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REUSE IN ENVIRONMENTAL IMPACT ASSESSMENT TOOLS

A prospective report

Interreg NWE 739 - FCRBE

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Introduction

Actors in the construction industry are increasingly required to take into account the environmental impacts of building projects. Initially seen mostly (if not only) through the lens of energy efficiency during the use phase, this concern is now being extended to include the whole life cycle of buildings and their components. More specifically, the environmental impacts arising from the manufacturing of building materials have become a major point of attention. Since the production stage of the building materials can comprise up to 50% of all the environmental impacts of new and low energy buildings throughout their whole life-cycle [Douguet, 2021], this represents important leverage to minimise the environmental damage of the construction industry.

In this regard, reusing[1] building materials and components is a particularly efficient strategy for cutting down these impacts. Indeed, reusing existing elements prevents having to produce new ones and, therefore, avoids all the impacts related to their manufacture. Most of the time, the operations needed to reclaim a material (cleaning, sorting, restoring, etc.) are quite light and mostly labour-intensive (rather than energy-intensive). Reuse also fosters a local economy and enables the preservation of the cultural value embedded in building materials.

Over the last few years, various organisations have developed different tools aimed at assisting project developers in assessing (and by extension improving) the environmental impact of their building, including regarding the choice of building materials and components. In this report, we analyse environmental impact assessment (EIA) tools from a triple perspective:

1. Set the general context and understand how they work.
2. Understand if and how they model the environmental impacts and benefits of reusing building materials.
3. Learn from good practices to foster the further adoption of reuse practices by construction professionals.

The report is a deliverable of the FCRBE project, an Interreg NWE project aiming at developing reuse practices within the construction industry. More specifically, it is part of a facet of this project addressing the roll-out of reuse practices in the long term. For the construction industry to adopt more systematically reuse practices, it needs a general context favourable to reuse. This entails, among other things:

- The development and implementation of reuse-friendly public policies (addressed in the FCRBE deliverable LT 1.1)
- An acknowledgement of the benefits of reuse strategies in green building rating systems (addressed in the FCRBE deliverable LT 1.3)
- A close incorporation of reuse considerations in environmental-impact modelling and decision-making tools used by project developers (the topic of the present report).

1 The definition of 'reuse' (and its translation from one language to another) remains subject to different understandings and interpretations although a definition is given by the Waste Framework Directive. However, a definition is proposed in the FCRBE FutuREuse booklet [NAVAL, 2021] in which reuse includes materials used on the same site or off site for future reuse. If the transfer of material involves several sorting phases, or if the material is abandoned or deposited but a new holder comes forward with the desire to reuse it, the material will then go through a stage of preparation for reuse. It also include reusing elements for the same or another purpose.

2. Assessing environmental impacts

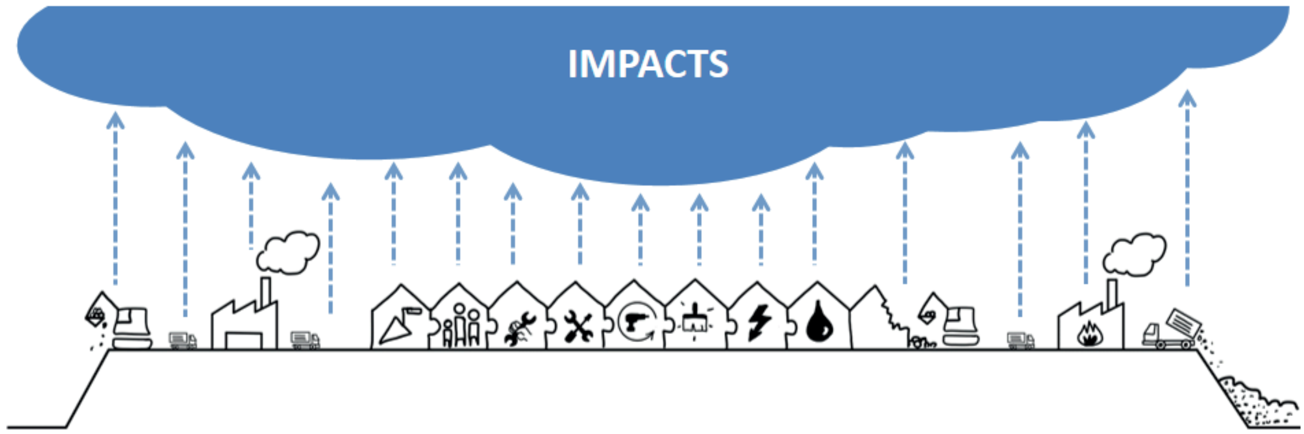


Figure 1: Environmental impacts are generated at different stages of the building life cycle.

From the production of their construction materials to their demolition, buildings cause various impacts on the environment.

Having a clear overview of these impacts can help designers to incorporate a more sustainable and less impacting approach into their projects (together with more classical considerations, such as technical, economic, aesthetic and legal issues). This, however, necessitates the use of models to represent and measure these impacts for each step of the building life cycle. To be useful for decision-making, these impacts should be clearly understood as to where and when they arise, what their consequences are and what their respective contribution to the overall impact is.

Life Cycle Assessment (LCA) methods are useful at answering these questions and tackling these challenges. Increasingly used since the 1970s, LCA methods make it possible to assess the environmental impact of a product, a component or even a whole building. In Europe, different standardisation frameworks have been developed to conduct such assessments at the level of buildings (EN 15978) and at that of construction products (EN 15804). These standards largely draw on international standards, namely ISO 14040 and ISO 14044 although these are not limited to the building industry but aim to address any type of material, service and activity.

The general LCA method is based on four main steps:

1. Definition of the goal and scope of the study, including defining the functional unit, the scope and the boundaries. This step is particularly important since it will have a strong influence on whether and to what extent the results of a specific LCA can be compared to those of another assessment. The interpretation of LCAs must always take into account the assumptions made and the preconditions (composition, replacement, methods, data, system limitations, etc.).[2]
2. Analysis of the life-cycle inventory, which means taking an inventory of the flows between the elementary processes and systems (materials, energy and services) and the flows into the biosphere (raw materials, waste and emissions) [Brohé, 2016, p.73]. This step is usually quite intense. It relies on collecting data and can involve on-site measurements but also reference to general databases gathering data from other manufacturers.
3. Life-cycle impact assessment, which translates the inventory into tangible impacts on the environment, such as contribution to climate change through greenhouse gas emissions, contribution to ocean acidification, toxicity, etc.

2 https://www.cstc.be/homepage/index.cfm?cat=publications&sub=infofiches&pag=64&lang=fr

4. Interpretation. At this phase, the analysts discuss their approach and draw conclusions. It is also at this phase that the different impacts can be aggregated, for instance through monetisation (i.e. an estimation of cost of the different environmental damages that have been identified and quantified).

Conducting LCAs may have different objectives. They can be used internally by manufacturers to identify the most impactful parts of their internal processes and adapt these in consequence. In this case, the boundaries of the analysis can be limited to the upper part of the life cycle, namely the product manufacturing stage, also referred to as a 'cradle-to-gate' analysis.

LCAs can also be used to declare the environmental impact of a product, with a view to informing customers on the consequences of using this or that material. This approach entails enlarging the boundaries to the whole life-cycle of a product, also referred to as a 'cradle-to-grave' analysis. In the case of a construction material or building, the analysis generally applies to the following life cycle phases: production (A1-A3), transport and installation on site (A4-A5), use phase, including maintenance (B), and managing the end of life (C) [Janssen, 2016; Douguet, 2021].

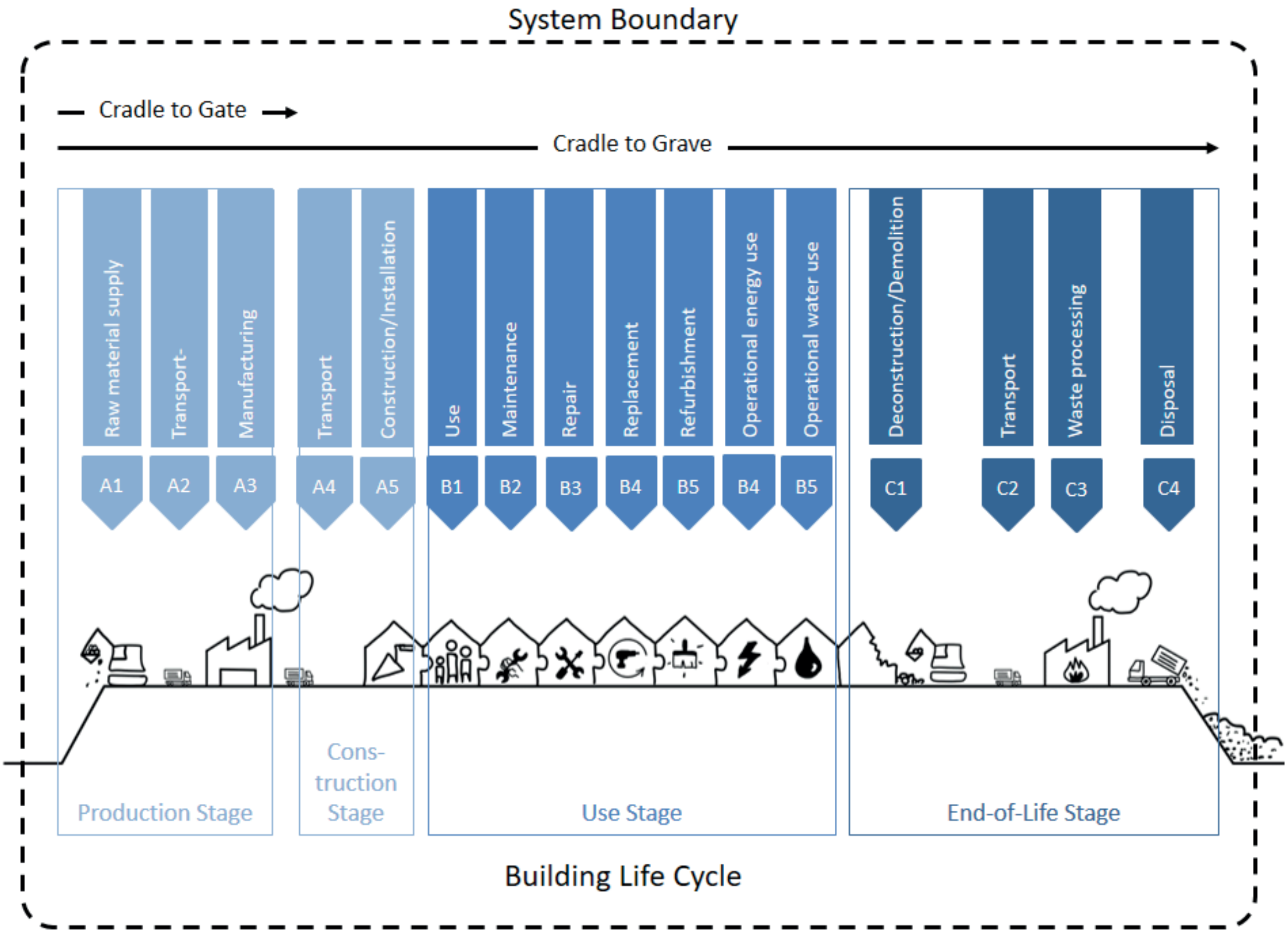


Figure 2: The different stages considered in a building life-cycle analysis.

3. The challenges of assessing the environmental impacts and benefits of reuse

Reusing materials is an excellent strategy to reduce the overall environmental impacts of a building project. Not only does reuse contribute to avoiding impacts related to the end of life of the original material but it also prevents the need to produce new materials and the impacts related to their manufacturing. Reuse preserves the use value of existing goods and lengthens their life cycle.

While the idea that reuse principles entail environmental benefits is easy to grasp with common sense, the modelling of these benefits through the LCA framework can be complex. In essence, an LCA is best suited to linear processes with a clear start and a clear end. By comparison, the circular economy, which aims at 'extending the service life of goods through reuse, repair, remanufacture and technological and fashion upgrading' [Stahel, 2019], implies a 'multi-cycling systems perspective' [Eberhardt et al., 2020]. The modelling of systems involving successive cycles raises many questions, notably how to allocate the different burdens and benefits through these successive cycles.

Since the 1990s, researchers, standardisation bodies and public authorities have developed and discussed different methods to incorporate this multi-cycle perspective into LCAs. These methods are still debated today since they all 'differ from each other on how the impacts are allocated in the various cycles of a component's life' [De Wolf et al., 2020]. Without entering too much into the technicalities, it is possible to summarise the main challenges at stake and how these are addressed through different methods.

3.1. Allocating impacts

Allocating impacts is probably the most discussed question in the scientific literature on LCAs for multi-cycle systems. Although most of these discussions are aimed at recycling, the general challenges they tackle are also valid for reuse-oriented discussions. From a multi-cycle perspective, it can be argued that the initial production impacts and/or those related to end of life should be shared among the different cycles. Broadly speaking, the different positions regarding the allocation of end-of-life impacts can be summarised into three general categories [Eberhardt et al., 2020]:

- The '100:0' approach, which attributes all the impacts to the first use and does not credit efforts for enhancing future recovery.
- The '0:100' approach, which credits the secondary cycle for the use of recovered materials.
- In between, there is a 'shared burden' approach, which proposes to allocate (and share) end-of-life impacts between successive cycles. In this sense, the '50:50' approach will then allocate end-of-life impacts equally between two successive cycles but other allocation keys can be considered.

The approach put forward in European standard EN:15804 for the declaration of the environmental impact of products would correspond to a 100:0 approach, also referred to as a 'cut-off' approach. It indeed deals with a multi-cycle product by excluding the loads and benefits of any future recovery loop from the system boundaries (as illustrated in Figure 3). It includes an additional phase, module D, which can be used to assess and express the potential benefits and loads of future loops. According to EN 15804+A2, Module D has to be taken into account in the EPD[3].

