmateriaalien-tietopankki?size=n_200_n

The construction materials database includes information on the properties, utilization, and harmfulness of old building materials. You can search for information by material or product name, period of use or purpose of use.

- Materials can be searched in the database by material (wood, concrete) or product name (Halltex, Siporex, etc.), period of use (for example, the year the house was completed) or purpose of use (external wall, water roof, etc.).
- Product name section lists the most common product names used for the material in question. Certain product names have been in use for decades, but the ingredients contained in the products may have changed: for example, harmful substances have been replaced by safer alternatives.
- Period of use means the period during which the material or product has been on the market or generally used in construction in Finland.
- In the Purpose of use section, it is explained for which different uses or in which parts of the building (external wall, top floor, surface treatment...) the material or product has typically been used.
- The Main properties of the material section summarizes the manufacturing of the product or material, the substances it contains and other properties.
- The Harmfulness when dismantled/left in place section describes the harmfulness of the material.
- In the Reuse and/or recovery sections, information is given about the possibilities of utilizing the discarded material or delivering it to a waste station. Reuse means using the product or part of it again for the same purpose for which it was originally designed (sale, delivery to a recycling center, etc.). Typical reusable parts and materials include e.g. doors, windows, fireplaces, hearths, logs, bricks, timber, etc. Utilization means using the material for a new purpose (for example, stone waste for land filling), as a raw material for a recycled product (glass as a raw material for glass wool) or utilization in energy production (decommissioned wood as fuel).
- The Waste disposal section explains how to act if the product / material cannot be utilized.

M1 database (FI)

Link:
https://cer.rts.fi/en/m1-emission-class-for-building-material/search-m1-paastoluokiteltuja-tuotteita/

Section (target group):

1 (1)

Solution for:

Chemical aspect VOC + odour

General description:

The Building Information Foundation RTS (Rakennustietosäätiö) is privately owned and provides information and expertise for the Finnish construction sector. Beside publications, guidelines, and training materials on various aspects of construction, including sustainable building practices, energy efficiency, and circular economy, RTS provides material/product databases. The Tuotetieto's database is the main database (containing M1 and RTS EPD). In this section only the M1 database is considered. For more information on RTS see section 3.

The M1 database contains construction material certified with the M1 label (see eco-labels), which aims at promoting the development of low-emission construction material and has a chemical focus on VOCs. The M1 database contains all materials and products certified with M1, if a product is not found, it is not certified. Should a company want to register its product in the database, an online application (via the webpage) is possible as a first step. Additional steps include laboratory tests according to protocol (sr, Materials) (only by accepted laboratories) and assessments by an interdisciplinary committee. The database is free of charge and part of RT-Tuotetieto database, but can be used separately, too. It is possible to search the M1 database by material or product type, market name or producer. The database covers various construction materials but does not contain any information on circularity or climate neutrality (sr, M1 criteria, kein Datum). The products are not clickable, only listed. Available information on the exact chemical content of each product is therefore also limited. M1 classified materials and products must fulfill the requirements presented on Rakennustieto webpages. Information on some of the products listed in the M1 database may be found within the RTS EPD database.

Sentinel Haus

Link:
https://www.sentinel-haus.de/de

Section (target group):

1 (1)

Solution for:

Chemical aspect linked with Health values

General description:

Sentinel Haus is an Institute emerged from a DBU research project and is known for its work in the field of healthy living. The heart is one of Europe's largest databases of health- and sustainability-tested products (Sentinel Portal).

The platform is freely accessible and can be used by professional planners as well as consumers. For DIY, there is a separate small section with practical advice for some typical do-it-yourself jobs, such as painting and tiling. The test criteria were developed more than 10 years ago together with experts from the eco-Institut and the criteria commission of "natureplus" and have been continuously adapted since then according to current scientific findings and regulatory requirements. The focus is on indoor quality, i.e. that the materials used do not pollute the indoor air with hazardous substances such as CMR substances to an extent that is harmful to health. The indoor guideline values of the Federal Environment Agency are decisive for the assessment. Particularly hazardous substances are considered from a threshold of 0.01 %. The labelling of a product as "tested for harmful substances" confirms compliance with the specific test criteria. All labels that are included in the product database "Sentinel Portal" are checked for quality and meaningfulness of the requirements. Additional labels are awarded for companies, professionals, or buildings. The label "QNG ready" meets criteria for DGNB Quality seal for sustainable buildings (QNG) as KfW funding requirements

Link:
https://www.sentinel-haus.de/de/Sentinel-Haus/Qualit%C3%A4ten/Qualitaeten-Pruefkriterien

This section introduces you to databases and platforms with features such as interactive project-logbooks, project databases, networking and certification options. These platforms offer straightforward information and assist in meeting documentation standards.

The list gives an overview intended for swiftly identifying the most suitable tool for the respective situation. Once the right resource is found, it is possible to dive deeper to better understand how it works and how it can best serve the respective needs.

Basta (SE)

Link: https://www.bastaonline.se/en

Section (target group):

1 (1,2)

Solution for:

Chemical aspect (focus), circularity and climate aspect (voluntary)

General description:

The BASTA system is addressed to anyone who wants to make informed product choices with the aim of phasing out substances with dangerous properties. This can be property owners, contractors, architects, private individuals and more. BASTA is a non-profit company and is owned by IVL- The Swedish Environmental Research Institute and The Swedish Construction Federation.

Basta has six assessment levels, the most common being Basta and Beta. The assessment level Basta is about the same level as BVBs "To be accepted" regarding the chemical content criteria, Beta and the rest of the assessment levels have lower requirements than "To be accepted" in BVB.

The suppliers self-declare the products which means that they decide if a product meets the criteria and when a product meets a certain criterion it is listed in the Basta system. Suppliers connect to Basta by signing a contract and after that, and introduction by Basta, they can register their products. The suppliers must keep the information in the system updated themselves. They can ask the support for help and use guidance documents. Basta makes audits of the suppliers to check that they have the right competence to self-declare products and have updated information.

Basta has free courses about logbooks, assessments and criteria and a half day criteria training course at a cost. The mandatory criteria mainly cover chemical content, and they also have some optional criteria covering lifecycle aspects. Basta has a scientific council that develop the criteria, represented by clients, building contractors, architects, and suppliers. Anyone can search for products, but an account is needed to make a logbook. The page with information about a product shows some general information and how the product meets the criteria. Documentation in optional for the supplier to show, most products does not show the product content or documents.

Considering the three-pillar perspective Basta includes some aspects:
• The toxicity aspect is party covered by the chemical content criteria but as said above most products do not show the content. This is something that both BVB and Sunda Hus do.
• Considering circularity Basta has voluntary criteria. A supplier can report if a product complies with criteria about recycled material content, renewable material content, if a product can be reused or recycled and if the company has a circular business model for the product.
• Basta has a chemical content criterion about greenhouse gases that affect the climate. Is it also optional for the supplier to show climate data from a third party EPD (environmental product declaration).

Byggvarubedömningen (SE)

Link: https://byggvarubedomningen.com/

Section (target group):

2 (2)

Solution for:

Chemical and life cycle focus, social and climate aspects frequently considered, interactive logbook tool for documentation processes

General description:

Byggvarubedömningen (BVB) is a non-profit, member owned organisation. They have more than 70 members that consists of property owners, municipalities, county councils, architect firms, construction companies and their wholly owned subsidiaries. The members are active in the board and in different forums that contribute to the development of the company.

BVB was founded in the beginning of 2000 because the industry experienced major challenges, health risks and expensive decontamination due to the use of substances such as asbestos and PCB. The industry needed help to document the built-in materials and to make sustainable product choices. The base for a logbook tool was designed, where projects could choose from assessed products, assessed and document them in a logbook. The aim with the logbook was to know what exactly was built in when the building in the future would be renovated or demolished.

There are three assessment levels with the colours of a traffic light, green is called "To be recommended", yellow "To be accepted" and red "To be avoided". A product receives one assessment level on content criteria, one on lifecycle criteria and one on total assessment combining the two. BVB also has optional criteria for sustainable supply chains, based on the UN principles on business and human rights.

Both chemical products and articles are assessed based on different criteria. The chemical content criteria are based on EU legislation such as REACH and CLP and on PRIO, The Swedish Chemicals Agency's Prioritization guide for substitution. The lifecycle criteria are based on legislation, national practice, research studies and policy. These two areas of criteria are mandatory and are updated regularly to comply with laws and regulations. The criteria are updated by a criteria group consisting of representatives from members organisations.

