Resource and material passports

as central instruments for the future of the construction industry and how their application generates added value

Experience from eight years of development and application

EPEA GmbH - Part of Drees & Sommer

Pascal Keppler, Fenja Kamps, Peter Mösle

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MANAGEMENT SUMMARY

Resource and material passports are a prerequisite for funding, financing or certification in many situations. In addition, there are limit values that must be complied with in the individual indicators of the resource passports. This introduction could change the construction industry as fundamentally as the introduction of the energy certificate, since for the first time, recyclability will be included as a mandatory criterion in the choice of materials.

In order to comply with emerging requirements such as the EU taxonomy and the German BEG subsidy, planning must be optimized on the basis of resource passports. As long as these are not digitized and harmonized in form and methodology, this means a considerable additional effort for planners and builders.

Since EPEA has already been creating material passports (in the form of the Circularity Passport®) for eight years and has been able to gather in-depth experience on their added value, this report explains the following results:

For resource- and material passports to function successfully in the long term, the following important framework conditions should be created:

- The accounting method and scope must be harmonized.
- It is highly recommend that documentation occurs on digital platforms to learn from the data in the short and long term.
- Stock preservation/refurbishment can and should be mapped in the same format and has a strong positive impact in all indicators.
- Life cycle assessments must be understood as an integral part of material passports and not as a separate tool.
- A material passport comprises of at least the following information categories: Material types and quantities, CO_2 footprint, material sourcing and material recycling.
- The clear definition and harmonization of these information categories are crucial for comparable results.

The following factors will become seminal in the creation of material passports:

- The influence of optimization in design is significant. Thus, sustainable design can lead to substantial improvements in the outcome of the material fit.
- The solid components (such as reinforced concrete) are the biggest influencing factor on the overall result in all information categories. Therefore, RC aggregate, recyclable shoring, low CO_2 cement and reinforcing steel become crucial factors for a good result in the material passport.
- Only timber or composite structures have thus far achieved very good results. However, alternative load-bearing structures to reinforced concrete are no guarantee for good results.
- In order to achieve ambitious results, specific products from manufacturers with high sustainability standards must also be selectively chosen. Optimization based purely on material types is not always sufficient.
- The geological framework should be taken into account when designing reference and limit values. Otherwise, construction projects will fall through the cracks of subsidies simply because of their plot.

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1 BACKGROUND RESOURCE & MATERIAL PASSPORTS

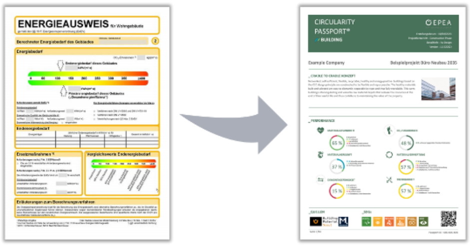
1.1 INTRODUCTION

> *"We will create the basis for taking a closer look at the use of gray energy and lifecycle costs. To this end, we are introducing, among other things, a digital **building resource passport.** In this way, we also want to achieve a circular economy in the building sector."*[1]

This promise made by the current coalition government of the Federal Republic of Germany in its 2021 coalition agreement led to a great deal of attention and movement among experts in the construction industry. Above all, however, it led to many different interpretations of what exactly is meant. The term "building resource passport" - which was then as now in the room without further context - can mean many things. In order to be clear about its definition, one must become aware of the history of sustainable building.

The idea of a resource or material passport is comparable to the energy certificate for buildings [1]. This was introduced in 2004 and aims:

1. To make transparent to users and potential buyers of buildings how much energy is consumed and thus a large part of the operating costs.
2. To drive the energy transition in the building sector. In order to be able to apply and enforce energy efficiency targets, the measurement of a building's energy efficiency had to be clearly defined and a structure developed to ensure consistent application.



The energy certificate is thus one of the central instruments for preparing the construction industry for the greatest challenges of the present and future (climate change and cost of living). However, it completely ignores an important component: the building structure itself. The materials used in buildings plus the manner in which they are incorporated and removed, all have an impact on the ecological, economic and sociocultural balance of the building.

[1] Translated from: [8]

Closing this gap is the fundamental idea behind resource or material passports. They extend the calculation boundary from an isolated consideration of use to a consideration of the entire life cycle of buildings. The introduction of a building resource passport could therefore mean nothing less than a paradigm shift in the construction industry.

Whether "Material Passport" or "Resource Passport": all these names describe summarized information about the materiality of buildings and their recyclability. These serve – just like the energy passport – on the one hand to **document** the built condition, but on the other hand also as a **planning tool,** which gives planning teams the opportunity to optimize buildings on the basis of measurable characteristic values.

EPEA is a pioneer in this respect and has been using building resource passports in this form since the first material passports were developed as part of the EU research project "Buildings As Material Banks (BAMB)" [2]. For eight years, EPEA has thus been able to gain in-depth experience with a practical application of material passports (in the form of the Circularity Passport®) and their added value. In the following, we would like to share this experience in order to provide some orientation:

How to efficiently create a material or resource passport.
What clarifications are needed to make material passports comparable.
What results can be expected when creating material passports.

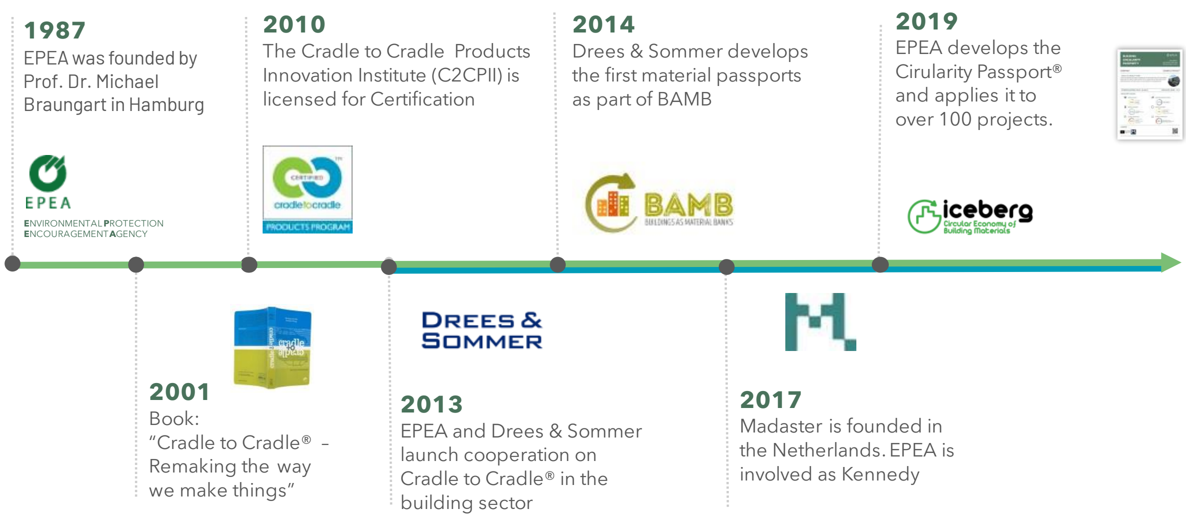


Figure 1: History of the development of the Circularity Passport®.

1.2 RESOURCE AND MATERIAL PASSPORTS: OVERVIEW AND DEFINITION

To understand what exactly a material or resource passport is, it is worth looking at existing initiatives. In recent years, some initiatives have already developed approaches to material passports for buildings.