By comparison, the approach proposed in the European Commission Environmental Footprint initiative, which aims at a much larger scope than construction products, uses the third approach. A 50:50 approach 'allocating shared end-of-life processes equally between the previous and subsequent product' was first used [Allacker, 2016]. But the most recent version of the Product Environmental Footprint (PEF) proposes a shared

3. All construction products and materials shall declare modules A1-A3, modules C1-C4 and module D. For the Belgian EPD database (B-EPD), it has always been mandatory to take into account module D.

burden approach based on several parameters, such as the quality of the of reused input/reusable outputs thereby reconsidering the previous allocation key[4] [EC, 2017, p.112]. Other methods, such as the Publicly Available Specifications 2050 [BSI, 2008], or the BPX 50/50 approach established in France by Ademe and the French Standardisation Agency [AFNOR, 2011] are also modelled on the third 50:50 approach.

In the FCRBE FutuREuse booklet [Douguet, 2021], a cut-off approach applied to the case of reusing building material is illustrated and developed. To put it briefly, this will usually consider that the system boundaries start when the product loses its 'end-of-waste' state[5] (regardless of what happened in its early history). It then considers the different steps of the reclamation process as the 'product' phase (A1-A3), for which it is possible to take a classical life-cycle inventory and convert it into environmental impacts. The same applies to the following steps (transport to site, installation, use-phase and end-of-life), in a very similar way to LCAs of 'classical' products. The impacts of a possible future loop may be reported in the module D, but they will not be accounted for in the environmental impact declaration.

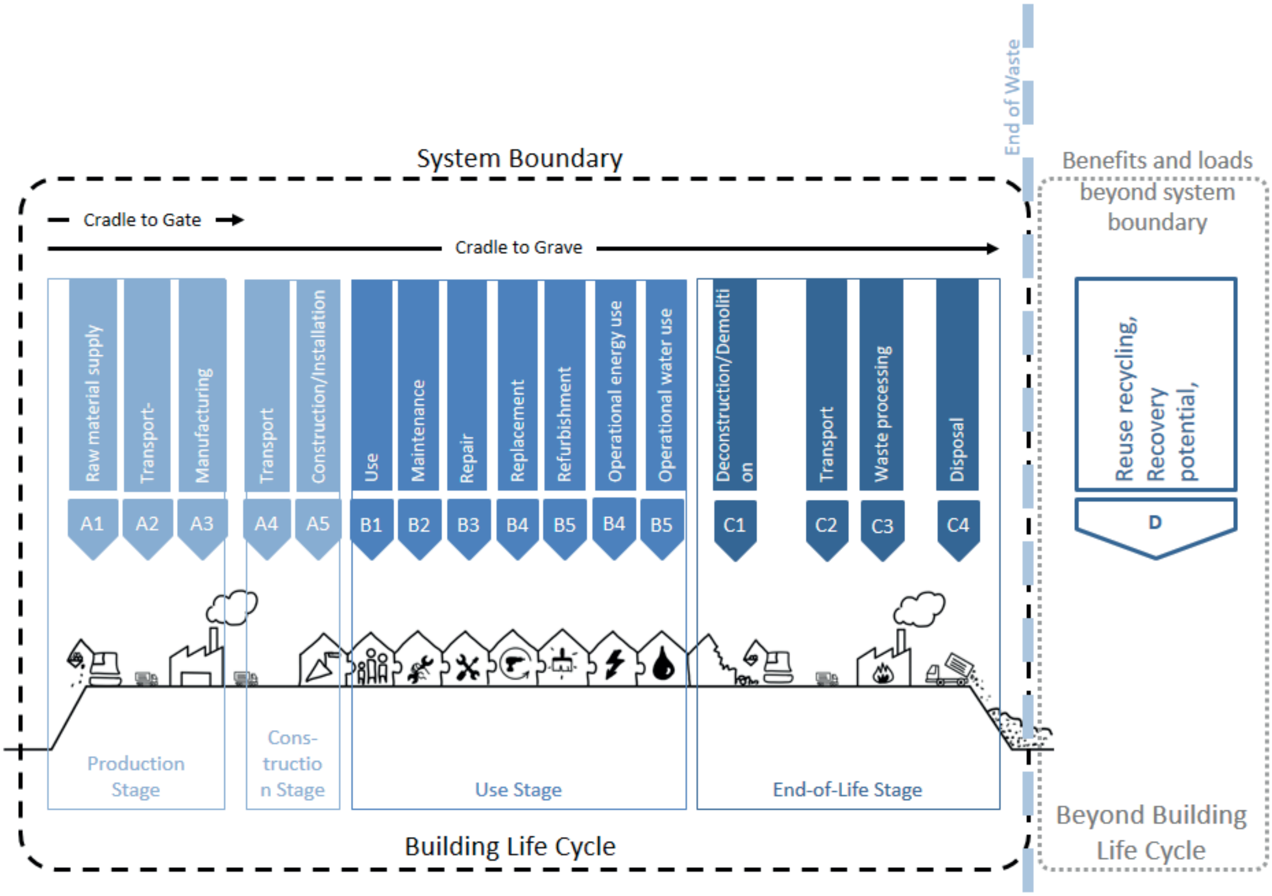


Figure 3: The impacts of a possible future loop may be reported in the module D, but they will not be accounted for in the environmental impact declaration.

4. The method is explained in the Product Environmental Footprint Category Rules Guidance - Version 6.3 – May 2018, p.112.
5. The recovered material, product or construction element reaches its 'end-of-waste state' where the following conditions are met:
   - 'the recovered material, product or construction element is commonly used for specific purposes'
   - 'a market or demand, identified e.g. by a positive economic value, exists for such a recovered material, product or construction element'
   - 'the recovered material, product or construction element fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products'
   - 'the use of the recovered material, product or construction element will not lead to overall adverse environmental or human health impacts'

3.2. *Taking credit for impacts that are avoided*

If a process uses recovered materials instead of virgin resources, it also helps to avoid the environmental impacts related to the extraction and manufacture of these resources. The successive cycles created through reuse and recycling could thus be credited with avoided impacts.

How to measure these potentially avoided impacts without double counting the environmental impacts is a huge discussion on its own. It requires a strict framework to ensure the comparability of substitution scenarios [ADEME, 2020]. It may also require taking into account possible loss of quality during successive cycles (although this issue is more relevant to recycling processes than to reuse, which by definition preserves the integrity of materials).

While some methods clearly incorporate these avoided impacts (such as the European Commission Environmental Footprint approach), others don't. As such, the cut-off approach developed in the EN standards does not explicitly incorporate this aspect. That's why, since 2019, the approach has been completed by Module D. However, it allows for a possible workaround by means of a comparison between the LCA of a reclaimed product and that of a new equivalent product. As suggested in the FCRBE FutuREuse booklet [Douguet, 2021], the savings from reusing a material could be estimated by looking at the difference between the impacts of a new material and those related to a reclaimed one (see Figure 4).

This, of course, supposes that a comparison is possible. In practice, it may be complicated. Antique materials, for instance, may not have comparable equivalents today. Such comparison hinges on a clear definition of the functional unit, which, as pointed out by Brohé [2016, 72-73], is inevitably restrictive. Some parameters are much harder - if not impossible - to include. This is notably the case for more subjective and intangible aspects such as cultural value, embedded craftsmanship, beauty, etc. which are often important for many clients who opt for reclaimed materials.

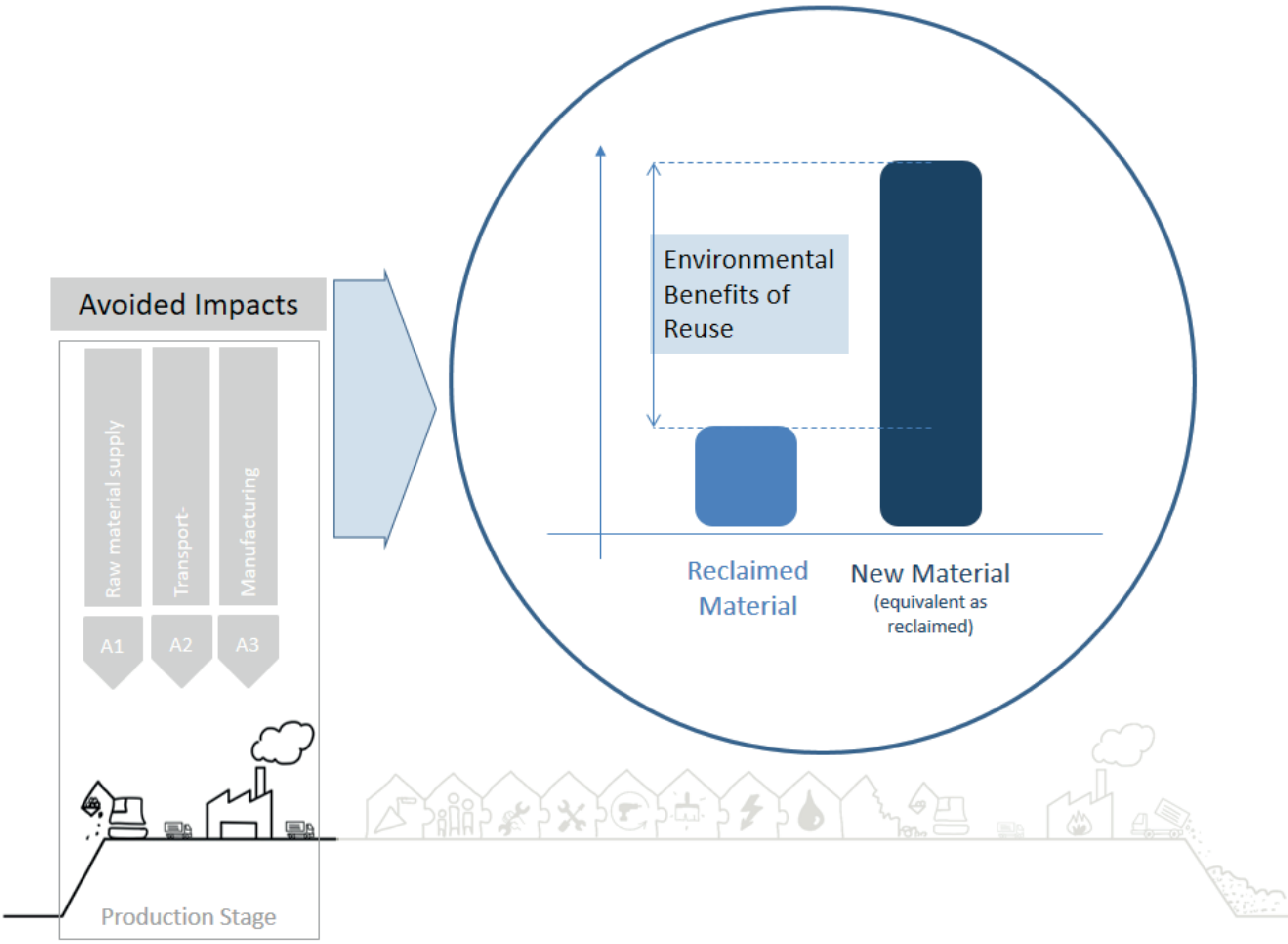


Figure 4: Environmental benefits of reclaimed material compared to new material (and avoided impacts).

3.3. *Dealing with expected service life and number of cycles*

In all LCA approaches, time is a crucial issue. When it comes to declaring the environmental impact of a product, time is usually included in the functional unit (example: 'covering 10 m² of floor for 50 years'). This is also referred to as the 'expected service life' of the product. This aspect is even more crucial for multi-cycle assessments. In this case, the number of cycles may also have a major impact on the allocation key.

Here again, some methods take this aspect into account. This is notably the case for the Degressive Linear methods discussed by Allacker et al. [2016]. Interestingly, although deemed more accurate from a physical point of view, this approach was eventually discarded in favour of a 'shared burden' method when elaborating the European Commission Environmental Footprint initiative [EC, 2017, p.112]. This choice was made in the light of practical aspects. The Degressive Linear model indeed relies crucially on accurate information on the number of cycles for a given material. In practice, this information is often extremely difficult to find or even estimate. Although mathematically satisfying, the application of such approaches may be cumbersome.

By definition, the cut-off method does not consider future cycles in the environmental declaration of a product. Drawing on the aforementioned workaround (focusing on the savings of reusing a material by making the difference between the impacts of a new material and those related to a reclaimed one), it would however be possible to estimate the cumulative benefit of successive reuse. See figure below:

An interesting approach regarding estimated lifespan and specifically addressing the case of reuse is currently being developed by the Swiss standardisation organisation [SIA 2032, 2018 quoted by De Wolf et al. 2020]. They indeed consider using the ratio between the actual lifespan of an element and its estimated service life as an allocation key between different cycles. If the ratio is >1 (i.e. the actual lifespan exceeds the announced service life), all the burdens would be allocated to the first cycle and none to the new cycle. In this case, it is considered that the original impacts have been paid-off at the end of the first cycle. If, however, this ratio is <1 (i.e. the actual lifespan is lower than the estimated one), the burdens are shared between the two cycles, at the pro rata of said ratio. In this case, reuse would be considered as a necessary action to avoid wasting a material.
However promising, this approach will need to address the difficult question of setting the 'useful life' of a material. Beside the most evident technical aspects, how a material actually ages depends on multiple factors, likely to elude modelling attempts.

