MATERIALS PASSPORTS - BEST PRACTICE

Matthias Heinrich, Werner Lang

This project has received funding from
the European Union's Horizon 2020
research and innovation programme
under grant agreement No 642384.

BAMB
BUILDINGS AS MATERIAL BANKS

Materials Passports - Best Practice
Innovative Solutions for a Transition to a Circular Economy in the Built Environment

Publisher
Technische Universität München, in association with BAMB
Fakultät für Architektur
Arcisstr. 21, 80333 München
www.ar.tum.de, verlag@ar.tum.de
ISBN 978-3-941370-96-8

Published in co-operation with
Department of Civil, Geo and Environmental Engineering, Technical University of Munich,

Published with support from the Horizon2020 buildings as materials banks program (BAMB). The BAMB project has received funding from European Union's Horizon 2020 research and innovation programme. For more information on the BAMB project and its partners, see http://www.bamb2020.eu.

We would like to thank all members of the BAMB team for their valuable support and contributions.

Graphic support: Fernandina Valdebenito

MATERIALS PASSPORTS - BEST PRACTICE

Innovative Solutions for a Transition to a Circular Economy in the Built Environment

For a successful transition towards a circular economy in the built environment, reliable and standardised information on material flows and material composition of building products and buildings is needed. As one of the greatest users of resources and producers of waste, the building industry has a central role in making this transition a reality.

One element that is currently emerging, which can provide the necessary methodology and data structure for collecting and handling the relevant information, is the so-called materials passport. These digital datasets aim to catalogue and disseminate the circular economy characteristics of building materials, components and products. Materials passports can help to bridge the current information gap and exchange between the relevant actors in the building industry.

This publication provides a guideline for actors along the construction value chain and show the benefits of materials passports and how these can be implemented into general building practice. Furthermore, the publication provides an overview on the types of material and product-related information. Standardised information exchange is one of the keys for a successful transition to a circular economy.

Table of Contents

1. INTRODUCTION

1.1. Background

1 INTRODUCTION

Closing the Loop – an EU Action Plan for a Circular Economy aims at transforming Europe's economy into a more sustainable one (European Commission 2015). The construction industry, one of the most resource-intensive industries, uses around 40% of worldwide material resources by mass and produces around one-third of the total anthropogenic CO_2 emissions (Becqué R. et al. 2016). To promote a circular economy and resource efficiency in the construction industry, information on the material composition of the building stock and material flows (e.g. raw materials, building materials, waste etc) is needed (Heinrich 2019a). The availability of structured information on materials (e.g. spacial, temporal, materiality etc) is key towards a transition from a linear to a circular economy (figure 1).

An instrument that offers a platform and repository for storing, linking and providing relevant information on materials in buildings (e.g. building products) to the relevant actors along the value chain is a so-called **materials passport [MP]**, which is also known as a product passport or circularity passport. There are different initiatives such as research projects, databases etc. that aim at promoting the use of material-related data sources. The majority of current initiatives are limited to defined areas of application. Some data sources, for example, are focused primarily on information on health, environmental or other aspects. To provide a solid data source for a circular built environment, holistic information from different fields is needed.

The EU Horizon 2020 project Buildings as Material Banks (BAMB) is an important initiative, which aims at bridging the current information

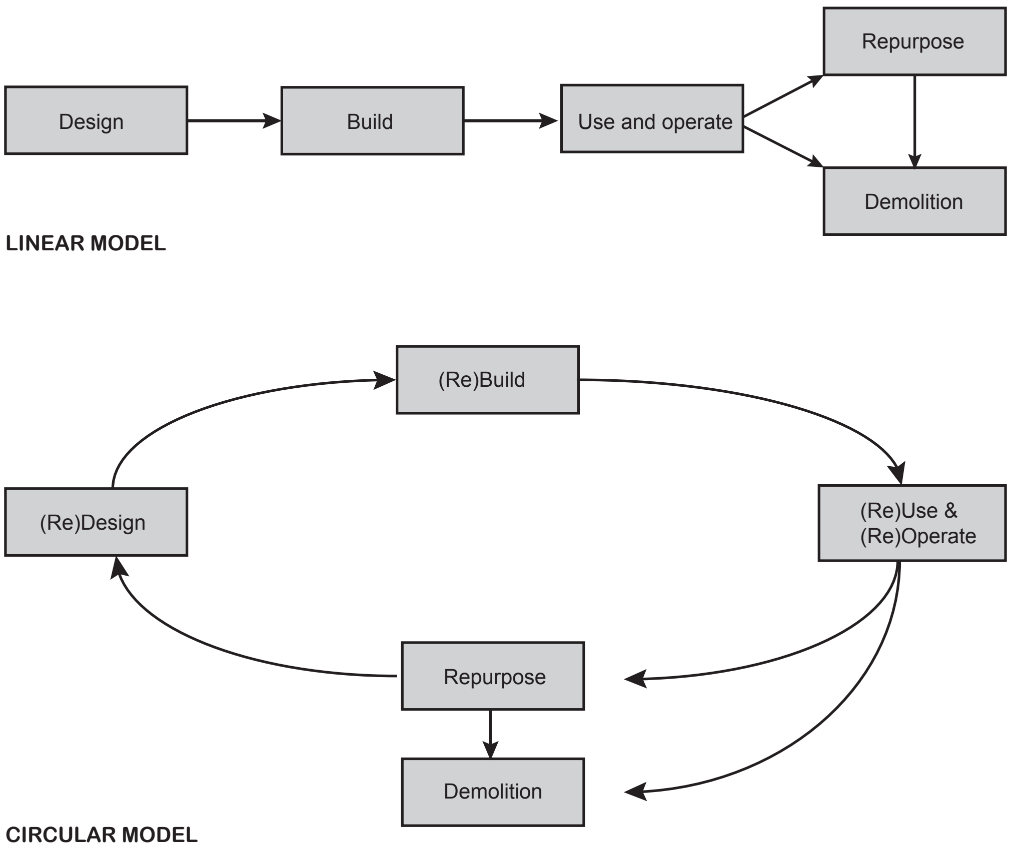


Figure 1: Shift from a linear to a circular economy (Peters M. et al. 2016)

gap and providing relevant tools to enforce a shift to a circular economy within the building industry. A central aspect is the development of a Materials Passports Platform (MPP) that is linked to building information modelling (BIM), reversible design tools, business models and other relevant fields.

Within BAMB materials passports are defined as:

Materials passports (MP) are (digital) sets of data describing defined characteristics of materials and components in products and systems that give them value for present use, recovery, and reuse. MPs are an information and education tool that addresses questions often not covered by other documents or certifications related to building products, especially in relation to the circularity of products. MPs do not assess the data output and are not an evaluator of data. Instead, they provide information that supports the assessment and certification by other parties and allows existing assessments and certifications to be entered into the passport as uploaded documents (Mullhall et al. 2017).

In brief, a materials passport is a digital report containing circular economy relevant data that is entered into and then extracted from a centralised database in the form of reports customised to the needs of diverse users (Luscuere and Mulhall 2017).

The scope of a materials passport is focused on different hierarchy levels. These include the level of materials, components, products and systems that make up a building (Figure 2). For a material, for example, a materials passport can define its value for recovery. For products and systems, it can define general characteristics that make them valuable for recovery, such as their design for disassembly, but it can also describe specifics of a single product or system in its application. For instance, how a product is linked to a building is essential to understand its value for recovery (Luscuere L. 2016).

The material and product level (materials passport) can be seen as part of a building's documentation or assessment.

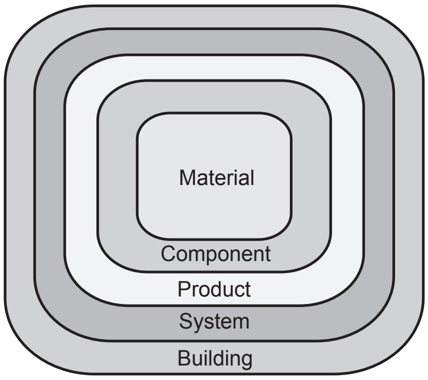


Figure 2: Hierarchy levels covered in materials passports (Luscuere and Mulhall 2017)

For a holistic evaluation, non-material-related factors, such as energy performance and use, need to be addressed as well. Figure 3 shows the classification of materials passports from a building and regional (geographic) perspective.

Within this publication the concepts of materials passports and best practices are explored, without being platform-specific. Information on relevant data and data sources and requirements, information exchange between relevant actors in the value chain, and other aspects relevant to material circularity in the building industry are addressed.

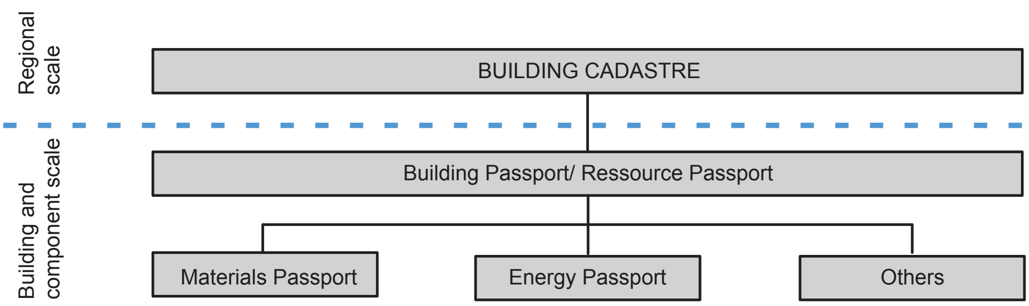


Figure 3: Classification of materials passports from a building and regional scale (Heinrich 2019b)

1.1 BACKGROUND

The worldwide resource use in 2017 was around 85 billion tonnes of materials. On a European level this corresponds to around 20 tonnes/person/year (International Resource Panel 2017). The building sector is responsible for around 40% of material resource use (by mass) and 40% of waste production (by volume) (UNEP 2016). As the largest user of resources and the largest producer of waste, the building sector plays an important role in reducing their impact on our planet.

Keeping in mind the capacity of our planet and the increasing world population a resource scarcity is expected, which will most likely lead to a price increase for materials required for building. The International Resource Panel estimates that resource use may more than double until 2050 (International Resource Panel 2017).

In conjunction, the energy required for the production of building materials and buildings and corresponding CO_2 emissions will increase further, with substantial impact on our ecosystem. Based on present data and trends, the supply of resources and the disposal of waste (already a serious issue today) will further intensify in the future.

The development of solutions to counteract this increasing problem is of central importance. A chance for counteracting this 'resource problem' lies in the implementation of closed material cycles. For this reason, the European Commission formulated their action plan for a circular economy to allow for a sustainable, CO_2-reduced, resource-efficient and competitive economy (European Commission 2015).

In a circular economy materials are kept in use for as long as possible. The key is to maintain the value of materials, products or components at the same level. Materials are valuable if they are accessible, functional and attractive. This requires that materials or building products can be removed from a building after their lifetime with minimal effort, contamination and without loss of quality.

Currently, a large proportion of materials coming from buildings is either downcycled (e.g. used as road aggregate or backfilling) or ends up in landfills. Recycling material for use in new buildings or the reuse of building components and systems rarely takes place.

Historically, building materials and products have generally been reused at a higher level to construct new buildings. In the last 70 years this procedure has decreased (Hobbs and Adams 2017). There are many reasons for this shift, but one important challenge in the reuse and recycling of materials and products is their increasing complexity. Today, many products contain a large amount of different types of materials that are attached to each other in different ways to provide the relevant mechanical and physical properties for a product's application.

Currently, there is an information gap of material and product information. Often the composition and properties of materials and products is unknown or not communicated to the relevant actors in the construction value chain at the required time. Therefore, standardised methods of data collection for materials and products within buildings throughout a building's life cycle are very much needed.

For assessing and promoting a circular economy, a wide range of information is needed from different actors along the value chain. Not all information collected in materials passports is relevant for all actors and it might only be needed at a certain life cycle stage (e.g. decommissioning, maintenance etc). Other types of data might not be needed at this stage, but can be a requirement for future assessments.

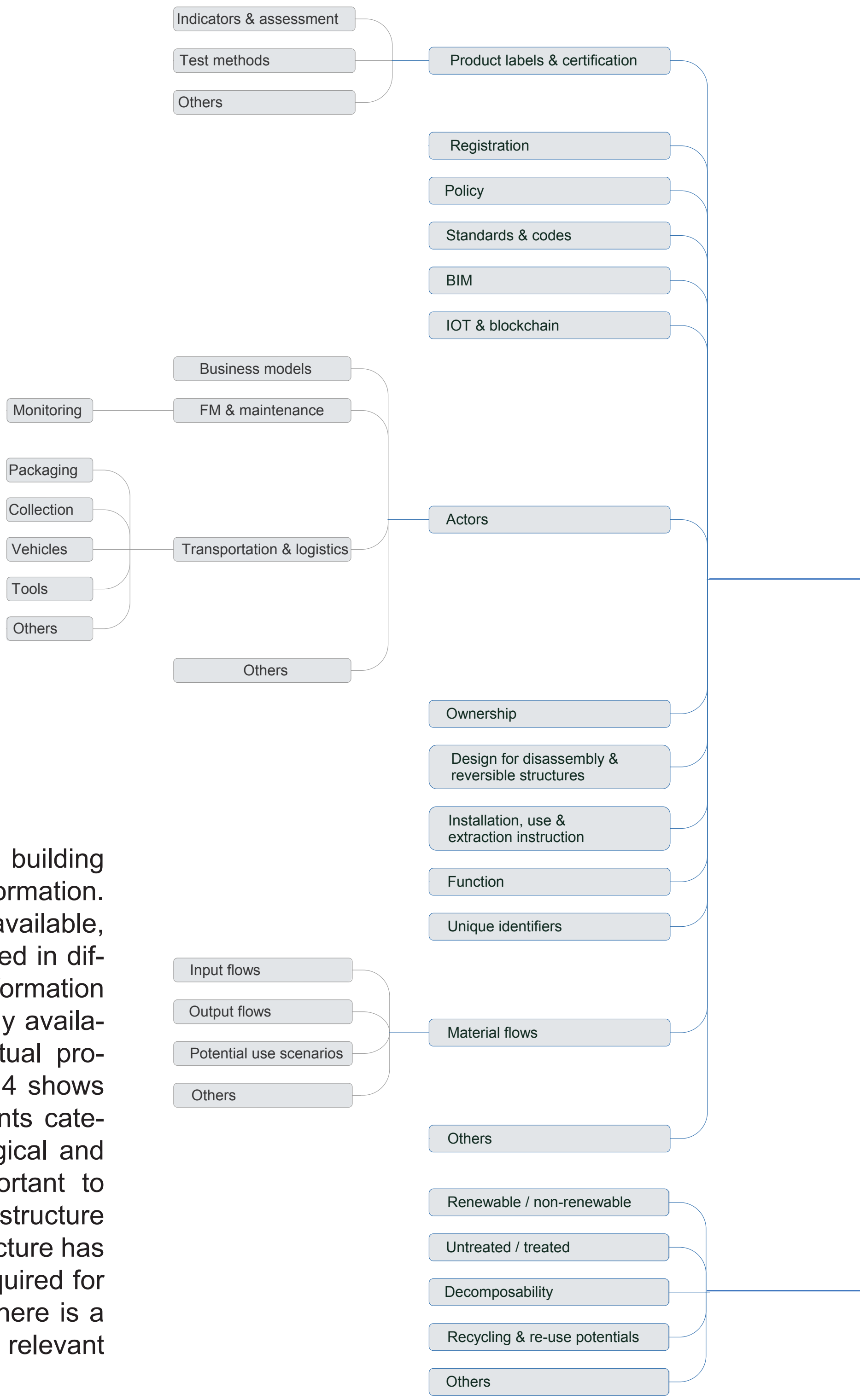
Furthermore, information from materials passports can be used for various assessments (e.g. building assessment and certification [CBA, LCA, LCC, DGNB, BREEAM], material flow analysis (MFA), energy assessments and simulation etc), reversible design protocols, product innovation and others. The main goals and benefits are outlined below (BAMB 2017):

MAIN GOALS AND BENEFITS OF MATERIALS PASSPORTS

- Keep or increase the value of materials, products and components over time (i.e. residual value)
- Create incentives for suppliers to produce healthy, sustainable and circular materials and building products
- Enable circular product design, material recovery and chain of possession partnerships
- Support material choices in reversible building design projects
- Reduce the eco-footprint
- Make it easier for developers, managers and renovators to choose healthy, sustainable and circular building materials
- Facilitate reversed logistics and reclaim products, materials and components
- Assessment of future material flows
- Management of supply and demand
- Assessment and forecast of potential secondary raw materials
- Systematic recovery and utilisation strategies can be identified and further developed
- Strategic positioning of plants (e.g. recycling, material traders etc) and supply chain management
- Link and make relevant data available for assessments on various hierarchy levels
- Reduce the costs by managing resources rather than managing waste
- Develop a sustainable life cycle management of materials, products and buildings
- Eliminate waste and reduce the use of virgin resources
- Improve the quality, value and security of material supply
- Provide a tool to move from a linear system to a circular one
- Others.