Some information for users in the system:
• Suppliers need an account to apply for assessments.
• There are free webinars about the assessment process and supplier support by both email and phone.
• Project members need an account to search for products and to make a logbook.
• After a project and logbook is finished it is saved in the BVB system.
• The search tool has different possibilities, e.g., search for product name, supplier, filter for different assessment levels, choose a chemical to avoid etc.
• On the product card information is shown about e.g., product name, supplier, product assessment for the different criteria, content of the product, documentation and how the product complies with different certification systems.
• There are free webinars such as introduction to BVB and the logbook tool. There are a logbook and account support reached by both email and phone.

Considering the NonHazCity three-pillar perspective BVB covers the aspects in different ways. Toxicity is mainly covered by the chemical content criteria. The content criteria apply to the substances in products and include different hazard classifications and content limits that should be reached for the product to achieve the three assessment levels. The criteria cover both health and environmental aspects, e.g., allergenicity, acute toxicity, hazardous to the environment and endocrine disruption.

There are lifecycle criteria that cover the toxicity aspect as well: requirements for emissions of VOC (volatile substances) to the indoor environment, a criterion about hazardous waste and one about leaching of hazardous substances to the environment.

The circularity aspect is covered by several lifecycle aspects criteria, e.g.:
• Products that contain ≥50% renewable raw material or ≥50% recycled material are premiered.
• Wood certified with FSC/PEFC are premiered and products containing endangered wood species receive "To be avoided".
• A product is premiered if renewable resources account for ≥50% of the primary energy in the manufacturing phase.
• Products that can be reused or recycled are premiered.
• Products that are placed in landfill receive "To be avoided".

One lifecycle criterion that covers both circularity and climate is the one that premiers renewable primary energy in the manufacturing phase. It is also a criterion with concentration limits for greenhouse gases. BVB extract climate data from product specific EPDs (Environmental product declarations) that is shown on the product cards. This data can be used by projects to make climate declarations. BVB has initiated a collaboration with Plant, a company that provides a climate calculation-tool that makes calculations using data from BIM-models. With the two systems integrated users will be able to make climate calculations based on BIM-models and see the climate data of products in their logbooks.

Concular (DE)

Link:
https://concular.de/

Section (target group):
2 (2,3)
Solution for:
Circularity aspect
General description:
A somewhat different approach to the above described institutes, is taken by Concular. It is a company, which evolved out of the first larger circular market place "restado" in 2020 and handles re-useable construction material. The company offers circularity checks (including a visit to the building) for demolition and handling (selling and procuring) of re-useable materials, and a platform on which they may be sold. Additionally, they work on digital building profiles and passports, which may be used as management tool for all stages of a building´s (and product´s) life, some of which use the DGNB approach and LCA for the whole and all parts of the building. However, this is currently still in the beta phase. They offer consulting services on several topics: circulating materials, LCA, scenarios and variants, material choices, compliance with reporting and calculating value.

The materials sold in the shop are tested for functionality as well as hazardous substances. The responsibility lays with the building owner. Concular takes into account the documents that are made available by the sales person.

Danish Building Research Institute (SBi) BYG-ERFA database (DK)

Link:
https://build.dk/

Section (target group):
2 (2,3)
Solution for:
General sustainability
General description:
As an independent research and consultancy organisation, affiliated with Aalborg University, the SBi focuses on sustainable construction and provides information on climate neutrality and circularity of building materials via their published reports and links. Besides research and consultancy services they develop guidelines and offer tools to support sustainable building practices.

One associated tool is the database called "BYG-ERFA database", which provides information on building evaluations, experiences, and best practices in Denmark. Its goal is to facilitate knowledge sharing and mutual learning, continuously improving sustainable construction (practices) in Denmark projects.

The database can be accessed with an account free of charge and is meant for professionals. The database also shows results from the BYGGE RATING tool, for users that have subscribed to this organisation.

In summary, this database alongside the extensive reports and publications by the SBi serves as a valuable resource for professionals in the construction industry, learning from past experiences and making informed decisions for future projects.

DGNB Navigator and DGNB System (DE, international)

Link:
https://www.dgnb.de/en/

Section (target group):
2 (2)
Solution for:
Overall sustainability
General description:
The DGNB Navigator is an online platform provided by the German Sustainable Building Council. It aims to promote sustainable building practices by offering a comprehensive product-database and evaluating construction products. The login-part of the platform is made for manufacturers, architects and planners, as well as DGNB auditors. It serves also as a bridge to DGNB certification.

The DGNB Navigator in a nutshell
Aiming to promote sustainable construction practices the DGNB Navigator offers comprehensive information, guidance and a management system connected to the DGNB building certification system for professionals. The database offered is a product-database. All products published are assessed by the DGNB.

Should a manufacturer want to let a product be assessed, the relevant data is provided and maintained by him*her. The DGNB provides a standardised mask for the uptake of products, checks plausibility and completeness of the entered data during evaluation and includes a comparison between products regarding sustainability aspects. Here pollutant or hazardous substance content, CO_2 emissions during manufacturing and ease of recycling are important topics. The products published in the DGNB Navigator will not show first or second level certifications, as these do not consider the situation of installation. Promoting transparency the DGNB highlights products with especially high standards on transparency and data quality. For such products all data have been made publicly available and a product-specific EPD is available.

Product search is possible via material, cost group, manufacturer or via the general search. As the manufacturer decides which information is available on the product-page detail varies between products. The connection to the DGNB building certification criteria is shown directly and colourfully under the product description. If manufacturers provide this information, it is here where chemical content may be found.

When certification for a building (project) is sought, the DGNB auditor may add DGNB Navigator published and evaluated products to the project. Should a product not be present in the DGNB Navigator the auditor is responsible for adding, evaluating, and uploading required proof to the certification area. Contact to manufacturers of the product is possible within the login-area. The certification area also serves as a documentation process for DGNB certified buildings and is only open to DGNB auditors.

Upon registration and login, projects (and products in projects) are easily comparable due to a systematic (and unified) approach of registration and assessments of products and comprehensive structuring of information on a product.

Additionally, the platform provides guidance through clearly structured and comprehensive information regarding the assessment and certification process, the product search and information found as targeted information for professionals. However, also building owners may effectively use the product database for initial product search, which then could be supplemented by the search for respective EPDs. The complete datasets and certifications are only available after login (intended only for professionals).

The DGNB System (international) is a network of 2000+ members ranging from individuals over architects to industry. It comprises the DGNB Academy, with its training platform on sustainable building practices and the DGNB Navigator, with its database as well as the connected certification system.
How and what kind of information the DGNB System members present and which tools they offer, may vary from country to country and over time.

Green Building Council Denmark (DGNB Denmark)
The Green Building Council Denmark is a non-profit organisation and part of the DGNB System since 2011, that is also connected to the certification system of the DGNB for buildings. The GBC-DK itself comprises a network of 315 members from companies and organisations to individuals, all acting on sustainable transformation in the built environment.

In 2020 an international version of the DGNB was released. This version contains all criteria of the German 2018 version as well as updated fire safter rules. In Denmark the international version is adapted to Danish requirements and regulations.

Link:
https://www.dgnb-system.de/en/system/international/denmark/index.php;

https://www.dgnb.de/en/certification/important-facts-about-dgnb-certification/certify-projects-internationally

Sunda Hus (SE)

Link:
https://www.sundahus.se/en/

Section (target group):
2 (2)
Solution for:
Chemical focus, climate and circularity via LCA
General description:
Sunda Hus is a private company that was founded in 1990 to help organisations to improve the indoor environment. Today they aim to give construction projects the opportunity to make sustainable product choices and to document products in a logbook.

The assessments are made by employees. Sunda Hus has consultant services to help organisations with the construction process with focus on product choice and documentation. There are clients such as municipalities and construction companies that use Sunda Hus as their assessment system.

To search for products and make a logbook an account is needed. The product information shows general information such as product name, supplier etc, how the product meets the criteria, assessment level, product content, documents and more.

Sunda Hus has a course at a cost several times every semester that covers their system, criteria, the assessment process and how certifications are shown in the system. They can also do customized courses at a cost. On the webpage there is a support page with questions and answers.

The criteria have the assessment levels A, B, C+, C- and D. The criteria that cover chemical content are based on the EU legislation CLP and PRIO, The Swedish Chemicals Agency's Prioritization guide for substitution. Sunda Hus has some criteria that cover some lifecycle aspects. e.g. recycling.

Sunda Hus includes parts of the three-pillar perspective. The toxicity perspective is covered by the chemical content criteria with classifications and concentration limits that are used to assess all chemical products and articles. The criteria cover both health and environmental hazards. Sunda Hus also has criteria related to toxicity that includes requirements for emissions of formaldehyde, hazardous substances in the production phase, hazardous waste and the smog potential in products that contains volatile substances. Some circularity aspects are required to get the highest assessment level "A"; the product need waste information, it can't go to landfill and some product types needs to have a lifespan of >25 years. Regarding climate Sunda Hus has a tool that help projects with climate declarations. A criterion with concentration limits for greenhouse gases also affect the climate aspect.