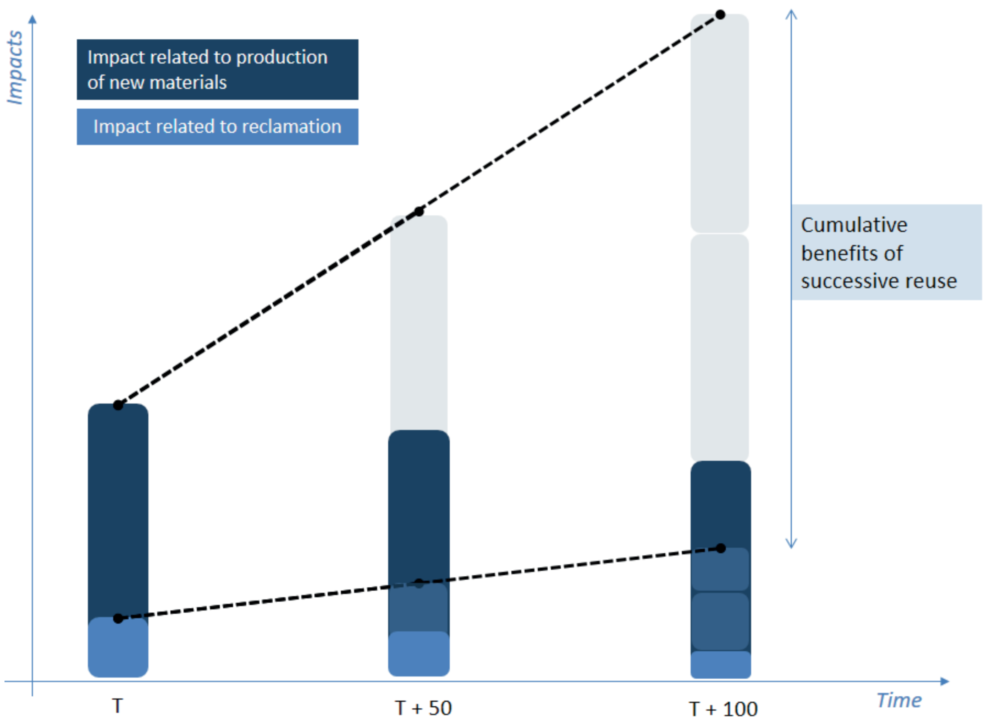


Figure 5: Cumulative benefits of successive reuse (compared to the production of new materials). It is assumed that global impact for both producing new products and reclaiming existing ones will decrease through time thanks to a progressive decarbonisation of the economy.

3.4. Dealing with the phasing of emissions: dynamic[7] LCAs

Even without considering the multi-cycle perspective, LCA methods may have to deal with the phasing of the different impacts (notably the impacts on climate change through greenhouse gas emissions). In practice, LCA studies are mainly static and propose an aggregated result for the entire life cycle of a product or sometimes by phases (production, construction, use and end-of-life). Yet, when dealing with long-lasting products and systems, as is the case with building and building materials, the use of more dynamic approaches may be necessary.

This approach is being progressively addressed by some public authorities, such as in France where the government is considering enforcing the use of (simplified) dynamic LCAs for assessment of the Global Warming impact (kg CO2 eq) generated by a building during its life cycle.

Broadly speaking, dynamic LCAs have been developed to give a more precise overview of the moment at which the considered impacts effectively occur (especially for the emissions of greenhouse gases). As explained by Levasseur et al. [2012], 'a dynamic LCA approach to account for the timing of emissions in LCAs [...] uses a dynamic inventory, which details each emission through time (i.e., the amount of pollutant released at every given time step), and dynamic characterisation factors to determine the impact of emissions for every time step.'

Adopting this approach in official frameworks would mostly make a big difference for bio-based building materials (e.g. wood).

Through photosynthesis, plants and trees indeed take up carbon from the atmosphere and metabolise it for their growth. They can thus be considered as (temporary) reservoirs of carbon. This effect is increased if, in addition, new trees are planted, thereby contributing to the increase

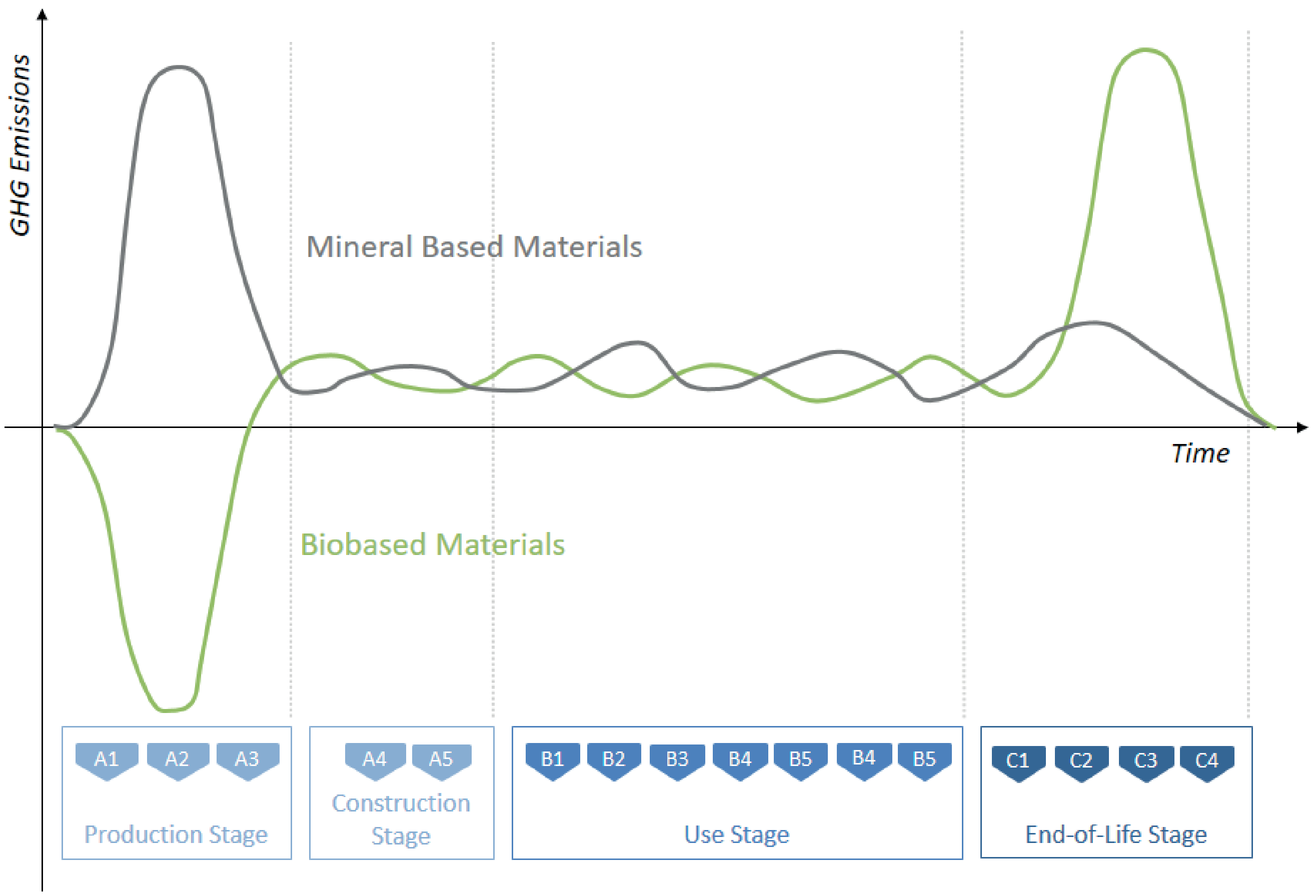


Figure 6: Flow chart illustrating dynamic life cycle assessment considering mineral and bio-based materials.

7. By dynamic LCA, we mean that impacts are released at different times and stage in the life cycle of a product which are not highlighted by LCA studies. Furthermore, in many cases, the term 'dynamic LCA' refers rather to the change over time of different parameters that can influence the calculations such as the evolution of energy mixes, the impact of global warming on models, etc.

in the overall volume of this valuable non-atmospheric carbon sink. Bio-based materials cease to be a carbon sink when they arrive at the end of their life cycle because traditional waste management methods tend to release greenhouse gases (namely CO2, CO or CH4) into the atmosphere 'as a result of the oxidation and/or reduction of biomass by means of its transformation or degradation (e.g. combustion, digestion, composting, landfill)' [Hoxha et al. 2020].

As a result, the general emission profiles of bio-based materials tend to be quite different from those of inert, mineral-based materials (see figure). The latter will have most of their greenhouse gas emissions associated with the product manufacturing phase (usually because they entail some sort of cooking involving burning fuels, hence GHG emissions). By comparison, the impacts at their end of life are less important. By contrast, bio-based materials will present the most important emissions at their end-of-life phase, whereas their manufacturing phase may result in negative emissions since they take credit for the atmospheric carbon taken up by the trees' metabolism. Most of the time, the overall balance of GHG emissions of biobased materials remains positive. In other words, during their complete life cycle, they emit more greenhouse gases to the atmosphere than they take up atmospheric carbon. But the moment at which these emissions arise is very different from non-bio-based materials and, in the current climatic situation, this may matter a great deal.

In this view, reusing biobased materials can be seen as an excellent way to preserve existing carbon sinks and prevent the release of greenhouse gases. How this can blend in the possible generalisation of dynamic LCAs and other frameworks is still to be determined. According to EN15804+A2, reclaimed bio-based products are credited for their embedded biogenic carbon in modules A1-A3[8].

3.5. Perspectives

As demonstrated in the previous paragraphs, there are many different approaches that deal with multi-cycle perspectives. Depending on how the different methods tackle the different questions, they end up incentivising different behaviours - encouraging the development of new materials and products that present a high potential to be recovered in the future (notably through reclamation and reuse) or fostering the recovery (notably through reuse) of already existing goods, for instance [De Wolf, 2020].

This is a double-edged sword. Pushing the development of the assessment framework in one direction may contribute to fostering virtuous practices but can also have the opposite effect of overlooking them. Despite the development of an increasing number of environmental product declarations, there are currently only a few specific to re-use (in France and Denmark). Although it is likely that developments are to be expected in this respect, it has to be noted that reclaimed materials are completely under-represented in the existing database of environmental product declarations.

Many factors can explain this situation. The cost of conducting LCAs and establishing subsequent EPD may be prohibitive for SMEs, which constitute the vast majority of the reclamation sector [Bougrain, 2021]. Such investments are also more profitable when the volumes of production are predictable and consequent, which is less often the case in the reclamation industry where dealers can have a much-diversified offer.

These aspects indicate the need for a more coordinated approach in which the reclamation industry would be offered a specific framework and/or some sort of support to demonstrate the benefits of their activities and of reusing building materials in general. More broadly, this brief overview also shows that neither the frameworks put in place by public authorities nor the scientific methods currently under discussion offer a fully adapted approach to the assessment and expression of the environmental benefits of reclaimed materials. This clearly calls for further developments.

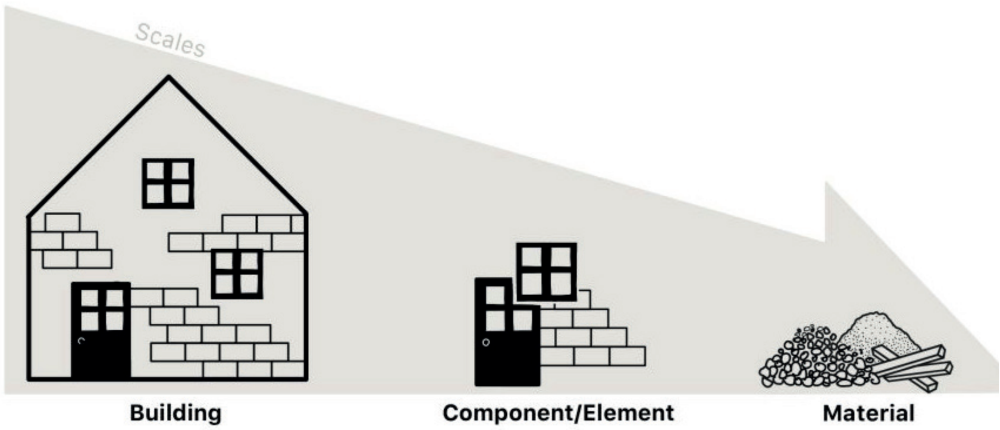
8. 'The removal of biogenic CO2 into biomass (with the exclusion of biomass of native forests) and transfers from previous product systems shall be characterised in the LCIA as –1 kg CO2 eq./kg CO2 when entering the product system. Emissions of biogenic CO2 from biomass and transfers of biomass into subsequent product systems (with the exclusion of biomass of native forests) shall be characterized as +1 kg CO2 eq./kg CO2 of biogenic carbon, see EN ISO 14067:2018, 6.5.2.' + EN 16485 Round and sawn timber - Environmental Product Declarations – Product category rules for wood and wood-based products for use in construction for more explanations.

Some initiatives are taking shape to address this issue, such as the MRA. MRA or 'multiple reclamation assessment' is a method devised by Salvo for measuring the carbon benefit of the reclamation and reuse of reclaimed building material, products and elements. MRA measures the difference between the embodied carbon of cycles of reclamation and reuse and carbon cost of the use of new material. It is analogous to LCAs (life cycle assessment), which measures the environmental impacts of a building material or product, usually with a single life. Based on a global reflection on carbon sequestration, MRA thus aims to measure the carbon benefit that reuse materials can have in order to encourage their use which is the prime objective of the European Interreg - FCRBE project.

This type of approach proves that the question arouses the interest of the sector. However, it is important to note that there is no scientific consensus on the working hypotheses at this stage.

4. Environmental impact assessment (EIA) as a tool for decision making in design processes

Architects usually play an important role in the choice of materials used in a building project. By extension, their decisions can have a strong influence on how the building will impact the environment. To assist them in making such decisions, different tools have been developed. These cover a wide range of situations, from supporting decisions in the early design stages to assessing the performance of buildings once these are completed. They also address different scales: from materials to components to buildings as a whole.



4.1. On the scale of building materials and elements

On the scale of building materials and elements, different tools and devices have been developed to inform designers and customers in general on the environmental impacts. These tools are usually built on an LCA approach. They often need to find a trade-off between user-friendliness and consistency of information.