2. MATERIAL DATA FOR A CIRCULAR ECONOMY

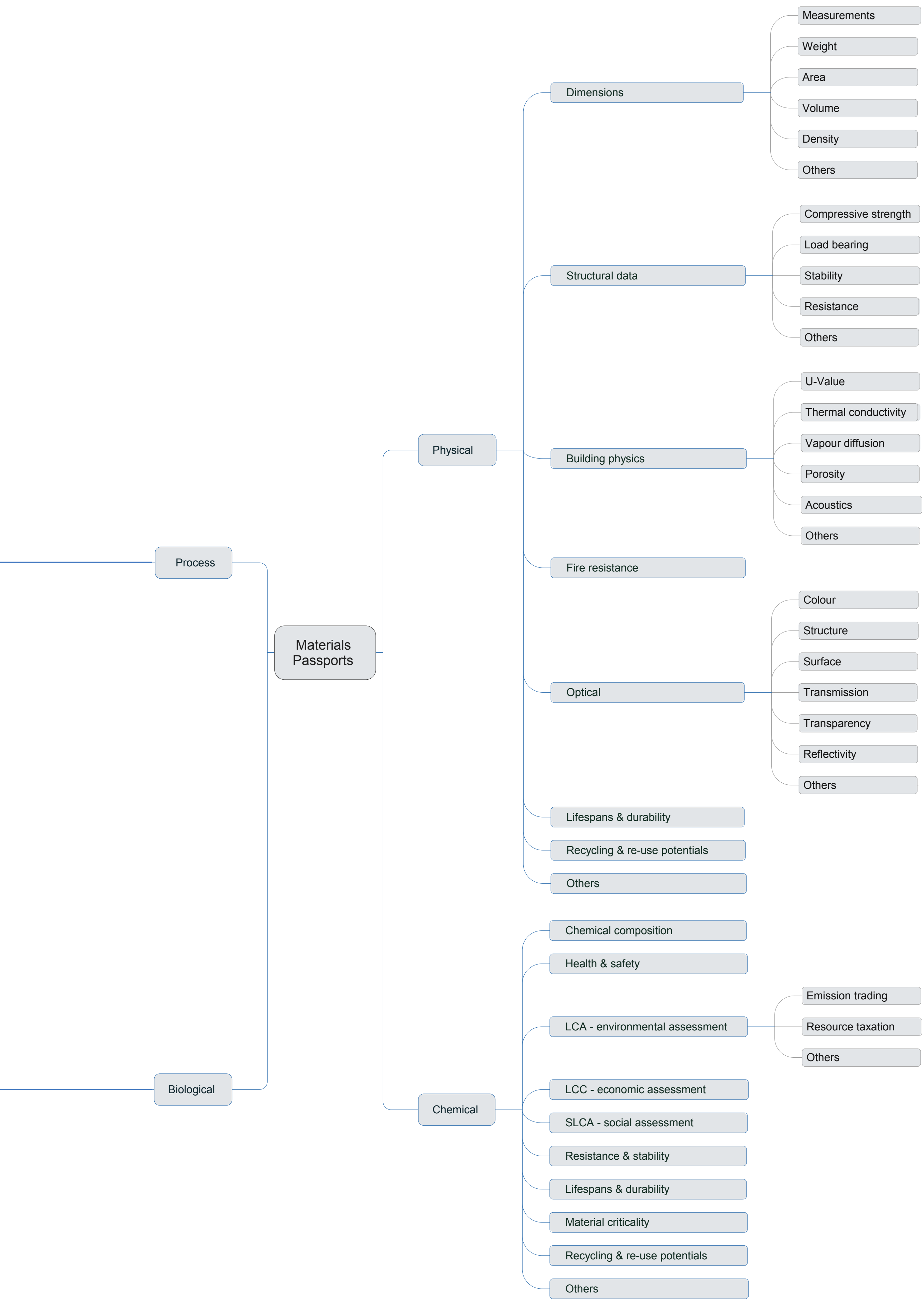
2 MATERIAL DATA FOR A CIRCULAR ECONOMY



Promoting a circular economy in the building sector requires a large amount of information. Some of the information is already available, but not in a centralised place (i.e. stored in different data sources). Other types of information are simply unknown, or are not publicly available, due to the protection of intellectual property rights by manufacturers. Figure 4 shows an overview of information requirements categorised into physical, chemical, biological and process-related properties. It is important to note that there are numerous ways to structure data, but for ease of simplicity this structure has been chosen. Some data might be required for several uses (e.g. assessments), so there is a natural overlap and link between the relevant categories.

In the following chapters the most relevant material and product information types for a circular and sustainable economy are analysed and discussed.

Figure 4: Materials passport overview


Materials Passports
Process
Biological
Physical
Dimensions
Measurements
Weight
Area
Volume
Density
Others
Structural data
Compressive strength
Load bearing
Stability
Resistance
Others
Building physics
U-Value
Thermal conductivity
Vapour diffusion
Porosity
Acoustics
Others
Fire resistance
Optical
Colour
Structure
Surface
Transmission
Transparency
Reflectivity
Others
Lifespans & durability
Recycling & re-use potentials
Others
Chemical
Chemical composition
Health & safety
LCA - environmental assessment
Emission trading
Resource taxation
Others
LCC - economic assessment
SLCA - social assessment
Resistance & stability
Lifespans & durability
Material criticality
Recycling & re-use potentials
Others

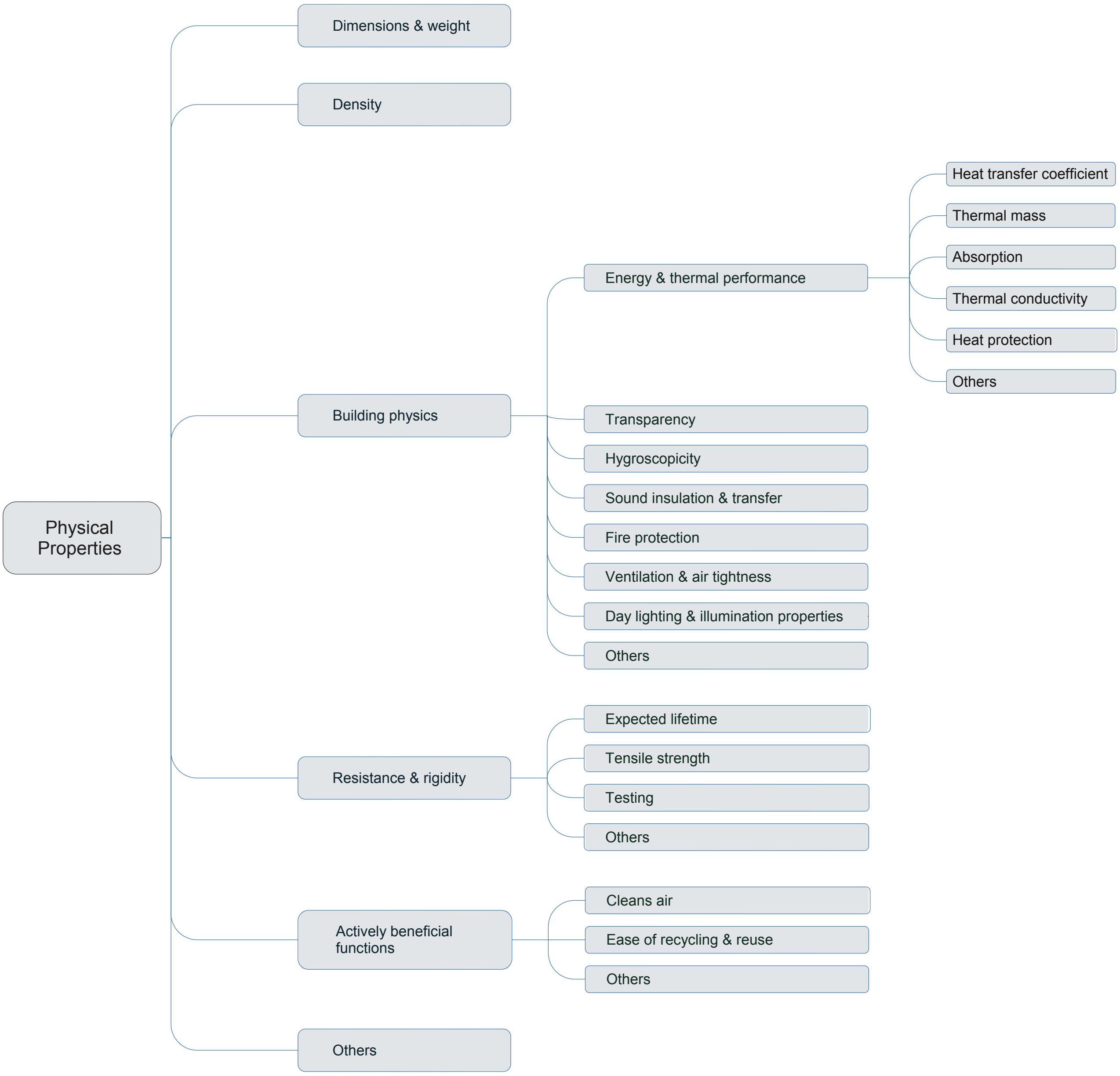


Figure 5: Overview of main physical properties

2.1 Physical Properties

Depending on the type of product or material, different physicals aspects need to be addressed. Not all aspects apply to all types of materials or products. For example, tensile strength is an important type of information for structural elements (e.g. steel beams), but less important for flooring or doors. For flooring, it is necessary to know how easily it can be maintained (i.e. cleaning) or its effect on indoor air quality. Figure 5 shows an overview of data on physical properties.

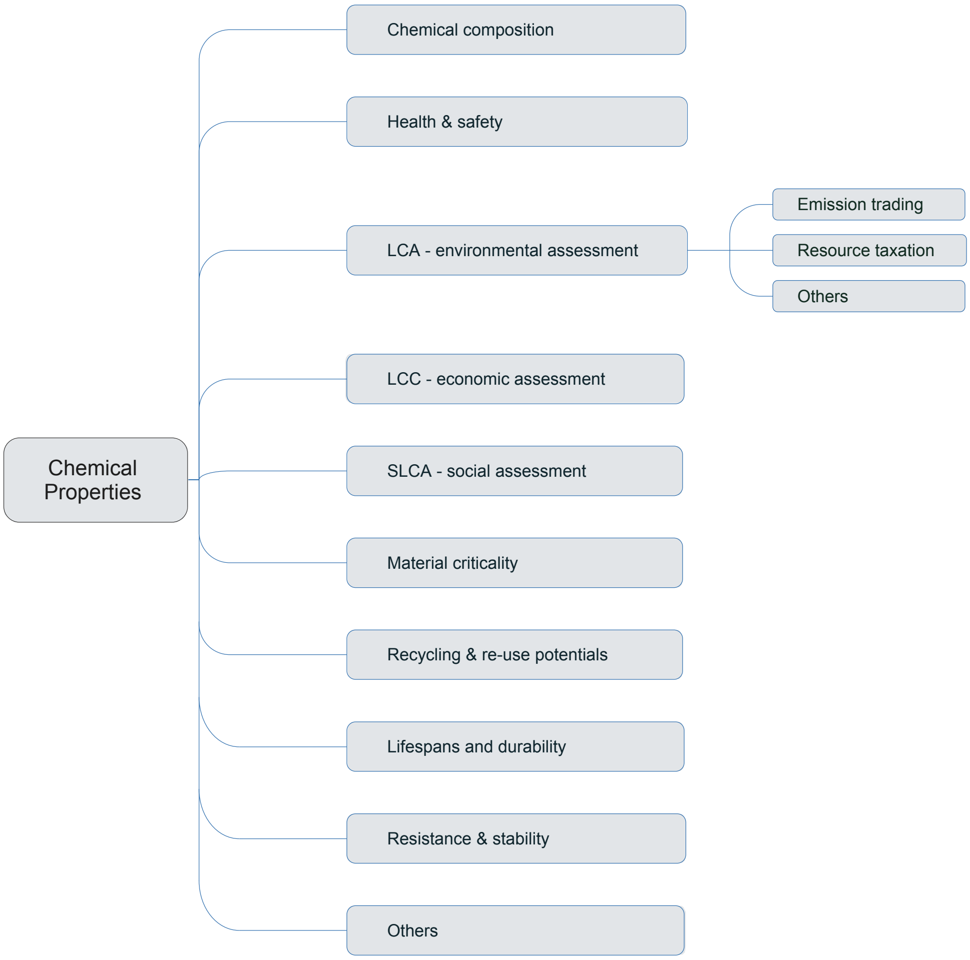


Figure 6: Overview of chemical properties

2.2 Chemical Properties

An important factor for many material-related issues (e.g. environmental and human risks, reusability etc) is a material or product's elemental composition or ingredients. The ingredients define a product and its functions.

As part of a Cradle to Cradle certification process, for example, materials and substances at a concentration of 100 ppm (parts per million) or higher must be reported. In addition, banned chemicals must be reported at any level (McDonough et al. 2012).

2.3 Biological Properties

For the use of renewable materials and products (e.g. timber), information on their biological properties is required. This can include information on potential treatment or biodegradability. These aspects are relevant for future reuse options. Timber, for instance, that is chemically treated might pose a health and environmental risk and may need to be landfilled or thermally incinerated.

Knowing the properties of timber products can increase the potential for cascading systems (i.e. production of jib board from structural timber, production of biofuels) or other second life options within the biological cycle.

2.4 Material Health

People spend around 90% of their time indoors. This figure is based on an extensive two-year study published by the Lawrence Berkley National Laboratory funded by the U.S. Environmental Protection Agency surveying close to 10,000 respondents (Klepeis et al. 2001).

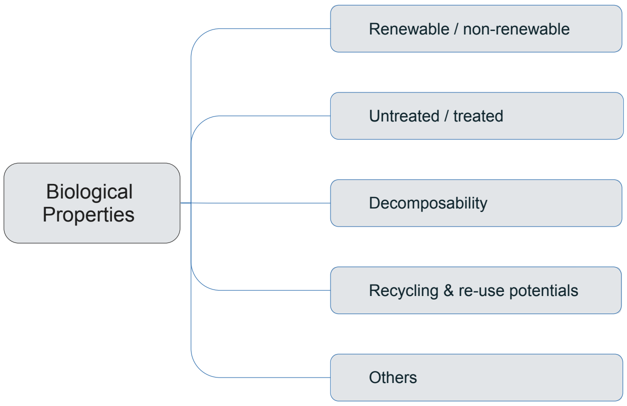


Figure 7: Overview of biological properties

The building resident´s comfort plays a vital role in people's well-being and health. For planners, investors and other key actors in the value chain, people's health and comfort have become an important criterion that can have a substantial influence on the usability and use value of a building and its components.

Personal comfort is influenced by factors such as:

- Thermal comfort (e.g. temperature, humidity)
- Acoustic comfort (e.g. transfer of sounds)
- Visual comfort (e.g. windows)
- Indoor air quality (e.g. influenced by material choices)
- Outdoor air quality
- Others

These factors, especially indoor air quality, can be substantially affected by material choices we make when buildings. Furthermore, numerous studies have shown that people's health can be negatively influenced by choosing the wrong type of materials. An example of this is the long-term exposure to volatile organic compounds (VOCs), which are gaseous emissions from products.

Material surfaces, especially the first 2 cm of a building component's cross-section, have the greatest effect on air quality due to the greater exposure area. Due to an increase in thermally-sealed construction practice, low-emission building materials play an increasing role in air quality.

Typically the largest proportions in a company's operating cost are due to personnel costs (up to 90%), around 9% to rent and mortgage, followed by energy costs (around 1%) (Terrapin Bright Green 2012). Hence, the wellbeing and productivity of the workforce should be a major concern in any organisation's day-to-day business. A wise choice in construction materials, for instance, can have a positive influence by reducing the number of sick days, which improves the productivity of the workforce. Furthermore, it has also been shown that through sustainable choices in building material selection achievable rental revenues can be increased and the deconstruction and recyclability of a building or structure can be optimised.

To make a choice on which materials should be used for a healthy built environment and indoor climate, relevant information on materials and products is required. One vital source of information is the elemental or chemical composition of the material or product (what it is made of e.g. coating) because this largely influences its properties and behaviour over a product's life cycle.

To minimise the risks for humans and the environment, building materials and products should fulfil certain minimal requirements. The aim is to minimise, avoid and substitute the installation of potentially harmful products. In the DGNB sustainable building rating system, for instance, materials that can currently not be assessed using life cycle assessment (LCA) are rated on the basis of four quality levels formulating varying minimal requirements, which are built on one another. The focus within this specific system is based on the following material groups in figure 8.

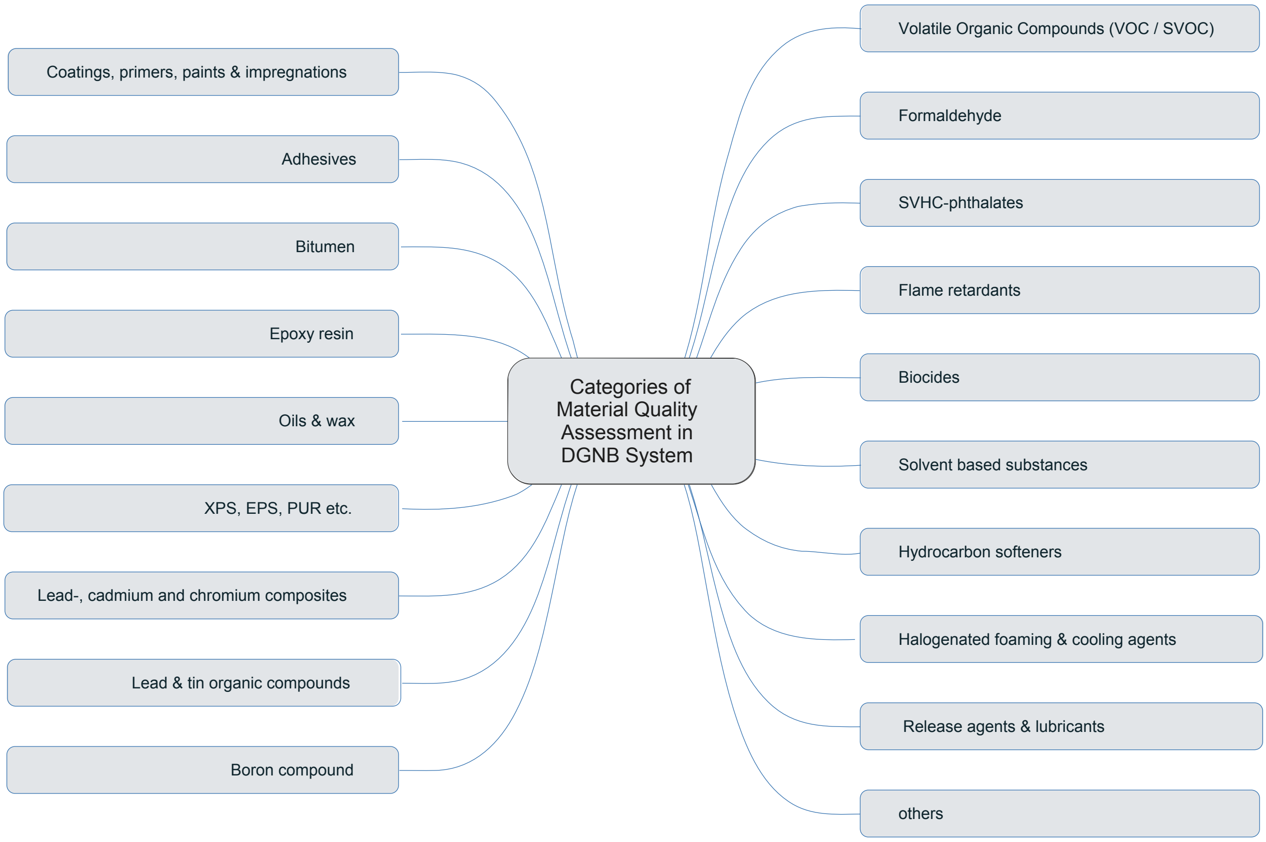


Figure 8: Main categories of material quality assessment within the DGNB rating system

Substances and chemicals that fall into the following categories in terms of their toxic endpoint effects are ranked as particularly hazardous (DGNB):

- Carcinogenic, mutagenic and toxic for reproduction
- Persistent, bioaccumulating and toxic
- Very persistent and very bioaccumulating
- Similarly worrying (e.g. endocrine disruptors)
- Radiation
- Others

Through compliance with a higher quality level, depending on the category, the indoor air quality, conscientious resource extraction (e.g. environmental hazards in the country of origin), and the reuse and recycling potential of buildings and its components can be positively influenced.