The Estonian Register of Buildings (Eesti Riiklik Ehitisregister) (EE)

Link:
www.ehr.ee;

https://livekluster.ehr.ee/ui/ehr/v1

Section (target group):
2 (2)
Solution for:
No specific focus on any of the NHC3 pillars, but a possibility to track what is built in where
General description:
The building register is a database. The purpose of the building register is to store, provide and disclose information about planned, under construction and existing buildings and related procedures. The building register is freely usable for everyone and serves as a working environment for local governments when processing documents related to construction.

The technical data and documentation of the building are entered in the register (e.g. building data, location data, construction data, building audit data, building maintenance manual, data on building or construction-related applications and design conditions, notices, permits and prescriptions, state supervision data and energy label data).

In this section you find descriptions of resources that require advanced knowledge in the respective field. You are deeply committed to understanding and implementing sustainable practices? Then this is likely to be an interesting chapter for you, as these resources offer in-depth insights into sustainable building.

The list gives an overview intended for swiftly identifying the most suitable tool for the respective situation. Once the right resource is found, it is possible to dive deeper to better understand how it works and how it can best serve the respective needs.

Climate databases and tools (SE)

Section (target group):
3 (3)
Solution for:
Climate aspect using LCA data
General description:

Sweden also has several climate databases and tools since it is mandatory in EU since 2022 to calculate the climate impact of construction projects. One is operated by the authority The National Board of Housing, Building and Planning. They provide a database with conservatively set generic climate data about different building material to use when making a climate declaration for a construction project. However, they encourage projects to use product specific data from product specific EPDs (Environmental product declarations) to get a more accurate climate calculation. The database provides climate impact of material, it is not a tool to make climate declarations.

Three tools that can help projects make climate declarations is Plant, One Click LCA and BM (the Construction sectors Climate calculation tool). To use the tools an account is needed. To create an account at Plant or One Click LCA comes with a cost. BM has a free version where projects can write their climate data manually, but it comes with a cost to access more functions such as digitally data loading. Plant can make climate calculations using data from BIM-models and has a collaboration with Byggvarubedömningen.

Link:
https://www.boverket.se/en/start/building-in-sweden/developer/rfq-documentation/climate-declaration/climate-database/about-climate-database/

https://en.plant.se/

https://www.oneclicklca.com/

https://www.ivl.se/projektwebbar/byggsektorns-miljoberakningsverktyg.html

Building Information Foundation RTS (Rakennustietosäätiö) with RTS EPD (FI)

Section (target group):
3 (3)
Solution for:
LCA data
General description:

The Building Information Foundation RTS (Rakennustietosäätiö) is privately owned and provides information and expertise for the Finnish construction sector. Beside publications, guidelines, and training materials on various aspects of construction, including sustainable building practices, energy efficiency, and circular economy, RTS provides material/product databases. The Tuotetieto's database is the main database (containing M1 and RTS EPD). The database provides product-related information for over 150 000 products. Beside basic product information several documents are provided. These may include a declaration of performance documents (DOPs), technical information, user manuals, certifications, EPDs etc. The database enables the search by product and has many filtering opportunities: company, trademark, product line, common name (e.g. ceramic tile), GWP calculation standard, inhibition of bacterial growth, blue angel certificate, BREEAM certificate, CE mark, EU Ecolabel, Formaldehyde emission class, thermal conductivity just to name a few.

The M1 database contains construction material certified with the M1 label (see eco-labels), which aims at promoting the development of low-emission construction material and has a chemical focus on VOCs and is described in section 1.

Information on some of the products listed in the M1 database may be found within the RTS EPD database. It too is free of charge and a sub-databases of Rakennustieto material database, but may be used individually. The search tool allows to search the RTS EPD database by material or product type, market name or producer and covers various construction materials (but not all in the M1 database). It provides some information on circularity, climate, and chemical content via the EPDs for download. There are indicators, that describe the environmental impacts caused during the product life cycle, including: climate change impact, ozone-depleting substances, acidifying emissions to soil and water bodies, depletion of non-renewable energy resources and mineral flows (typical LCA indicators). It is not mandatory to use this database in Finland.

Should a company want to list its products in the RTS EPD database this can be done over the online application tool on the RTS website. After all documents (listed on the website, which also provides a guide on the process) have been sent to RTS the EPD committee assesses the product. Once the product is verified the EPD is published in the RTS EPD database and has the option to also be published on the ECOplatform of the EU.

Link:
https://cer.rts.fi/en/rts-epd/search-for-rts-epds/;

https://haku.tuotetieto.fi/

The Building Information Foundation RTS in a nutshell
The RTS Hato Tuotetieto is a major construction product database in Finland. It comprises the two sub-databases of M1 classified products and the RTS-EPD database. While the two latter can also be used separately, they serve special sustainability needs (TVOC for M1 and EPDs as general environmental type 3 label including LCA information. The search and filter function in the overall database enables finding products for explicit uses and also includes environmental labels as well as technical information.

Link:
https://www.eco-platform.org/home.html

IBU (DE)

Section (target group):
3 (3)
Solution for:
LCA data
General description:

The Institute for Construction and Environment (IBU: Institut Bauen und Umwelt was created out of an initiative of manufacturers of construction products and components who decided to support the demand for more sustainability in the construction sector) is a German non-profit organisation, which has specialised in creating and providing EPDs for construction products. They do this by hosting an EPD-database ibu.data, where either EPDs can be searched via the search tool (product name, language, IBU Classification, Region, Valid until, Type (of dataset), manufacturer) or download an XML file. EPDs may also be downloaded as PDF files.

The IBU also provides the online and offline EPD editor software including tutorials for its use. This way suppliers are able to create EPDs for a product following the so-called PCR (product category rules), a guiding document for each product group. The EPD is valid for 5 years after verification and publishing by the IBU. After publishing the EPDs are available to public via the download from the IBU webpage, ÖKOBAUDAT and IBU.data.

Additionally, the IBU provides the user with an extensive amount of information on the topic EPD and their creation. Hence, according to the platform, an EPD summarises scientifically determined values of the products LCA, functional and technical properties as well as information on circularity aspects and it does this in an objective manner. Before publishing an EPD it is verified by an independent third party. Aspects of verification include completeness, plausibility, and compliance

Link:
https://ibu-epd.com/

IBU in a nutshell
The institute for construction and environment manages the EPD programme within the construction industry. It primarily helps suppliers create EPDs by providing tools, verification processes, publishing and providing the EPDs. Additionally, the platform provides background information, as well as information on how to use the different tools.

with standards.

SuPIM is an information system provided by the IBU, in which suppliers may put together product-specific information regarding the criteria of certification systems such as DGNB, BNB, LEED and BREEAM. It serves as a system for product-specific sustainable information and may be used by auditors of the respective certification systems. Architects, planners, building owners and other stakeholders may use the SuPIM as a database with search function e.g. in the material search phase. Also, project and certificate management is possible on SuPIM. Product data is entered and modified by the supplier but can be validated by the IBU on request (comes with a cost). Product contents can be disclosed within the system; however it is not obligatory. The database is publicly available via registration under www.epd-online.com. The usage is free of charge, only cost that may apply is when the IBU verifies the supplier´s assessments.

Link:
https://epd-online.com/

CMEPD (https://ibu-epd.com/cm-epd/) stands for circularity module EPD and describes an addition of circularity data (information needed for planning and implementing circular approaches) to the existing building material datasets. The aim of the CMEPDs is to eliminate the uncertainty of what or how to handle construction products when recovered or disposed after dismantling. This should promote the re-use and recycling-orientated planning and implementation of construction materials in buildings. Furthermore, CMEPDs may be used as LCA information for re-used raw materials.

Link:
https://ibu-epd.com/cm-epd/

ÖKOBAUDAT (DE)

Link:
https://www.oekobaudat.de/en.html

Section (target group):
3 (3)
Solution for:
LCA data
General description:
ÖKOBAUDAT is a platform that serves as a standardized online database using LCA datasets. It is provided by the Federal Ministry for Housing, Urban Development and Building and is accessible free of charge.

It is a mandatory database for BNB certified products (Bewertungssystem Nachhaltiges Bauen) and includes generic as well as specific life cycle assessment datasets (regularly updated, last update considered 2023) as well as product-specific Environmental Product Declarations (EPDs). The database covers various types of products from the building sector. Ökobaudat´s database is connected to the background database “GaBi” and complemented with data from the “ecoinvent” background database.