The table below offers a short overview of some of these tools:

EPD
Environmental Product Declarations (EPD) are developed by materials producers. For construction products marketed in Europe, the EPDs need to comply with international and European standards on environmental products declaration to ensure reliability and verifiability of their content. These are always based on LCAs. EPDs are often collected on national databases which are publicly accessible. In practice, the use of EPD meets different challenges[9]: • the existence of different programmes in charge of framing EPDs • the existence of different standards on which these declarations can be established and the competition between these standards on certain aspects (namely between EN 15804 and the European Commission Environmental Footprint method) • the variation of the modules analysed in the LCAs from one EPD to another (some use a cradle-to-gate approach, others a cradle-to-grave one) EPD is declarative and does not necessarily imply a low environmental impact. Reuse-wise, as explained above, EPDs for reclaimed products are overly rare. To the authors' best knowledge, only two European reclamation dealers have developed an EPD (or EPD-like formats) for their products: a Danish dealer in reclaimed bricks and a French dealer in reclaimed raised floors systems.
Environmental scoring systems *(Nibe, Green Guide, Material Pyramid, etc.)*
Throughout the years, different approaches have been developed to affix an 'environmental score' to building materials with a view to providing designers and decision-makers with general indications on their environmental impact. The materials are usually classified in libraries or other visually appealing ways, to facilitate the overview and the search of more precise information. An interesting example of this approach is the Material Pyramid developed by the Centre for Industrialised Architecture (CINARK) at the Royal Danish Academy. It draws on collections of EPD and LCA results to classify common building materials according to different environmental indicators. It uses a clever representation to show the most and the less impacting materials. However, it only considers modules A1-A3. As a result, it creates a serious bias towards biobased materials regarding the global warming potential (GWP) impact. Also, not all of these materials can provide the same functionality (e.g. different structural resistance or transmittance), hence preventing their comparison. Reuse-wise, reclaimed materials are often absent from such libraries (with the only exception of the Danish material pyramid which incorporates the case of reclaimed bricks, based on the existing EPD).
Environmental labels *(EU Flower, Blauer Engel, Nature Plus, NF Environnement, Nordic Swan, Milieu-keur, etc.)*
There are many environmental labels that assess certain characteristics of the products to which they are affixed. As for EPD, environmental labelling is regulated. There are, however, different sorts of labels, ranging from self-declaration to labels certified by third-parties. Existing labels can cover a wide range of aspects, from ensuring the existence of a chain-of-custody warranting a sustainable origin (for wood, for instance) to covering health and toxicity aspects. But giving a label to a product does not necessarily means that this is the most ecological choice. Moreover, the LCA is not always included on labels. Reuse aspects are seldom incorporated in the scope of the labels and reclaimed products are rarely labelled (and even less so with third-party certified labels). A notable exception to this statement is the truly reclaimed label (currently under development), which guarantees the truly reclaimed origin of reclaimed products and, in a future iteration, may also include aspects regarding environmental benefits. It can also be noted that a specific version of the FSC-label is certifying the use of recycled or reclaimed content in wooden products and is used by some reclamation dealers.

Table 1: Environmental impacts tools at the material or element scale.

9. For a more detailed overview, see [Passer 2015].

4.2. At the scale of buildings

When it comes to assessing the global environmental impact of a building, the use of LCAs is the most holistic approach. This is indeed considered to be 'the most suitable and objective assessment method to quantify the energy and resource consumption, emission and waste generation and the environmental impacts of a building over its whole life cycle' [Meex et al. 2018].

If these tools are commonplace for researchers specialised in LCAs, their uptake by designers poses a series of challenges. The relatively quick pace of the workflow of designers, especially in early design stages, can be quite intense, with a lot of different scenarios being tested, explored - and sometimes dismissed as quickly. At these stages, designers mostly need indications to support general orientations throughout the complex process of dealing with many different - and sometimes contradictory - constraints. More generally speaking, architects are already managing a lot of aspects and can be reluctant to incorporate yet another layer of considerations - unless they are specifically required to do so.

This need for speed and versatility can be at odds with the inherent complexity of LCAs. As explained above, LCAs can entail tedious data collection, complex interpretations and expert knowledge. This may explain why most LCA-based environmental impact assessment (EIA) tools are rather used in later stages by engineers and specialised consultants for conducting 'a post-construction evaluation of the building' [Meex et al. 2018].

In a recent overview of such tools, Brussels Environment proposes to distinguish 'simple tools' from 'complex' ones. While the former are aimed at providing architects with general guidelines in the design phase, the latter are intended to be used by specialist consultants to assess the environmental performance of a building (usually after its completion). Simple tools usually favour a comparative and iterative approach. They make it possible to compare different options on the spot and thereby to contribute to the progressive development of the project. The interpretation of the results must always be circumstantiated.

SIMPLE TOOLS	Totem (BE), Elodie (FR), Impact (UK), Eco2soft (AU), Eco-bat (CH),), LCAbyg (DK)...
COMPLEX TOOLS	Gabi Build-It, Simapro...

Table 2: Environmental impacts tools at the building scale.

4.3. Perspectives

It is interesting to note that some architects want to adopt EIA tools. Not only because they can help limit the environmental impacts of buildings but also because they could contribute to renewing the architectural discipline more broadly. As pointed out by Carlisle [2017, 174]: 'while LCA is a practice based on hard science, it also supports deep thinking about materials and places. Life cycle assessment provides architects with a means and method to explore a richer narrative about the full history of materials - the mechanisms of their production as well as the landscapes of power, labour, energy, extraction, and transformation that they perpetuate. A close examination of materials does not limit design: it empowers and grounds creative practice.'

Many researchers [Attia et al. 2009; Basbagill et al. 2013; Meex et al. 2018...] and developers of software alike point out the potential of Building Information Modeling (BIM) to support the incorporation of LCAs into designers' everyday workspaces. The possibility of coupling 3D geometric models with sets of information regarding the materials modelled indeed offers a wide range of applications in terms of supporting decision-making, simulating global environmental impacts, etc.

It must be noted that such applications inherently rely on pre-established libraries and databases of information. This may give rise to many questions regarding the source, liability, consistency and relevance of this information. When it comes to fostering reuse practices, one may doubt that such libraries will contain much more information on reclaimed products than, say, current databases of EPDs. Whether these pieces of software will make it possible to model reuse strategies, and how, remains to be seen. The next section of this report offers a first overview on possible approaches.

5. TOTEM tool (Belgium)

5.1. General Information

5.1.1. Creation and future evolution

TOTEM stands for Tool for Optimising the Total Environmental impact of Materials. As the name makes explicit, this Belgian environmental impact assessment tool has been developed to assist the construction industry in modelling and reducing the environmental impacts of buildings. Initiated in 2011, this tool is currently supported by the three Belgian Regions (through OVAM, Brussels Environment and the Walloon Public Service), in collaboration with the federal administration (FPS Public Health). Its development was concurrent to that of a Belgian database of manufacturers' Environmental Product Declarations (EPDs).

Since October 2020, TOTEM has been gradually incorporating the environmental declarations of manufacturers' products into its database, with 31 EPDs already recorded in July 2021. For building materials for which this specific data is not (yet) available, TOTEM uses the generic data from the Swiss database ECOINVENT.

To foster the uptake of this tool by designers, the authorities are providing guidance, training sessions and help desks. The fact that the tool is free also makes it possible to reach a wider audience. Nevertheless, its current use remains voluntary and a regulation enforcing the systematic use of TOTEM is not yet on the political agenda. In a first step, a closer collaboration is envisaged between tools that are already mandatory, such as the EPB-regulation or the GRO guidelines. Nevertheless, the use of the TOTEM tool is gradually becoming increasingly required in the context of public tenders.

At the same time, a "TOTEM design study" premium has been created to encourage designers to use the tool. It aims to financially support (up to €200 per housing unit) the use of a study in TOTEM for the renovation of housing in the Brussels Capital Region.

The tool is still being improved and progressively incorporates new manufacturers' EPDs and circularity aspects into the assessment of buildings. The quantitative assessment (environmental impacts) should be accompanied by a qualitative assessment (circularity) by 2022.

5.1.2. Objectives

The TOTEM tool was developed to meet a double objective:

1. Provide a Belgian framework (adapted to the Belgian construction market) for assessing the environmental impacts of buildings throughout their life cycle.
2. Provide a tool to optimise the architectural choices of Belgian designers in order to reduce the environmental impact of a construction or renovation project. The optimisation is proposed by comparing design variants at element or building levels (e.g. building system, building volume, renovation/construction scenario).

5.1.3. Target group

The tool is mainly intended to be used by designers (architects and engineering offices), but also public authorities and, to a lesser extent, material producers, researchers and students. At present, the tool has 4,400 registered users, including 600 architects who have been specifically trained. Various developments and improvements are regularly identified and will be progressively deployed to extend its use to the sector as well as to incorporate module D in the impact assessment.

5.1.4. Scale

TOTEM allows a project to be modelled, evaluated and optimised at the scale of a building and also at the scale of a building element, both for new constructions and renovation projects. TOTEM currently focuses on residential and office buildings. The library of elements and components therefore mainly concerns these types of building. The components usually consist of a main material and its fixing systems. For instance, the component 'plasterboard' will include the screws, 'bricks' the mortar, 'timber frame' the screws, etc.

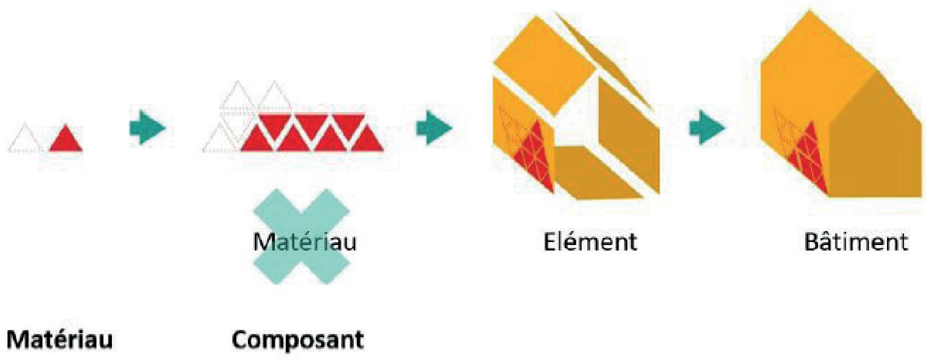


Figure 7: The different scales analysed in the TOTEM tool.

5.2. Methodology

5.2.1. Approach

To develop the comprehensive scientific methodology that serves as the basis of TOTEM, there was an intensive collaboration with universities and study agencies for 5 years. As a result, the TOTEM tool uses an LCA-based methodology that is based on the standard EN 15804-A2 (Sustainability of construction works - Environmental declarations of products - Basic rules for the product group of construction products) and the standard EN 15978:2012 (Sustainability of constructions - Assessment of environmental performance of buildings - Calculation method).

These standards define a uniform framework for assessing the environmental performance throughout the life cycle of materials (called «components» in TOTEM) and buildings. The data used in TOTEM is adapted to the Belgian context via the MMG-methodology [Allacker, 2018]. It considers the entire life cycle of the building (from production of the materials to final disposal), for a reference period of 60 years.

The environmental impact is assessed by a set of 19 environmental impact indicators grouped into 12 main categories (e.g., climate change, ozone depletion, human toxicity, particulate matter formation, etc.). Using the PEF weighting method, these indicators are compiled into an aggregated score which simplifies the decision-making process and comparison of the environmental performance of different alternatives [Sala, 2018].

Central values of TOTEM are objectivity and transparency. This enables actors from the Belgian construction sector to identify and limit the environmental impact of buildings from the very start of the design phase. In order to continue to evaluate the environmental impact of buildings as correctly as possible, the methodology and data on which TOTEM is based are constantly evaluated and optimised.

Figure 8: 12 main categories of environmental impacts.

Is the effect of temporary carbon storage called biogenic carbon taken into account in TOTEM?

> The temporary carbon storage effect on global warming (temporary delaying the concentration of greenhouse gases in the atmosphere) is not taken into account in the TOTEM method. In fact, in accordance with the European standards for life cycle assessment of construction products and buildings (EN 15 804 & EN 15 978), the biogenic carbon balance is considered as zero by the TOTEM method because the quantity absorbed to produce the biobased material is equivalent to the quantity emitted or transferred at the end of its life.
>
> Note: the consideration of biogenic carbon only concerns biosourced materials whose resource renewal rate is rapid. Petroleum products, although derived from natural raw materials but whose formation process is very long (well beyond the human scale), are not included as biogenic carbon sinks.

5.2.2. Results

The environmental impacts of an element or a building are represented in TOTEM at different levels, either through an aggregated total environmental score expressed in "points", or as detailed scores:

- In % distributed by category of element (score at building level)
- In % broken down by component (score at element level)
- With details for the "materials" and "energy" share
- With details by environmental impact indicator
- With details by life cycle stage

The total environmental score is proposed to facilitate comparison between variants. It considers the different environmental impacts which are aggregated into a single score expressed in millipoints per functional unit. This environmental score is obtained by pre-multiplying the scores of each indicator by a specific aggregation factor. The total score is calculated in two steps. First, the environmental indicators are normalised by comparing them to the reference impact (overall impact per person). Then, in a second step, the normalised scores are weighted and summed to obtain the total score. The weighting factors are determined based on stakeholder consultation, factual criteria and expert advice. An additional correction for the reliability of the indicators is also applied to the weighting [Sala, 2018].

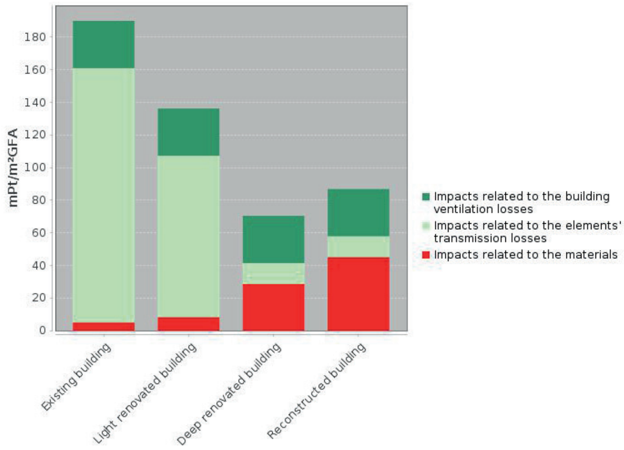


Figure 9: Results at building level with energy-related impact in green and material-related impact in red.

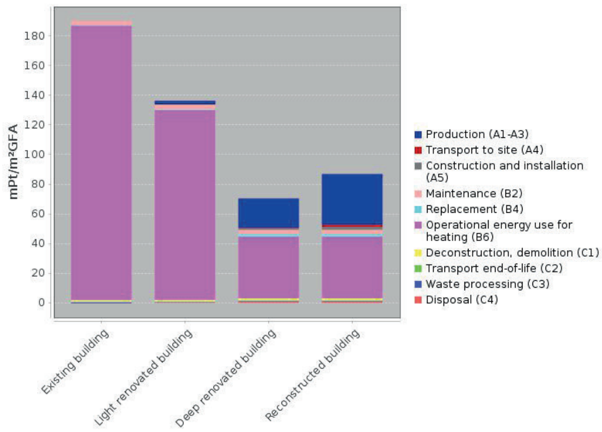


Figure 10: Presentation of impact results by life cycle phase.