The compilation of an ecological material component catalogue, for instance, provides the client and others actors along the value chain (e.g. disassemblers) with important information on quality assurance in the construction process. This can also aid in the clarification of potential building defects, their proper elimination and cost-optimised maintenance. These aspects provide an important contribution to the value stability of a building.

Data Sources Relevant for Health Assessments

- **REACH** (Registration, Evaluation, Authorisati on and Restriction of Chemicals)
  European regulation addressing the production of chemical substances for production or import into the EU (around 143,000)
- **SVHC** (Substances of Very High Concern)
  First step of restriction procedure of substances listed by the European Chemicals Agency (ECHA)
- **CMR** (Carcinogenic Mutagen Reprotoxic)
  Substances that are carcinogenic, mutagenic and toxic for reproduction
- **CLP**-Regulation (Classification, Labelling and Packaging)
  European regulation

- **GHS** (Globally Harmonized System of Classi fication, Labelling and Packaging of Chemi cals)
  Worldwide classification and labelling system for hazardous chemicals and materials – the data is obtained from tests, practical experi ence and literature

- **MSDS** (Material Safety Data Sheet)
  Datasheet providing information on the health and safety aspects of a product

- **Product assessments** and certifications (see chapter 4), which can provide a guideline about making selective choices

- **BOM** (Bill of Materials)
  and direct information from manufacturers and suppliers

- **TRGS** (Technical Rules for Hazardous Sub-stances)
  Is a German system characterising and labe-ling hazardous substances, based on state-of-the-art, health and safety, hygiene and other scientific knowledge

- **Material declarations**
  (e.g. Declaration of Performance or DoP)

- **Material databases**
  (e.g. Building Material Scout, Cradle2Cradle material database etc)

- Others.

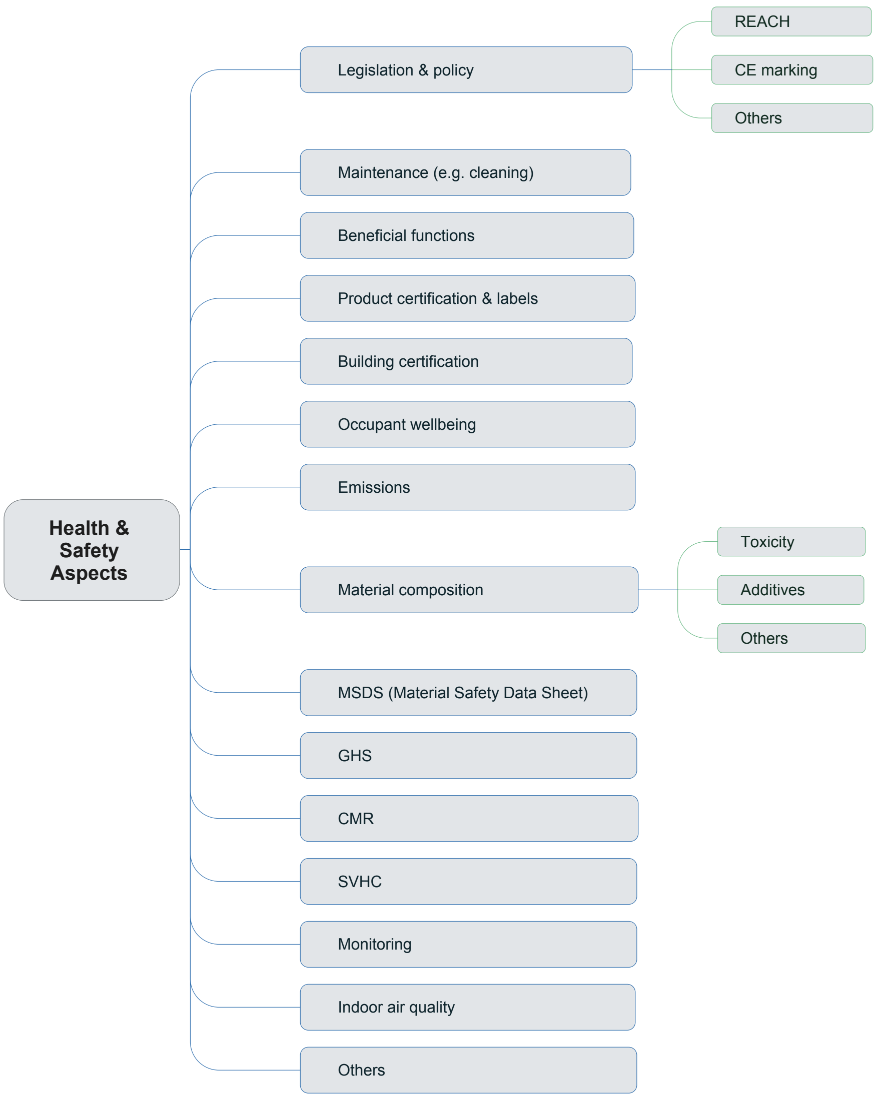


Figure 9: Overview of selected data for health and safety aspects

Summary of Benefits of Healthy and Ecological Building Material Choices

- Optimisation of indoor air quality
- Increase in value stability
- Optimisation of dismantling and recycling po tentials
  (e.g. reduction of the disposal costs by the avoidance of impurities)
- Increased employee satisfaction
  (e.g. lower absenteeism, health promotion)
- Quality assurance in construction
- Optimisation of resource extraction
  (sustainable consumption and climate protection)
- Compliance with increasingly stronger regulatory requirements
- Contribution to the achievement of national and international goals and standards
  (e.g. UN Sustainable Development Goals, Circular Economy Goals)
- Cost-optimised maintenance
- Others.

The aim is to eliminate potentially hazardous substances. Also, if scientific knowledge changes over time (e.g. previously thought unproblematic substances turn out to be hazardous), then they can easily be localised in the building because the location is known and documented in a materials passport that is part of a building passport or model.

One example is the current use or synthetic nanomaterials. Their effect on the environment or human health has not been adequately studied. Another example is the use of flame retardant substances (e.g. HBCD in EPS thermal insulation). While many million square metres have been installed in the past, in October 2016 the EU has posed a trade and use ban on HBCD that has caused a sharp rise in landfill costs. Material health is considered a planning task to keep harmful substances out of buildings. As the complexity of products increases, material health becomes ever more important.

Figure 10: Long lasting facade from renewable material

2.5 Unique Product and System Identifiers

An important aspect of materials passports is tracing materials and products throughout their whole life cycle and beyond. Therefore, the products need to be distinctly identified. This is especially important because a building is made up of a multitude of individual components, which generally have long lifetimes compared to consumer goods. It needs to be guaranteed for example, that when a building is decommissioned and taken apart that the whereabouts of materials and products can still be reconstructed. Also, the material-related information needs to be directly linked to the corresponding physical object within a building for a materials passport system to be functional. The use of unique identifiers is also highly relevant for logistic and transportation requirements (see chapter 2.7 Transportation and Logistics).

Furthermore, the origin of the dataset needs to be clear and reconstructable. Parts of the information requirements are considered as so called metadata, which is information on other data (e.g. creator, year of creation etc). An overview of relevant information that can be collected to identify materials and products and their individual instances is given in figure 11.

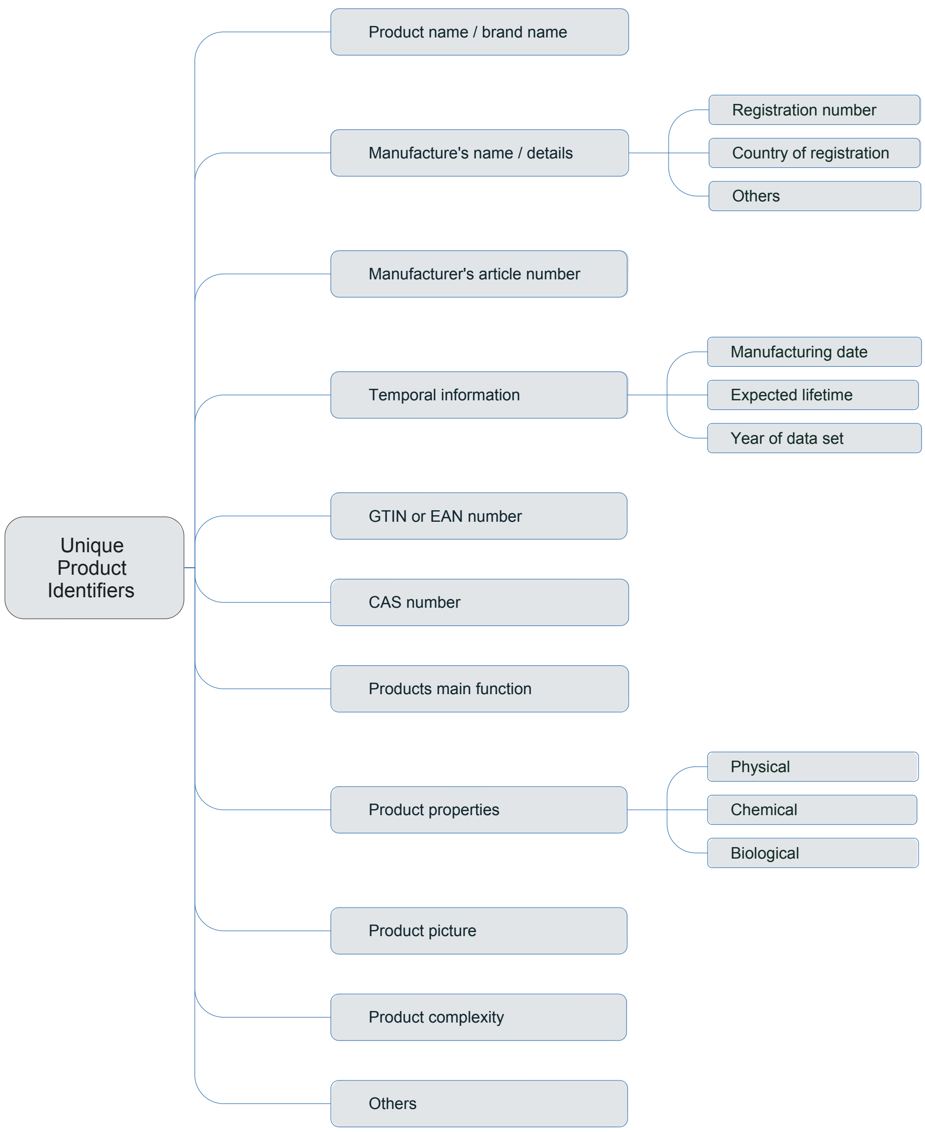


Figure 11: Overview of main product identifiers and metadata

Unique product identifiers that are currently used include:

- **CAS Registry Number** – is a unique numerical identifier assigned by the Chemical Abstract Service (CAS) to every chemical substance in open scientific literature. Currently over 144 million unique organic and inorganic substances are captured.

- **GTIN** (Global Trade Item Number) – is a unique identification number that is currently used for barcodes or RFID-tags. Until 2005 this was known as the EAN (European Article Number), which was used until 2009.

Furthermore, information on the manufacturer (e.g. registration number, country of origin, name etc) is required, which is particularly important when it comes to collecting and linking data from different sources. Also, if there are take-back systems (e.g. recycling) in place (see chapter 2.11 Reuse and Recycling), it is fundamental to know who is responsible for further handling of the product or material.

2.6 Design and Production

The way a product or system is designed and manufactured has a vital influence on its impact and future fate. This can include impacts on the environment or people's health in all life cycle stages and beyond – starting from the procurement of the required raw materials for the manufacturing process until a product's final decommissioning or second life.

In particular, the design phase offers a large opportunity for circularity. Designing a product or building that can be easily taken apart, be recommissioned, remanufactured or refurbished is a central pillar of a functioning circular economy. This includes the concept of design for disassembly, design for recycling or similar concepts.

Another aspect is the use of materials. In the design and production phase choices about material use are made, including responsible sourcing (e.g. resource criticality) or consideration of recycling aspects (e.g. recycled content). Materials passports offer the opportunity to manage the necessary information. Through the extensive amount of information that can be incorporated in a materials passport the design and manufacturing process can profit by new and innovative circular solutions (e.g. take-back systems) that have previously been left unconsidered. An overview of information in the production stage is shown in figure 12.

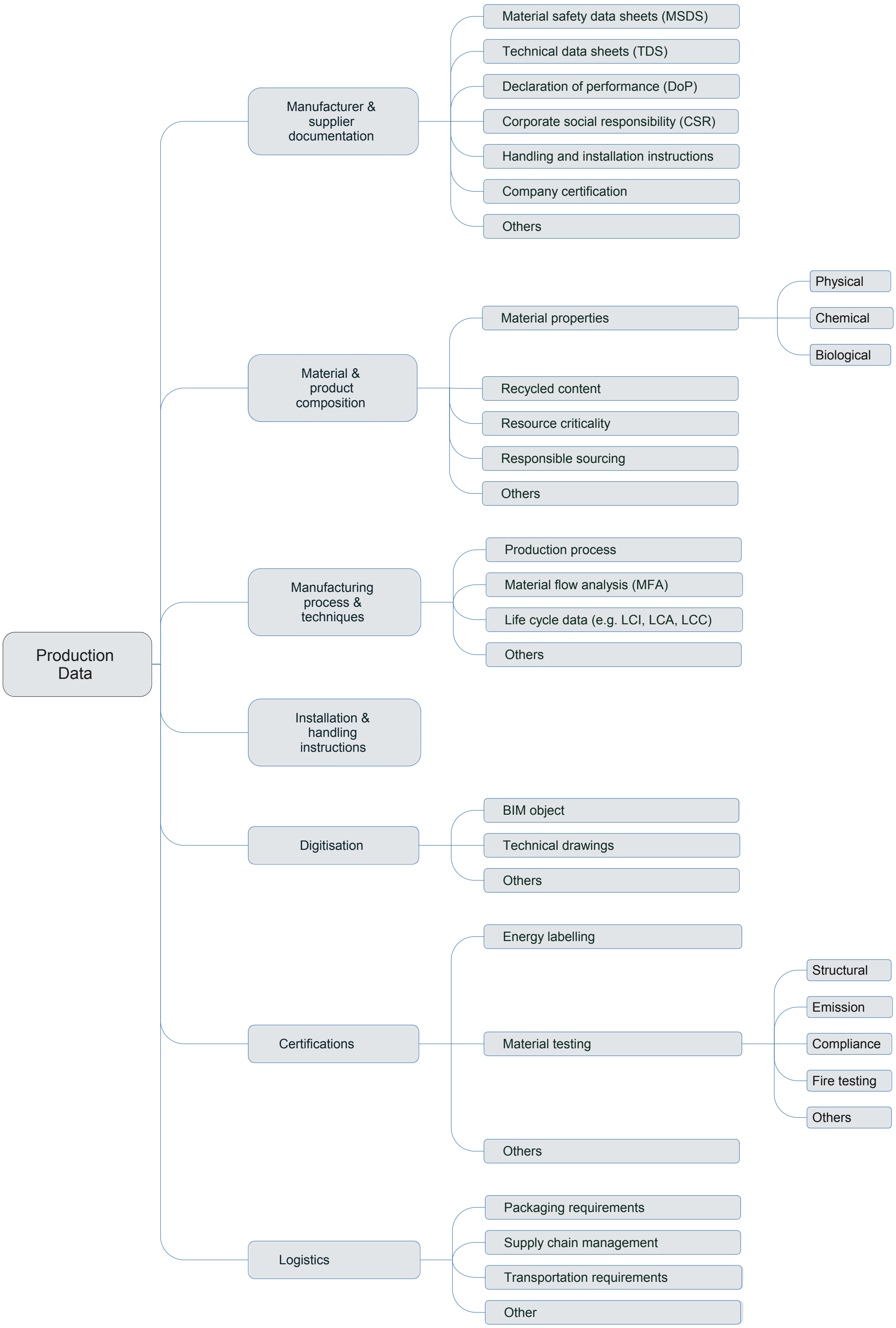


Figure 12: Overview of production data

2.7 Transportation and Logistics

Transportation and logistics are involved in every life cycle stage, which begins by sourcing raw materials and typically ends with the End-of-Life (EOL) phase of a product or building. In an ideal circular economy the aim is to have no EOL because the vision is to keep materials and products in circulation for as long as possible.

However, every production or handling operation (e.g. recycling) is associated with system losses (e.g. construction wastes, dissipative losses), which also requires transportation processes to a product's or material's final sink (e.g. landfill).

Products and materials need to be traceable (i.e. unique identifiers), and information about their properties is required for providing a supply chain that is customised to a circular economy. The relevant data that can be supplied for materials passports is shown in figure 13.

2.8 Construction – Identifying Material and Product Locations Within Buildings

In a building's construction stage, material and product decisions have already been made. Within the construction process, it is necessary to document material and product locations and the way they are connected to each other, which is preferably done in a digital manner (i.e. BIM). Also if alterations have been made (i.e. use of alternative products), these need to be documented (see chapter 6 on Information Exchange).

Through standardised documentation procedures (i.e. materials passports) and digital technology the time taken for this task can be optimised. As this type of documentation is unusual in general business practice, new roles or actors need to be introduced (e.g. a digital architect). Furthermore, funds need to be made available in the budget to cover the documentation procedures.

The additional labour costs for documentation need to be accounted for. In the long run, however, the circularity potential of the asset will be increased, which leads to further financial benefits when it comes to maintenance, decommissioning and deconstruction. Only through the provision of data on material and product composition and location within the building will circularity potential be achieved and buildings become true material banks.