ÖKOBAUDAT is free of charge and accessible without a login as its aim is to provide comprehensive and transparent data on the sustainability aspects of building elements.

In addition to providing datasets for download, the platform is connected to several tools, that increase its usability. One tool that is directly connected to the Ökobaudat database is the eLCA tool, which helps producers create life cycle assessments for their products. It allows the modelling of individual building components and even entire buildings, using a component editor and graphical interface. The calculated environmental impacts are complemented by relevant data/information about the building and then compared to the BNB benchmarks. The assessments can be exported to the eBNB system (Elektronisches Bewertungssytem Nachhaltiges Bauen), which serves as a project management tool regarding the implementation of construction activities in line with BNB criteria. However, it is an instrument, which is available only for employees of the Federal Construction Departments (Raumordnung, kein Datum), as it was specifically developed for the implementation of BNB in federal construction.

ÖKOBAUDAT in a nutshell
The platform focusses on the assessment of construction material on the basis of life cycle assessments and environmental product declarations. While LCA datasets give an overview on the environmental and circularity aspects of a product throughout its lifetime, exact chemical content of the specific product is potentially found in EPDs. In order to make sophisticated choices regarding which construction material to use in a building, obtained information, however, must be compared and interpreted by the end-user.

Another tool, which is connected to ÖKOBAUDAT database, is a list of datasets with building materials enabling a product search. It uses ÖKOBAUDAT data to provide information on sustainable construction products and their environmental performance. Users can search for specific products, access EPDs, and make informed decisions based on the available information. This tool is part of the ÖKOBAUDAT platform and open to all users.

By accessing EPDs via the list search tool connected to ÖKOBAUDAT, users can also obtain information on the chemical content of products to make informed decisions regarding their selection and use in construction projects. However, the information found within an EPD is in need of interpretation, which may be difficult for laypeople. Guidance on which product(group) to prefer from which perspective is missing. There is no simple visualisation or evaluation in the sense of “approved”, “accepted” or “to be avoided” such as in BVB for example. This information needs to be derived via comparison of considered products.

For example, there is a PVC layer with softener (Phthalate) DINP 29% in a product specific EPD x.
The user now needs to decide whether this is acceptable or not.
Some aspects are considered roughly:
• The product/item/at least one component contains substances from the Candidate List (date xx.xx.xx) above 0.1% by weight: no
• The product/item/at least one component contains other CMR (Carcinogenic, Mutagenic, or Reprotoxic) substances of Category 1A or 1B, not listed on the Candidate List, above 0.1% by weight in at least one component: no.
• Biocidal products have been added to the present construction product or it has been treated with biocidal products (thus classified as a treated article according to the Biocidal Products Regulation (EU) No 528/2012): yes (Dichloro-octylisothiazolinone; DCOIT).
The plasticizer used is Diisononyl phthalate (DINP).

Wecobis (DE)

Link:
https://www.wecobis.de/

Section (target group):
3 (3)
Solution for:
Scientific data including LCA data
General description:
WECOBIS stands for “Web-based Ecological Building Information System.” It is an online platform providing information on ecological and sustainable building materials, products, and technologies. It is held by the Federal Ministry of Housing, Urban Development, and Construction.

The platform aims to support diverse target groups (architects, engineers, planners, tendering entities, BNB coordinators, teachers, scientists, students and pupils, municipalities, institutions and society in general) regarding their work with and interest in construction materials, technologies and processes. For this purpose, there are various links to articles, other platforms, information and certification systems and other relevant information sites tackling sustainable construction topics.

Additionally, WECOBIS provides structured data on groups of construction products (boards, flooring, insulation materials, seals and water proofing products, wooden construction material, adhesives and more), in a product-neutral manner.

Each product group comes with a general description, before a table with relevant products and their main raw material, is shown (e.g in construction boards, there is general information on them followed by a division into gypsum boards, cement boards, plastic boards etc.).

Information on e.g. gypsum plasterboards is found including a definition, main raw materials, characteristics (e.g. naturally flame retardant), but also information on "especially relevant properties in terms of environmental and health", state of delivery and (special) areas of application. The information is presented in text format and refers to further relevant information sources.

Beside the information in the overview tab, other tabs provide information on planning, declaration, BNB-criteria and technical information for the product (group) chosen.

Where meaningful there are tables, showing other materials of the product group (e.g. different kinds of boards) in order to provide a comparison between the products. There is also information on circularity (including various ways of installation-glued, screwed etc- of a product).

The Topics health, circularity and environment are found in the several places. Hence, it is important to click through all the tabs available for the respective product.

Some products also have an extra (green coloured) tab-group called life cycle. This group includes - sometimes substantial amounts of - information on material composition (including chemical information) and environmental impacts and processes/situations of circularity.

Information in general may vary in length and detail depending on the product.

WECOBIS in a nutshell
The information platform provides comprehensive information on various construction materials, their properties, function, and impact. It also links to many different articles, websites and other publications including template tendering texts and is meant for various professionals as well as broader public and scientists. The information is product-neutral but provides information on material composition (including chemical content), processes, environmental impacts, circularity in life cycle tabs. Information on certifications is also available.

The answer to the question "what is used in which country" is complex. It depends on what kind of user you are and what kind of information you would like to get out of the system. Many systems will also work for your country. If you are specifically interested in one of the described ones, check out their websites and get into contact with them. They will provide you with further information tailored to your needs. And maybe you will initiate the spreading of the respective system to your country and join us on our journey to make the construction sector really sustainable.

Special situation in Lithuania

In Lithuania no national sustainable construction product databases or certification schemes for green building products are developed as the sustainable construction is a recent emerging topic. However, a national building certification scheme "Lithuanian Building Sustainability Assessment System" was founded by the Lithuanian Green Building Council who disseminate and popularise the sustainable construction topic. In 2022, the Green Public Procurement rules have been updated to include mandatory "green" criteria for construction materials and building design services. This is presently, one of the main factors influencing the selection of the "greener" construction materials.

Lithuanian Building Sustainability Assessment System (LBSAS)

The Lithuanian Building Sustainability Assessment System is designed to objectively and transparently assess the level of sustainability of territories and buildings in Lithuania in a professional manner. The LBSAS is prepared according to globally recognized international assessment methodologies (BREEAM, LEED, DGNB, etc.). It is adapted and applicable to the local market and covers 8 areas: energy, transport, water and wastewater handling, construction materials/substances (preference for local materials and avoidance of hazardous chemicals), waste management and pollution, project management, land plot use and ecology, health and well-being. It encourages the design and construction of healthy, comfortable, long-lasting, cost-effective, energy efficient buildings that rationally use natural resources at all stages of the life-cycle of the building.

LBSAS is adapted specifically to Lithuania, it considers natural conditions, legal environment and local market needs. As of 2023, 7 buildings have been certified with LBSAS. The system is applicable for buildings at the design phase, as well as construction phase or already complete buildings.

8 Labelling and certification systems

Throughout the lifecycle phases, from construction till demolition, buildings use energy, water, raw materials, generate waste, and emit (hazardous) substances. These realities triggered the establishment of labelling schemes, standards, certifications, and rating systems designed to curb buildings' impact on the environment through sustainable design practices. The variety of labelling relevant to the construction sector, as well as building certifications, is huge in the world.

The environmental and health aspects of construction products can be highlighted with a help of statements, symbols or other marks. These assertions are known as environmental claims. They suggest that a product or service is better for the environment. All varieties of environmental claims and labels on products can be divided into three types:
• Ecolabels and environmental labels, verified by an independent third party (Type I; ISO 14024);
• Self-declared environmental claims (Type II; ISO 14021);
• Environmental product declarations, verified by an independent third party (Type III; ISO 14025).

Self-declared environmental claims
are developed by a manufacturer or service provider and are not third-party certified but expected to be verifiable and accurate. Unfortunately, this is not always a case; some of them appear to be misleading and lead to the so-called "greenwashing".
The best way to choose products with reduced environmental impact is to choose those with ecolabels and environmental labels that are verified by an independent third party. Ecolabels, based on life cycle considerations, identify the overall environmental preference of a product within a product category. Environmental labels share the same characteristics as ecolabels but are focused on specific single or multiple aspects, such as the composition of a product or the emissions and resource consumption during the production and use of a product.

Environmental product declarations
provide quantified environmental data of a product, under pre-set categories of parameters based on life cycle assessment and verified by an independent third party. EPDs do not state the benefits of the product, but provide verifiable information. EPDs can be understood as a kind of "fact sheet" of the declared product. They are accepted in various building certification systems (e.g. BREEAM, LEED), Building Information Management (BIM) software for building LCAs and Green Public Procurement.