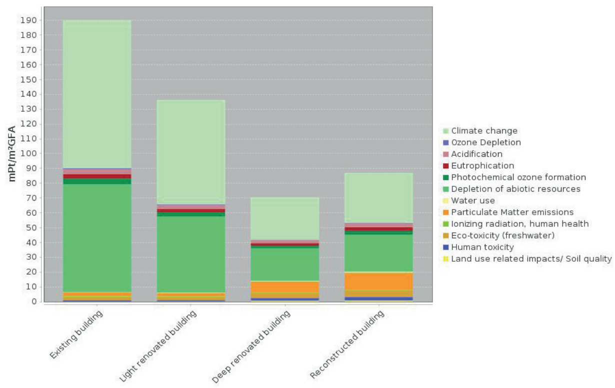


Figure 11: Presentation of impact results by environmental indicator.

5.2.3. Compatibility with other tools

In recent years, a number of tools have been developed to meet the challenges of the sector and the expectations of the market, of which tools for assessing the energy performance of buildings, BIM modelling and digitalisation tools and certification schemes are the most common. Environmental impact assessments are an additional tool to juggle with. It is therefore important to ensure a certain coherence between these tools and above all to avoid burdening designers and engineering offices with double (or even triple) encoding. This is why the development should allow a certain compatibility and operability between tools. TOTEM aims to incorporate this type of approach.

For example, from March 2020, TOTEM can be used for BREEAM certification. More specifically, TOTEM can be used to assess the MAT01 criterion. With TOTEM, the maximum score of "5+ EXEMPLARY" or "6+ EXEMPLARY" (depending on the rating system) can be obtained. Note that the achievement of this result is set by BREEAM in consideration of the tool, based on the methodology applied and the number of elements proposed. There is no requirement for an environmental performance threshold to be achieved as such.

In the same way, the use of TOTEM is also required in the context of GRO, specifically in the MAT2 criterion on the choice of materials in construction projects. The GRO manual is a Belgian sustainability tool to implement a uniform and holistic level of ambition in the sustainable and circular building sector for construction projects. However, this GRO criterion can be validated simply by demonstrating that Totem has been used in an iterative way (alternative solutions must be proposed for the four most impacting elements in the overall environmental balance) but there is no requirement on an environmental score to be reached as such.

Another challenge for the future development of the TOTEM tool is to import the data and calculation methods used in the EPB software developed for the evaluation of the energy performance of buildings (and thus incorporate the energy consumption during the use phase of the building). At the moment this functionality is not yet provided. It should be implemented in 2022. This is also planned for projects modelled in BIM.

5.3. *What about reuse?*

5.3.1. How is reuse incorporated in the tool?

In the current version of the TOTEM tool, the environmental impact is identified over one building life cycle of 60 years. However, depending on the nature of the connections and construction techniques used and the design of the building, parts of a building element could be reused for new construction applications and thus have several life cycles. This reuse potential is not (yet) taken into account (as added value) and is therefore not taken into account in the environmental calculation of the element.

- Nevertheless, the TOTEM tool already partly incorporates reuse into the modelling through the material and component choices. When encoding the building elements and its components and materials, the user can choose for each of the layers among different statuses:
- New (this is the status displayed by default): a new component for which all stages of the material's life cycle are taken into account (and therefore not incorporated into a circular economy).
- Existing: a component present in the project and retained in the same place without any change.

Reused in situ: a component within the project that will be disassembled and reused in another place in the same project (without transport[13]).

- Reused ex situ: a component coming from the reclamation market and dealers in reclaimed materials (thus outside the project).

5.3.2. How is it calculated?

Depending on the status of a component, TOTEM takes into account the impacts of the life-cycle phases. For a new material, according to the TOTEM methodology which follows European standards, the life-cycle phases included in are:

- Production (A1-A3)
- Construction (A4-A5) including pre-transport (A4)

13. Even if elements reused in situ can cause a need for transport (often very low), the TOTEM tool does not consider this step in the environmental balance of these elements (see explanations given in 'How is it calculated').

- Use: maintenance and replacements of a component (B1-B7)
- End of life (C1-C4)

When modelling preservation and reuse scenarios, TOTEM does not refer to a database specific to antique and reclaimed materials (for which data are almost non-existent). As a proxy, it starts from the databases available for new materials (ECOINVENT and EPD’s) but exclude certain cycle phases in the calculation of the impact.

For a material or component coming from the reclamation sector, the impact of the production phase is not considered. According to the reasoning of the LCA standards, it was already taken into account when the building started its first life cycle and should therefore not be reallocated to a new life cycle for the components concerned. So, the assessment only takes into account:

- The preliminary transportation to the site (module A4)
- The construction on site (module A5): the impacts related to this phase are limited to the following aspects:
    - Some execution processes: excavation, energy-consuming processes
    - Material loss: for this purpose, a loss of 5% is assumed for all components.
- The use phase, including maintenance and replacements of a component (modules B). It is assumed that the reused material will have a similar behaviour as a new product (same needs of maintenance, same service life, and same rate of replacement, etc.)
- End-of-life phase (modules C)

For components modelled with the status 'reused in situ’, the transportation stage prior to the construction site will also be deducted from the assessment.

Finally, for components modelled with the status 'existing', only the 'use' stages are taken into account in the environmental impact assessment.

MATERIAL STATUS	***LIFE CYCLE STAGES CONSIDERED IN THE ASSESSMENT OF IMPACTS IN TOTEM***				
	PRODUCTION (A1>A3)	***CONSTRUCTION***		***USE (B)***	***END-OF-LIFE (C)***
		TRANSPORT (A4)	***IMPLEMENTATION (A5)***		
New (EN15978)	X	X	X	X	X
Reused ex-situ		X	X	X	X
Reused ex-situ			X	X	X
Existing				X	X

Table 3: Stages considered in relation to the choice of material status.

The example below presents comparative results between the impact of the different statuses chosen at the scale of an element which is, in this case, a massive wall (26 cm) composed of clay bricks laid on cement mortar; the components that make up the element were modelled in the 4 statuses proposed in TOTEM.

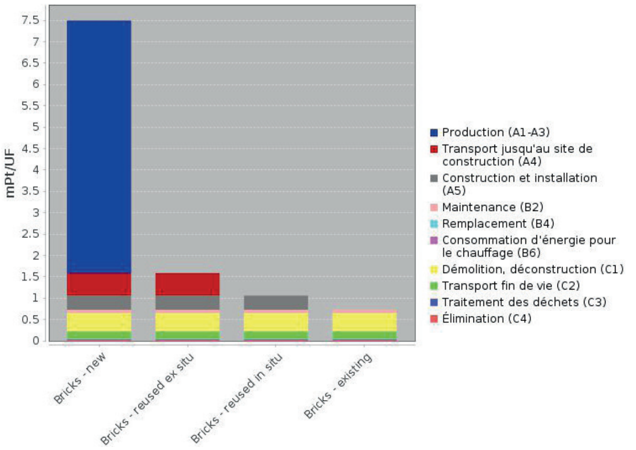


Figure 12: impact of the 4 different statuses for a massive clay brick wall.

Below is another example with results at the scale of a building for which reuse materials have been simulated and which concern: façade bricks, tiles, ceramic tiles (floor), window frames, and external door. Even if it is not as "obvious" as at the element level, the graph clearly shows that reusing materials reduces environmental impacts.

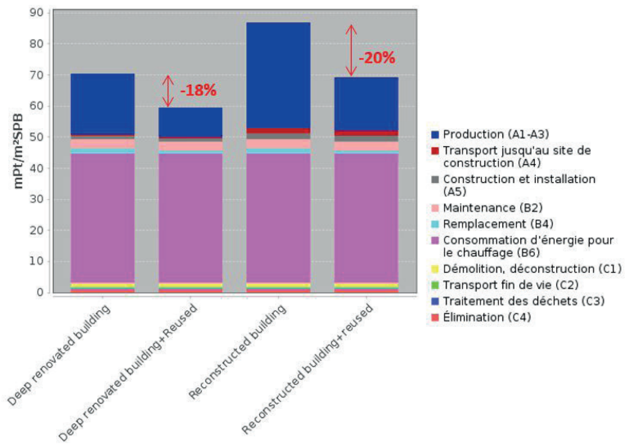


Figure 13: impacts of several scenarios including reuse elements at the building level.

By allowing the choice of reuse options (in-situ or ex-situ) among different status of materials and components, the tool thus incorporates reclaimed materials as an alternative to new materials. It may also raise users' awareness of this possibility in the design process. In addition, the premium introduced to encourage the use of TOTEM design studies for projects also partly encourages the use of reclaimed building materials. The requirements specify that certain steps are to be followed which include the modelling of alternative options for the 4 project elements with the greatest environmental impact. Alternatives such as maintaining existing elements or opting for reuse are put forward. The project should then be adapted considering the most environmentally interesting variant and the project constraints.

The current approach is neither perfect nor complete, but the evolutions of the TOTEM tool aim to further incorporate renovation and reuse, both present and future. Indeed, it is planned to add a qualitative assessment of the reuse potential which would make it possible to take into account the added value of a reversible and circular design that can allow several cycles of use.

6. ELODIE (France)

6.1. General information

6.1.1. Creation and future evolution

ELODIE [Évaluation à L'échelle de l'Ouvrage Des Impacts Environnementaux] is a French environmental impact evaluation tool at the building scale. Initially developed by CSTB in 2008 under the name of ELODIE, it forked in 2021: while the CSTB will continue to develop the LCA calculation core under the name COMENV, another party, Cype, will market the software named 'ELODIE by Cype'.

ELODIE was created with the aim of providing building developers with a tool that assesses the impacts of construction products and equipment present in a building, drawing on the EPDs available in the French national EPD database INIES*. ELODIE also uses generic data from INIES that are developed and updated under the governance of the Ministry of Ecological Transition in France.

ELODIE has been widely used by the CSTB for research purposes in the studies and preparations for the new environmental regulation in France RE2020. It was also used as a tool to assess the Energy-Carbon performance of a building in the E+C- experimentation (associated with the E+C- label) [Naval, 2021].

6.1.2. Objectives

ELODIE was developed to serve as an LCA tool at building scale in order to help building designers and project owners in identifying the environmental impacts generated by their building since the early design stage. The goal is to identify the most impacting components of the project and enable alternative, less impacting scenarios.

6.1.3. Scope

ELODIE can be used to evaluate both new construction and renovation. In 2019, ELODIE's latest version took into account the impacts related to four different aspects of a project development, which are considered to contribute the most to the environmental impacts:

- Contributor 1: Construction Products and Equipment
- Contributor 2: Energy consumption
- Contributor 3: Water consumption and discharge
- Contributor 4: Construction site impacts related to water, energy, waste and transport

6.1.4. Target group

ELODIE is a voluntary licence-based online tool used by LCA researchers, design offices, architects, project managers and environmental offices in France. It is a collaborative tool that allows sharing projects easily between design teams. For the past 10 years ELODIE has had 1,500 active users with professional as well as student licences.

6.1.5 Scale

As mentioned before, ELODIE's model focuses on four different aspects of a building development including new and renovation projects. Each aspect, also called 'contributor', entails a specific range of LCA phases that are taken into account:
The impacts related to construction products and equipment. These are considered all the way down from their product phase (A1-A3) to their end-of-life (C1-C4).

The impacts related to the energy consumption, which are considered during the use-phase of the building (B1-B7).

The impacts related to water consumption and discharge, which are also considered during the use-phase of the building (B1-B7).

The impacts related to the construction works, which are considered during the construction phase (A4-A5).

This is illustrated in the figure below:

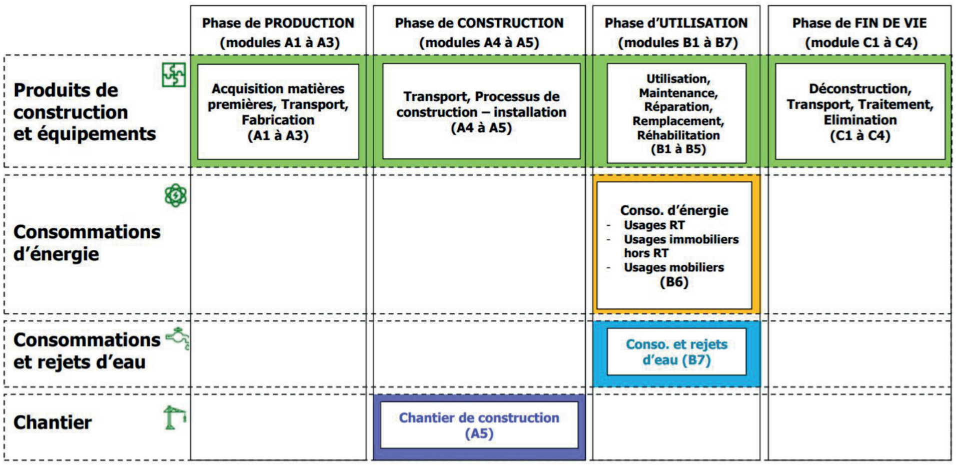


Figure 14: Specific range of LCA phases taken into account considering four 'contributors'.

As far as construction products and equipment are concerned, ELODIE uses a by-default classification of construction batches and sub-batches (lot et sous-lot), which is in line with the E+C- nomenclature. However, users always have the possibility of adding a batch or a sub-batch specific to their project. Users are invited to select an EPD and classify it under each batch or sub-batch.