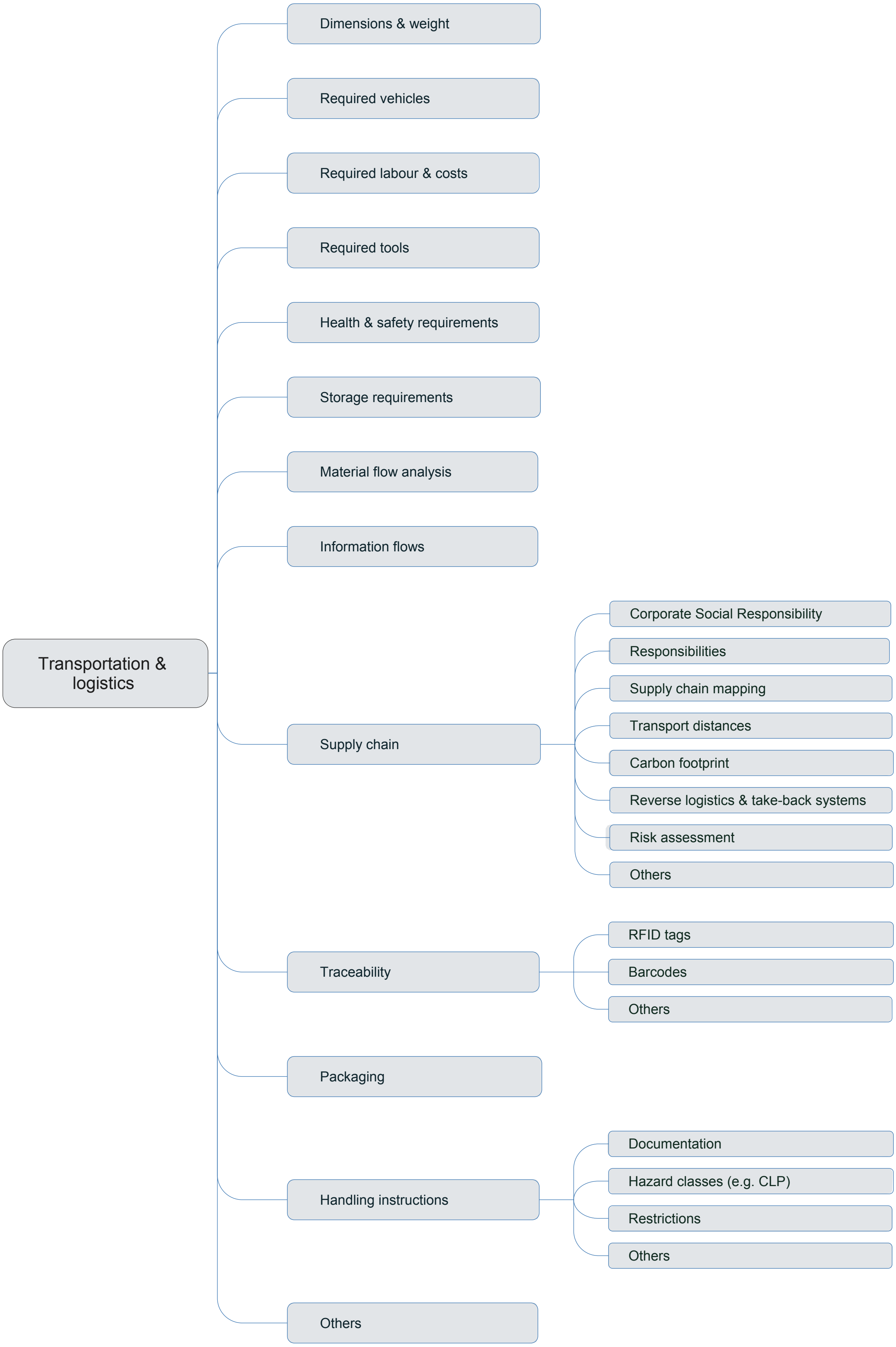


Figure 13: Overview of information needs for transportation and logistics

2.9 Use and Operate Phase

During a building's usage, information needs to be updated (see chapter 6 on Information Exchange) when changes are made to a building and its parts. During the use phase information on materials and components can aid the facility management (e.g. maintenance) or alteration process (e.g. transformation). An Overview of information requirements is shown in figure 14.

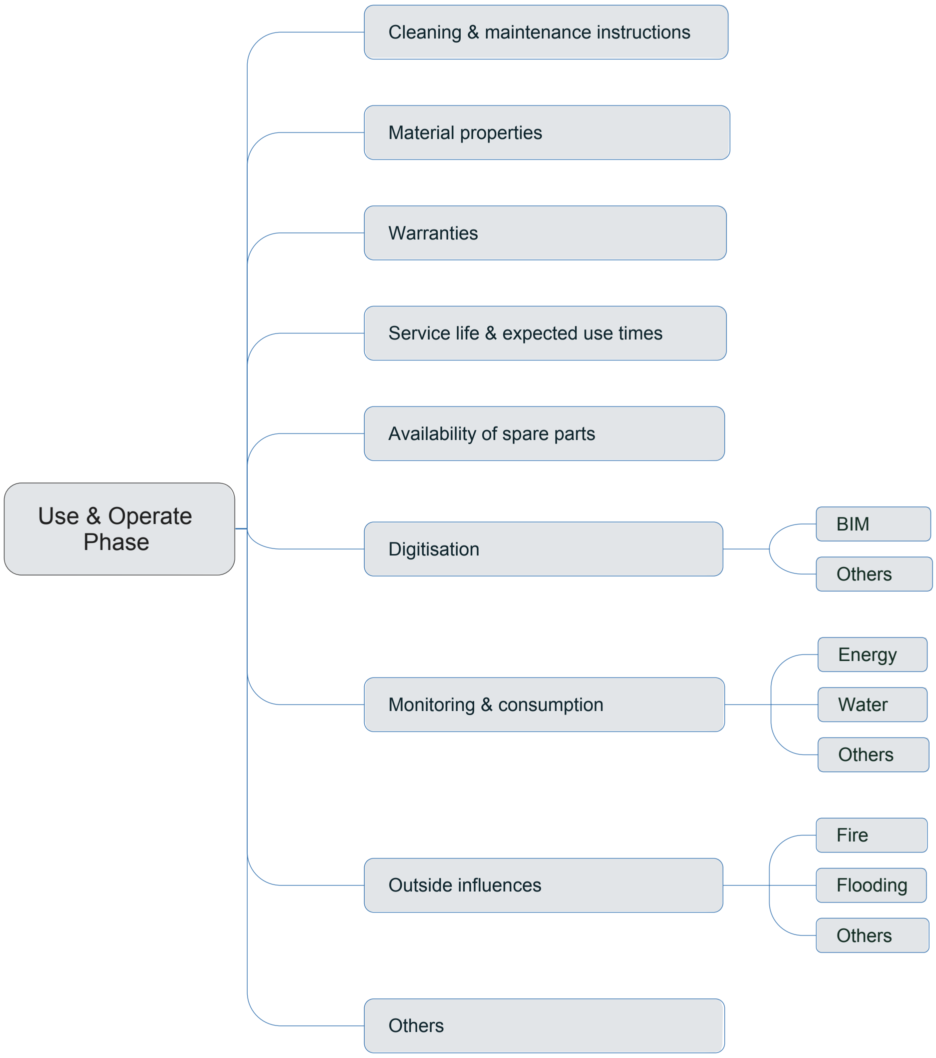


Figure 14: Overview of information needs for use and operation

2.10 Disassembly and Reversibility

Reversible building design (or circular design) is a design and construction strategy to provide products (or buildings) that can easily be deconstructed, or where parts can be removed and added easily without damaging the product (or building), with components or materials (Durmisevic et al. 2018).

This strategy enables products or buildings to be easily adapted, transformed and disassembled, which helps to maintain a product's value to encourage reuse, reduces risks for second life options and enables the closing of material loops.

Building owners, for example, profit through decreased costs for modernisation and transformation and the fact that buildings can be treated as material banks.

In BAMB, tools are developed to increase the reuse and transformation potential of buildings and products. Material-related data is a vital component in the assessment and implementation of these strategies.

When it comes to the point that buildings are no longer fulfilling their purpose, and transformations to other use types are not feasible or possible, they tend to be demolished (i.e. complete destruction). In current practice, classic demolition is still the predominant method of taking down old buildings. This often leads to the complete destruction of a building and its components and leaves different piles of material fractions that might be contaminated, which makes it very difficult or impossible to reuse the materials. Components and systems that would be still fit for future use are rarely reused.

The goals for disassembly, material sorting and recovery are:

- Conservation of natural resources (e.g. material, energy)

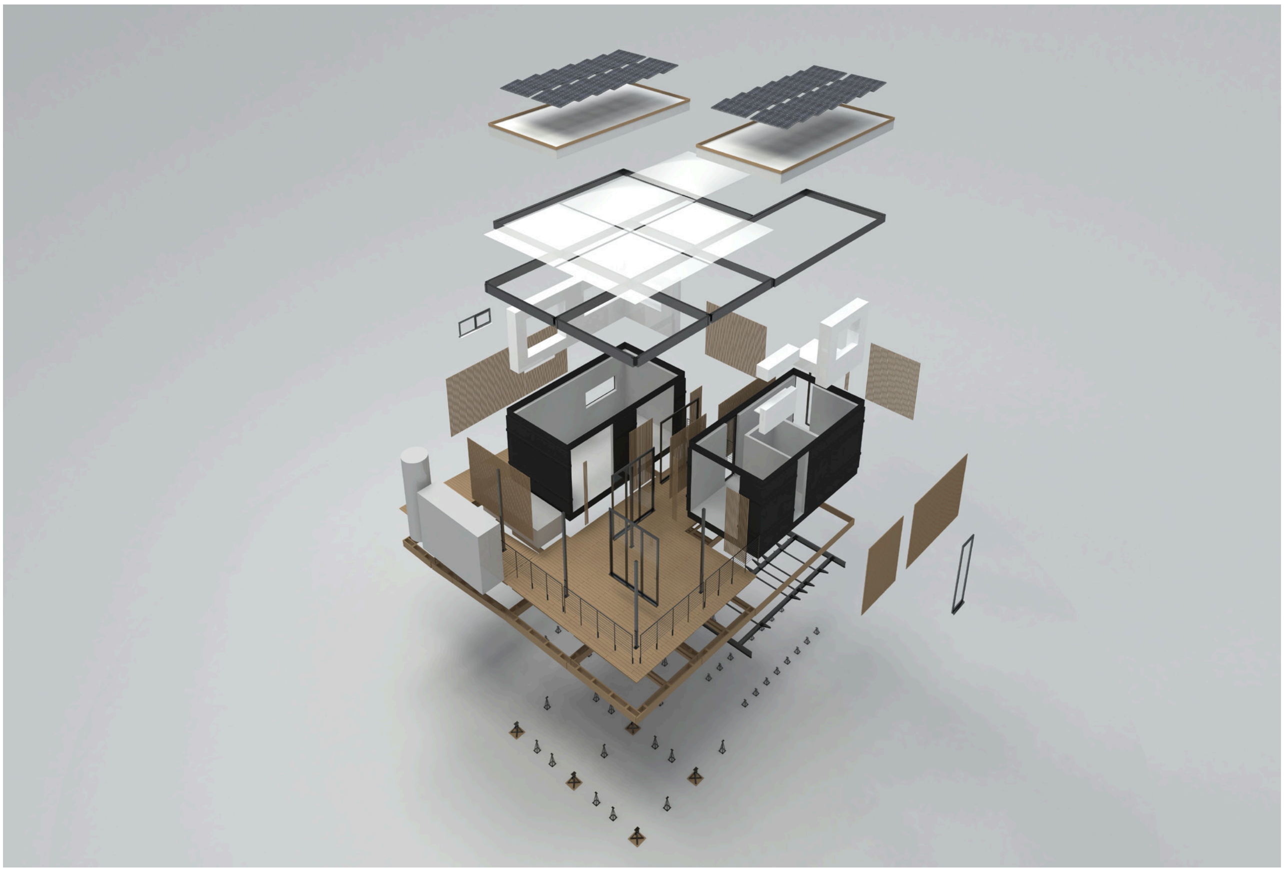


Figure 15: Disassembly strategies of building components – NexusHaus (TUM/ UTSoA)

- Avoidance of waste
  (e.g. saving landfill space)

- Use of recyclable and reusable materials, products and components

- Use of structures and products that can be easily disassembled and reused
  (e.g. design for disassembly)

- Others.

In comparison, disassembly is a more selective method of deconstruction in order to minimise the damage to components or materials that are worthwhile being reclaimed (and hence reused) in another building. Controlled disassembly requires more time and funds than traditional demolition. However, due to the reclamation of materials and components (i.e. higher value) a financial benefit can arise through the sale of materials and components and a reduction in landfill costs. This is often important, because not only the prices for materials are rising, but also the cost for landfilling due to a limited number of landfill sites.

A materials passport can provide information to promote disassembly and therefore increase the reuse potential for materials, products and systems. This, however, also relies on the actuality of the materials passport dataset over relatively long lifespans, which are common to building products.

To estimate the cost and effort of demolition, a pre-demolition audit is necessary to get an overview of what kind of materials are present. To identify the necessary information on materials in a building is a major task, depending on the size of the building. An up-to-date building model (e.g. BIM), with information provided by materials passports, can reduce the time necessary to perform this task because a building's composition and relevant information on deconstruction and reuse options for materials and products is already known. Currently, information for pre-demolition audits is generally unknown and needs to be collected from scratch.

Figure 16: Use of components that can be easily disassembled and reused (TUM/ UTSoA)

2.11 Reuse and Recycling

In current building practice (business as usual) the second life of materials is mainly focused on recycling at a material level. This includes the production of aggregates for road construction or backfilling, for example, which can be categorised as a form of downcycling. As the term implies, downcycling reduces the value and quality of a material in contrast to upcycling procedures. Downcycling is against the principles of a circular economy.

To a certain extent and under consideration of the relevant standards and technical specifications, mineral aggregate from demolition can be used to produce, for instance, recycled concrete, which is a higher-level form of recycling. However, the use of recycled concrete today is still regarded as a niche product and the uptake is very low compared to the production of concrete from primary sources. Hence, incentives and an increased acceptance of recycled materials are required.

In contrast to material level recycling, the reuse of building components still has a high potential that is currently largely unused. There are many reasons for this (e.g. quality of components, information gaps, financial risks, scepticism about reuse, quality assurance, warranties, liabilities etc). The main obstacles to increase and improve the reuse of materials and components are (Durmisevic et al. 2018):

1. There is little or no information on the current composition of buildings. Often the composition is only known at the point when a building is dismantled or demolished.

2. There is little information for the relevant actors on the reuse and transformation potential of components and buildings.

3. There is little or no connection between the supply and demand for components. Hence, it is necessary to know a component's exact location (in a building and geographically), as well as the time it is likely to be available for the market.

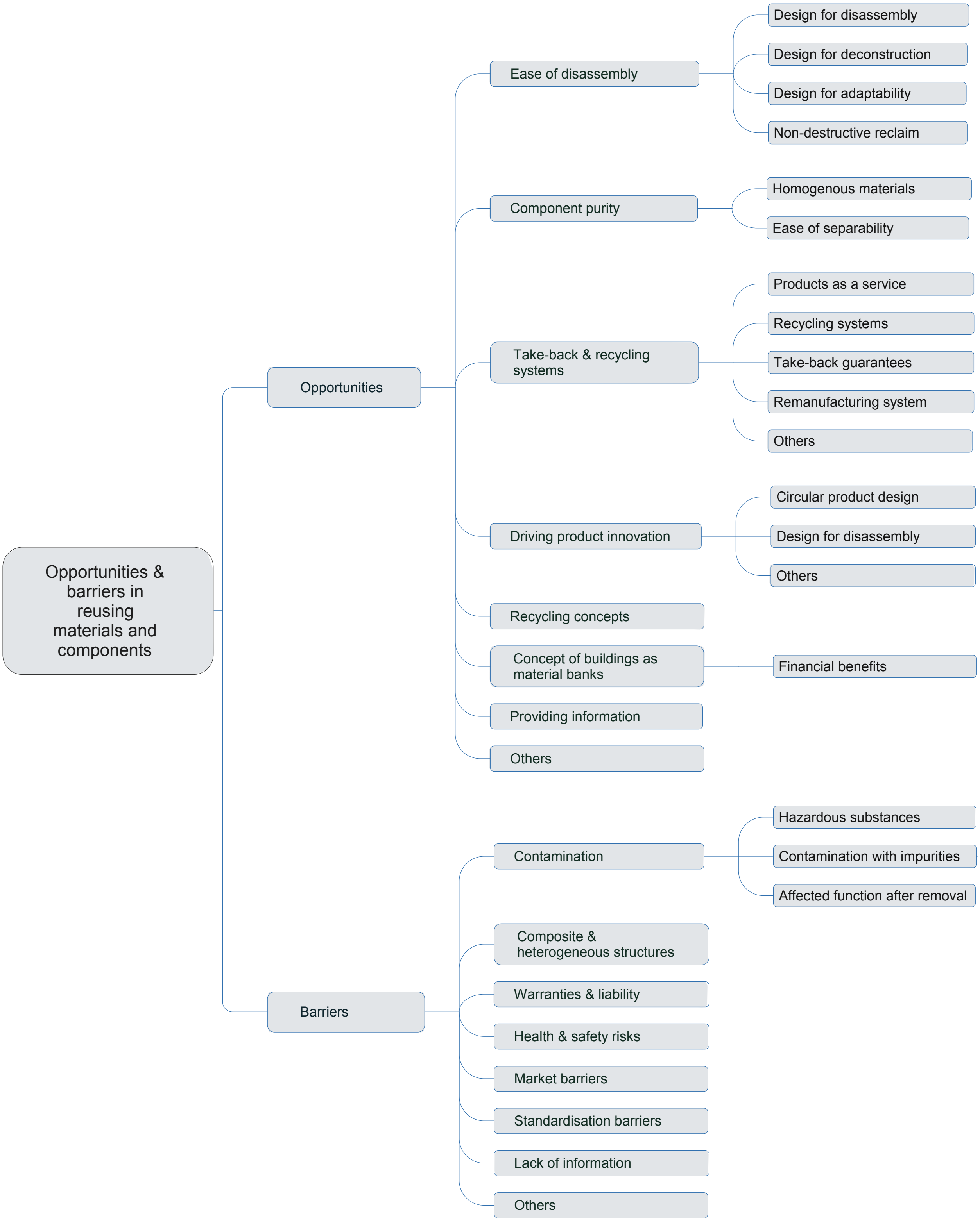


Figure 17: Opportunities and barriers in reusing materials and components

These aspects need to be addressed in a materials passport promoting circular buildings:
Data requirements to promote disassembly and reuse, which also need to be considered in the design and production stages, are:

- Disassembly process (i.e. extraction) methods, specialised knowledge and costs
- Required tools, transportation modes, storage requirements and labour (i.e. disassembly – and handling – instructions)
- Material and product composition (i.e. potentially harmful substances, health risks etc)
- Physical properties
    - Dimensions and weight (e.g. cross-sections)
    - Applied coatings
    - Service live and expected use periods
    - Grade
    - Weldability (e.g. for steel)
    - Source mill (where does the material come from?)
    - Production date
    - Usage history
        - Loading history
        - Building purposes
        - Exposure to fire
        - Others
- Location and quantity of product in the building
- Traceability (i.e. RFID-tags etc)
- Product warranties
- Availability of spare parts
- Generated by-products
- Product ownership and responsibilities (i.e. product leasing, take-back guarantees, recycling system with logistics etc)
- Reuse potential and recyclability
- Connection types of products and systems itself and connection to a building
- Second life options (e.g. refurbishment etc)
- Certification for reused products
- Residual values
- Products exposure history (e.g. through monitoring)
- Geometry/dimensions
- Affected function after removal
- Others.

Materials passports can reduce the potential risks and obstacles by providing the relevant information for actors in the value chain at the right time (figure 17). This includes the knowledge of a product's composition (i.e. its ingredients that include potential hazards), its current condition and history (i.e. through maintenance and exposure history), its location in the building, current ownership, ease of disassembly, transportation requirements and others.