Building certification systems
are used to assess and recognise buildings that meet certain sustainability requirements or standards. They look at whole building, not just parts of the construction. Certifications vary in their approach and can be applied to the planning and design, construction, operation, maintenance, renovation, and eventual demolition phases of a building.
A number of certification systems use ratings for buildings. For example in BREEAM, buildings are rated and certified on a scale of Unclassified, Pass, Good, Very Good, Excellent and Outstanding. Some popular databases/ building materials assessment tools in the region have their own criteria for assigning construction products to certain categories, levels, etc. The assignment of these levels relates to hazardous chemicals in construction products (e.g. "recommended", "accepted" or "to be avoided" in the BVB database, Basta and Beta products in the Basta database).

This chapter presents eco-labels, environmental labelling, and building certification systems, which originated and/ or are common in the countries of the Baltic Sea region.
A few labels (namely The Blue Angel, the Nordic Swan, M1, Danish Indoor Climate Labelling) were created and are widely used in the region. Environmental product declarations (EPDs), which are now used globally, originated from Sweden. Several countries in the Baltic Sea region have their own national green building councils, which have developed certification programs for local conditions. At the same time BREEAM and LEED – green building certification systems that are used globally – are popular also in the countries of the Baltic Sea region.

The table below will direct you to labelling and building certification systems, depending on what are your needs: to choose building products with lower environmental and health impacts, to choose the right products by examining the detailed product information or by taking into account the ready-made product rating, or maybe you want the building to be certified or given an environmental label (the latter option is provided by the Nordic Swan). The expanded information is available directly below the table.

What are your needs?	Label / declaration / rating / certification	Focus on products / buildings	Focus on aspects
Acquire products with lower environmental and health impact	The EU Ecolabel	3 groups of construction products	Multiple aspects, lifecycle approach
	The Nordic Swan	9 groups of construction products	Multiple aspects, lifecycle approach
	The Blue Angel	17 groups of construction products	Multiple aspects, lifecycle approach
	M1	Building and decoration materials, fixtures and furniture used in living and working spaces	Single aspect: emissions
	Danish Indoor Climate Labelling	Building materials, furniture, and fixtures	Single aspect: emissions
Get information about the product	Environmental Product Declaration (EPD)	~64 Product Category Rules for construction products	Multiple aspects, lifecycle assessment
Ecolabel the building	The Nordic Swan	New buildings; Renovation	Multiple aspects, lifecycle approach

What are your needs?	Label / declaration / rating / certification	Focus on products / buildings	Focus on aspects
Certify the building	BREEAM (Building Research Establishment Environmental Assessment Method)	New constructions; in-use buildings; refurbishments; communities; infrastructure	Evaluation areas: energy; health and wellbeing; transport; water; materials; waste; land use and ecology
	LEED (Leadership in Energy and Environmental Design	New buildings; existing buildings; interiors; neighbourhood development; cities and communities	Evaluation areas: sustainable sites; water efficiency; energy & atmosphere; materials & resources; indoor environmental quality; innovation in design; location and transportation; regional priority.
	DGNB (The German Sustainable Building Council)	New buildings; commercial interiors; renovations; existing buildings; urban areas	Evaluation areas: ecological quality, economic quality, socio-cultural and functional quality, technical quality, and process quality. Lifecycle perspective emphasized.
	Miljöbyggnad	New buildings; renovations; existing buildings	Evaluation areas: energy use and climate aspects, indoor environment, materials (hazardous substances), climate risks, biodiversity and circularity.
	Noll CO2	Various buildings	Climate impact of a building
	Citylab	Whole districts: planning process, or districts that are up and running.	social values, climate impact, water management, energy systems, transports, air quality and hazardous substances; trust, indoor environment, travel habits, energy use of buildings, climate impact, biodiversity and stormwater treatment
	LPTVS (The Lithuanian Green Building Council)	New buildings	Evaluation areas: health; energy; transport; land use and ecology; materials; waste management and pollution; project management; water management.
	Zielony dom	New buildings (residential)	Evaluation areas: energy consumption; materials; rainwater management; tap water quality; indoor air quality; facilities for seniors and disabled people; close access to amenities.
	Level(s)	All types of construction over the entire EU	Evaluation areas: greenhouse gas and air pollutant emissions; resource efficient and circular material cycles; efficient use of water resources; healthy and comfortable spaces; adaptation and resilience to climate change; optimised life cycle cost and value.

Ecolabels

The EU Ecolabel, also known as the Flower Certification, is an eco-labelling scheme introduced by the European Commission in 1992. It covers 24 product and service groups across 11 categories. Of them, 3 groups are related to the construction sector:

- Indoor and outdoor paints;
- Wood-, cork- and bamboo-based floor coverings;
- Hard covering products.

More than 40,000 construction products have been awarded the EU Ecolabel, majority of them indoor and outdoor paints (>36,000).

The Nordic Swan is an official ecolabel for the Nordic countries (Denmark, Finland, Iceland, Norway, and Sweden), established by the Nordic Council of Ministers in 1989. Nordic Swan covers 56 product areas, encompassing over 200 product types. Within the construction sector, there are 7 categories for materials and 2 categories for buildings themselves:

- New buildings,
- Renovation,
- Chemical building products,
- Construction and facade panels, and mouldings,
- Floor coverings,
- Indoor paints and varnishes,
- Windows and Exterior doors,
- Durable/resistant wood for outdoor use
- Outdoor furniture, playground, and park equipment.

In total, more than 25,000 different products have been awarded the Nordic Swan Ecolabel.

The Blue Angel was launched by the German government in 1978. The Federal Environmental Agency (UBA) establishes the specialized criteria that products and services must meet to receive certification. There are some 96 groups of products and services that can be labelled with the Blue Angel, of which 17 are intended for the construction sector. For example, they cover:

- Paints and varnishes,
- Wallpapers, panels, plasters,
- Floor coverings (elastic, textile, wood),
- Roofing materials
- Insulation materials,
- Sealants, fasteners,
- concrete products.

In total, more than 20,000 products and services have been awarded the Blue Angel.

It is important to note that different ecolabeling schemes do not necessarily apply the same criteria even to the same groups of products; and in case criteria definition is the same, numeric values may differ. Depending on the construction product group, the following are among requirements covered by criteria:

- Chemicals:
    - Restrictions on substances classified into certain hazard classes and categories,
    - Restrictions on Substances of Very High Concern (SVHCs),
    - Restrictions that apply to specific hazardous substances,
    - Content of VOCs and SVOCs,
    - Limits on emissions / discharges
- Climate considerations:
    - Global warming potential limit during lifecycle,
    - Sourcing of electricity (renewable) in the production,
    - Offsetting of CO2 emissions,
- Circularity:
    - Performance requirements (potentially prolongs use-phase),
    - Use of recycled materials.

For labelling of buildings with the Nordic Swan, criteria are summarized as follows:

New Buildings

- Chemicals

Construction materials and chemical products have restrictions regarding hazardous environmental and health properties and emissions of formaldehyde from sheet material

- Climate considerations

Low energy demand (use stage) of minimum 10 % better than NZEB (near zero energy buildings);
Climate impact requirements for concrete, steel, aluminium etc

- Circularity

A material logbook to ensure traceability of the building components;
Requirements for construction waste;
Voluntary requirements for reuse of products/materials

Renovations

- Chemicals

Good indoor environment and low emissions of hazardous chemicals;
Building materials, materials and chemical products meet high environmental and health requirements

- Climate considerations

Low energy consumption after renovation

- Circularity

Promoted reuse of construction products and materials

Environmental labels

The emission classification of building materials has encouraged the development and use of low-emission building materials, interior design products, and furniture since 1996. Rakennustieto Oy (RTS), Finland, oversees the rating process.

This labelling system was designed for classifying materials, fixtures, and furniture used in both living and working spaces.

In terms of criteria, the M1 classification sets limits for emissions of volatile organic compounds (VOCs), formaldehyde, and ammonia, and also evaluates the acceptability of the product's odour. There are over 6800 M1 emission-classified products.

Danish Indoor Climate Labelling (DICL) is a certification program that systematically tracks the emission of chemical compounds into indoor air. Established in 1993 under the initiative of the Danish housing minister, it has been consistently managed by the Danish Technological Institute.

Products bearing the Indoor Climate Label undergo a comprehensive testing process that results in detailed documentation of the release of chemical compounds, as well as an evaluation of the product's sensory attributes, ensuring they are within acceptable limits.

Testing within DICL covers various product groups, including building materials, furniture, and indoor fixtures. The general labelling criteria encompass factors such as volatile organic compounds (VOCs), carcinogens, and formaldehyde, which are applicable to all product categories. Additionally, ceiling products must undergo testing for particle emissions. Products bearing the indoor climate label must not emit carcinogenic substances. The label itself is divided into three emission classes.