At European level, the “Buildings as Material Banks (**BAMB**)” research project is an important milestone. The first material passports for buildings and building products were developed as a pilot project at European level in 2015 with the participation of **EPEA** and Drees & Sommer. [2]

Since 2017, **Madaster** has been active as a platform at the European level and has developed its own methodology for balancing material passes [3].

Another instrument that has emerged in the university context in Germany is the **Urban Mining Index (UMI).** This is designed as a measurement method for the circularity of buildings and can thus also be understood in a broader sense as a method for material passports [4].

In addition, as a recent development, the German Sustainable Building Council (**DGNB**) has published a framework for a building resource passport that “establishes a basis for a consistent circular economy in the building sector, in which early and late life cycle phases (product design and product recycling) are optimally coordinated and interlocked with each other” [5].

Looking at these initiatives, it is noticeable that some of the content of the passports overlaps, while others differ greatly. These overlaps are shown in Figure 1:

All of the initiatives listed include material inventories, i.e. a quantitative determination of all materials used, and classify them into categories. This serves to create transparency and is a prerequisite for the future creation of a material cadastre.

All initiatives also include a life cycle assessment of the construction, which is usually carried out in accordance with EN 15978. As a rule, only the impact category “Global Warming Potential (GWP)”, i.e. the CO2 footprint, is output from this, as this environmental impact is currently regarded as the most important.

In addition, the sourcing of materials is generally analyzed. The aim of this analysis is to use as few resources as possible and to use reused, recycled or renewable materials instead. All the initiatives mentioned cover this category of information and vary only slightly in the methodology and naming of the category.

The future recycling possibilities are analyzed separately from the material sourcing. The aim of this indicator is to enable materials that are used today to be reused in the future in a high-quality manner. Again, all of the initiatives listed show this category of information. However, there are still major discrepancies in the methods here. This will be discussed in more detail later.

Furthermore, all initiatives have documented additional information in the material passports. The Circularity Passport® from EPEA, for example, still covers the categories “material health”, “separability” and “dismountability”. Madaster shows a “material residual value” and the Urban Mining Index takes into account aspects like “deconstruction effort – labor factor” or “non-destructive detachability”. However, all these categories currently vary so much in their methodology that they will not be further considered in this report.

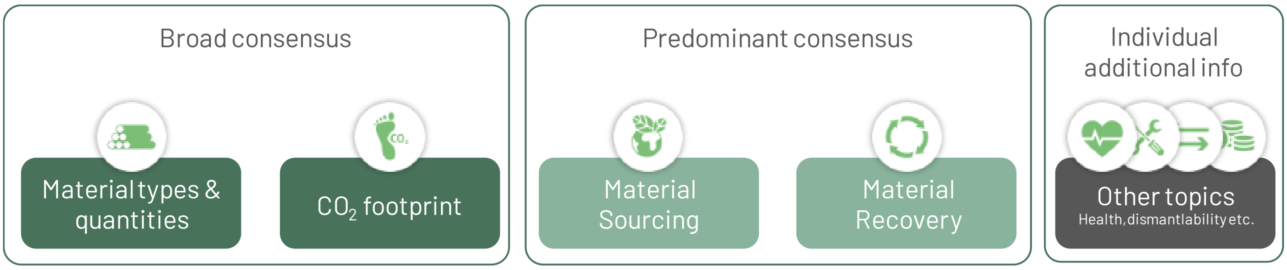


Figure 2: Contents of different material passport initiatives and their overlaps

1.3 CONNECTION BETWEEN MATERIAL PASSPORTS AND LIFE CYCLE ASSESSMENTS

Another current development is that more and more regulations on sustainable buildings are shifting from purely assessing energy efficiency to assessing the life cycle balance of the building. This means that in addition to the environmental impact of the use of the building, the impact of the construction and its recycling must also be accounted for. For example, EU taxonomy or BEG funding now requires a life cycle assessment of the building.

It is important to understand that the basics of the life cycle assessment are nothing else than combined contents from the material passport and the energy performance certificate. The delineation varies slightly depending on the Material Passport methodology. For example, in the DGNB Resource Passport, the life cycle assessment is fully included, while in Madaster or the Circularity Passport®, the Material Passport only covers the construction and forms a life cycle assessment in combination with the contents of the Energy Performance Certificate. This means that material passports are already indirectly a funding prerequisite or requirement for classification as a "sustainable building" (according to EU taxonomy).

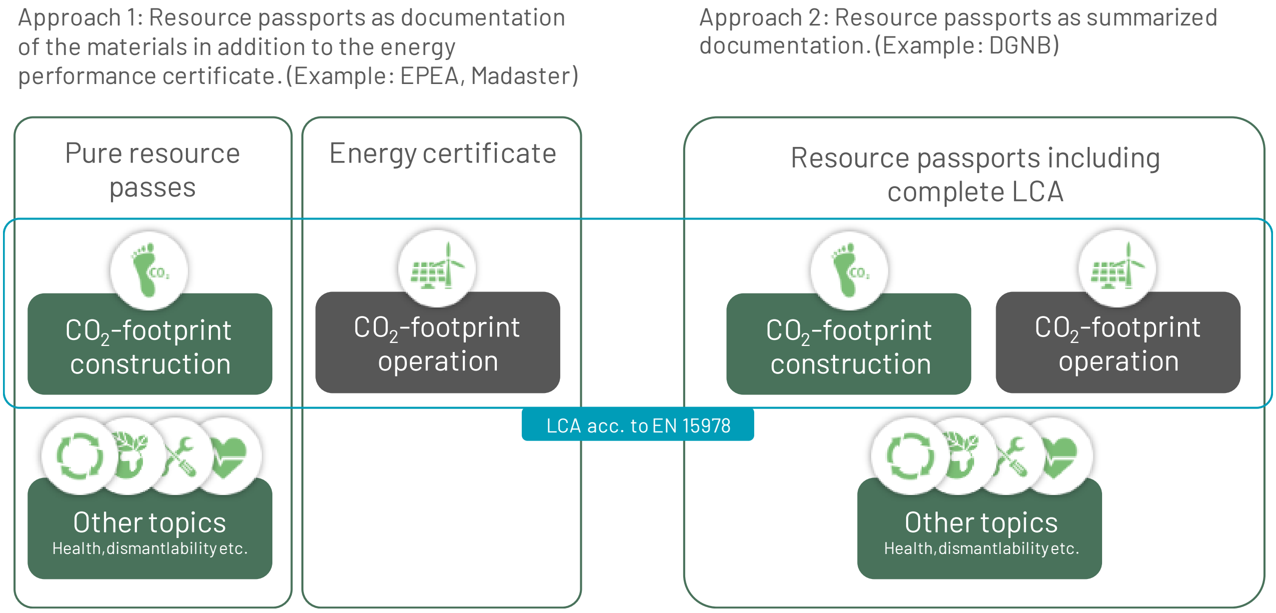


Figure 3: Material passports and life cycle assessments according to EN 15978 - illustration of overlapping content

2 INFORMATION CATEGORIES OF MATERIAL PASSPORTS

In order to clarify how the accounting is carried out within the scope of the Circularity Passport® and how other material passports may deviate from it, the four information categories "material types and quantities", "carbon footprint", "material sourcing" and "material recycling" will be discussed again below. The detailed description of the other categories can be viewed at https://epea.slite.page/ if required.

All statements on comparison systems (Madaster, DGNB) refer to their latest publicly available version as of October 1st, 2023. [3] [5]

2.1 MATERIAL INVENTORY

The evaluation of the material quantities is the most basic information in all material passports. However, the way in which the material quantities are determined currently still varies in all the initiatives mentioned.