Through materials passports the relevant components can be rated prior to a building's demolition as the relevant properties and history are documented. This allows time for the planning of a selected disassembly process and finding a market for the reclaimed components at an early stage. This strategic reclamation can further reduce the risks for companies involved in the second-hand product trade (e.g. urban miners, material traders, etc).


glich
öffnet
Lagenwei

3. LIFE CYCLE MANAGEMENT

3 LIFE CYCLE MANAGEMENT

3.1 Material Flow Analysis

Material Flow Analysis (MFA) also referred to as substance flow analysis, is a tool to quantify the flows and stocks of materials (including substances, goods, products etc) in complex systems over space and time. It connects the sources, the pathways, and the intermediate and final sinks of a material (Brunner and Rechberger 2004). MFA can provide useful information about the pattern or resource use, production steps, material losses, and waste creation, amongst many other applications. MFA can therefore be used to collect data for the inventory analysis as part of an LCA.

MFA can be compared to an accounting system that balances inputs and outputs of processes and puts processes into relationship to one another (figure 18). With MFA it is possible to track materials and substances and measure their accumulation in individual processes (e.g. production steps). Further uses include:

- Balancing industrial input and output to natural ecosystem capacity
- Dematerialising industrial output (i.e. reducing material use)
- Creating loop-closing industrial practices controlling pathways for material use and industrial processes
- Resource management
- Process chain analysis
- Balancing flows between the anthroposphere and the environment
- Modelling elemental composition of products and wastes
- Others

Tracking assets over time is an important issue within a circular economy. This is closely linked to the supply chain logistics, transportation processes and other aspects. MFA can help with the tracking and documentation process.

It is not only relevant to have material flow information on a product or material level (e.g. production process), but also on a building, local, regional level or beyond (i.e. international).

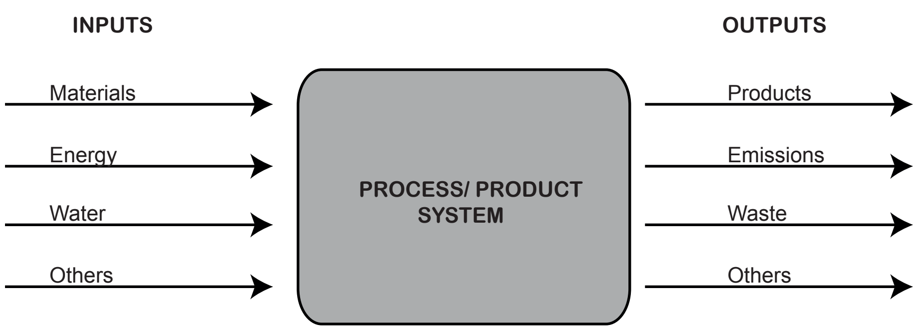


Figure 18: Material Flow Analysis (MFA)

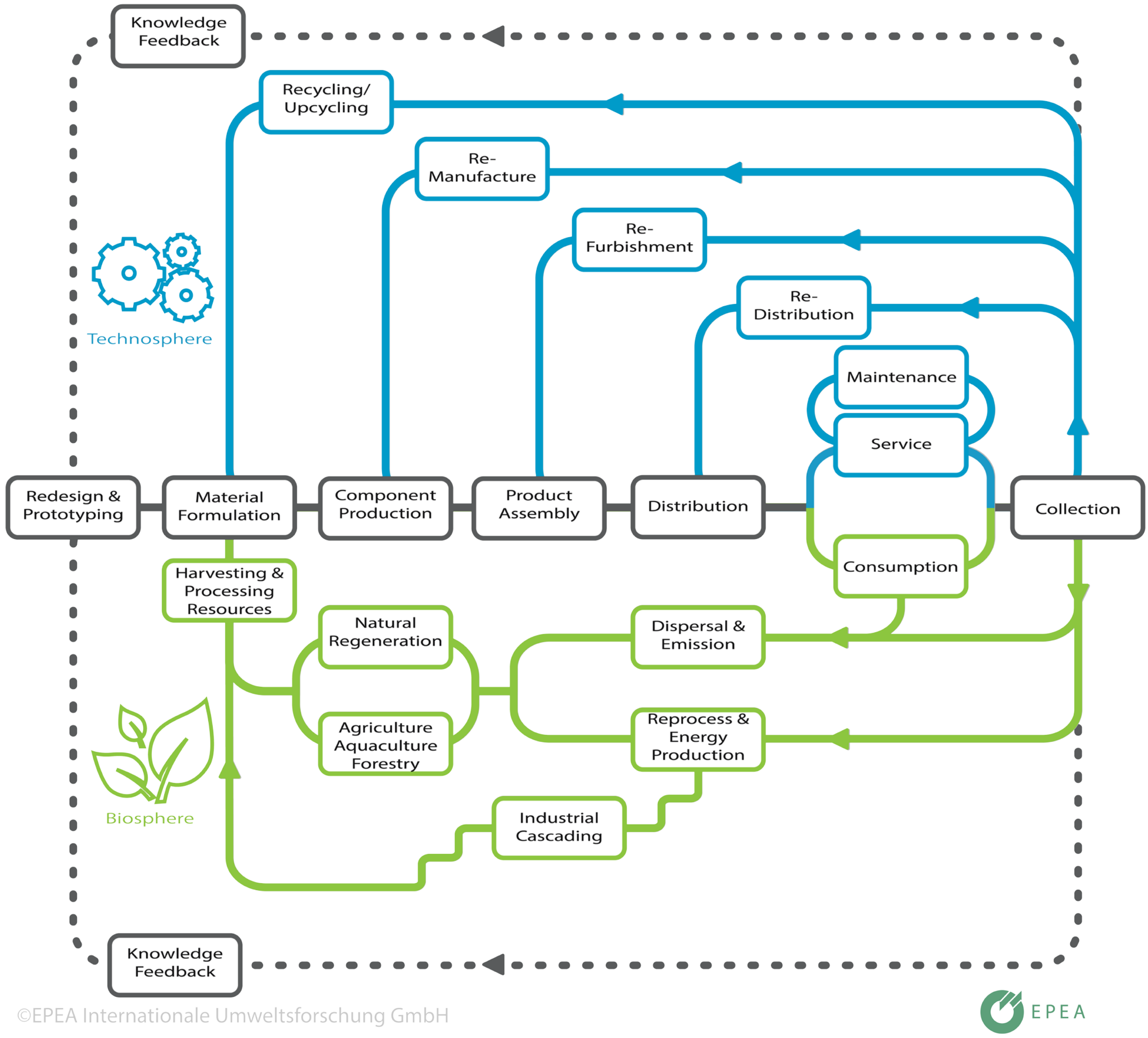


Figure 19: Material flows in the technosphere and biosphere (EPEA)

It is important, for instance, to know where a product is currently located within a building and what condition (e.g. how it is connected to a building, current quality etc) it is likely to be in.

These issues, amongst others, directly influence the future use- options. Potential flow scenarios are shown in the example in figure 19. Within materials passports an automated flow diagram could be appointed, which changes according to the information provided. For example, a service product (i.e. take-back-system, leasing etc) will have a different use than a material or product that contains harmful substances and cannot be fully recycled. Depending on the future reuse option, different types of information are required.

3.2 Service Life and Lifespans

Materials, products and systems used in buildings have long lifespans compared to standard consumer goods. In construction this is often referred to as Reference Service Life (RSL).

Reliable data on the service life of building products is fundamental for conducting further assessments, such as LCA or LCC. Furthermore, the data can aid in the planning of maintenance, refurbishment or disassembly tasks. The RSL can be an indication of when a material product or system can be taken out of a building and be recommissioned.

The service life for a specific product can have a broad range in values because it is largely dependent on the way it is installed and maintained, as well as its exposure (e.g. rain, sun) and other factors. An overview of factors affecting the RSL is given in figure 20.

Data sources for estimating RSL:

- Information from manufacturers
- Facility management handbooks
- Guideline for Sustainable Building (Federal Ministry of the Interior, Building and Community – Germany)
- Standard ISO 15686 – Buildings and constructed assets – Service life planning
- Others

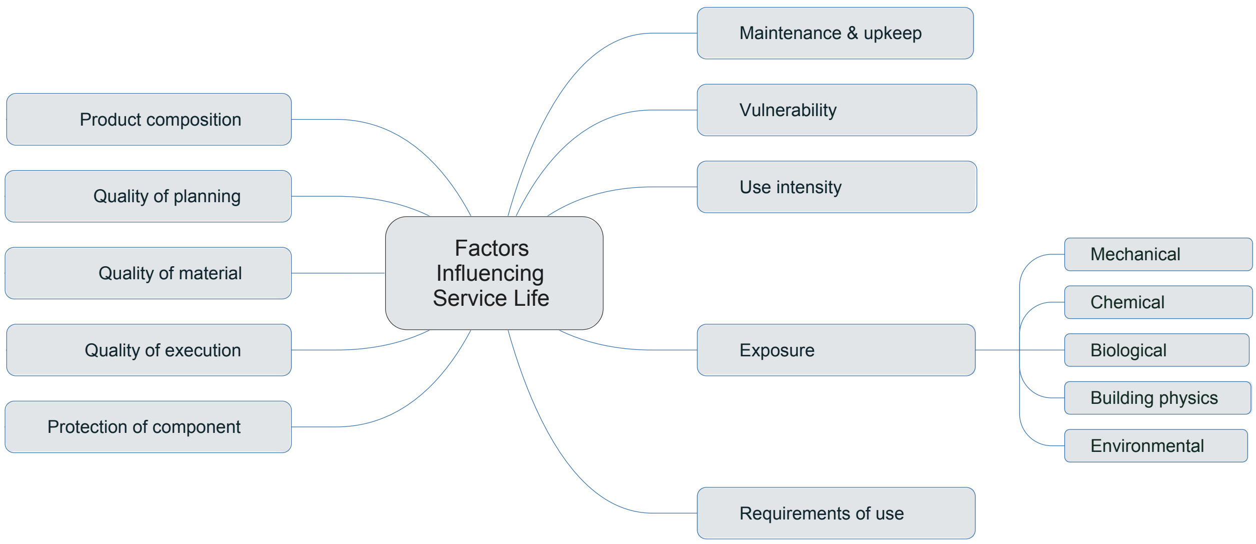


Figure 20: Selected factors influencing the Reference Service Life (RSL) of materials and products (Heinrich 2019b).

3.3 Life Cycle Assessment – Environmental Analysis

Life Cycle Assessment (LCA) is an analytical methodology to analyse and quantify environmental aspects and impacts of product systems (e.g. materials, products, processes, buildings) over their life cycle (figure 21). Application includes product development and product improvement, amongst other uses. A substantial amount of product and process-specific data has already been compiled in a standardised way (e.g. in EPDs, LCA databases). The relevant information can be linked to the corresponding materials passports to avoid multiple data collection.

The standards ISO EN 14040 and 14044 provide a common framework for the application of an LCA and figure 22 shows an overview of the steps involved. After defining the goal and scope (e.g. system boundaries, functional unit) of an LCA study, the inventory analysis is a major step. At this stage knowledge of the system along different types of data is required. The aim is to identify all the relevant processes (e.g. production steps, transportation, recycling, reuse etc). Depending on the scope and the system boundaries, this can involve large and complex systems. One of the methodologies that can be used to capture the individual processes and the relationship between them is MFA, which is a procedure to identify and quantify the inputs and outputs of a process or system (see chapter 3.1 Material Flow Analysis).

In the next step the developed inventory and dataset is linked to potential environmental impacts (impact assessment) that can be obtained

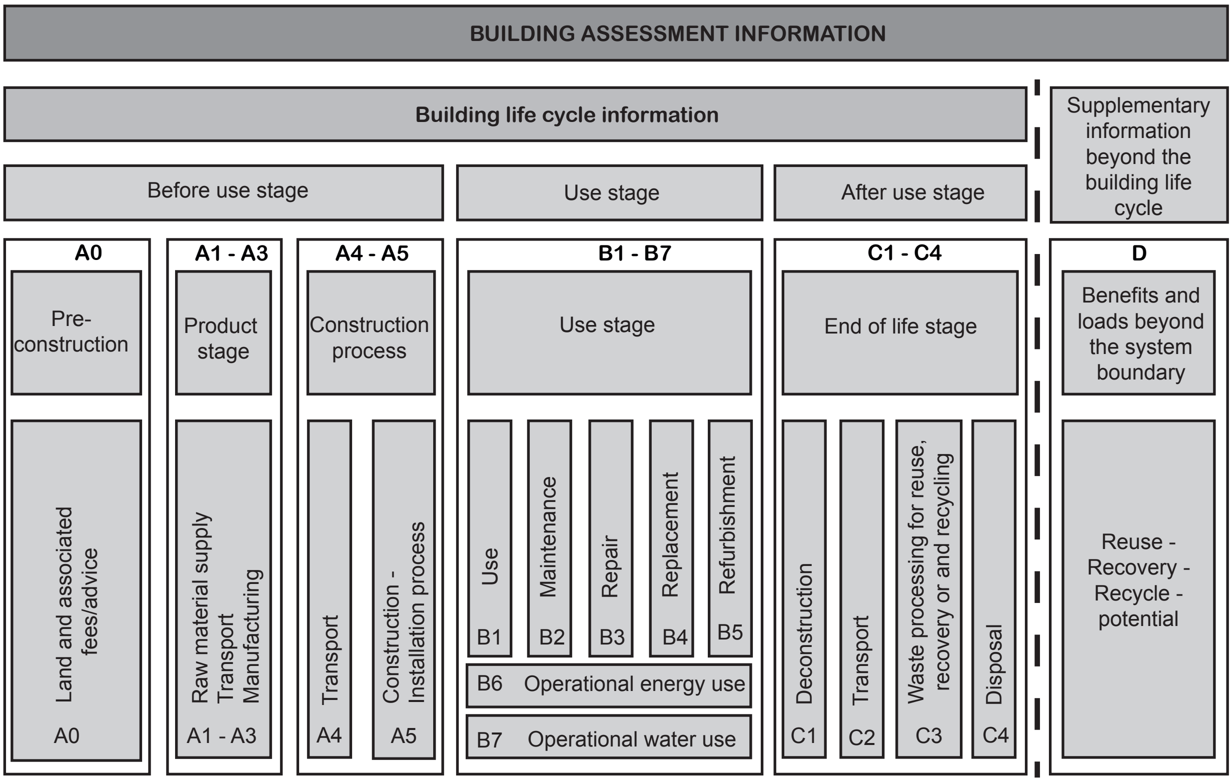


Figure 21: Classic life cycle phases of buildings and building products (DIN EN 15643)

from various datasets (figure 23), such as Environmental Product Declarations (EPDs). Often the assessment of certain indicators is dependent on the scope of the study or the availability of robust data and calculation methods.

In the interpretation process conclusions are drawn based on the results and the goal and scope of the study. As LCA is an iterative process, it is possible to move back to previous steps to redefine a system or other factors.

Within the impact assessment various indicators can be addressed (figure 24), but not all potential impacts can be assessed using an LCA. There have been numerous attempts to include

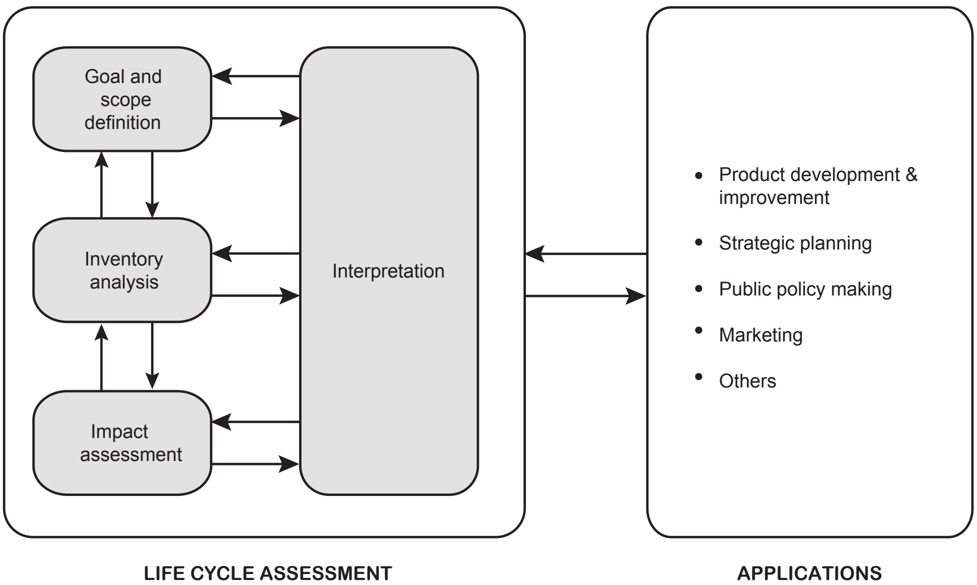


Figure 22: Stages of conducting a Life Cycle Assessment (LCA) (ISO DIN EN 14040)

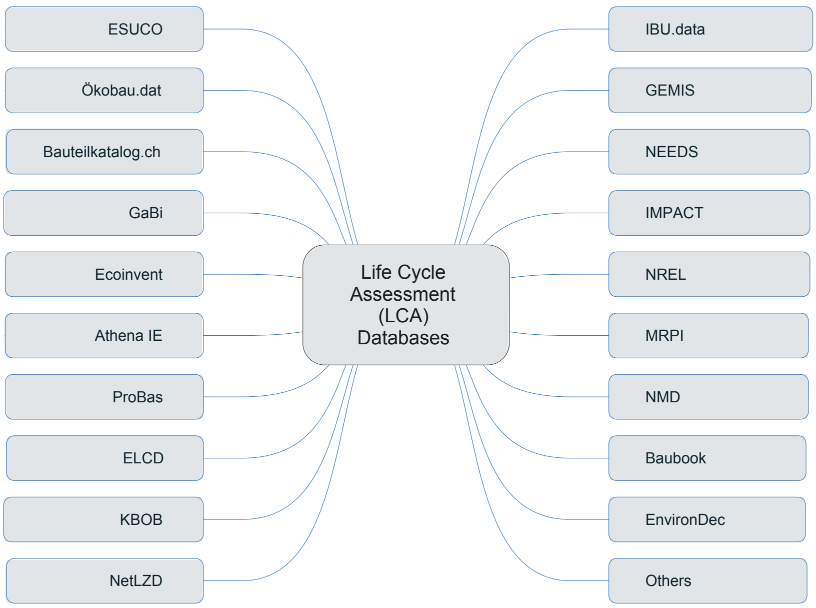


Figure 23: Overview of available LCA databases

health effects in the calculations. However, due to the lack of broad consensus and harmonisation in the LCA community, there is no clear guidance on how to achieve this in practice. Hence, many LCA practitioners exclude toxicity-related impacts. Based on 2015 figures, only 3% of all chemicals are covered to characterise the impact on human toxicity and 15% for eco-toxicological impacts. Currently, there is an ongoing debate within the standardisation committees on this matter (CEN/TC 350).