Environmental product declarations (EPD)

Environmental product declarations have a binding, generally valid basis; they are prepared by experts and independently verified- nevertheless, the manufacturer bears the responsibility for the EPDs.

The International EPD System is the world's first and longest operational EPD programme, originally founded in 1998 as the Swedish EPD System. EPD International is the overarching global program. It has a global service network (independent licensees) with exclusive representations in a few countries and regions. All other nations are managed via EPD International AB from the offices in Sweden.

Some countries have their own EPD organisations. In the Baltic Sea region, it is IBU EPD (Germany) and EPD Danmark (Denmark). They operate independently but adhere to the guidelines and standards established by EPD International. EPD International has Mutual Recognition Agreements with IBU EPD and EPD Danmark.

EPD International has developed or is still in the process of developing about 64 Product Category Rules (PCRs) for construction products. PCR offer guidelines for life cycle assessments and EPD development in specific product categories. They determine the scope, functional unit, and environmental impact categories. For construction products, the EPD programme complies with the European standard EN 15804 (Product Category Rules (PCR) for EPD development in the construction sector). The Institut Bauen und Umwelt e.V. (IBU) has already published 1,800+ EPDs in its database system. Database of EPD Danmark has over 450 EPDs.

Rakennustieto EPD (RTS EPD) (Finland) is an environmental declaration that presents the environmental impacts of the product. The calculations for those are based on life cycle analysis (LCA) throughout the whole life span of the product.

All Rakennustieto EPDs have been drawn up in accordance with EN 15804 and product group-specific standards. Therefore, they can be used within the EU. Database of Rakennustieto EPD contains over 450 EPDs.

Sustainable building certifications

BREEAM, which stands for Building Research Establishment Environmental Assessment Method, is among the most widely adopted and recognized environmental assessment methods for both buildings and infrastructure projects. It was developed in the United Kingdom in 1990. BREEAM serves as a comprehensive framework for evaluating the sustainability performance of buildings and offers a standardized approach to assess their environmental, social, and economic implications across their entire lifecycle. The compliance with BREEAM standards is validated by an independent third-party organization.

The BREEAM certification system encompasses critical criteria, including energy efficiency, health and wellbeing, accessibility by transport, water usage and management, environmental impact of materials, waste reduction, and the influence on the surrounding environment. The results are classified into five categories for new buildings and six for existing ones, representing varying levels of excellence.

LEED, short for Leadership in Energy and Environmental Design, is another most widely used and recognized green building certification program, established by the U.S. Green Building Council in 2000. LEED uses a point-based rating system, where buildings accumulate points by meeting specific sustainability criteria. This rating system encompasses various aspects of a building's design, construction, operation, and maintenance. Based on the number of points earned, a building can attain different certification levels, namely Certified, Silver, Gold, or Platinum. The LEED certification system relies on several critical criteria in the categories of Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation in Design.

The German Sustainable Building Council (DGNB) is a sustainable building certification system that originated in Germany in 2007. DGNB conducts a comprehensive assessment of a project's sustainability, addressing ecological, economic, sociocultural, and functional dimensions. It places a strong emphasis on a life cycle perspective, considering the entire journey of a building from construction through to demolition and recycling. DGNB awards quality labels in various levels, including bronze (not applicable to new buildings), silver, gold, and platinum. For exceptional architectural excellence, buildings with gold or platinum status may also qualify for a diamond award. Notably, entire neighbourhoods can also attain certification. DGNB's evaluation encompasses a wide array of areas, including ecology, economics, and social aspects. While prerequisites must be met, optional criteria offer opportunities for additional points.

Miljöbyggnad is the most widespread environmental certification system for buildings in Sweden. Environmental properties of a building are assessed by a third party. These properties determine whether it is given a rating of Bronze, Silver, or Gold. Assessment includes fifteen different indicators for energy use and climate, indoor environment (e.g. materials and hazardous substances), outdoor environment and circularity. Miljöbyggnad has requirements regarding chemicals and materials: avoid hazardous substances and a project needs to have logbook to document content and information about material and products that are built-in. The indicators also include requirements for climate impact of the building (climate calculation) and climate adaption. Regarding circularity there are requirements about the design being more resource efficient, adaptable, flexible and demountable, circular material flows, and the recycling of construction waste. Miljöbyggnad is aligned with the EU-taxonomy.

Noll CO2 means Zero CO2 and is a certification focused on the climate impact of a building. It's a new certification that started in Sweden in 2020. A climate calculation is made for the entire life cycle of the building, from production to end use, and it is balanced out with climate measures to receive a net zero climate impact. Assessment includes nine indicators about legislation requirements, climate impact in different phases of a buildings' lifecycle and an indicator about climate measures.

Citylab is a certification for whole districts and the first manual came in 2019. There are two certifications to work with, one evaluates the sustainability of the planning process of urban districts, and another evaluates the sustainability of urban districts where the residents are moved in, and businesses are started and ongoing.

Evaluation of the planning of urban districts has 17 indicators, some examples are social values, climate impact, water management, energy systems, transports, air quality and hazardous substances.
The Citylab certification for urban districts that are up and running includes 15 indicators such as trust, indoor environment, travel habits, energy use of buildings, climate impact, biodiversity, and stormwater treatment. This certification has a requirement that at least 80% of the buildings should be certified with e.g. Miljöbyggnad, BREEAM, LEED or the Nordic Swan. They have requirements about air quality and that every building should have a logbook with documentation of built-in hazardous substances, that the use of hazardous substances is minimised etc.

The Lithuanian Green Building Council has introduced a regional building sustainability assessment standard and certification system tailored to the Lithuanian market. This system provides an objective evaluation of buildings in Lithuania, taking into account local natural conditions, legal requirements, and market demands. It applies to various building types and offers ratings that range from Assessed to Good, Very Good, Excellent, and Outstanding. The LPTVS assessment system encompasses eight categories: Health, Energy, Transport, Land Use and Ecology, Materials, Waste Management and Pollution, Project Management, and Water Management. Within these categories, there are 29 specific criteria used for assessment.

The Polish Green Building Association (PLGBC) has launched the ZIELONY DOM (GREEN HOUSE) certification system, which evaluates the energy and ecological efficiency of residential buildings. This system applies to both multi-family and single-family homes and assesses sustainability across all phases, from design stage, during construction and operation. The criteria encompass six key areas: investment management, location and site, materials and resources, user health and comfort, water management, and energy consumption optimization.

Level(s) is a free of cost European framework designed for the evaluation of sustainability in the construction sector. It places a strong emphasis on circular economy principles and assesses 6 so-called macro-objectives: greenhouse gas and pollutant emissions, circular material cycles, water use, indoor comfort, climate resilience, and cost optimization. The name "Level(s)" is derived from the different levels a building can be assessed in.

The framework defines three different levels of detailed assessment: level 1 includes basic principles and understanding of the indicator, level 2 mostly provides checklists and assessments, and level 3 evaluates the as-built parameters of the building. The framework provides e-learning tools, spreadsheets, and manuals to carry out the assessment. Furthermore, the tool is matched with European legislation and goals in sustainable construction sector. It can be used on all types of construction over the entire EU. Also, it encourages the use of BIM (building integrated modelling) in the construction sector which allows to collect, store and communicate different building data among stakeholders.

The QNG Ready certification is an official German government-backed seal of approval that takes a holistic approach to assessing a building and its surrounding environment as an interconnected system. Unlike solely focusing on energy consumption during use, this certification evaluates the entire life cycle of a building. This includes aspects such as production, subsequent material recycling, and health considerations, among others. The QNG Ready label has been a mandatory requirement for securing a promotional loan as part of the BEG promotion; whether current political challenges are able to sustain this financially, will be decided in the nearer future. The criteria outlined in the QNG manual ensure that a building adheres to standards related to climate protection, conservation of natural resources, health protection, and the quality of the planning process.

Summary

The world of labels and certifications is vast and diverse. These labels, particularly eco-labels, are primarily focused on building materials. However, an exception to this is the Nordic Swan label, which uniquely extends its certification to the buildings themselves.

When it comes to certification systems for buildings, they vary greatly in their approach, application, and the criteria they use. This variety means that the extent to which they cover hazardous chemicals also differs significantly. For instance:

- The Nordic Swan eco-label stands out for giving the most attention to chemicals, closely followed by the Miljöbyggnad certification system.
- DGNB also considers hazardous chemicals, but to a lesser extent.
- LEED and BREEAM include considerations of health and the environment in their assessments. However, they do not specifically focus on the content of hazardous substances.