Circularity Passports® are always quality assured before handover through expert preparation by EPEA staff. This also ensures that the scope of the balancing always corresponds to the specifications of the simplified procedure of the DGNB criterion ENV1.1. This has been specified in such a way because, from EPEA's experience including with international clients, this definition is the most clearly formulated definition of delimitation rules, which can be applied.

Madaster can process mass lists in Excel format or IFC models. When importing an IFC model, the platform automatically checks whether all building elements can be assigned to a material. This is to ensure that the entire model is represented in the mass determination.

At the time of writing, the DGNB Resource Passport does not yet define the minimum quantities of the building that must be included. Only descriptive information on the system boundary and the scope of documented masses must be provided. In addition, a data quality index is shown, depending on how precisely the quantities were determined.

The classification into material types is based on the Dutch NL-SfB classification for the Circularity Passport® and Madaster. The DGNB Resource Passport prescribes its own classification, which is based on LEVELS.

2.2 MATERIAL SOURCING

In this category, the material sourcing of the selected materials or products is evaluated. The goal is for all materials to be either from renewable sources (i.e., renewable raw materials) or from secondary raw materials (i.e., recycled materials or the highest possible percentage thereof). To determine a summary indicator, the mass of all sustainably renewable materials and all recycled materials is added together and divided by the total mass of the building. This gives a result in (mass) percentages where one hundred percent is an ideal building and zero percent is the worst possible result.

Rating	Description	Quality Factor
Secondary material	Products made from secondary material. This includes all maintained, reused, refurbished or post-consumer recycled materials.	100%
Sustainably renewable material	Products made from renewable material from certified sustainable cultivation. The criteria to classify a product as "sustainably sourced" is taken from the EU-Taxonomy definition.	100%
Primary, non-renewable material	New raw material that has never undergone any processing other than manufacturing. This also includes pre-consumer recycled materials. In case the source of the materials is unknown it is assumed to be primary material.	0%

Figure 4: Evaluation categories for the material sourcing in a building

Taking into account the quality factors and mass, the indicator is calculated as follows:

$$\mathrm{SRC} = \frac{\sum \mathrm{w}_{\mathrm{SRC,\,mat.}} \times \mathrm{m}_{mat.}}{\mathrm{m}_{\mathrm{bui.}}}$$

Whereby:
SRC = indicator material sourcing
w_SRC, mat. = quality factor of each individual material
m_mat. = mass of each individual material
m_bui. = Total mass of the building

The evaluation in Madaster is virtually identical, except that the categories are broken down in even greater detail.
In the DGNB Resource Passport, the same applies with the exception of the "avoidance" category, where material that has been saved is to be accounted for.

2.3 MATERIAL RECYCLING

One of the most important aspects of designing a Cradle to Cradle® circular building is considering how resources can be reused after they have been used. They must be able to serve as raw materials or components for new, pollutant-free products or systems of the same quality. High-quality recycling must therefore be taken into account as early as the product design stage.

Current legislation often considers downcycling or even energy recovery as a form of recycling. To make it clear that these recycling methods are suboptimal, they are weighted with a reduced quality factor when aggregated at building level in the Circularity Passport®.

Rating	Description	Quality Factor
Recycling / Upcycling	The material can be recycled without significant loss of quality and can thus replace a primary raw material of at least the same material quality.	100%
Downcycling	Through recycling, the material experiences a significant loss of material quality.	50%
Incineration	The material is used as substitute fuel (min. 11 MJ/kg calorific value (§ 6 para. 2 KrW-/AbfG)).	0%
Landfill	The material is disposed of in landfills or incinerated without energy benefit (calorific value < 11 MJ/kg)	0%
Not assessable	There is not enough information available for an evaluation.	0%

Figure 5: Evaluation categories for Material Recovery

In addition to the quality factor, the weighting in this category is based on the mass of the individual materials. Thus, to obtain a score at the building level, the calculation is performed as follows:

$$REC = \frac{\sum w_{REC,\,mat.} \times \mathrm{m}_{mat.}}{m_{bui.}}$$

Whereby:
REC = Material Recovery Indicator
w_REC, mat. = quality factor of each individual material
m_mat. = mass of each individual material
m_bui. = Total mass of the building

The most important difference between the various initiatives is differentiation of "recycling" and "downcycling". Madaster does not make this distinction, but covers the quality gradation by the fact that a material can be fed to different recovery routes in proportion to its mass.

The DGNB Resource Passport differentiates between "Reuse (preparation)", "Material qualitative recycling" and "Material recycling".

In the evaluation in the following chapter, it will become apparent that how these categories are defined and weighted is crucial for the final results.

2.4 CO_2- FOOTPRINT

The calculation of the CO_2 footprint (or Global Warming Potential (GWP)) is standardized in Germany by DIN EN 15978 as part of the life cycle assessment (LCA). All listed initiatives calculate according to the specifications of this standard. Whether the results of this assessment are comparable also depends on the following influencing factors, which are not specified in DIN EN 15978:

Calculation framework of quantity determination: Explained in chapter 2.1
Calculation framework of the life cycle modules

- The DGNB limits the scope to the modules A1-A3, B4, B6, C3, C4 and D, in order to ensure comparability of the results.
- The Circularity Passport® is based on the same accounting scope.
- Madaster has no predefined delimitation of modules and allows calculations according to different scopes.
- In the following analyses, module B6 is excluded in order to be able to focus on construction.

Basic data

- For all initiatives listed, only verified EPD (Environmental Production Declaration) data may be used for calculation. Other initiatives, such as the Quality Seal for Sustainable Buildings (QNG), restrict this further in some cases, which leads to changes in data availability and thus to deviating results.

Manufacturing phase			Establishment phase		Use phase							Disposal phase				Credits
Raw material supply	Transportation	Production	Transportation	Construction/Installation	Use	Maintenance	Repair	Replacement	Conversion/Renovation	Operational energy use	Operational water use	Demolition	Transportation	Waste Management	Landfill	Reuse, recovery, recycling potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
x	x	x						x						x	x	x

Table 1: Life cycle modules according to DIN EN 15978 (source: www.oekobaudat.de) (Modules included in the present analysis are marked with a green "x").

3 RESULTS OF THE ANALYSIS

3.1 DESCRIPTION OF THE SAMPLE

Since 2021, EPEA has been balancing all life cycle assessments and Circularity Passports® via an internal database. In order to create a meaningful and uniform accounting basis, the existing database was first reviewed and completed, and the construction projects recorded were categorized.
Due to the diversity and heterogeneity of the projects surveyed, characteristics were collected for the quality assurance of the sample. For this purpose, information on the planning status and level of detail, accounting scope of modeling and for the type of consulting service was collected from the projects.

The sample is not to be understood as representative, as it only includes 48 buildings. Especially for composite or pure timber structures, only a few pilot projects have been included in the sample. Therefore, it should be noted that the present study can only show orientation values and cannot provide clear reference values. It includes some buildings that were built entirely conventionally and others with a strong focus on optimizing recyclability. Therefore, a large variance in the results is to be expected, which at the same time also reflects the variance between conventional and sustainably optimized construction methods.