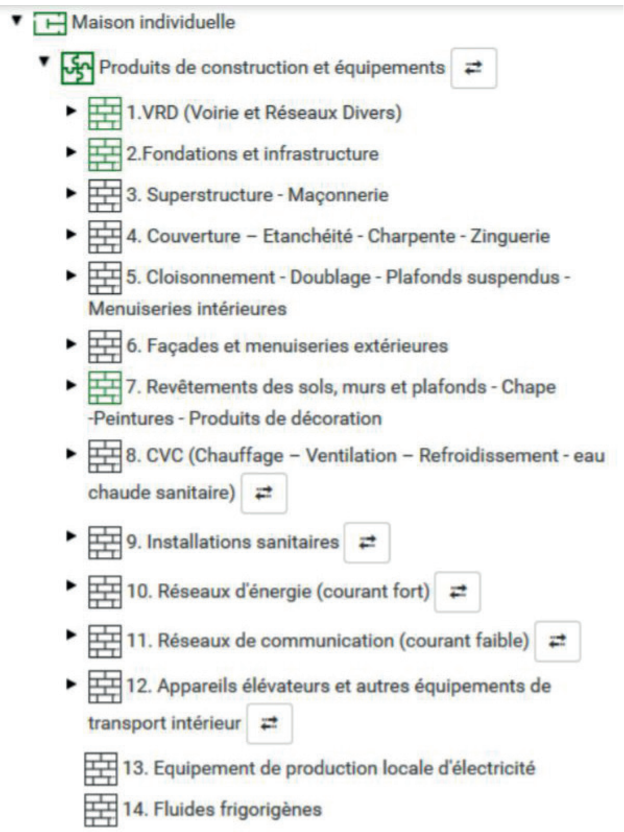


Figure 15: E+C- nomenclature for construction batches.

6.2. *Methodology of the tool*

6.2.1. Approach

The version of ELODIE in 2013 used a calculation method compatible with the French national regulation RT2012 for the calculation of environmental impacts generated by a construction project. In the preparatory phase of the new national environmental regulation RE2020, the E+C- research experimentation took place in France to develop the LCA method to be adopted.

As a result, the LCA calculation method used in ELODIE evolved to be compatible with that to be used for the RE2020. Hence the approach used in ELODIE is in constant evolution to ensure compatibility with national regulations.

The EPDs present on the French EPD database INIES, and that are used in ELODIE to model and characterise project components, are compatible with the national complement of the standard EN 15804 (Sustainability of construction works - Environmental declarations of products - Basic rules for the product group of construction products).

After modelling a project in ELODIE, the environmental impacts of the project are assessed by LCA indicators calculated according to the national complement of the standard EN 15804, in addition to two indicators exclusive to the E+C- methodology that determine the 'carbon level' of the project:

- Eges: greenhouse gas emissions over the entire life cycle of the building and at the product level accordingly, and
- EgesPCE: a zoom on the greenhouse gas emissions related exclusively to the Products of Construction and Equipment (PCE).

6.2.2. Results

The results of the environmental impacts in ELODIE are presented in the form of the indicators mentioned above, each in its corresponding unit. The results can be presented for each of the four contributors apart or aggregated. It is also possible to express the distribution of each indicator between the different sub-levels (project zone, contributor, batch, sub-batch, and element). The results can be represented in the form of a table and in the form of a graph as shown in the figures below. The results can also be exported to an Excel file.

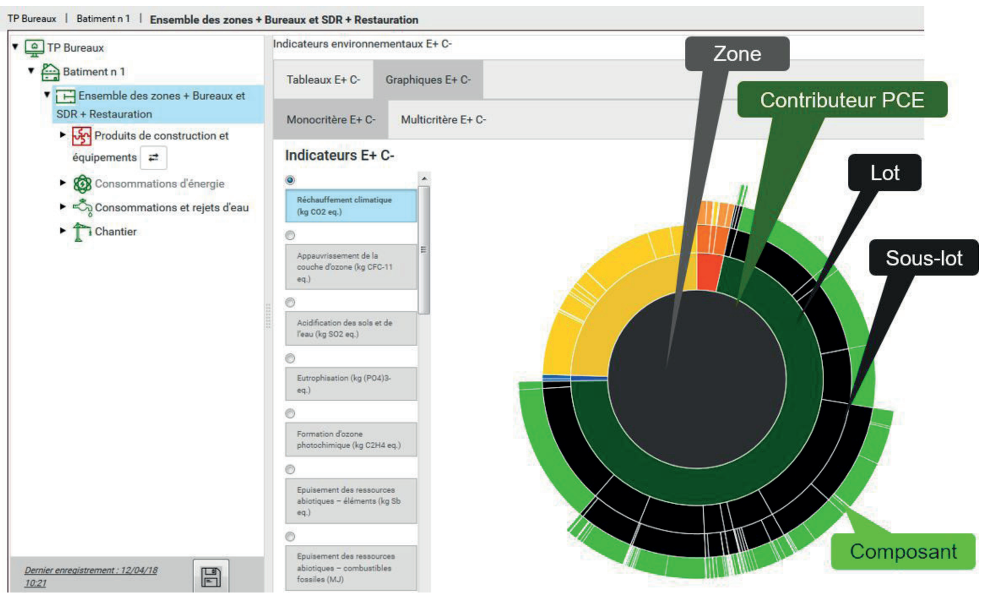


Figure 16: Distribution of the different sub-levels considering one indicator (monocriteria: global warming).

Figure 17: Another type of graph generated considering several indicators and sub-levels (multi-criteria).

Indicateurs environnementaux E+ C-   Afficher les phases optionnelles

Tableaux E+ C- | Graphiques E+ C-

Impacts environnementaux | Consommation des ressources | Déchets | Flux sortants

	Étape de production	Étape du processus de construction	Étape d'utilisation	Étape de fin de vie	Total cycle de vie
Réchauffement climatique (kg CO2 eq.)	5.53e+1	4.58e-1	-	3.30e-1	3.55e+4
Appauvrissement de la couche d'ozone (kg CFC-11 eq.)	1.38e-5	2.14e-9	-	8.43e-9	6.94e-5
Acidification des sols et de l'eau (kg SO2 eq.)	9.06e-2	2.11e-3	-	1.26e-3	1.28e+2
Eutrophisation (kg (PO4)3- eq.)	2.22e-2	1.23e-3	-	1.43e-3	1.24e-1
Formation d'ozone photochimique (kg C2H4 eq.)	9.78e-3	1.50e-4	-	9.81e-5	1.30e+1
Epuisement des ressources abiotiques – éléments (kg Sb eq.)	2.05e-2	1.93e-8	-	2.13e-8	1.03e-1
Epuisement des ressources abiotiques – combustibles fossiles (MJ)	5.75e+2	6.41e+0	-	4.71e+0	2.93e+3
Pollution de l'air (m³ d'air)	1.04e+4	7.27e+1	-	3.73e+1	5.28e+4
Pollution de l'eau (m³ d'eau)	4.66e+3	3.41e+1	-	3.91e+1	2.70e+4

Figure 18 Results generated in the form of a table of LCA indicators calculated for the project under study .

6.2.3 Compatibility with other tools

As mentioned above, ELODIE produces the results of the project evaluation in line with the label E+C-. It is possible to calculate the indicators related to the GHG emissions and energy performance levels attained for the E+C- label as shown in the figures below:

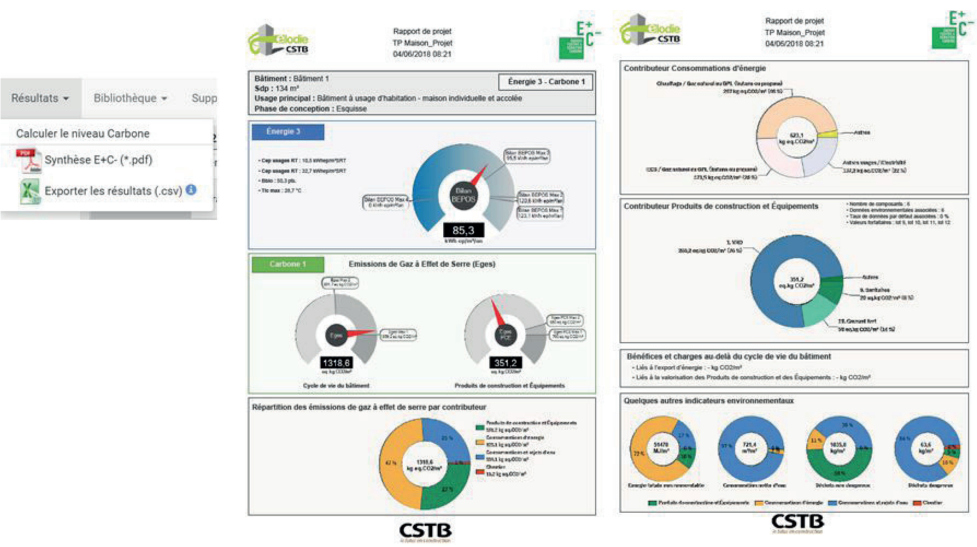


Figure 19: Indicators related to the GHG emissions and energy performance levels attained for the E+C- label.

6.3. What about reuse?

6.3.1. How is reuse incorporated in the tool?

In the existing version of ELODIE, reuse is not directly taken into account. As the environmental data related to project elements is directly extracted from the French EPD database INIES, associating an EPD of a reclaimed product is currently the only way to model the benefits of reusing building materials. It should be noted that EPDs of reclaimed products are very rare to find on INIES. Therefore, in practice, reuse is not much present in the current version of ELODIE.

6.3.2. Potential of evolution with the RE2020

In the new building environmental regulation RE2020 in France, the impact of reclaimed products reused in a building is to be considered as zero in the calculation of the impact at the building level. Accordingly, an update of calculation methods is expected to take place in order to incorporate reuse in existing building environmental impact assessment tools in France like ELODIE. The creation of specific reuse EPD in the national database INIES may be considered in order to help model a project that incorporates reclaimed products.

6.3.3. The label 'Label bas-carbone' and reuse

In France, the label 'Label bas-carbone'[14] was developed in 2019 by the ministry of Ecological Transition in the aim of achieving France's national objectives in reducing GHG emissions in different sectors (agriculture, transportation, forestry and others). Recently, the CSTB collaborated with the ministry as well as other partners to develop a methodology[15] to apply this label to renovation operations with an objective to encourage project stakeholders to incorporate reclaimed products in all types of renovation projects. The methodology also applies to energetic renovation projects that incorporate low carbon products. The renovation project that targets this label is awarded with a financial compensation depending on the impacts (in kgCO2e) reduced due to the use of reclaimed or low carbon products.

14. https://www.ecologie.gouv.fr/label-bas-carbone
15. https://www.ecologie.gouv.fr/sites/default/files/M%C3%A9thode%20r%C3%A9novation%20label%20bas%20carbone%20%20240621.pdf

7. MPG tools (The Netherlands)

7.1. General Information

7.1.1. Creation and future evolution

The **Dutch environmental performance calculation** (MPG 'Milieuprestatie Gebouwen') is a crucial standard for determining the sustainability of buildings in the Netherlands. It is used to measure the environmental impact of all materials present in buildings. A calculation of the MPG is compulsory in the Netherlands for new residential buildings and office buildings larger than 100m².

The MPG calculates the environmental impact of buildings and makes the impacts visible in a single monetised score, expressed in euro per square metre gross floor area (GFA) per year. The scope is limited to embodied impacts of the building products, since the operational energy use is not included in the MPG score. This means that a lower the MPG score indicates a more sustainable material usage in buildings (also called the shadow price of a building).

The MPG score is determined according to a national standardised methodology, called the '**Bepalingsmethode Milieuprestatie Gebouwen**' (Determination Method) [SBK, 2020a]. This Determination Method is a uniform measurement method for calculating the material-related environmental life cycle impact of construction works in an unambiguous, verifiable and reproducible way. The environmental performance of various designs can be compared with the aim of reducing the total environmental impact of a building. The method has existed since 2012 and has been developed and adapted over the last 10 years in close collaboration with the building industry, designers, the national government, software developers, etc.

In parallel, the **National Environmental Database** (NMD) was established, containing **product cards, item cards and base profiles** for both buildings and infrastructure works. The product files include data on environmental profiles and quantities that are used in the construction design. The NMD was established to ensure the verifiability of the environmental data submitted by producers and to ensure uniform use of the data when calculating the environmental performance, and is thus consequently linked with the Dutch Determination Method. NMD has set up a verification protocol to assess the conformity of the environmental data provided by producers willing to incorporate the database. The NMD Foundation is responsible for managing and maintaining the database, including quality assurance of the environmental data supplied [SBK, 2020b].

The maximum MPG score in the Netherlands has been set to 1.0 Euro/m² GFA/year in 2018 for new residential buildings and office buildings larger than 100m². From the 1st of July 2021, new residential buildings have to comply to a maximum score of 0.8 Euro/m² GFA/year. Furthermore, the aim is to support circular construction by gradually diminishing the maximum MPG score from €1.0 towards €0.5/m² GFA/year by 2030 for both offices and residential buildings[16].

The MPG environmental performance can be determined by means of **free software** (MPGcalc, MRPI MPG software) or **commercial calculation instruments** (e.g. GPR Materiaal, One Click LCA) that have been pre-validated by the NMD Foundation. The overview of the list of validated calculation tools is updated and published regularly[17]. By validating commercial tools based on the MPG calculation method, tool developers are stimulated to provide better and more user-friendly tools as building practitioners can choose what tool is most suited for their particular needs. The main drawback is the need to implement a validation procedure to ensure the comparability of the LCA results between the different LCA tools [Trigaux, 2021].

Today it is being examined if the environmental MPG requirements can be extended to other building functions and to renovation of buildings. Also, further adaptations in the MPG calculation method are studied concerning e.g. the incorporation of the effects of CO2 storage in biobased materials (like wood).

16 https://www.rijksoverheid.nl/actueel/nieuws/2021/03/11/milieuprestatie-voor-gebouwen-wordt-1-juli-2021-aangescherpt
17. https://milieudatabase.nl/milieuprestatie/rekeninstrumenten

7.1.2. Objectives

The Milieuprestatie Gebouwen (MPG), its Determination Method and the National Environmental Database were developed to:

- Provide a standardised and uniform measurement method to calculate the environmental performance of buildings (MPG score) in a compulsory Dutch building regulation framework;
- Provide a measurement method that enables designers, policy makers, etc. to compare the environmental life cycle impact of different building solutions and to diminish the environmental impact of buildings, by optimising the building design at product and material level;
- Make a method available to builders and developers to make agreements about the quality level of a building project, whilst offering flexibility for innovative solutions.

7.1.3. Target group

A calculation of the MPG is compulsory in the Netherlands for all new residential buildings and office buildings larger than 100m². Therefore, the main target group of (tools that enable to calculate) the MPG score are building practitioners like architects, engineering and consultancy offices (e.g. LCA consultants), building developers and public authorities.