Additionally, indoor emissions are specifically addressed by the M1 and DICL certifications. Yet, these certifications primarily focus on volatile organic compounds (VOCs) and do not account for the content of hazardous substances in the material. This oversight means that non-volatile or semi-volatile hazardous substances, like phthalates, OFR, BFR, etc., might be present. These substances aren't typically measured or analysed in the M1 certification process.

Moreover, in some certification systems, such as NollCO2, health and environmental aspects are either absent or not clearly defined.

Remember:

- If you plan to certify a whole building, start considerations already in the first phase conceptual needs.
- If your goal is to use as much eco-labelled material as possible, changing to labelled products is even possible in later phases.

9 Construction process

This chapter realises that construction processes do not only differ by region, but especially by country. This is the result of varying national regulations as well as setting standards within organisations involved. Nevertheless, there are general considerations important to take into account if a building and its construction process shall be tox free, circular and climate neutral.

The underlying question of what to consider in which phase of construction in order to reach the goal building:

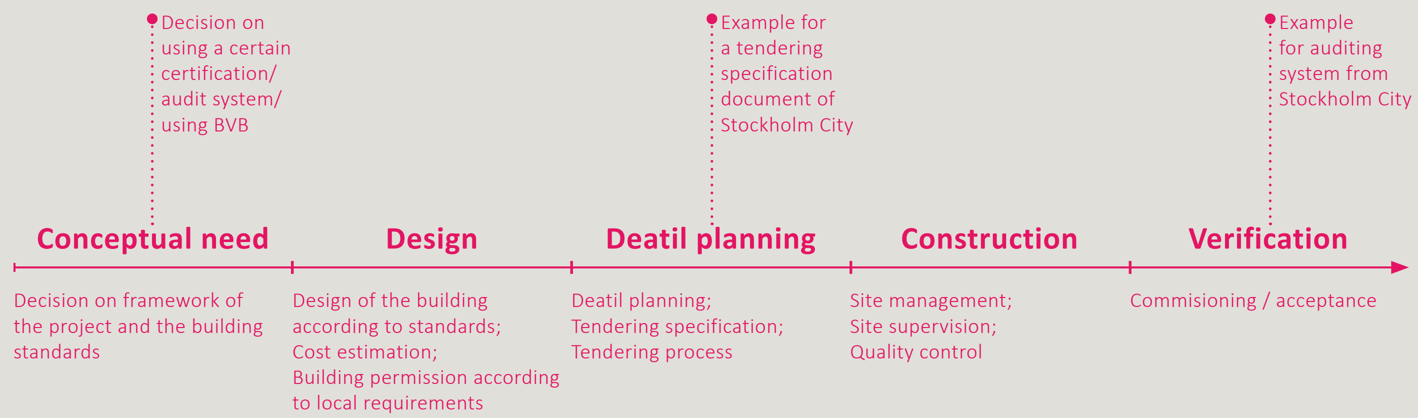
• Tox free – avoiding hazardous substances completely or at least minimising concentrations

• Circular – aiming at high amounts of recyclability/reusability and easy to repair designs

• Climate-neutral – reducing GHG emissions by e.g., prioritising materials with low embodied energy and high thermal performance, and taking into account transportation aspects as well as renewable energy and passive heating or cooling systems.

While construction phases and phases of permission by the respective institution or stakeholder may vary in name, length and timing between countries; starting to consider the three NonHazCity pillars as early as possible is vital. Figure 9.1 conceptualises the phases that every building project eventually goes though. The definition of the conceptual need, the rough design of the building, detailed planning, construction and verification. Throughout theses phases the decision on whether or not the building is aimed to be certified needs to be taken early, whereas actual material choice may be made in a later phase.

In the next section the processes of procurement, tendering and constructing using environmental building assessment systems tools and databases such as BVB is exemplified.



An example from Stockholm City, Sweden

Building- and construction materials account for significant share of the volume of a municipal's public procurement. Thousands of chemical substances are used in the construction sector, but there are few governmental regulations regarding reporting of chemical content. To control and limit hazardous chemical substances used in construction, the chemicals that are allowed need to be determined already in the procurement stage. It is also necessary to set requirements for a digital logbook, documenting the materials used and their chemical composition. A logbook facilitates substitution of hazardous materials, products, and substances. It also provides valuable information if the knowledge of what is considered non-hazardous today changes in the future.

This chapter describes the requirements for building processes in the city of Stockholm in Sweden. The conditions for consultants and contractors operating within the city are that all products, materials, and goods need to be assessed in the assessment system BVB, and the products used in construction need to be registered in a digital logbook.

The construction process

To get a better understanding of the power to influence selection of non-hazardous construction- and building materials, it is necessary to understand the construction process where materials are selected and when procurement and purchase of materials take place. In a construction project, there are different important responsibilities that need to be staffed:

• Construction project manager: The construction project manager (CPM) is responsible for delivering information to the BVB manager. In addition, a CPM must ensure that designers and contractors fulfil their mission in BVB.

• Designer: Responsible for ensuring that the chosen products and goods meet the requirements and are recorded in the logbook in BVB during the detailed design.

• Contractor: Responsible for ensuring that all goods and chemical products used in the building as well as consumable products meet the requirements and are recorded in the logbook in BVB.

• BVB manager: Administers the work in BVB and handles deviations. This includes creating logbooks, inviting designers and contractors to logbooks as well as training and attending construction meetings as needed.

• Head of unit, environmental unit (Customer side): Approves or rejects deviations in planning and production. Is the owner of all logbooks in BVB.

Planning and programming

The developer should at an early stage decide levels of ambitions and tools for verification, to ensure the selection of materials without hazardous substances used in the construction process. At this stage, decisions need to be taken about target levels and verification, tools for documentation (logbook) and verification of chemical content, preferred product groups. These requirements shall be incorporated in the specifications for the procurement of contractors and designers.

Design (architectural and engineering design)

The contract between developer and consultant should indicate that the consultant undertakes to comply with the requirements and objectives that the developer set, in relation to chemical substances in construction materials. During the design phase, it is possible to choose design and functions, but it is also important to control that chosen construction material fulfils requirements of non-hazardous content.

In the design phase, the BVB manager creates a logbook in BVB and invites relevant actors, assists with training, creates licenses, and distributes routines. The BVB manager is also available for questions about material selection during the detailed design. The construction project manager informs the BVB manager about quantities of goods for registration. The BVB manager reviews the logbook in BVB prior to construction start.

Construction
During construction, the contractor´s purchasing organization has an important role to play in relation to selection of non-hazardous construction material and compliance with requirements in the agreement with the developer. At the end, the BVB manager reviews the logbook within the framework of the final inspection and reports back to the responsible construction project manager.

Management
Management of buildings in relation to non-hazardous materials is not very common. Chemical considerations in the management process may be important to consider because a large volume of products could be used for maintenance during the user phase. Maintenance is often performed by subcontractors in municipalities.

In the agreement with a contractor, it is necessary to use the chosen chemical products and construction products that are registered in the project-specific logbook in the BVB-system. Consultants and contractors must have the skills and routines necessary to ensure that products, chemicals, and materials are assessed, and with an overall accepted level of assessment in BVB. Chemical products and goods that do not meet the municipality's requirements are handled as deviations, as described below.

Material requirements

Assessment of construction products in BVB
The party that specifies or intends to use a product is responsible for ensuring that it is assessed in accordance with BVB's criteria, and that the product meets the following assessment levels:
• Products that have gotten the overall assessment Recommended or Accepted are approved for use. The higher level Recommended must be prioritized over the assessment Accepted.
• Products with the overall assessment To be Avoided may only be used after approval from the customer before use. Products with this assessment must be handled as a deviation (see Deviation management below).

To ensure that products and goods fulfil the requirements, they must be verified according to BVB's criteria in the design phase and before purchase and use. The criteria of BVB are updated regularly. This means that even if a product previously met the requirement for an assessment level, the assessment could have changed. Therefore, the current assessment of a product must always be confirmed prior to use.

A hired consultant or contractor is responsible for documenting goods on BVB's web portal before they are purchased and used. The customer reimburses the verified license cost for BVB for one user per consulting company or contractor per project. Prior to final reporting, the consultant or contractor must notify the customer when registration of all included goods is completed.

Handling of unassessed products and goods
The priority is to use products and goods that are assessed in BVB. If the desired product is not assessed in BVB, the consultant or contractor must search for an alternative product. The product should have the overall assessment Recommended or Accepted. If there is no satisfactory alternative, the consultant or contractor must contact the supplier of the initial product to request an assessment of the product. The supplier must bear the cost for the assessment.