As a minimum requirement for the inclusion of a building in the sample, it was defined that the scope of all materials covered must meet the requirements of *DGNB Version 2018 ENV1.1 "simplified procedure".*

After filtering all the buildings covered in terms of analysis detail and completeness of the model as well as quality of the data, the result is a sample of 48 buildings on which the present analysis is based. These are divided into the following uses (Figure 6) and structure types (Figure 7):

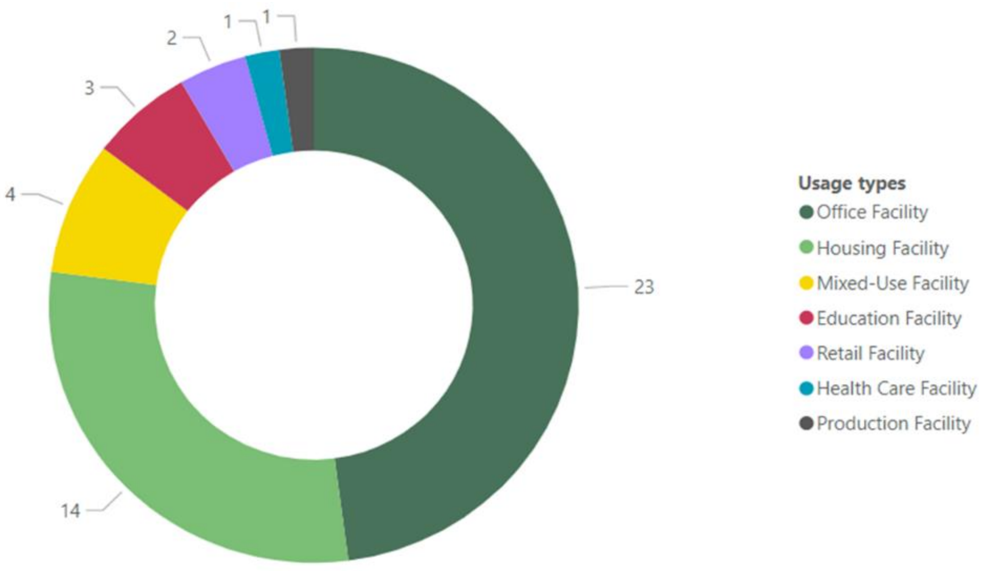


Figure 6: Composition of the sample according to usage types (classified according to Omniclass Table 11).

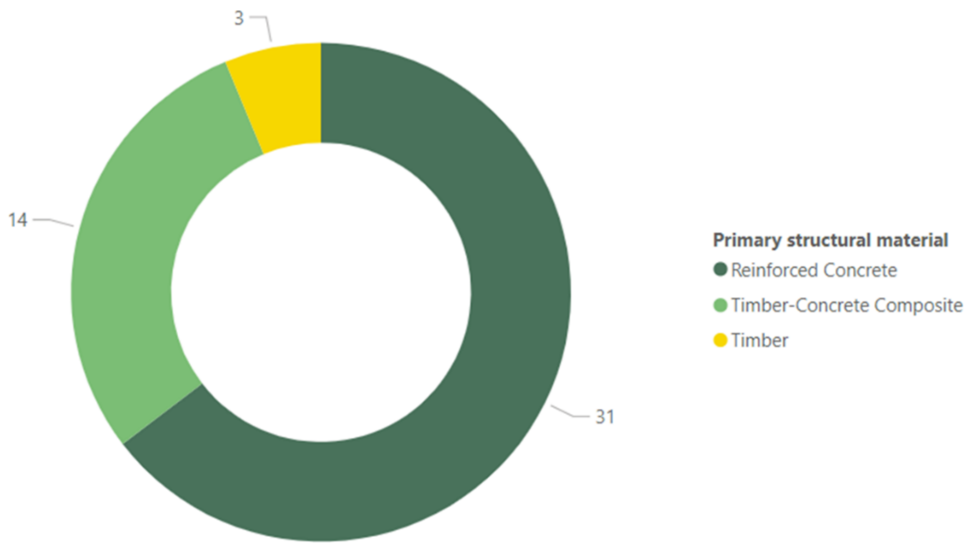


Figure 7 : Composition of the sample by material of the primary load-bearing structure

3.1.1 CARBON FOOTPRINT ANALYSIS

The analyzed sample was uniformly evaluated with the LCA method (according to the DGNB -simplified method) and thus the GWP in kg CO_2 equivalents was determined. The results are presented in emissions per net floor area (NRF) and year in order to create comparability with reference values of the DGNB (German Sustainable Building Council - DGNB e.V. 2021)..

In addition, a look at the building mass will be taken to see if there is a correlation between building mass and carbon footprint.

Figure 8: Representation of the sample by mass per NRF [kg/m²] and GWP per NRF and year [kgCO2e/m²a]. Coloring by material of the primary supporting structure and size of the points by NRF of the building.

First, it can be seen that there is a large variance in the carbon footprint, indicating that significant optimization is certainly possible given the current state of the art. The evaluation of the scatter plot also shows a clear correlation between building mass and GWP. Buildings with timber (composite) load-bearing structures often have a low mass and a low GWP. At the same time, it is also visible that some buildings with composite structures are heavier and more CO_2 intensive than some reinforced concrete buildings. The three timber buildings considered have the lowest GWP. Furthermore, it is not apparent that the size of a building has a direct impact on GWP.

Also noticeable are a few buildings which have a significantly higher mass than others in the sample. It was determined that these are exclusively buildings that are erected on geologically challenging soils and therefore require significantly more massive foundations. From EPEA's point of view, this is a situation that should definitely be taken into account when designing reference values in the future, as the external conditions in these projects mean that limit values may not be achieved despite optimizations, thus eliminating funding or certification opportunities.

The following diagrams (Figure 9) show the distribution of the values over the entire sample as well as divided according to the material of the primary supporting structure.

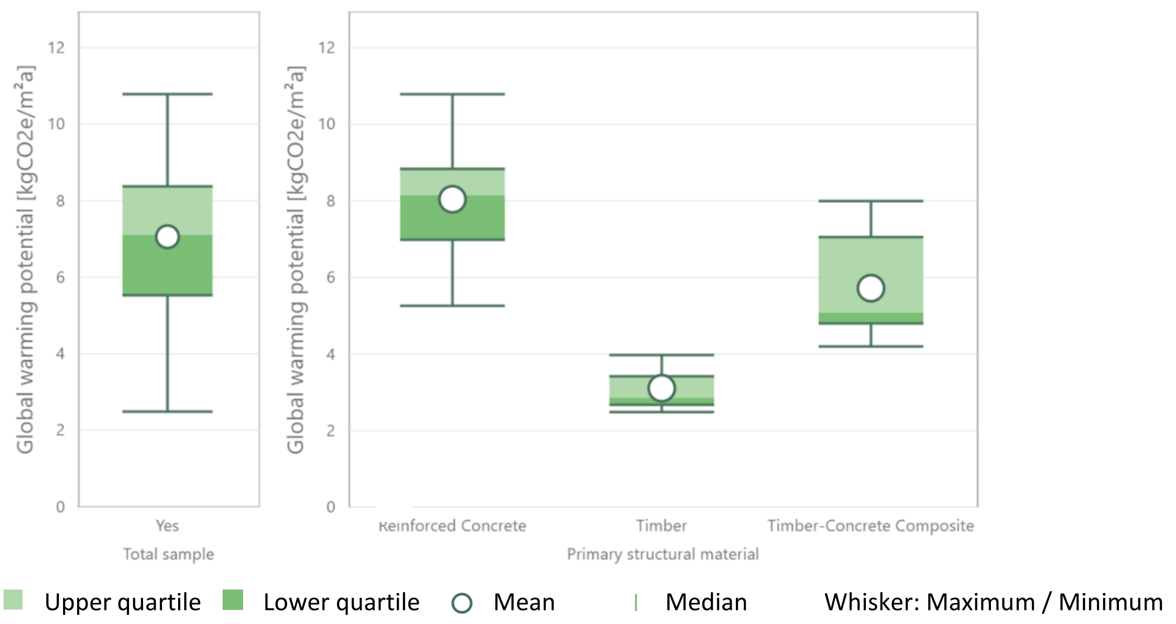


Figure 9: Distribution of the data for the characteristic value of the CO2 footprint (GWP), consideration of the entire sample and divided according to the material of the primary supporting structure.