LCA data, such as EPDs, offer a standardised set of information that can be linked to materials passports.

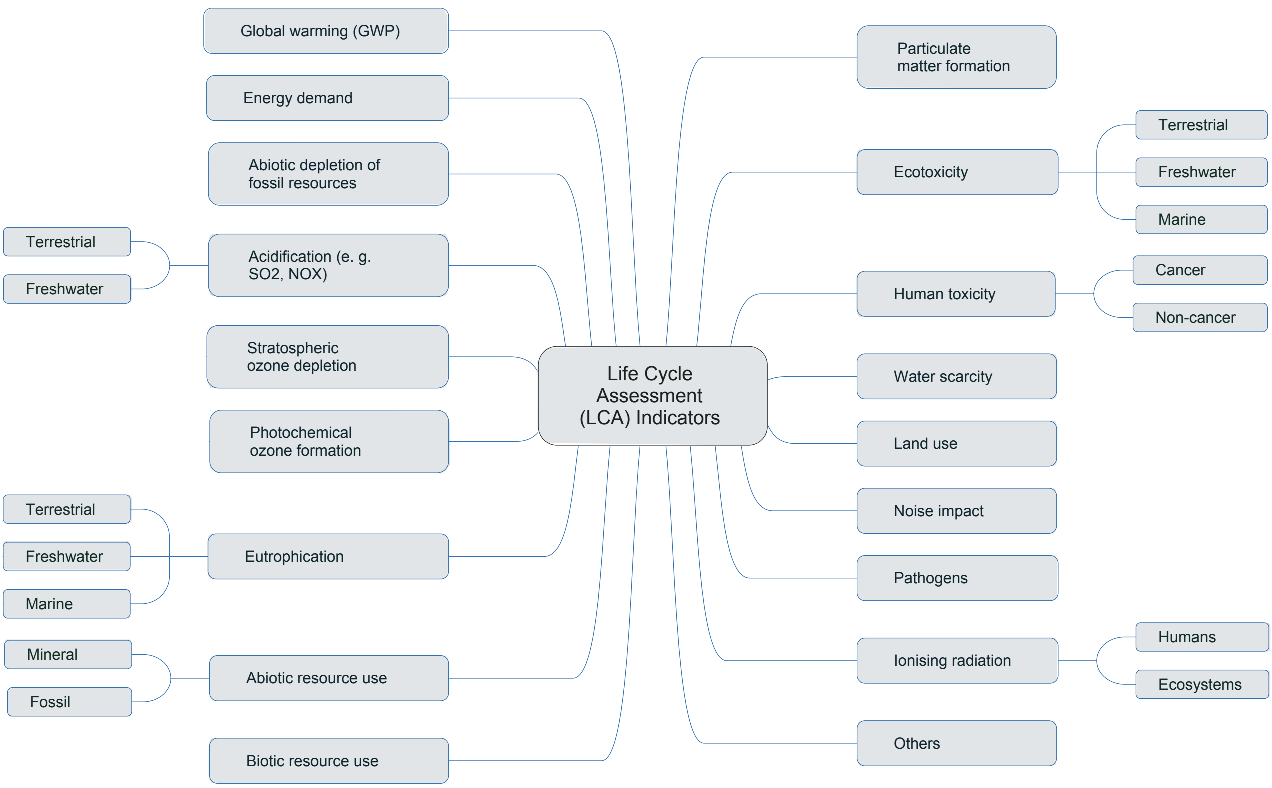


Figure 24: Overview of indicators in an LCA

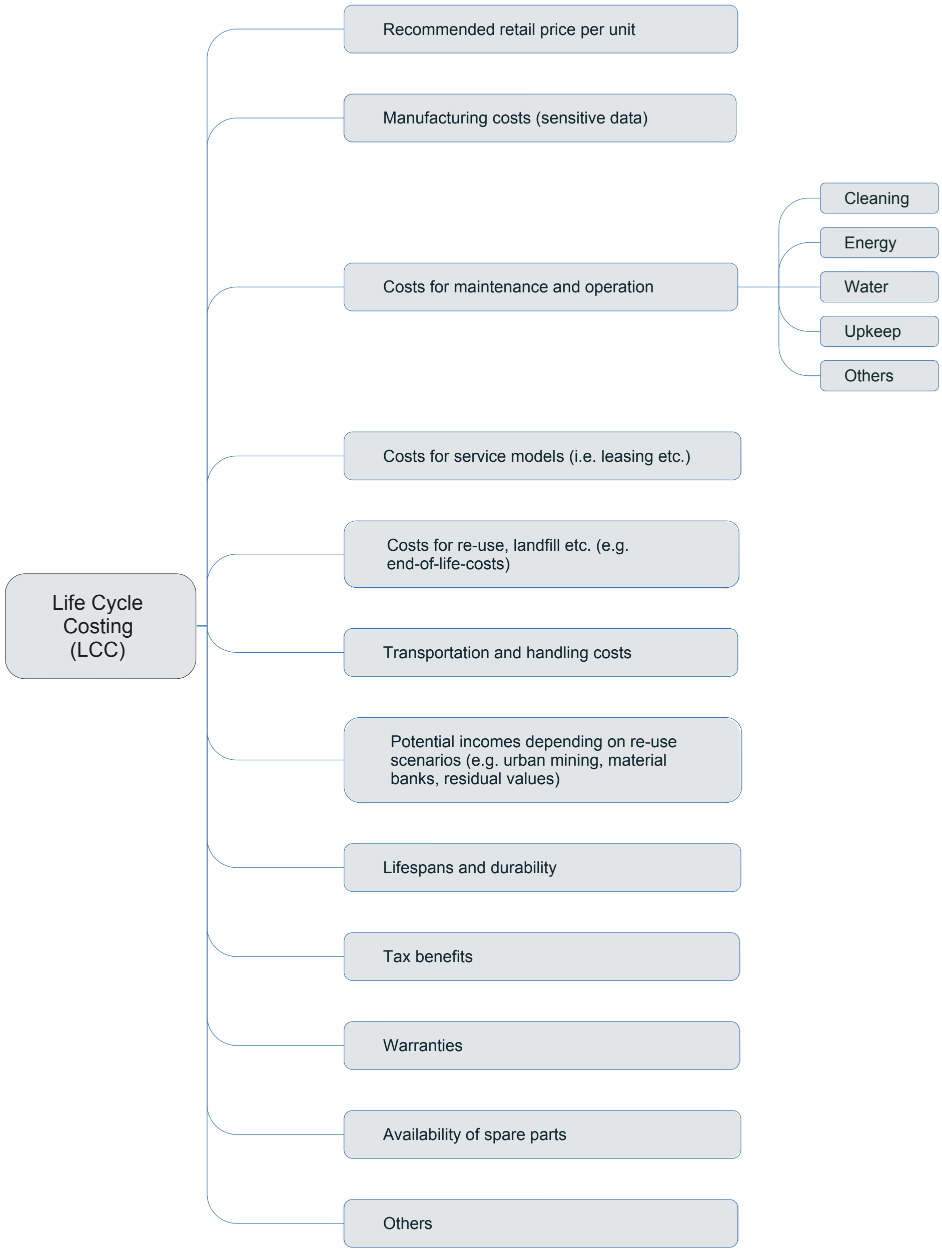


Figure 25: Overview of date requirements for Life Cycle Costing (LCC)

3.4 Life Cycle Costing – Financial Analysis

Life Cycle Costing (LCC) is a methodology to estimate the total cost of ownership of a system over its lifetime. As economic factors often determine the use of certain materials or products, as well as potential reuse options, it is necessary to include this type of information in a holistic materials passport. Information that can be incorporated is shown in figure 25.

Hence, it is also important to know who owns the product at a certain time (i.e. who has the responsibility or obtains the revenue). Due to the long lives and use times of building-related products, ownership can change. Therefore, it is important to incorporate this information within the materials passports and, more importantly, keep it up to date. Currently, there are many uncertainties in calculating the residual value (e.g. change in demand). Materials passports alone cannot solve this issue, but by providing relevant up-to-date information, they can be a helpful tool because they provide the necessary information.

3.5 Social Life Cycle Assessment – Social Analysis

The method of Social Life Cycle Assessment (SLCA) can be used to analyse the social and sociological aspects (e.g. human rights, working conditions, governance, health and safety etc) of products and potential positive and negative impacts along a products life cycle (UN 2017). Human well-being is the central focus of SLCA. The social assessment of products is a relatively new method and currently under development as unified rules do not exist at this point. SLCA is not as advanced as current environmental assessment methods (LCA) and only a limited number of SLCA studies are available (Muthu 2015).

SLCA methods are favourably applied to a specific product because generic data is generally not useful. One critical issue is the accessibility of relevant data (Muthu 2015). Not all relevant assessment data can be supplied by materials passports because most is not product related but on a company basis (e.g. business practice). However, a materials passport can incorporate relevant criterion to complement the assessment. Aspects that can be accessed via SLCA are shown in figure 26.

Some product labels (e.g. fair stone label) or Corporate Social Responsibility (CSR), for example, already address certain aspects.

Reasons for a responsible resource extraction

- Societal and entrepreneurial responsibility for materials and products
- Transparent production chain and uncritical origin of resources
- Ecological and social standard in countries of production
- Replacing primary materials with secondary materials.

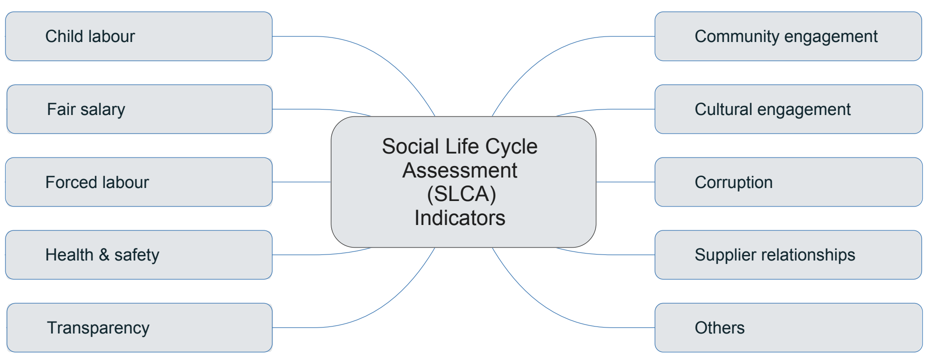


Figure 26: Overview of indicators in Social Life Cycle Assessment (SLCA)

4. ASSESSMENT AND CERTIFICATION

4.1. Product Assessment and Certification

4.2. Environmental Labelling

4.3. Building Assessment and Certification

4 Assessment and Certification

Currently, a large range of tools for assessment and labelling with an extensive width of complexity and varying scopes of application are available on the market. To name a few, these can range from assessments and certifications of city districts and buildings, and building products and materials towards businesses or individual business processes (figure 27).

A common basis of these schemes is the requirement of data. Depending on the hierarchy, level and the type of assessment, varying information on materials and material use are required. In contrast, information already raised for assessment purposes can be used within the materials passports. This would reduce the need of multiple data entries, which is cost-intensive and prone to mistakes.

A detailed description of each of the systems and data requirements is beyond the scope of this publication. Also due to the dynamic nature of the presented schemes, data requirements can change over time. Hence, further information should be taken from relevant literature sources addressing the specific topic in more detail.

4.1 Product Assessment and Certification

There are numerous product labels and assessment schemes available on the market today. These address various fields (i.e. environmental, health etc), life cycle stages (e.g. resource extraction), geographic regions or different types of materials (e.g. non-renewable/ renewable). Some of the labels might address health aspects, whereas others focus more on environmental topics or social issues (e.g. working conditions). The Ecolabel Index, for instance, has listed over 450 different labels from 199 countries and 25 industry sectors (www.ecolabelindex.com).

Furthermore, there is a wide range in reputability, assessment requirements and acceptability between the different initiatives. This has certainly also to do with the fact that some of the initiatives are industry schemes, whereas others tend to be more independent and are naturally less biased. In addition, several labels have strict criteria that require a third-party validation process. The majority of labels are voluntary schemes, but they can also be mandatory (e.g. EU Energy label). Figure 28 shows an overview of common schemes that include building-related materials and products within their portfolio. The list is not exclusive because there are further initiatives currently on the market.

One aspect that the presented labels and schemes have in common is the requirement for data in order to provide a sound assessment. The data required for the evaluation process can potentially be taken from materials passports, or conversely the data from product labelling can be used to enrich a materials passport. Product labels and materials passports should not be seen as competitors, but should complement each other.

4.2 Environmental Labelling

Environmental labelling can be categorised into different groups. The ISO 14020 series (part of ISO 14000 series) defines three types of labels and declarations: “Type I” and “Type III” are life cycle based in contrast to “Type II”.

Type I environmental labels are voluntary initiatives, multi-criteria based and third-party verified labels that indicate the overall environmental preference in a life cycle perspective of a product or service within a specific product category (ISO 14024).

Type II environmental labels are self-declared claims that can be made by manufacturers for marketing or other reasons (ISO 14021). Data taken from these sources should be critically questioned.

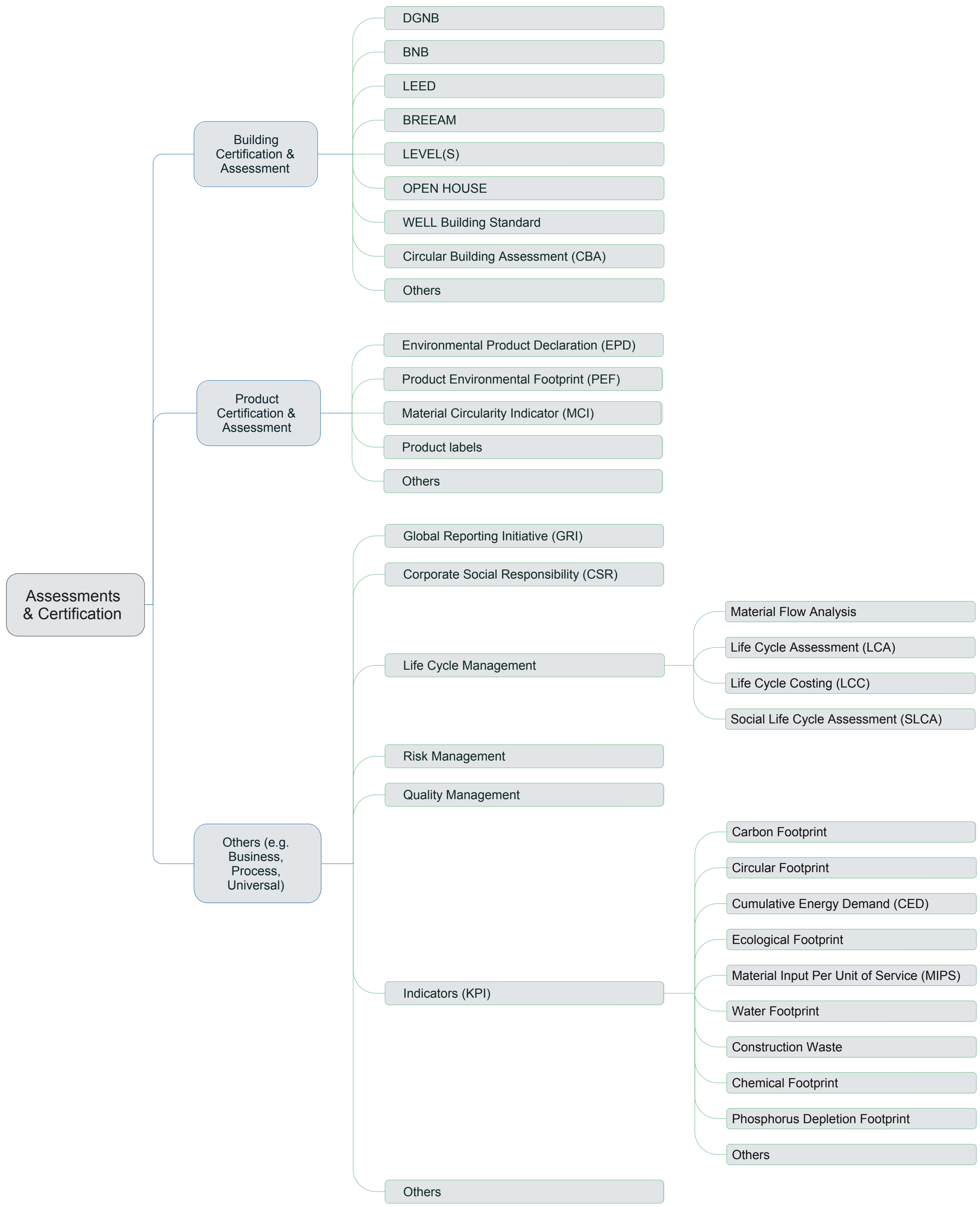


Figure 27: Hierarchy levels of selected assessment systems and labelling schemes

Figure 28: Selected assessment and certification schemes for products

Type III environmental declarations are quantified environmental data based on an LCA, primarily intended for business-to-business (B2B) communication to be able to compare the environmental performance of different products fulfilling the same function (ISO 14025). An example of this would be the EPD, which communicates environmental information. The data is generally used for conducting LCA studies and should therefore be incorporated into materials passports.

Furthermore, the Product Environmental Footprint (PEF) that is currently under development as part of the EU strategy to a Resource Efficient Europe falls under the Type III category.

4.3 Building Assessment and Certification

Building assessment schemes require a large quantity of data within the various indicators and fields of focus. The use of building materials and products is a central issue that directly influences multiple indicators within the assessment systems and can have a large impact on the final score or rating.

Building assessment tools are used to:

- Promote sustainable and circular practices within the building sector
- Serve as an effective planning tool
- Limit environmental impact of buildings – saving resources and avoiding pollution
- Provide comfortable and healthy living space for users
- Minimise costs over a building's life cycle

- Verify and certify the quality of a building – objective third-party verification
- Allow objective comparisons between buildings
- Serve as a marketing tool
- Others.

Different systems are currently used worldwide with various characteristics and focal areas. An overview of the most common systems currently available is shown in figure 29.

Data from materials passports can be directly linked to assess the relevant indicators within building certification systems. This could go as far as providing an automated assessment.