The priority order for a situation where a product is not assessed in BVB is shown below.
• The consultant or contractor contacts the supplier of the desired product and asks them to submit the goods for assessment in BVB.
• During the assessment period for the product, the consultant or contractor can enter the product in BVB with a placeholder ("Own product").
• The consultant or contractor asks the supplier to be notified of the BVB identification number (BVB ID) when the product is assessed in BVB.
• When the product is assessed, "Own product" must be replaced with the assessed product in the logbook (BVB ID required).

The product may not be used until all steps above have been completed and the product has been published with its assessment in the BVB system.

If the supplier cannot assess the product and there are no alternative products that meet the specified requirements, the product must be registered in BVB as an "Own product" and handled as a deviation. The consultant or contractor must be able to confirm that the supplier has been contacted before a deviation can be established.

Deviation management

All products, materials, and goods must be logged before they are used or installed. Designers and contractors must document and justify deviations from material requirements in a deviation report in BVB. The BVB manager from the contractor's side is responsible for the deviation management.

Deviations must be reported to the customer. The decision whether a product with a deviation should be used or not must be made by the person responsible for the project prior to use of the product on the construction site. Quantity and location of products that have received the assessment To be Avoided or products that are not assessed at all ("Own products") must be declared as deviations in BVB. If the deviation routine is not followed and thereby prevents the correct actions, this may become an inspection remark.

When a deviation is registered in BVB, the attempts that have been made to find an alternative product as well as a summary of the dialogue with the supplier must be submitted alongside the deviation.

If the product has the assessment To be Avoided due to a lack of documentation, the person who proposed the product must contact the supplier and ask them to update the documentation for reassessment of the product.

The following deviations cannot be approved:
- Products that lack complete or correct assessment documentation.
- Products that are logged in the logbook after they have been installed or used.

Depending on the requirements set in the procurement documents, different follow-up processes can be used. Below are some examples:
- Follow-up meetings with the contractor and/or material supplier.
- Measurement of quality through indicators or key figures.
- Randomized verification of invoices.
- Survey submitted to suppliers, clients or third parties (e.g., residents).
- Follow-up of self-reporting from suppliers.
- Follow-up of management systems for environment and quality.
- Notified or unannounced follow-up visits to the supplier.
- Planned or randomized audits of a supplier.

10 Supplier and supply chain information in the BSR

For a municipality, working with sustainable supplier chains in construction processes aligns with environmental and social responsibility, regulatory compliance, long-term viability, cost savings, stakeholder expectations, innovation, and efficient risk management.

Sustainable supply chain information in the construction sector encompasses a broad range of topics focused on ensuring that the entire lifecycle of construction materials and processes are environmentally friendly, socially responsible, and economically viable. Here is an overview of key aspects:

- Sourcing of Materials: This involves selecting raw materials that are sustainably produced, harvested, and extracted. It includes considerations like the use of recycled materials, renewable resources, and materials with lower environmental footprints.
- Energy Efficiency in Production: Focusing on how materials are produced, including the energy consumption and the carbon footprint of manufacturing processes. Sustainable supply chains aim to reduce greenhouse gas emissions and energy use in the production stage.
- Transport and Logistics: Managing the environmental impact of transporting materials. This includes optimizing transport routes for efficiency, using vehicles with lower emissions, and considering local sourcing to reduce travel distances.
- Supplier Selection and Management: Choosing suppliers who adhere to sustainable practices, such as fair labor practices, environmentally friendly operations, and ethical business behaviors. Regular audits and assessments are part of maintaining sustainable supplier relationships.
- Waste Reduction and Management: Strategies to minimize waste during construction, including recycling and reusing materials, efficient material usage, and disposing of waste in an environmentally responsible manner.
- Lifecycle Analysis and End-of-Life Management: Assessing the environmental impact of materials and construction methods over their entire lifecycle, from production to disposal. This includes planning for the end-of-life of materials, such as recycling or safe disposal.
- Certification and Compliance: Adhering to industry standards and certifications that validate sustainable practices, such as LEED (Leadership in Energy and Environmental Design) or BREEAM (Building Research Establishment Environmental Assessment Method).
- Transparency and Reporting: Providing clear and accurate information about the sustainability of supply chain practices, including sourcing, labor practices, and environmental impacts. This can involve sustainability reports and third-party audits.
- Community and Social Impact: Considering the social implications of the supply chain, including the impact on local communities, indigenous populations, and overall social welfare.
- Innovation and Continuous Improvement: Continuously seeking new methods, materials, and technologies to improve sustainability in the supply chain. This includes staying abreast of sustainable construction trends and investing in research and development.

Sustainable supply chain management in construction is not just about reducing environmental harm, but also about creating positive social and economic outcomes, thereby contributing to the overall sustainability of the construction industry.

As a municipal procurer, it is crucial to be aware of the content of building materials regarding hazardous substances. Equally important is having information about other material types and the substances the material consists of. This necessitates transparency and information sharing across all parties in the production chain. Certain legal requirements exist, primarily for technical features but also for substances of very high concern (substances on the candidate list, REACH Article 33).

Since the supply chain is lengthy and complex, often involving multiple suppliers, information about whether the material contains hazardous substances on the candidate list must be shared by an upstream provider (producer, distributor, assembler) with downstream users according to REACH Article 33. A downstream user must, in turn, share this information. Under this legislation, there is an obligation for producers to report this information to the EU's SCIP database. SCIP, an acronym for "Substances of Concern In articles as such or in complex objects (Products)," has been established under the Waste Framework Directive.

However, REACH legislation does not cover information about the entire substance content of the product, which is crucial for traceability, future investigations, exchanges, and circularity. The upcoming legislation will impose more requirements on information sharing and sustainable design through the Ecodesign for Sustainable Products Regulation (ESPR) directive. This will include requirements for digital product passports that (hopefully) mandate the disclosure of all substances and materials. Before these laws come into effect, municipal procurers need to specify in procurement which materials should be used and demand the full substance/material declaration.

This information can be obtained by requesting details (in an environmental declaration) about a product's entire substance content, which also requires effective information sharing at all levels. In BVB (the Swedish Building Database), suppliers are required to fill in a building product declaration. The declaration must specify the quantity of substances and materials in percentage terms. The information in the building product declaration is transferred to the BVB database and is also used in the logbook. This makes the information searchable for future mapping, removal, recycling, reuse, etc. Therefore, using BVB and its logbook provides the procurer with insight into what is being incorporated and in what quantity – crucial from various sustainability perspectives, for follow-up processes and impact assessment of the procurement.

The use of BVB and its logbook also makes it easier for a procurer to map manufacturers and suppliers of specific product categories and the content of substances/materials of interest. The procurer may also have reason to further investigate this information to trace the origin of, for example, a rare earth metal or any other material relevant for understanding more about sustainable production. In this case, BVB's criteria for social sustainability are useful, as described in upcoming chapters.

BVB offers several tools, including the product search, database, and logbook tool. The product search allows construction projects to use filters for informed product selection. Users can filter based on criteria such as avoiding specific substances or classifications, steering clear of phase-out substances, or candidate substances. Additionally, users can search by product group or seek products certified under various building standards like The Nordic Swan, BREEAM, or Miljöbyggnad.

Suppliers assessing products in BVB receive support and assistance from assessors, accessible via both email and phone. Sub-suppliers can, if needed, provide their information and documentation as confidential third-party information. Assessing products in BVB is advantageous in the market, as many projects have requirements for products to undergo assessment.

BVB incorporates voluntary social criteria focusing on four fundamental aspects: human rights, working conditions, environment, and anti-corruption. Suppliers can apply for assessment regarding their compliance with these social criteria in their operations and the product's supply chain. The criteria are aligned with international conventions and guidelines, such as The UN Universal Declaration of Human Rights and The UN Convention on the Rights of the Child.

More information can be found here: https://byggvarubedomningen.com/assessments/sustainable-supply-chains/

Fig. 76
Number of suppliers with products assessed in BVB, per country.

Country	Number of suppliers
Sweden	almost 2000
Finland	about 100
Estonia	about 60
Denmark	about 130
Germany	about 150
Latvia	about 50
Lithuania	about 50
Poland	about 70
Austria	about 30

As part of this project, suppliers were encouraged to register and evaluate their products in the BVB system (GoA1.3). Concurrently, BVB gathered information regarding the number of suppliers per country, as shown in Table 6.1 below. One conclusion drawn from this table is that suppliers in the BSR countries contribute to the assessment tool, indicating that BVB is well-established and recognized among building material suppliers in the BSR.

Digital product passports play a crucial role in advancing sustainable supply chains, by enhancing transparency, promoting responsible sourcing and production, and facilitating informed decision-making. They align with the growing global focus on sustainability and responsible business practices.