The presentation of the visual sample with respect to the GWP of the buildings shows a moderate scatter and almost symmetrical distribution. The mean value of the GWP of all examined buildings is 6.96 $kgCO_2e/m^2$ a, with values ranging from 2.38 to 10.78 $kgCO_2e/m^2a$.

A differentiated analysis of the sample according to the material of the primary load-bearing structure also shows that reinforced concrete buildings tend to have the largest CO_2 footprint. The mean value is 7.97 kgCO e/m_2^2 a. Composite structures average 27% lower at 5.83 kgCO_2e/m^2a. The assessed timber structures have an average of 2.80 kgCO_2e/m^2a, which is 65% lower GWP. However, it must also be noted here that the sample of timber buildings in particular is not meaningful and further analysis with a larger sample is needed. However, it can be seen that the GWP of the three timber buildings studied is lower than even the lowest values of buildings with timber-concrete composite structure or reinforced concrete construction. The trend can thus be clearly seen.

Figure 10 also shows which components (by cost group according to DIN276) have the greatest influence on the carbon footprint.

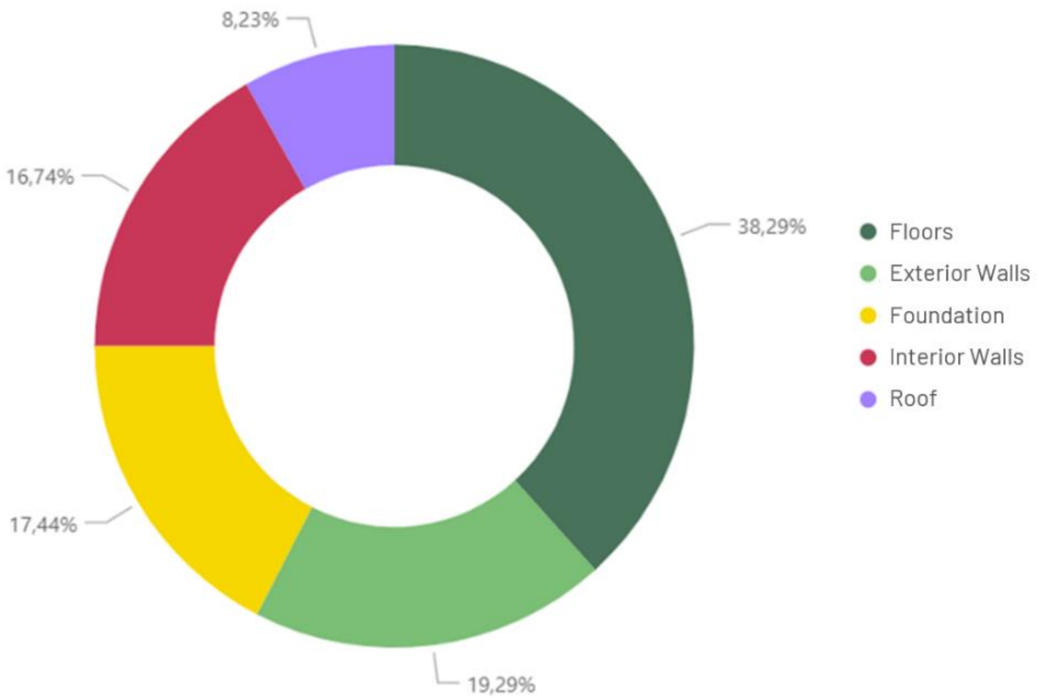


Figure 10 : Breakdown of GWP of the entire sample by second-level cost groups (DIN 276)

3.1.2 ANALYSIS OF MATERIAL SOURCING

Figure 11 shows the result of the sample for the characteristic value of the material sourcing, both for the entire sample and divided according to the material of the primary supporting structure.

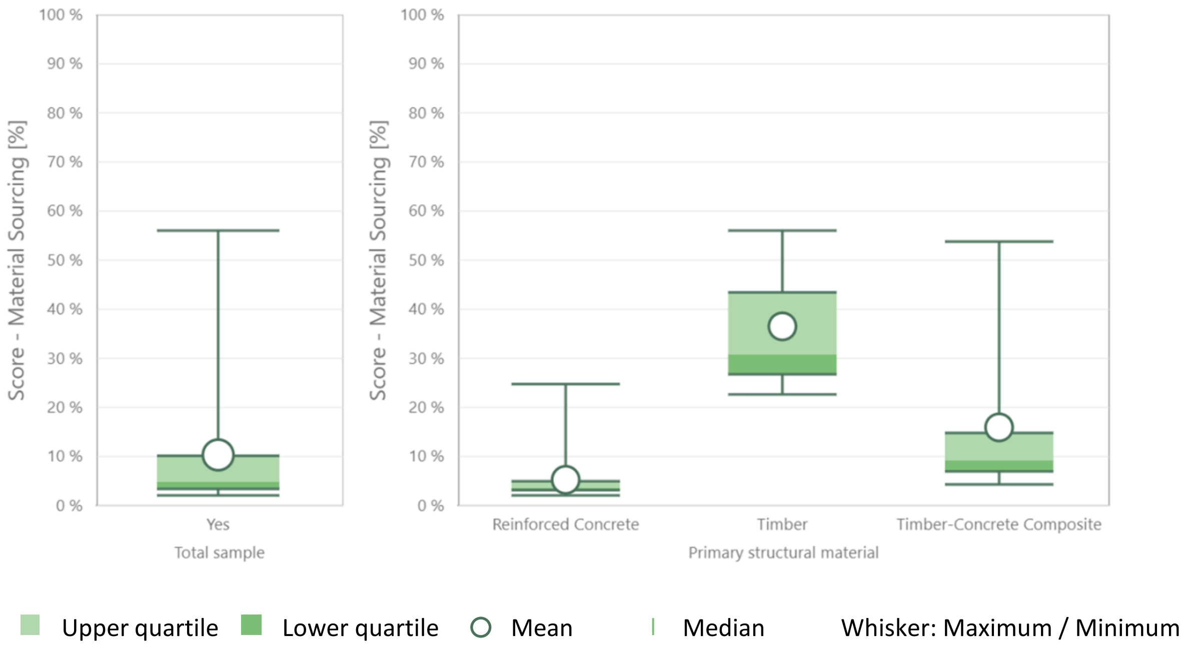


Figure 11: Distribution of data for the material origin parameter (SRC), for the whole sample and by material of the primary supporting structure (in %).

When looking at the material sourcing, the representation of the sample initially shows a strong scattering of the data, with outliers especially at the top. This shows firstly, that it is certainly possible to significantly optimize buildings for a sustainable material sourcing according to the current state of the art. This can be explained as follows:

The majority of all building materials are conventionally produced from non-renewable primary materials. If projects do not focus on the use of secondary or renewable materials, usually only some metals (such as the reinforcing steel) are made from secondary materials. Isolated renewable materials such as flooring made from timber have very little mass and therefore have a minor impact on this indicator. As a result, buildings that are not specifically optimized for this indicator generally have values of <10% in this indicator. Therefore, the values in the lower range accumulate.