The MPG environmental performance calculation is a tool that, on the one hand, enables one to check if the MPG score of the buildings remains under the defined national benchmark and, on the other hand, acts as an objective support in the design process of buildings and the choice of building materials. The environmental performance calculation can be a support in sustainable decision-making in e.g. the client's brief or procurement requirements in order to lay down the result of a design process between architects, engineers, contractors, etc.

Besides the free available MPG software tools, commercial software developers provide alternative MPG calculation tools for specific actors with additional calculation or representation features, like GPR Materiaal (W/E adviseurs), One Click LCA (Bionova), MPG Toetshulp (Bimpact BV). From the 1st of January 2021 on, all MPG calculations need to be in line with the latest update of the Determination Method 1.0 [SBK, 2020a][18].

7.1.4. Scale

Depending on the **software tool** a project can be modelled, evaluated and optimised at the scale of building materials, building elements or at building level. The free MPG tools focus on a canvas for solutions in new construction (residential and office buildings), whilst commercial tools may incorporate a wider set of building functions. In line with the current compulsory framework, today, the Dutch LCA database (NMD) mainly contains product and items cards of building solutions that are applied in the residential construction or for offices.

In the product information, the impact of auxiliary materials and fixings are included in the impact of components. However, fixings are not usually described in detail. The incorporation of more details on the type and number of connections could however support the evaluation of future scenarios for (future) reuse or recycling.

18. Not all available (free) tools have been aligned with the last update, meaning they cannot be used for official calculations of the MPG score (until a new version is available).

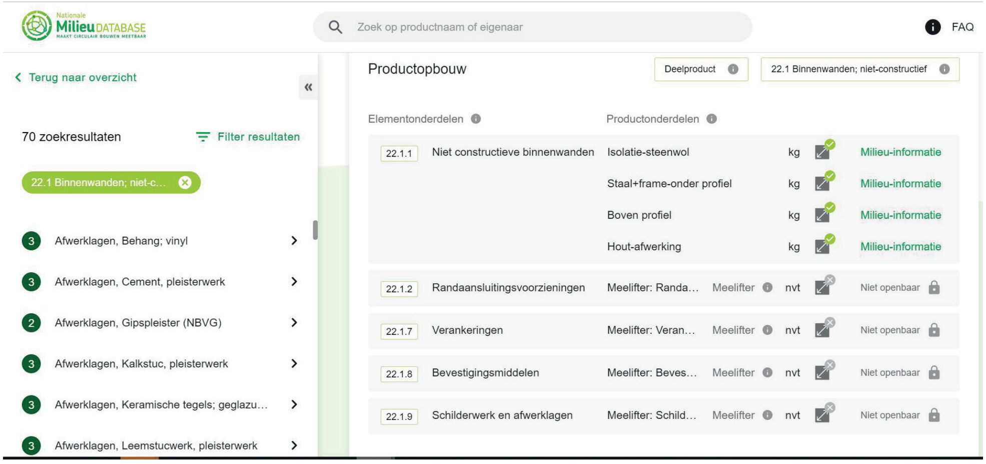


Figure 20: Example of a product assembly in the NMD[19].

7.2. Methodology

7.2.1. Approach

The national calculation method MPG is made up of two main parts; rules for making life cycle analyses of construction products (EPD) and rules for making an environmental performance calculation at building level.

MPG uses an LCA-based methodology that is based on the standard EN 15804 (Sustainability of construction works - Environmental declarations of products - Basic rules for the product group of construction products). This standard is incorporated for the determination of the environmental performance of construction works and supplemented with scenarios that are applicable to the Dutch context [SBK, 2020a]. As of July 2021, the new Determination Method 1.0 has been incorporated in the Building Decree, meaning that the rules for LCAs have been updated to reflect the revision of the European assessment method[20].

The Determination method considers the entire life cycle of the building (from production of the materials to final disposal), for a reference period of 50 or 75 years, depending on the building function (e.g. 50 years for an office building, 75 years for a residential building)[21]. The operational energy of the building is not included in the MPG calculation.

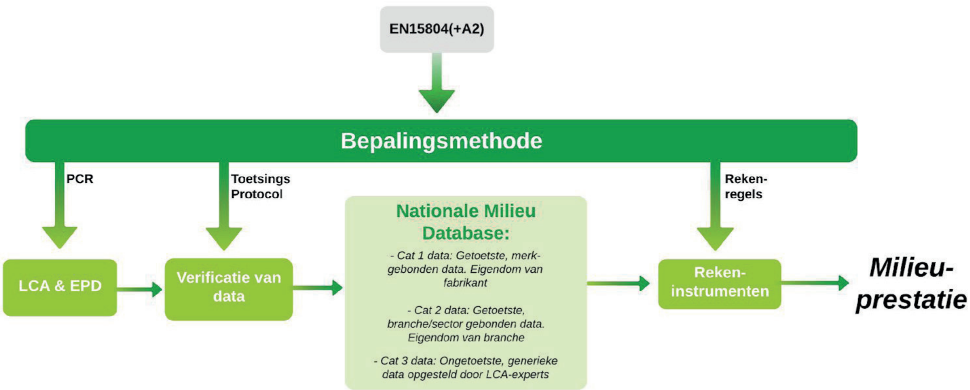


Figure 21: Visualisation of the links between the two databases of NMD, the Determination Method, the calculation tools and the MPG score (SBK 2020a).

19. https://viewer.milieudatabase.nl/producten
20. https://www.lbpsight.nl/nieuws/waar-staan-we-met-de-mpg
21. It is allowed to use an alternative value, if substantiated and justified. In case of a deviating service life, the 'Specific Building Service Life Guideline; addition to the Determination Method Environmental Performance Construction Works' may be used. In addition, ISO 15686-8 can be used, which provides further academic guidelines for calculating the estimated service life using the factor method.

The result of the environmental performance calculation is an environmental profile which, until recently, comprised eleven environmental impact categories (in accordance with EN 15804+A1) including e.g. depletion of raw materials, the greenhouse effect, and depletion of the ozone layer [SBK, 2020].

The single score of MPG is calculated by multiplying the results of the LCA (the environmental impacts per category) with weighting factors, and dividing the aggregated result by the Gross Floor Area and the lifespan of the building. The weighting factors are determined on a member state level (based on prevention cost) and indicate the (relative) severity of the environmental effects.
The Determination Method is amended according to the EN15804+A2 as from 1 July 2020. This means that the Determination Method uses the prescribed environmental profile with nineteen environmental impact categories[22].

Impact category	Indicator	Unit
Climate change – total	GWP-total	kg CO2-eq.
Climate change – fossil	GWP-fossil	kg CO2-eq.
Climate change – biogenic	GWP biogenic	kg CO2-eq.
Climate change – land use and change to land use	GWP-luluc	kg CO2-eq.
Ozone layer depletion	ODP	kg CFC11-eq.
Acidification	AP	mol H+-eq.
Freshwater eutrophication	EP freshwater	kg PO4-eq.
Seawater eutrophication	EP-seawater	kg N-eq.
Land eutrophication	EP-land	mol N-eq.
Photochemical ozone formation	POCP	kg NMVOC-eq.
Depletion of abiotic raw materials, minerals, and metals	ADP-minerals&metals	kg Sb-eq.
Depletion of abiotic raw materials Fossil fuels	ADP-fossil	MJ, net cal. val.
Water use	WDP	m3 world eq. deprived
Fine particulate emissions	Illness due to PM	Illness incidence
Ionizing radiation	Human exposure	kBq U235-eq.
Ecotoxicity (freshwater)	CTU ecosystem	CTUe
Human toxicity, carcinogenic	CTU human	CTUh
Human toxicity, non-carcinogenic	CTU human	CTUh
Land-use related impact/soil quality	Soil quality index	Dimensionless

Figure 22: Environmental impact categories in accordance with the Determination Method valid after 1 January 2021 (SBK 2020a).

Also, the MPG method uses the **National Environmental Database** (NMD) in its calculations. In addition to p**roduct cards, item cards and base profiles**, the NMD includes an LCA database of raw materials and background processes, based on Ecoinvent and adapted for use in the context of the assessment method (process database). In addition to data on environmental impact categories, the NMD also includes environmental data relating to the reuse and recyclability of the materials, as well as the use of primary and secondary raw materials in products placed on the market[23]. This information is retrieved from LCA reports.

The product cards in the NMD are defined in **3 categories**: (1) data declared by a producer (EPD), (2) data declared by a group of producers (collective EPD), and (3) generic data. The Dutch EPD program operator MRPI (Environmentally Relevant Product Information Foundation (MRPI)) offers manufacturers the opportunity to publish an MRPI-EPD certificate on the basis of the Determination Method which can then be included in the NMD.

22. EN 15804 was amended in 2019 and, in terms of its methodology, harmonized with the LCA methodology of the PEF (Product Environmental Footprint) methodology of the European Commission (NEN-EN 15804:2012+A2:2019).
23. https://milieudatabase.nl/de-nmd-en-circulariteit/

7.2.2. Results

The representation of the results of the MPG calculation depends on the calculation tool (public or private) as the functionalities provided by commercial software developers can be more extended than the free tools.

The MPG score is generally calculated and represented as a single score at building level. Using a single-score indicator, expressing the environmental performance of the building, makes it easier to compare the calculated MPG score to the defined compulsory benchmark(s), but also to compare performances of different building variants [SBK, 2020a].

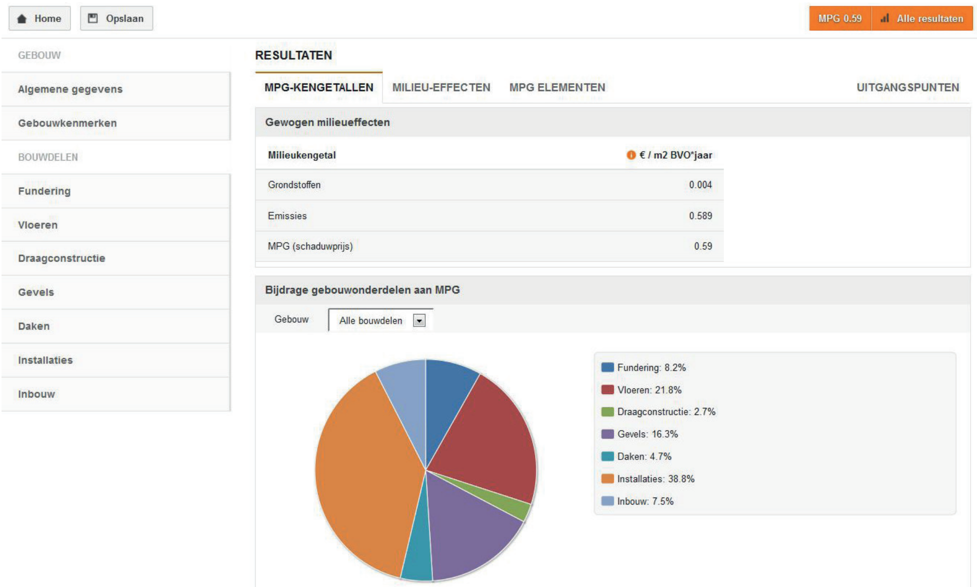


Figure 23: Representation of MPG calculation results via the GPR Gebouw / Bouwbesluit calculation tool[24].

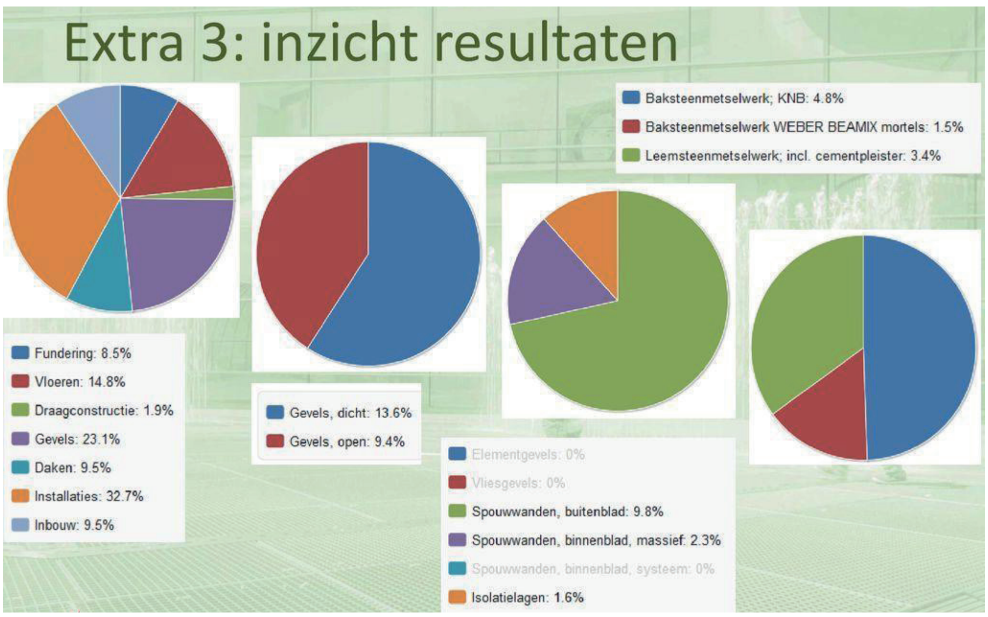


Figure 24: Representation of the repartition of the environmental impacts at different building levels in the GPR Bouwbesluit calculation tool[25].

24. https://www.w-e.nl/milieuprestatieberekening/
25. https://slideplayer.nl/slide/13732867/

Furthermore, the MPG calculation results of a project can be represented at different levels/ detail:

- In % distributed by category of element (score at building level)
- In % broken down by component (score at element level)
- With details by environmental impact indicator
- With details by life cycle stage

For instance, a representation is possible as the repartition (%) of the impacts between different buildings elements (e.g. foundations, floors, structure, façade, roof, installations, infill, etc.). Commercial software providers/developers enable an additional representation of detailed information related to the environmental impacts, e.g. at product level or by life cycle stage.