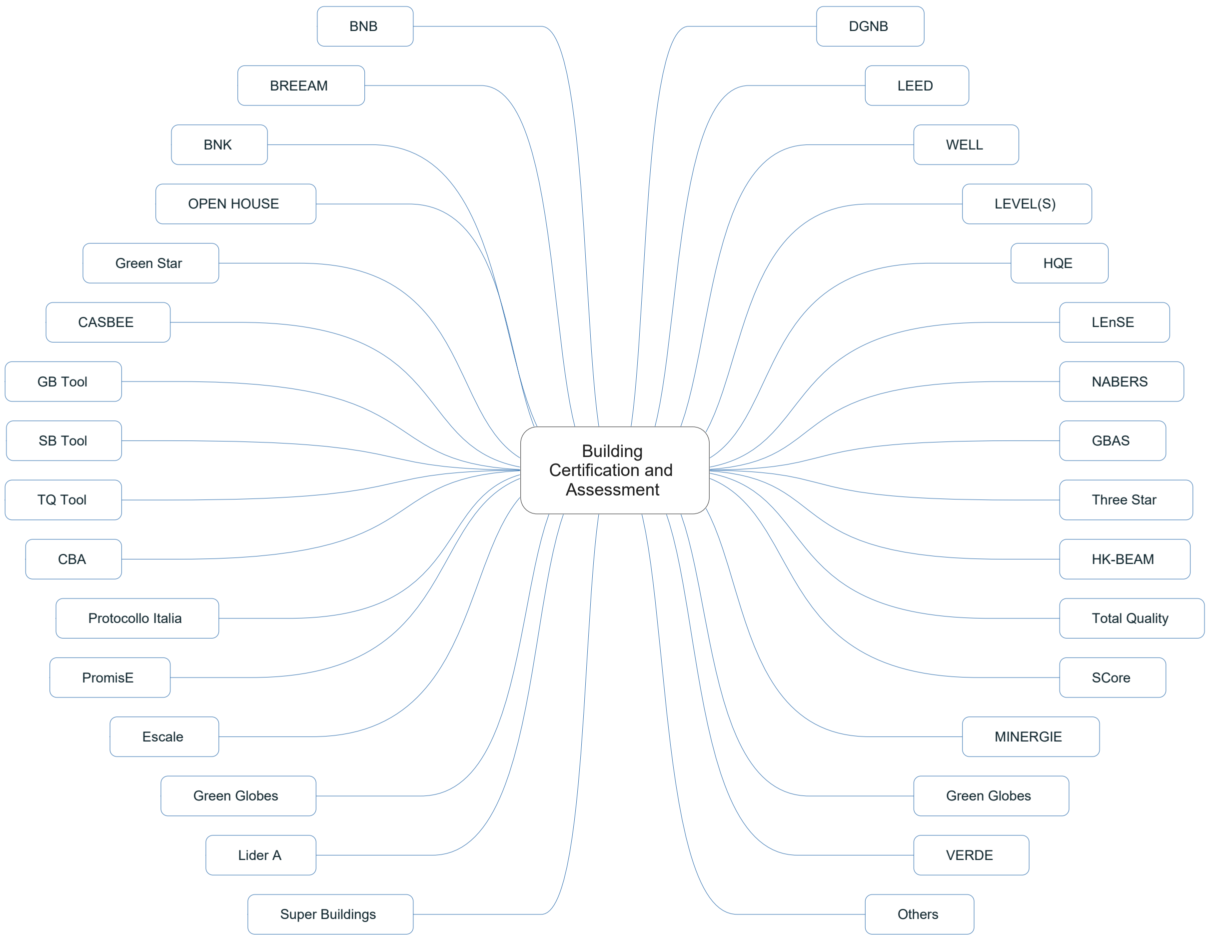
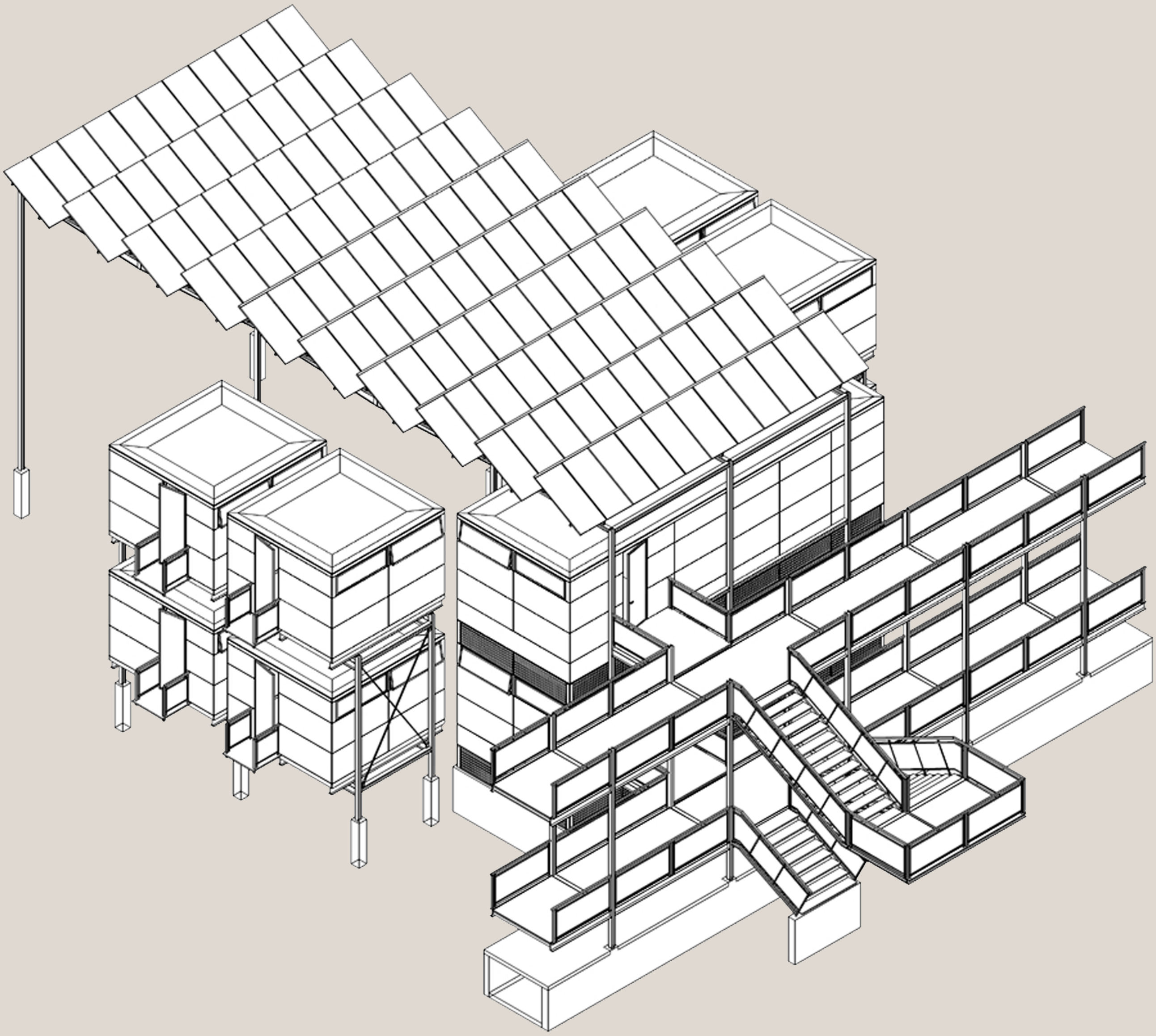
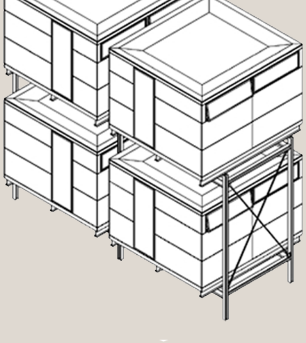
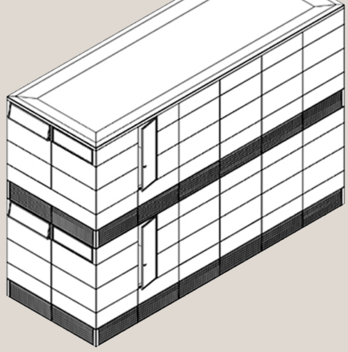
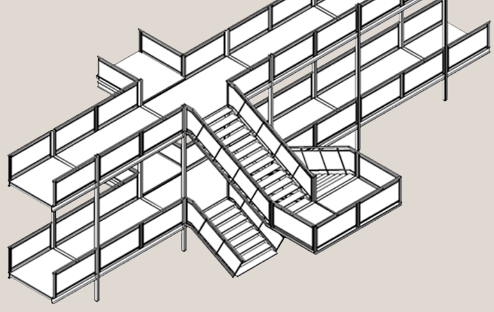


Figure 29: Overview of available certification systems for sustainable buildings









5. MATERIALS PASSPORTS AND THE POTENTIALS OF DIGITISATION

5 Materials Passports and the Potentials of Digitisation

The construction sector is lagging behind when it comes to digitisation in comparison to other industry sectors (Friedrich et al. 2011) The industry is aware of the importance as there is no alternative to digitisation and the challenge lies in its implementation (Schober et al. 2016).

The rapid innovation and change in information technology offers a large opportunity for the implementation of tools for a circular economy. Through the increasing complexity and high number of materials and products in a building, digitisation, process automation and implementation of data standards need to be a prerequisite rather than an exception. Besides the revolutionary advantages of digital technology for building and operational processes as well as materials passports, the corresponding supply chain can profit as well.

The large amounts of involved data require digital solutions to collect, process, store and utilise information. Information stored in materials passports is only useful when it can be used by the relevant actors at the required time. In particular, machine readable data (e.g. through standardisation) can be incorporated into automated assessment methodologies to avoid the need for multiple data entries.

Materials passports need to be integrated into BIM to provide input data for assessments on reversible and circular design (e.g. circular building assessment tool (CBA)). BIM, which can be seen as a digital twin, will become a standard tool in the construction industry because it is capable of storing referencing and linking data of individual components within a building over its life cycle. Materials passports and BIM should be seen in combination as they complement each other.

For a spatial assessment in the context of a district, city or region, there are advances in combining BIM with Geoinformation Systems (GIS). This emerging methodology is referred to as Unified Building Modelling (UBM). Together with material-specific data on a building level and below (i.e. component, material), assessments on material flows and stocks in a spatial context (e.g. regional analysis) can be made. The analysis of material flows and stocks is essential for identifying supply and demand for materials and bringing them into relationship to one another. This allows for strategic decisions within the supply chain, especially when reusing materials and components.

The data collection process can be complemented by Augmented Reality (AR), which is an extension of the real world with computer-generated visual information. When walking through a building, digital information can be displayed (i.e. augmented or superimposed). This is not only useful within all building phases (e.g. facility management), but it can be useful for collecting material information from existing buildings by an auditor or surveyor. There are various data collection systems on the market, some of which are semi-automated. The goal is to move towards higher levels or automation, to reduce the collection effort (e.g. through laser scanning, point clouds, virtual-reality based methods).

Intelligent networking (connection of devices with the internet and communication between devices – also known as Internet of Things (IoT)) can be useful when incorporating automated data collection devices (e.g. remote sensing) or monitoring equipment that exchange information with corresponding materials passports. This could include monitoring data on consumption (e.g. energy, water) or exposure of products to estimate exchange intervals, service life, maintenance requirements or second life options.

For an effective use of IoT, the development of Artificial Intelligence (AI) plays a vital role. AI can be used to assess information based on patterns (e.g. for information transfer) or when collecting data. For example, an automated building façade scan can be interpreted (e.g. dimensions of windows) and analysed. Within the machine learning process there is a possibility to identify material composition in an automated way in the future.

Furthermore, it is important to transparently track changes (e.g. ownership, refurbishment) to datasets. This can be achieved through blockchain technology, for instance, which has its main application in tracking financial flows (e.g. bitcoins). This aspect becomes increasingly important (e.g. for verification) to ensure data validity when information from different databases is compiled.

Information technology is indispensable when it comes to capturing, storing and analysing dynamic information over long periods of time (figure 30). Digitisation is a central aspect when it comes to implementing materials passports and the circular economy in current building practice. Current and emerging technologies have seen a large jump in innovation in the previous years, but often their full potential is not always realised for all types of application. Digitisation and the establishment of relevant standards (e.g. data formats) are key for a successful transition towards a circular economy.

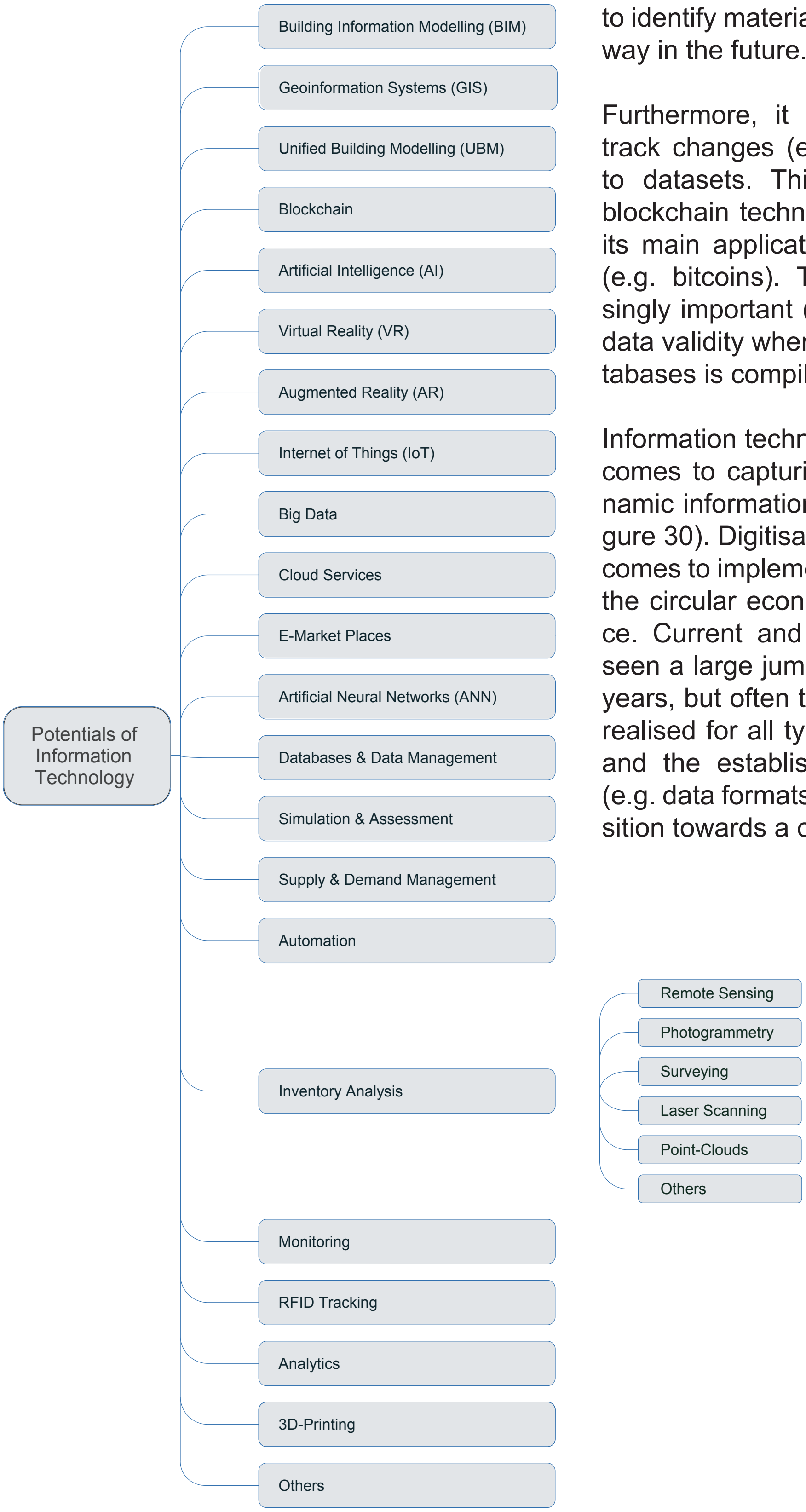


Figure 30: Overview of relevant information technologies

6. Actors and Information Exchange

6 ACTORS AND INFORMATION EXCHANGE

The transition towards a circular economy is an interdisciplinary task and will only work with the involvement of all the relevant actors along the construction value chain. The exchange of information between the relevant actors, however, is a central aspect towards a successful shift.

Generally, the highest level of information detail is provided when a building is commissioned. However, building and material-related information (e.g. material composition etc) is rarely passed on after a building is commissioned. Hence, a central dataspace is needed for all actors to obtain up-to-date information, which could be achieved by creating a BIM model that is linked to a materials passport database.

For a functioning circular economy, the information needs to be passed on and updated when changes are made to a building or its components (e.g. refurbishment, change of ownership). Hence, there is a need for an up-to-date building model with as-built material and component information when a building is handed over to the client. The building's digital twin needs to be made available to the relevant stakeholder and responsible actors (figure 31) within a building's operational phase (e.g. facility manager).

To ensure a smooth hand-over the information needs to be standardised to ensure its machine readability. Ideally, the data provided can be incorporated into a platform-unspecific model which can be read by all relevant software types.

As buildings and building products generally have long lifespans and can have multiple changes of ownership the information needs to be stored, updated and maintained for a long time (continuous information management). Through the introduction of new roles in construction practice (e.g. digital architect, information manager etc) the responsibility for this task can be clearly dedicated. Standard project management stages may need to be adapted in order to integrate circular strategies in current building practice.

During a building's operational phase all material-related changes need to be fed into the central data space to ensure that the digital twin always corresponds to the current state of the building. This can reduce the costs for maintenance as the relevant information and state of components is already documented.

When major refurbishments are planned, the information needs to be transferred to the relevant planners and construction firms who update the model with material-related changes. Therefore, the information flow is not limited to one direction because the information must be handed back to the operator.

When a building is decommissioned, the data model needs to be made available to the deconstruction firm. Life cycle costs are further reduced because the time taken for a deconstruction audit can be reduced and potential reuse options (i.e. resale of components) can be explored at an earlier stage. The detailed documentation provided by materials passports allows for finding a market place for reuse (i.e. trade platforms).

It is important to note that not all information is relevant for all types of materials and products. The tensile strength, for instance, does not apply to paints or coatings. Furthermore, different actors might require different information at different times and not all information is relevant for all actors. The facility manager might not be interested in information on transportation and logistics aspects, but needs it on cleaning and maintenance. Filter options in the materials passport platform can add to the user-friendliness (e.g. filter for life cycle stage, relevant actor, component type etc).