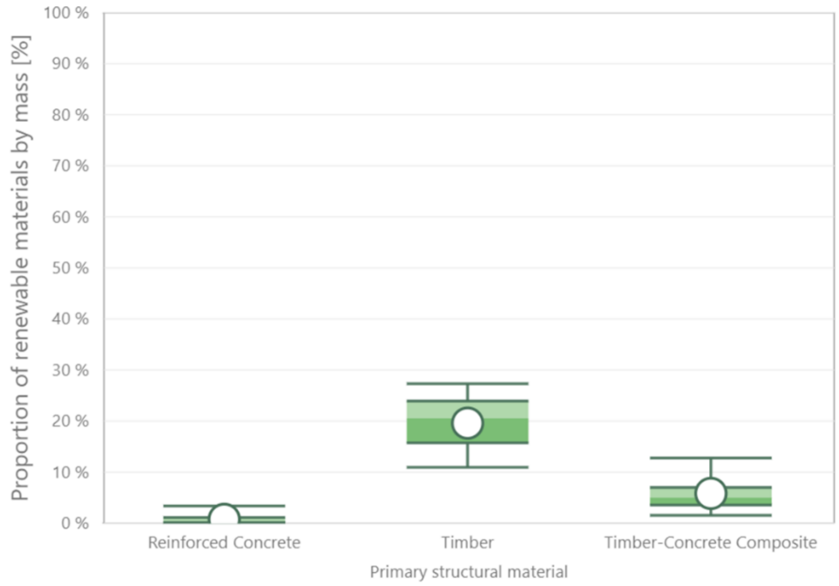
In contrast, if increased efforts were made and evidence provided that renewable and recycled materials were used, values of > 50% could be achieved in isolated cases. How these can be achieved becomes clear when broken down by the material of the primary supporting structure.

Buildings with a primary structure made of reinforced concrete achieve values between 4 and 25 %. The average value is 8 %. Here, too, there are mainly outliers upwards when this indicator was deliberately optimized, but in no case were values above 25 % achieved. Since reinforced concrete makes up the vast majority of the mass in these buildings, this material also offers the greatest potential for optimization for this indicator. The use of RC aggregate and fill made of recycled material has proven to be essential in order to achieve increased values here.

For timber-concrete composite structures, the mean value is already significantly higher at approx. 19 %. This is mainly driven up by some outliers, which lie at up to 56 %. The influence of these outliers is confirmed by the fact that the median value of 12 % is significantly lower than the mean value. These very high values (> 50 %) are exclusively found in projects that have optimized the recyclability throughout the entire planning process and have used secondary materials wherever possible. For this purpose, it is also necessary to optimize the materials not only on a type basis, but to select specific products from manufacturers who incorporate the use of secondary materials.

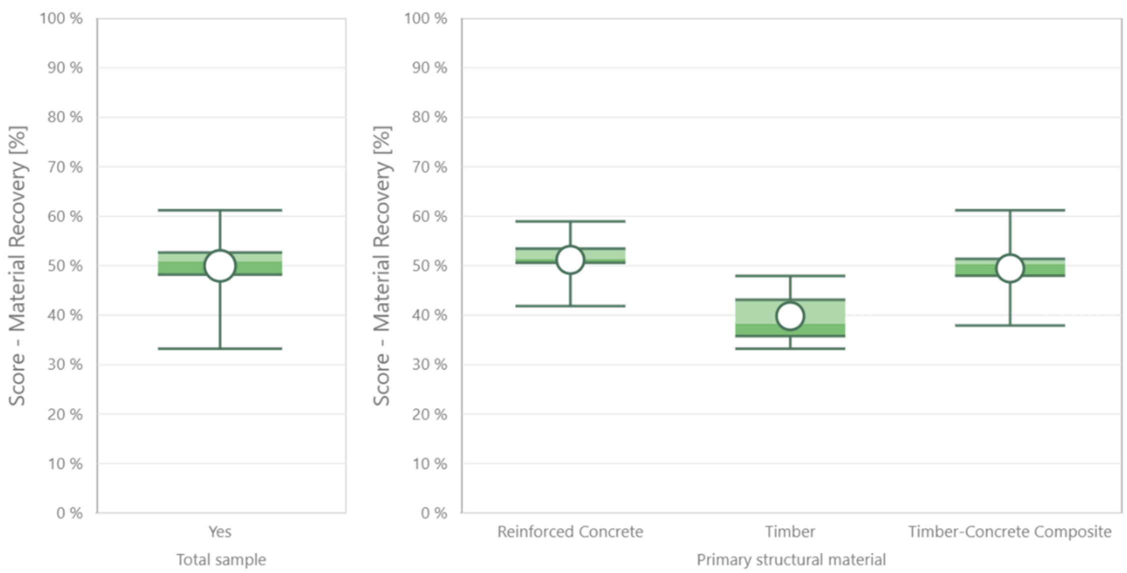
As expected, the scatter for composite buildings is very large, since the mass proportions of timber and reinforced concrete proportions are very variable. For timber-framed buildings, the size of the sample with only three buildings studied is not meaningful, but the basic tendency that buildings perform better the more timber is used is also evident here. Even the timber building with the lowest result (25%) is above the best performing reinforced concrete building (25%). The best value is a result of 56%, slightly above the best result for the composite structure category. This becomes particularly clear when the proportion of renewable material is considered in isolation.

Figure 12 shows that the share of renewable material is only 19.6 % on average even for purely timber constructions. The minimum for the timber buildings studied is 10.98 %. Thus, even in a timber building, the proportion of non-renewable materials is comparatively high due to, among other things, the finishing and the foundation. However, the reinforced concrete and composite buildings studied are significantly lower, with mean values of 0.71 % and 5.81 %, respectively.



Upper quartile Lower quartile Mean Median Whisker: Maximum / Minimum

Figure 12: Distribution of the data for the characteristic value of the material origin, here: Consideration of the share of renewable raw materials only, by material of the primary supporting structure (in %).



Upper quartile Lower quartile Mean Median Whisker: Maximum / Minimum

Figure 13: Distribution of data for the characteristic value of material recovery (REC), for the whole sample and by material of the primary supporting structure (in %).

3.1.3 ANALYSIS OF MATERIAL RECOVERY

Figure 13 shows the distribution of results in the Material Recovery indicator of the sample. When interpreting the results, it is important to note that the CP methodology (EPEA) only weights downcycling at 50%. The distinction between recycling and downcycling (and its reduced weighting of 50%) helps to find solutions in the planning process that promote high-quality recycling of materials. At the same time, it remains challenging to map the full variance of quality differences in recycling processes using this methodology.

Since many of the solid materials such as concrete fall under the downcycling category, the results for most buildings are concentrated around 50%. Considering that other systems weight downcycling differently (For example: DGNB: 100%, Madaster: no distinction between recycling and downcycling), the score in these systems would be significantly better (close to 100%).

It is also noticeable that the evaluation of timber or composite buildings is worse than that of reinforced concrete structures. This is due to the fact that, unless detailed information is available on the type of installation and auxiliary materials used, timberis classified in the "energy use" category. Only when it is ensured that the timbercan be degraded according to type can it be assumed that it will be recycled. This has not been done in many of the projects presented, which is why they score lower in the evaluation.