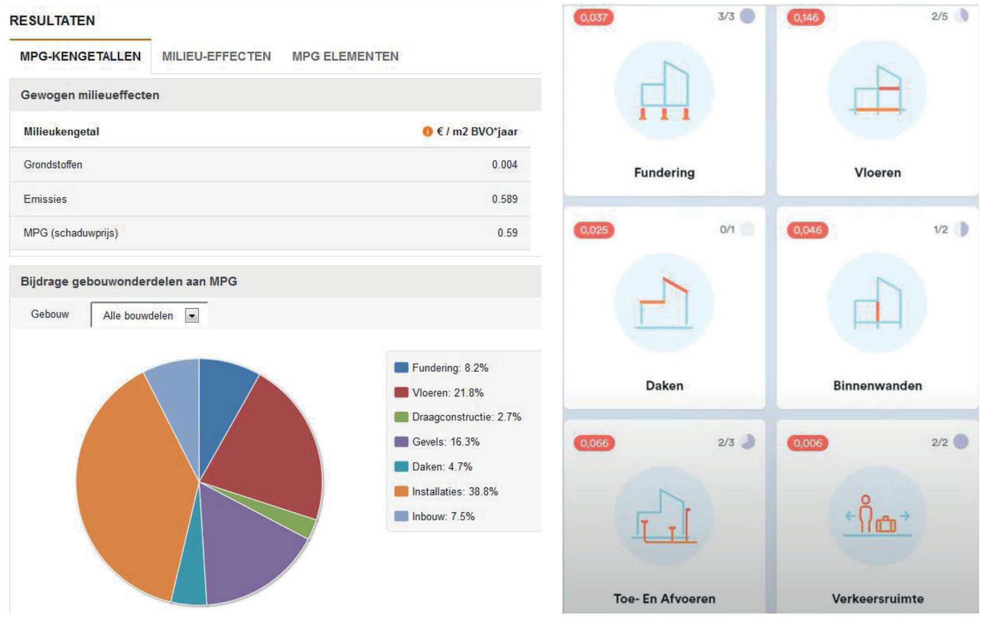


Figure 25: Representation of MPG calculation results via the GPR Gebouw / Bouwbesluit calculation tool (left)[26] or in the GPR Materiaal tool (right) [27].

Figure 26: Representation of the results of the MPG calculation per life cycle stage in the GPR Materiaal tool[28].

26. https://www.w-e.nl/milieuprestatieberekening/
27. https://www.youtube.com/watch?v=okz0yPg5sT4&ab_channel=W%2FEadviseurs
28. https://www.youtube.com/watch?v=okz0yPg5sT4&ab_channel=W%2FEadviseurs

7.2.3. Implementation of the Determination Method in regulations

The Determination Method is applied in various Dutch sustainable building schemes, such as certification in accordance with the Dutch certification method BREEAM-NL and the Dutch sustainability level GPR Gebouw. In both, the Buildings Decree and in the event of certification in accordance with BREEAM-NL and GPR Gebouw, the requirements and quality levels are imposed on the user function (functional unit) and not on the physical object to which the Determination Method relates [SBK, 2020b]. For instance, an MPG reference requirement is set in the BREAM-NL to score additional points: the MAT01 (Building Materials) criterion is assessed by means of an MPG calculation[29].

From a European perspective, the Dutch Determination Method support the action plans concerning circular economy strategies. It can be positioned as a life cycle assessment as referred to in 'A new Circular Economy - Action Plan for a Cleaner and More Competitive Europe' and it can be linked with the level 2.4 'Life Cycle Assessment' (impact/m²/year) of the European project LEVEL(s) [SBK, 2020b].

7.2.4. Compatibility with other tools

The development of MPG tools in terms of compatibility and operability between tools is also explored and developed in the Netherlands. A compatibility is developed between the MPG and BIM functionalities in a number of private MPG software tools. For instance, the 'MPG Toetshulp' application, part of the Dutch validated calculation tools ensures that the MPG calculation can be automatically generated from the underlying BIM model[30]. With an add-on linked to Revit, the environmental performance can be calculated without manually transferring data from the BIM model to the calculation tool.

7.3. What about reuse?

7.3.1 How is reuse incorporated in the tool?

In general, the Determination Method aims to include the benefits of reuse of existing structures, products, and building installations today and in the long term, as it recognises reuse as an important driver for circular construction.

Today, as in TOTEM, the MPG environmental performance is identified over one single building life cycle for a defined service life that depends on the building function (e.g. 75 years for residential buildings). The benefits of reusing building parts or products multiple times in the future during this life cycle (e.g. during building adaptations) is not included in the evaluation methodology.

However, having the modular structure of EN 15804, the Determination Method and the NMD offer the possibility of drawing up LCA reports in order to include, in a uniform manner, the high quality of reuse and recycling in input streams in performance declarations for construction products and installations. This enables a market-driven incentive for the recovery of construction and demolition waste and its material-specific fractions to be provided and supported. As in Totem and in line with the recent French regulation, the LCA environmental data for reused structures, products, and building installations are free of environmental burden at input level in accordance with Appendix III to the Determination Method Environmental Performance Construction Works [SBK, 2020b].

At the level of the entire life cycle, future benefits of reuse of building products can already be included at output level in the module D (Module D: Reuse, recovery and recycling potential). However, this module is not yet (often) used.

Also, only a limited number of product cards in the NMD include reclaimed building materials. It is expected that the NMD database will be further completed with additional product cards and data in the future which will also include environmental data relating to the future reuse (and recyclability) of the materials, as well as the use of primary and secondary raw materials in products placed on the market [SBK, 2020b]. This extension of the NMD database including more reclaimed (or reusable) building products is crucial to enable to include and assess the benefits of reuse in the modelling and calculation of the environmental performance of buildings by means of the MPG method.

29. For instance, 8 points can be gained when the environmental impact of the building materials is 60% lower than the reference value.
30. https://www.bimpact.nl/toetshulpen/

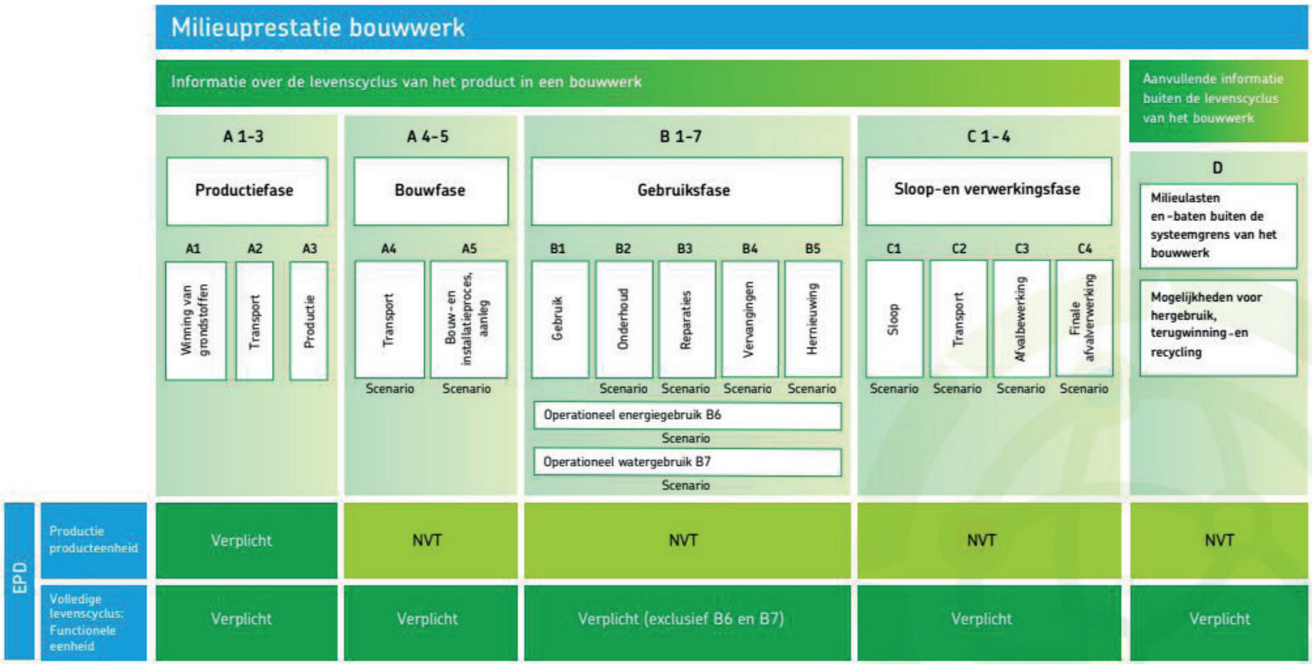


Figure 27: Considered life cycle stages in the EPD's [SBK, 2020a].

7.3.2 How is it calculated?

For new materials, the MPG calculation follows the European standards, including the following life cycle phases:

- Production (A1>A3),
- Construction (A4>A5) including pre-transport (A4),
- Use: maintenance and replacements of a component (B1>B5)
- End of life (C1>C4)
- Reuse, recovery and recycling potential (D)

For reused materials, the NMD starts from available databases for new materials (e.g. based on EPD's) and excludes the impacts of the life cycle phases that are avoided by choosing reclaimed components.

In order to evaluate the future reuse of building products, additional information is required regarding connection methods, the technical service life, the durability of the product, economic value, etc. These information sets should be further included in the product information (by e.g. product manufacturers) in order to enable to evaluate the benefits of future reuse potential of our buildings assembled today.

	LIFE CYCLE MODULES ACCORDING TO EN 15804: 2012 +A2 (CEN 2019)														
	A1-A3: PRODUCT STAGE	A4 :TRANSPORT TO SITE	A5: CONSTRUCTION, INSTALLATION PROCESS	B1: USE	B2: MAINTENANCE	B3: REPAIR	B4: REPLACEMENT	B5: REFURBISHMENT	B6: OPERATIONAL ENERGY USE	B7: OPERATIONAL WATER USE	C1: DECONSTRUCTION, DEMOLITION	C2: WASTE TRANSPORT	C3: WASTE PROCESSING	C4: WASTE DISPOSAL	D: REUSE, RECOVERY AND RECYCLING POTENTIAL
MPG: NEW	X	X	X	X	X	X	X	X			X	X	X	X	X
MPG: reused ex situ		X	X	X	X	X	X	X			X	X	X	X	X
MPG: reused in situ			X	X	X	X	X	X			X	X	X	X	X

Table 4: Life cycle modules that are incorporated in the MPG calculation for new and reused products / materials.

Conclusion

This report aimed to analyse how existing EIA tools incorporate and model reuse strategies in building projects. It made the hypothesis that such tools can be an important lever to accompany the development of reuse practices in the building sector, provided they clearly embed this aspect in their functioning. Reversely, failing to incorporate reuse considerations into EIA tools would result in preventing designers, specifiers and decision-makers in general from adopting more systematic reuse habits - resulting in a huge loss of opportunity for reducing the environmental impacts of the sector.

This brief overview showed that these tools touch on relatively new subjects and still raise many questions:

- From a methodological point of view, beyond the enforced standards, there is no consensus on how reuse strategies should be modelled through LCA methods. This question still raises many issues (e.g. regarding allocating burdens and credits, modelling avoided impacts, incorporating the time aspect and dealing with uncertainties), which are currently being discussed by an active part of the scientific community [Vandervaeren et al., 2019].
- From a practical point of view, most of EIA tools hinge on databases of environmental declarations which, for the moment, hardly include any data for reclaimed materials. The format and the conditions for establishing such declarations are difficult to match with the specifics of the reclamation sector. As a paradoxical result, very low impacting products are largely absent from these libraries of environmental impact declarations.
- Finally, in terms of software development, it is complicated to find the right balance between user-friendliness (an important condition for the adoption of these tools by designers) and the consistency of the approach, which needs to be transparent, reproducible and verifiable (especially when AIE tools get incorporated into public policies).

All these aspects call for specific developments on their own, which are beyond the scope of the present document.

Despite these major obstacles, some tools are already being developed. In this report, we analysed three of them more thoroughly:

- TOTEM (Belgium)
- ELODIE (France)
- MPG (the Netherlands)

Interestingly, two (TOTEM and MPG) had already found a workaround for incorporating reuse strategies into the model (same-site reuse and use of reclaimed materials bought from the reclamation market). They bypass the lack of data for reclaimed products by using data from equivalent new products and deducing specific modules from the global impact assessment (namely product phase and/or transport). As with any workaround, it is still imperfect and has many limits. For example, it does not yet incorporate the perspective of possible future reuse(s) or the impact of prior demolitions. Nevertheless, the evolution of the TOTEM tool plans to incorporate these two aspects. Progressive advances and improvements are to be expected in order to better incorporate reuse into these tools.

However, that reusing is explicitly mentioned and encouraged in these tools should be seen as an important and valuable step. Especially in the context of modelling iterative design scenarios, it clearly encourages designers to consider retaining and reusing existing elements (be it on site or from the reclamation market). Since this workaround deduces impacts from new products declaration, reusing materials will always lead to a better score than new materials. This general message has the merit to be clear and coherent - even though the underlying methodology can still be discussed.

The focus on these three AIE tools should not overlook the overall global development of such tools in recent years. Indeed, a variety of tools are currently available on the market. They present different profiles on a wide range of aspects:

- Developing organisations: public (in which case they are usually free), private (in which case they are usually paid for), or a mix of both (public/private partnership).
- Format: online software platforms, plug-

ins for modelling software (e.g. Tally on Revit), etc.

- Expression of the results: aggregated or not, monetised, expressed in millipoints or other forms of scoring systems.
- Analysed aspects: single indicator (such as the contribution to global warming) or multiple indicators.
- Scope: from the scale of the building elements to the building as a whole, including different life stages, etc.

This multiplication of EIA tools can be seen as a consequence of the building industry increasingly incorporating environmental considerations (although it remains to be seen how these tools effectively influence design choices in practice). However, it raises questions as to the choice of methodology and how the databases of information are populated. It seems desirable to set coherent frameworks ensuring transparency and avoiding 'black box' phenomena. Another important issue will be the coordination of these multiple tools at a regional or national level. Public authorities certainly have an important role to play here.

In essence, reuse and holistic analyses of the environmental impacts of buildings clearly share a common horizon: reducing the environmental damage of the construction sector and adopting more sustainable use of existing resources. This report gives hope that future EIA tools will increasingly build on this complementarity, delivering tools that are manageable, reliable, efficient ... and reuse-oriented!

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