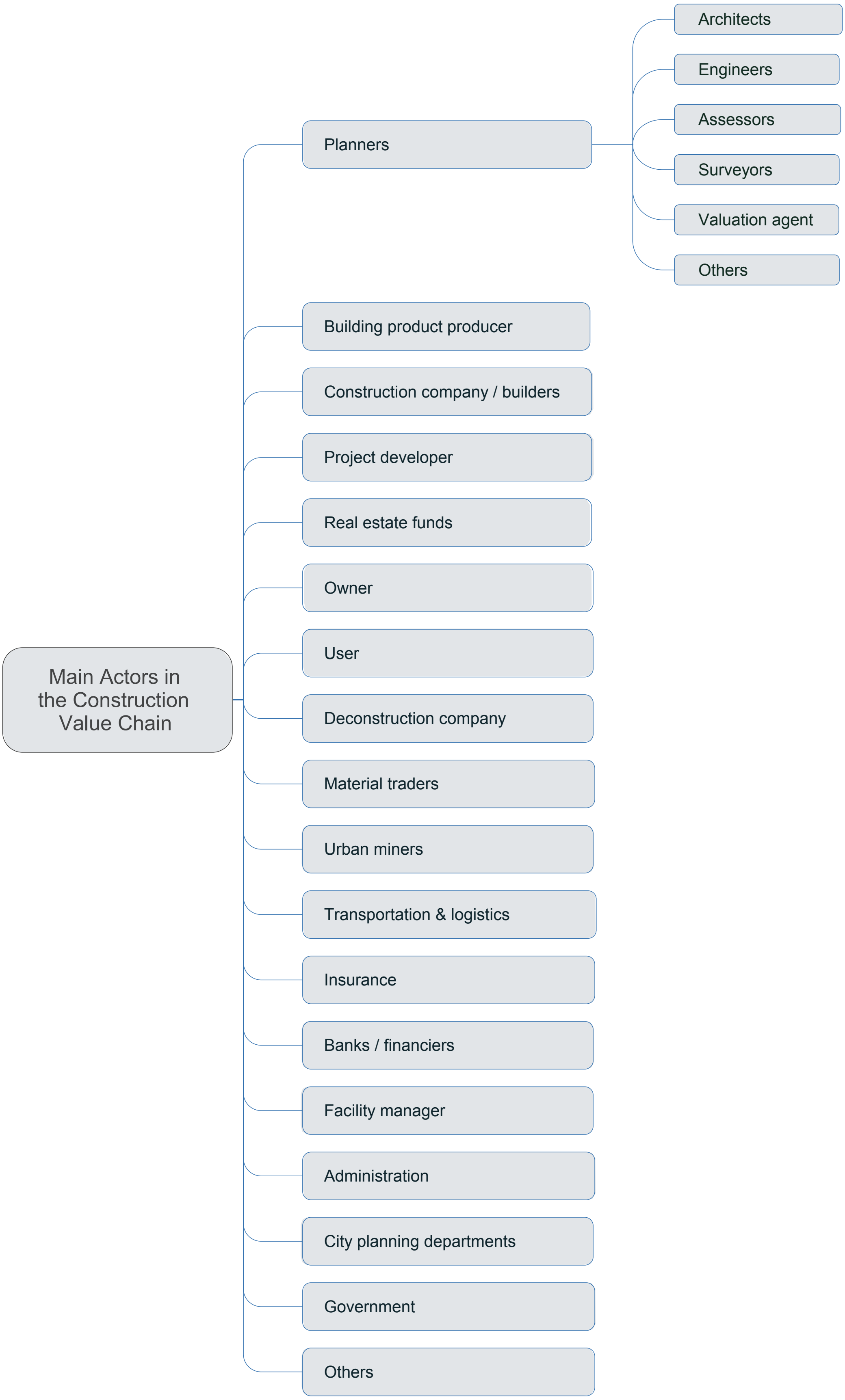


Figure 31: Involvement of all major actors in the construction value chain

It is, however, important that the relevant information can be accessed in a centralised way. It is not necessary to have a single database, but the information needs to be linked to increase the usability and avoid the need for multiple data entries (e.g. for different simulations or assessments). This reduces the effort and the probability of mistakes. A detailed description of information exchange can be found in the BAMB publication – D1 Synthesis State of the Art (Debacker et al. 2016).

Building a circular future means redesigning industry logic from building scale to business case (Guldager, Jensen and Sommer 2016). A shift to a circular economy in the construction industry as opposed to a linear system will have the effect that traditional roles can change and new roles will appear (e.g. urban miner, digital architect). To provide incentives for participation (e.g. information exchange) innovative business models (e.g. establishment of take-back-systems) are required, which have been addressed within the BAMB project (Peters M. et al. 2016; Wang et al. 2017). To obtain the maximum benefit from materials passports for a circular economy the exchange of relevant up-to-date information at the right time is key to a functioning value chain.

7. Outlook

7 OUTLOOK

Through the provision and linkage of material-, spatial-, and temporal information, building materials passports provide an important contribution to a systematic shift towards a circular economy in the building industry. The concept of materials passports must not be limited to construction-related products, but should also be expanded towards other industries because material flows occur across borders.

All actors need to be involved in the documentation process and the exchange of information. Updated material-related information (e.g. building model) needs to be passed on to the relevant actors at the right time. Hence, there is the need for standardised solutions where data needs to be in a machine-readable format that can be read by platform-unspecific software.

Standardised data allows for automated or semi-automated assessments (e.g. building certification, product labelling, simulation, LCA, MFA etc). Therefore, it is important to ensure that the information is provided in the correct format and that a framework for a common language is in place.

The implementation of materials passports must not be limited to newly-constructed buildings. The composition of the current building stock needs to be addressed because this is still largely unknown. Due to the large amounts of materials currently stored in existing buildings there is a vast opportunity to manage the material flows in a systematic, sustainable and circular way.

As the decommissioning (and hence the reclamation) of materials and components of newly-constructed buildings will be many decades into the future, due to the long lifespan of buildings, materials and components from the existing stock will be available at a much earlier stage in time. The documentation of material information is a major task considering the various building typologies and building methods. Digital solutions (e.g. automated systems) can aid in the data collection process.

Material-related data of existing and newly-constructed buildings can be fed into material flows and stock models. These can be used to forecast the future supply and demand of materials and components in a spacial and temporal context. For material and component reuse, the early identification of future market potential raises the chance of high-level reuse. The use of reclaimed materials and components need to be considered in the design stage, and hence the availability and condition of reclaimed products need to be known in advance.

Furthermore, the information in flow and stock models can be used to identify future exploitation and reuse strategies. Regional flow models (e.g. city scale) can be used to identify the need and positioning of recycling plants, landfill sites, logistic systems and other service providers.

The information provided within a specific materials passport can grow over time. Not all the relevant information will be available when the materials passport is created. Data fields in materials passports can, however, provide incentives to design products that fulfil the criterion of a circular economy (figure 32) or give an insight into future business models that can be adopted.

Materials passport data needs to be collected and updated over the whole life cycle. Currently, there is a lack of EOL information. This can be seen when evaluating EPDs, where the majority only contain production data. Due to changes in standardisation, EOL information will need to be provided in the future. The information should not be limited to material recycling or the production of energy (e.g. incineration, thermal treatment), but should include potential reuse options on a component level.

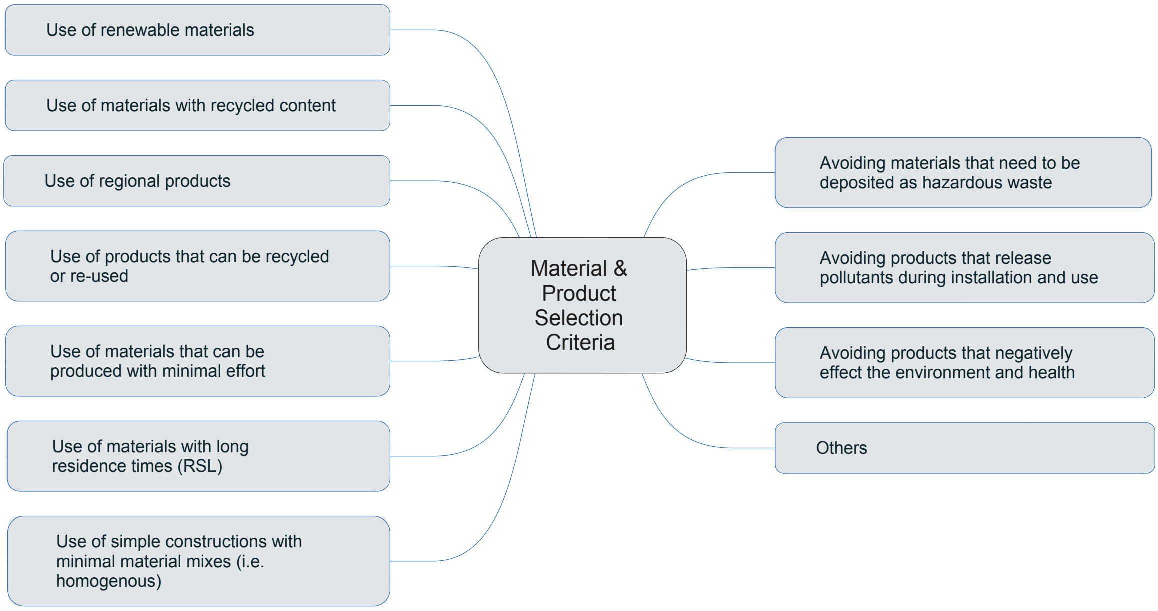


Figure 32: Material and product selection principles to enforce a circular economy

The adoption of reversible design strategies is of central importance when it comes to reclaiming materials and components at the EOL. Reversibility sets the path for future reuse to maintain a materials or components value. Today, it is technical feasible to build reversible structures – technology is not a barrier anymore. Deconstruction must be considered in the design stage. Currently, there is no regulation in place to ensure this (Durmisevic et al. 2018). To provide circular buildings in the future traditional design and deconstruction processes need to be adopted.

The availability of material data is a core aspect in a functioning circular economy. As buildings and components have long lifetimes and can have multiple changes of ownership and responsibilities, the data needs to be kept up to date and passed on to the relevant actors in a systematic way. A circular supply chain is only as strong as its weakest link, which requires incentives to ensure the participation of all parties. We need to start acting now in implementing the necessary steps in the building industry and its supply chain, because the establishment of a circular economy is a prerequisite for a sustainable development towards a sustainable and more circular future.

future green
THE ATLAS OF THE REAL WORLD
DER GARTEN
GARDENS
The Hotel Book
DAS NEUE MUSEUM BERLIN
Museen
PREFAB ARCHITECTURE
GREEN DESIGN
Passive Houses
BAUEN ZUKUNFT
century city
A Golden Thread
PRIZE
DIE SONNE
THE ENDLESS CITY
MATERIALS FOR DESIGN
DAS GLASHAUS
GLASS IN BUILDING
Bauen mit Membranen
EXTREME TEXTILES
EARTH ARCHITECTURE
ROBERT MAILLART
Holzbau Atlas
Glasbau Atlas
Fassaden Atlas
Facciate
SKINS FOR BUILDINGS
BIONIK
Fassaden Atlas
Skeletbau
SUN, WIND & LIGHT
European Carbon Atlas

ABBREVIATIONS AND LITERATURE

ABBREVIATIONS

General Abbreviations

AI	Artificial Intelligence
ANN	Artificial Neural Networks
AR	Augmented Reality
BAMB	Buildings as Material Banks
BIM	Building Information Modelling
BOM	Bill of Materials
BREEAM	Building Research Establishment Environmental Assessment Methodology
CAS	Chemical Abstract Service
CBA	Circular Building Assessment Tool
CED	Cumulative Energy Demand
CLP	Classification, Labelling and Packaging
CLP	Classification, Labelling and Packaging of Substances and Mixtures
CMR	Carcinogenic Mutagen Reprotoxic
CSR	Corporate Social Responsibility
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainability Council)
DoP	Declaration of Performance
EAN	European Article Number
EOL	End-of-Life
EPD	Environmental Product Declarations
EPS	Expanded Polystyrene
GHS	Globally Harmonized System of Classification, Labelling and Packaging of Chemicals
GIS	Geoinformation Systems
GRI	Global Reporting Initiative
GTIN	Global Trade Item Number
HBCD	Hexabromocyclododecane (flame retardant)
IoT	Internet of Things
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
MCI	Material Circularity Indicator
MFA	Material Flow Analysis
MIPS	Material Input Per Unit of Service
MP	Materials Passport
MPP	Materials Passports Platform
MSDS	Material Safety Data Sheet
PEF	Product Environmental Footprint
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RFID	Radio-Frequency Identification
RSL	Reference Service Life
SLCA	Social Life Cycle Assessment
SVHC	Substances of Very High Concern
TRGS	Technical Rules for Hazardous Substances
UBM	Unified Building Modelling
VOC	Volatile Organic Compound
VR	Virtual Reality

Rating System Abbreviations

BNB	Bewertungssystem Nachhaltiges Bauen
BNK	Bewertungssystem Nachhaltiger Kleinwohnhausbau
BREEAM	Building Research Establishment Environmental Assessment Methodology
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CBA	Circular Building Assessment Tool
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainability Council)
GB Tool	Green Building Assessment Tool
GBAS	Green Building Assessment Method
HK-BEAM	Building Environmental Assessment Method
HQE	Haute Qualité Environnementale
LEED	Leadership in Energy and Environmental Design
LEnSE	Label for Environmental, Social and Economic Buildings
NABERS	National Australian Built Environment Rating System
SB Tool	International Sustainable Building Tool
SCore	Sustainability Certification of Real Estate
TQ Tool	Total Quality Planning and Assessment

LITERATURE

BAMB. (2017): Materials Passports. BAMB – Building as Material Banks Consortium. https://www.bamb2020.eu/topics/materials-passports/.

Becqué R.; Mackres E.; Layke J.; Adam N.; Liu S. and Managan K. (2016): Accelerating Building Efficiency – Eight Actions for Urban Leaders. World Resources Institut (WRI). Washington, DC.

Brunner, P. and Rechberger, H. (2004): Practical Handbook of Material Flow Analysis. Advanced Methods in Resource and Waste Management. Lewis Publishers Florida USA.

Debacker, W.; Manshoven, S.; Apelman, L.; Beurskens, P.; Bideric, F.; Denis, F.; et. al. (2016): D1 Synthesis of the State of the Art. Key Barriers and Opportunities for Materials Passports and Reversible Building Design in the Current System. BAMB – Buildings as Material Banks Consortium.

Durmisevic, E.; Boogaart, E.; Serdarevic, M.; Hrasnica, H.; Biberkic, H.; Laat, P. and Hobbs, G. (2018): BAMB Deliverable D12.4 Reversible Building Design. User Requirements Report for Reversible Building Design Tools and Protocol.

European Commission. (2015): Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions – Closing the Loop – An EU Action Plan for the Circular Economy. European Commission. Brussels.

Friedrich, R.; Le Merle, M. and Koster, A. (2011): Measuring Industry Digitization. Leaders and Laggards in the Digital Economy. PwC Booz & Company.

Guldager Jensen, K. and Sommer, J. (2016): Building a Circular Future. 2nd ed. Copenhagen: GXN Innovation.

Heinrich, M. (2019a): Capture and Control of Material Flows and Stocks in Urban Residental Buildings. In: Building as Material Banks: A Pathway for a Circular Future. Conference Proceedings. Brussels.

Heinrich, M. (2019b): Erfassung und Steuerung von Stoffströmen im Urbanen Wohnungsbau. Am Beispiel der Wohnungswirtschaft in München-Freiham. Dissertation at the Technical University of Munich.

Hobbs, G. and Adams, K. (2017): Reuse of Building Products and Materials – Barriers and Opportunities. In: F. Di Maio, S. Lofti, M. Bakker, M. Hu and A. Vahidi: Hiser International Conference. Advances in Recycling and Management of Construction and Demolition Waste.

International Resource Panel. (2017): Assessing Global Resource Use. A Systems Approach to Resource Efficiency and Pollution Reduction. United Nations Environment Programme.

Klepeis, N. E.; Nelson, W. C.; Ott, W. R.; Robinson, J. P.; Tsang, A. M.; Switzer, P. et al. (2001): The National Human Activity Pattern Survey (NHAPS). A Resource for Assessing Exposure to Environmental Pollutants. In: Journal of Exposure Analysis and Environmental Epidemiology 11 (3), S. 231–252. DOI: 10.1038/sj.jea.7500165.

Luscuere, L. and Mulhall, D. (2017): Circularity Information Management for Buildings. The Example of Materials Passports.

Luscuere L. (2016): Materials Passports: Providing Insights into the Circularity of Materials, Products and Systems. In: Sustainable Innovation 2016. Circular Economy Innovation & Design; Towards Sustainable Product Design; 21st International Conference. Epsom, Surrey.

McDonough, W.; Braungart, M. and EPEA. (2012): Overview of the Cradle to Cradle Certified Product Standard. Version 3.0. Environmental Protection Encouragement Agency GmbH.

Mullhall, D.; Hansen, K.; Luscuere, L.; Zanatta, R.; Willems, R.; et. al. (2017): Framework for Materials Passports. Extract from an Internal BAMB Report. BAMB Consortium, EPEA, SundaHus.

Muthu, S. (2015): Social Life Cycle Assessment. An Insight. Environmental Footprints and Ecodesign of Products and Processes. Singapore: Springer.

Peters M.; Oseyran J. and Ribeiro A. (2016): BAMB Value Network by Phase. BAMB – Buildings as Material Banks Consortium.

Schober, K.; Hoff, P. and Nölling, K. (2016): Digitization in the Construction Industry. Building Europe‘s Road to Construction 4.0. Roland Berger GmbH.

Terrapin Bright Green. (2012): The Economics of Biophilia. Why Designing with Nature in Mind Makes Financial Sense. Terrapin Bright Green. New York, NY.

UN. (2017): Social Life Cycle Assessment (S-LCA) – Life Cycle Initiative.
https://www.lifecycleinitiative.org/starting-life-cycle-thinking/life-cycle-approaches/social-lca/.

UNEP. (2016): The 10YFP Programme on Sustainable Buildings and Construction. UNEP.

Wang, K.; Vanassche, S.; Ribeiro, A.; Peters, M. and Oseyran, J. (2017): Business Models for Building Material Circularity: Learnings from Frontrunner Cases. In: F. Di Maio, S. Lofti, M. Bakker, M. Hu and A. Vahidi: Hiser International Conference. Advances in Recycling and Management of Construction and Demolition Waste, S. 315–318.

IMAGE CREDITS

Inside cover: Demolition site in Munich, © Matthias Heinrich

Introduction: Demolition site in Munich, © Matthias Heinrich

Page 6: Facade in Brussels, © Matthias Heinrich

Page 15: Shingle facade St. Joseph Church in Holzkirchen, Germany, © Werner Lang

Page 27: Genussregal, winery in Styria, Austria, © Werner Lang

Page 28: Centre Pompidou in Paris, © Werner Lang

Page 38: Research Lab Singapore, © Werner Lang

Page 44: Building system for school buildings, © Thomas Herzog/ Werner Lang

Page 48: Bauma trade fair in Munich, © Matthias Heinrich

Page 54: Bibliothèque nationale de France in Paris, © Werner Lang

Page 58: Bookshelf at TUM, © Matthias Heinrich