In order to show how decisive the uniform evaluation of "downcycling" is, the sample was additionally evaluated completely with a weighting of the category "downcycling" with 100 %. This corresponds to the methodology of the DGNB Resource Passport and is therefore referred to as the "DGNB methodology" in the following. Compared to the methodology of EPEA (which only weights downcycling with 50 %), the evaluation here is significantly more positive. The mean value of the total sample here is 90% and some projects come very close to 100%.

These points show that a uniform definition of the categories and weightings in the evaluation category "material Recovery" is absolutely necessary to create comparability.

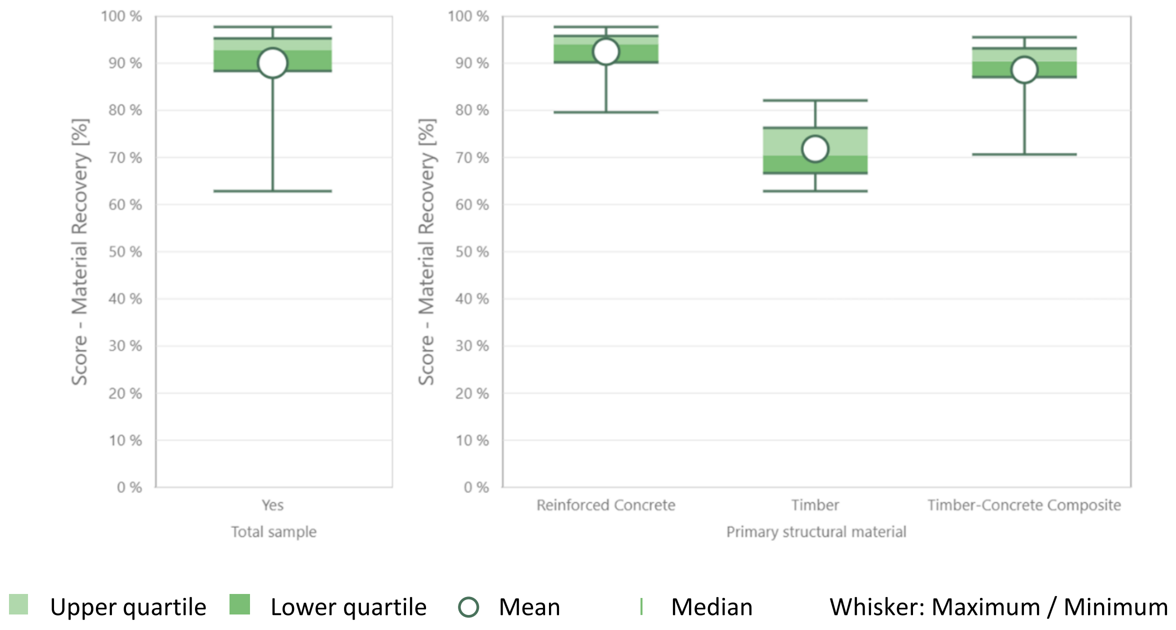


Figure 14: Distribution of data for the characteristic value of material recovery (REC), for the entire sample and by material of the primary supporting structure (in %) according to DGNB methodology.

4 CONCLUSIONS

4.1 CLASSIFICATION OF THE RESULTS IN THE CONTEXT OF THE DGNB RESOURCE PASSPORT

In the new DGNB criteria catalog (version 2023), specific target values for the indicators "material sourcing" and "recyclability - postuse paths" have already been defined in the criterion "TEC1.6: circular construction". However, there is currently no experience available as to how easy or difficult it will be to meet these target values.

As already explained in chapter 2, the assessment categories of EPEA can be directly transferred to the indicators of the DGNB Resource Passport. The results of the study can therefore be used as orientation for target achievement in the DGNB criteria ENV1.1 and TEC1.6. This comparison is shown in Figure 15. Marked in each case is the threshold value at which the DGNB awards half or full points in the criterion. For the global warming potential (GWP), the comparative values of the 2018 version were used, since the buildings in the sample were modeled according to these specifications.

It can be observed that when evaluating the **GWP**, the sample is for the most part within the comparative values. Individual outliers are above or below. This shows how much influence appropriate planning can have on the achievement of points in the DGNB system. With appropriate consideration of this indicator over the entire planning process, many points can be gained in the most important DGNB criterion.

In the case of **material sourcing,** on the other hand, the majority of projects are below the "moderate target rate", although some projects exceed the "high target rate". This shows that points in the criterion are not to be expected without targeted orientation of planning to this indicator. At the same time, it is quite possible to achieve the full number of points.

In contrast, the opposite picture can be observed for the indicator "**Material Recovery**" and "recyclability - subsequent use paths". The majority of projects are above the "high target rate", but individual projects fall short of the "moderate target rate". This shows that points in the criterion are to be expected, but can also be lost if they are neglected in the planning.

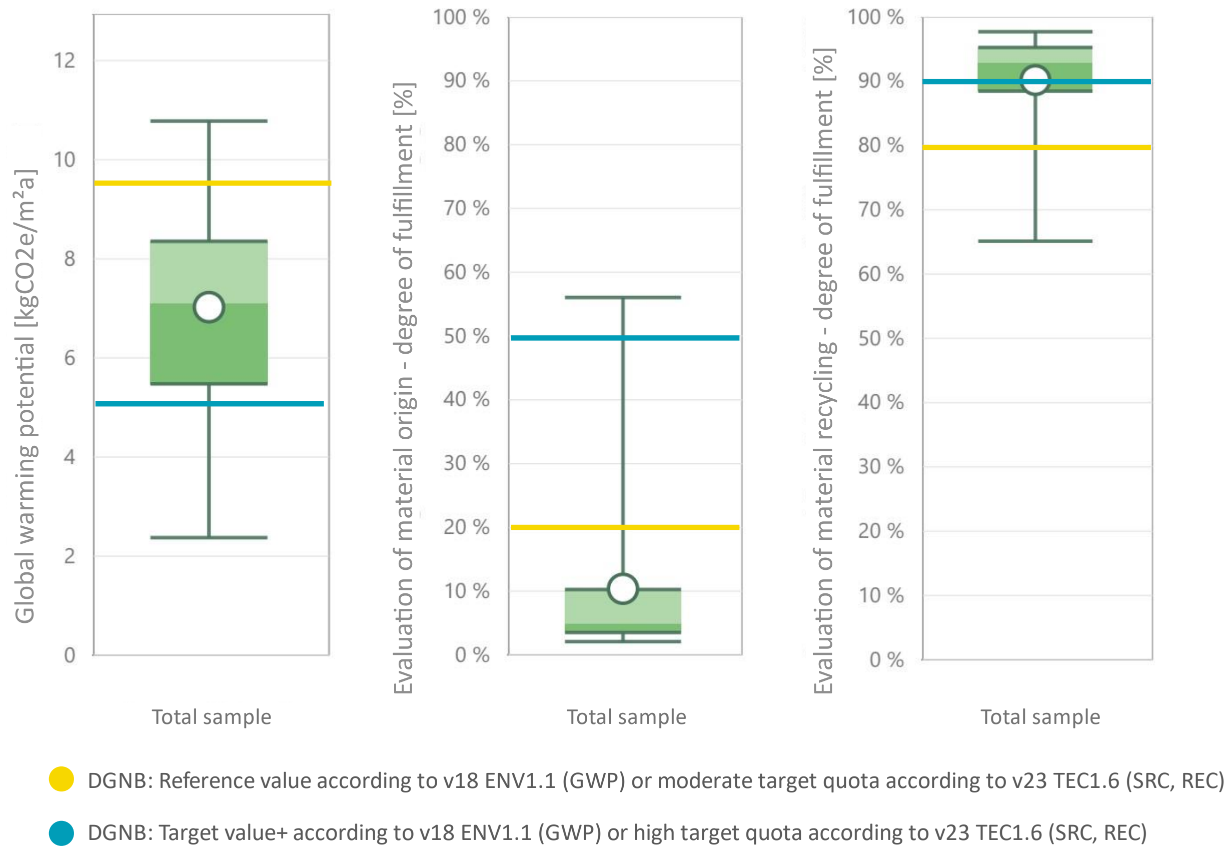


Figure 15 : Comparison of the results of the total sample with comparative values of the DGNB system (construction only (A1-A3, C3 , C4 , D), operating phase (B6) excluded)

4.2 CONCLUSION

The analysis of sustainability and circularity properties for buildings clearly shows the added value of building resource passports or the Circularity Passport®. From the evaluations of the projects assessed so far, it is evident that conventional and more sustainable construction methods differ greatly from each other across all criteria. This shows that the Circularity Passport® can quantify differences, thereby making recommendations for action derivable and also making buildings of the same use and construction method comparable.

The present evaluation provides initial orientation values for target indicators of resource passports. These can now be used to provide target values for initiatives that contribute to the transformation of the construction industry to a true circular economy according to the Cradle to Cradle principle. They can also provide guidance to planning teams for early planning phases. In order to further develop these orientation values, the uniform and digital collection of data is absolutely necessary.

The preparation of a Circularity Passport® not only allows the material values to be taken into account and the building to be documented for future deconstruction, but also provides great added value by highlighting the potential for optimization. Planners and decision-makers are supported in defining achievable goals and taking measures to implement them. The use of the Circularity Passport® as an optimization tool in early planning phases is therefore crucial to promote sustainable and circular construction and to improve the resource efficiency of buildings.

5 OUTLOOK AND DEMAND ON POLITICS

Whether and how quickly the transformation process of the construction sector to a true circular economy according to the cradle to cradle principle can be achieved, will depend to a large extent on how the political incentives are properly created. These should be formulated in a way that is both ambitious and feasible. Based on the experiences described in this report, EPEA believes that the following goals could and should be formulated in Germany for building construction (new construction, refurbishment and existing buildings alike) for the current decade:

40-80-100 - RULE FOR THE DECADE UNTIL 2030

Figure 16: Proposed targets for building construction for the decade up to 2030

40% RESOURCE SAVING:

40% of all materials used in building construction should come from secondary or sustainably renewable materials: The present evaluation has shown that quotas above 50% are quite possible already today in smaller new buildings. An ambitious target for all buildings of 40% would especially promote the technically established and long-standing use of RC aggregate in concrete and fill through urban mining, as well as the historically established use of timber and renewable materials, which are currently being thoroughly researched.

Simultaneous to the pure new construction, the focus would also be on the preservation of the existing building stock, which the quota of 40% is usually achievable by preserving the foundation with supporting structure. With the open technology target, a relevant market dynamic could be generated for new construction and refurbishment with urban mining as well as for the preservation of existing buildings, which will also have an impact on product and building material manufacturers. The following targets could then be further developed :

- Target for 2031-2045: 60%.
- Target as of 2045: **80%**

80% RENEWABLE OPERATION:

80% energy generation for building operation should come from renewable energy. Current sources or technologies are photovoltaic, solar thermal, geothermal, environmental energy, wind, hydropower, biomass.

The manufacture and production of building materials along the entire supply chain must also be decarbonized. In the current decade until 2030, the use of resource-efficient materials (see pos. 1.) simultaneously provides a substantial contribution to CO_2 emission minimization. For the following decade 2031-2040, however, manufacturing and production must also be increasingly from renewable energy sources, so that CO_2 emissions are considered over the entire life cycle of the building.

- Target for 2031-2045: **80%** Renewable energy generation for manufacturing and operations.
- Target from 2045: **90%** renewable energy generation for production and operation

100% RECYCLABLE ACCORDING TO THE CRADLE TO CRADLE PRINCIPLE:

100% of all materials used in building construction should be designed and installed according to the Cradle to Cradle principle for true recycling - thus turning buildings into real raw material depots.

A 100% recycling option goal for all materials should be formulated now in order to trigger innovations. All materials that we will use in the next few years and which we already know cannot be recycled to a high quality will burden the material stock for decades and should not even be used in construction.

The requirement clearly goes beyond the current Closed Substance Cycle Waste Management Act, since the quality of recycling is not sufficiently described there, and does not create an incentive for the market.

Using the digital solutions for material passports and material cadastres that are already available today, the foundations are already in place to digitally support material management both for today's construction activities and for refurbishment in the future.

CRADLE TO CRADLE ROADMAP TO 2045 IN THE CONSTRUCTION AND REAL ESTATE INDUSTRIES:

Based on our many years of experience in circular construction, the proposed quotas of

- **40-80-100** for the decade to 2030
- **60-80-100** for the period 2031 - 2045
- **80-90-100** from 2045

could result in a transformation of the construction and real estate industry towards a true circular economy based on the cradle to cradle principle by 2045.

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A. APPENDIX

Table 2: Statistical values for the entire sample - GWP (kgCO_2e/m^{2}a)

Statistical values (GWP)	Total sample
Quantity	48
Minimum	2,38
Maximum	10,78
Mean value	6,96
Median	7,08
1st quartile	5,33
3rd quartile	8,36

Table 3: Statistical values by material of the primary load-bearing structure - GWP (kgCO_2e/m^{2}a)

Statistical values (GWP)	Reinforced concrete	Timber-Concrete Composite	Timber
Quantity	31	14	3
Minimum	4,70	7,94	2,38
Maximum	10,78	4,00	3,53
Mean value	7,97	5,83	2,80
Median	8,03	5,03	2,49
1st quartile	6,93	4,71	2,45
3rd quartile	8,28	6,75	3,07

Table 4: Statistical values material sourcing (SRC_KPI) of the entire sample.

Statistical values	Total sample
Quantity	48
Minimum	4 %
Maximum	58 %
Mean value	13 %
Median	8 %
1st quartile	6 %
3rd quartile	13 %

Table 5: Statistical values of material sourcing (SRC_KPI) by material of the primary load-bearing structure

Statistical values	Reinforced concrete construction	Timber-Concrete Composite	Timber
Quantity	31	14	3
Minimum	4 %	7 %	7 %
Maximum	25 %	56 %	56 %
Mean value	8 %	19 %	19 %
Median	7 %	12 %	12 %
1st quartile	6 %	10 %	10 %
3rd quartile	8 %	17 %	17 %

Table 6: Statistical values material recovery (SRC_KPI) of the entire sample.

Statistical values	Total sample (EPEA)	Total sample (DGNB)
Quantity	48	48
Minimum	34 %	65 %
Maximum	61 %	98 %
Mean value	50 %	90 %
Median	51 %	93 %
1st quartile	48 %	88 %
3rd quartile	53 %	95 %

Table 7: Statistical values of Material Recovery (SRC_KPI) by material of the primary load-bearing structure

Statistical values	Reinforced concrete construction	Timber-Concrete Composite	Timber
Quantity	31	14	3
Minimum	42 %	38 %	34 %
Maximum	59 %	61 %	48 %
Mean value	51 %	50 %	40 %
Median	51 %	50 %	38 %
1st quartile	51 %	48 %	36 %
3rd quartile	53 %	51 %	43 %