Research Paper
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Circularity Overview

Making material use within architecture projects measurable and verifiable in an overview of what contributes to designing architecture for the upcoming Circular Economy

Abstract

The upcoming circular economy has consequences for the application of materials within the building sector, which requires a different mindset and way of designing from the architect. The aim of this research is to develop a Circularity Overview in which the materials of a building can be assessed for circularity and environmental impact. The Overview can thus be used as a tool to test materials of an existing building, materials for a design, or can be used as a tool during the design process for adaptive reuse. This allows for orderly weighing of options and making choices, therefore it is a tool that can be of interest to students and architects who will be working with circular material use. The Overview is developed from criteria that have been compiled through desk research, for which it was important that the criteria are measurable and verifiable so that results can be replicated and traced. Knowledge about circularity was generated through literature research, after which six case studies were analyzed with an objective view. By testing the Overview on both newly built circular projects and transformed buildings, it emerged that the combination of material use and construction technique of both, such as reusing materials, applying detachable connections, and keeping existing structures intact as much as possible, can lead to favorable outcomes in terms of circularity. The circularity of the case studies as well as the operation of the Overview itself have also become insightful as a result. Although the Circularity Overview has shortcomings due to the incomplete availability of data, it provides an indication of circularity in material use that can be used to support choices before, during, and after a design phase.

1. Introduction

The motivation for this research was to gain knowledge and insights from the material used in terms of circularity and minimise construction waste. The results could then be used to determine an approach for a design task. Circularity and the minimisation of construction waste are relevant, as by the year 2050, the Circular Economy should be 100% in force in the Netherlands, forcing the entire architecture industry to get involved *(Het ministerie van Infrastructuur en Waterstaat, 2021)*. Circularity is the phenomenon around sustaining and managing nature and the circular community, the latter implies the preservation of the resource stock through conscious handling, sharing and reuse is the norm *(Stahel, 2019).*

Rau & Oberhuber *(2016, p. 38-42)* wrote that responsibility over manufactured products is currently organized within the production chain in such a way that no one has to take it in relation to the consequences triggered by production and use. This leads to the mountains of waste being normal. The qualities and potential of the material are lost in large mountains or in the incinerator. According to Stahel, *(2019, p. 4)* waste coming from industry is a double loss, both for energy and for materials. Energy is needed to use the material to manufacture a product then the product is worth nothing, then new energy is needed to burn the product which means the material is permanently lost. When a consumer buys a product, its responsibility is transferred from the producer to the consumer. The consumer uses the product after which it is eventually thrown away. The current linear economy is therefore known as the 'Take, Make, Waste economy' *(Rau & Oberhuber (2016, p. 38-42)*. This phenomenon mainly occurs in the construction industry, considering the share of construction in total waste production in the year 2021 as visible in Figure 1

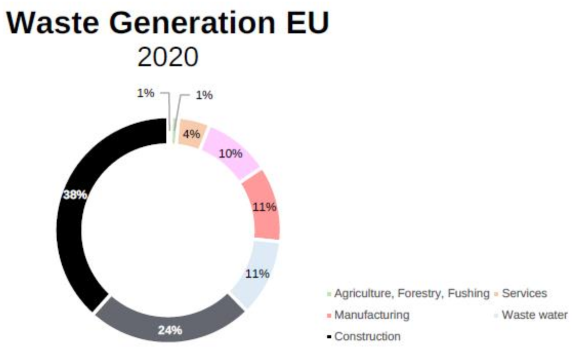


Figure 1: Waste generation, based on Afvalbeheer in De EU: Feiten En Cijfers (2022).

In addition, construction contributes to the exploitation of the supply of raw materials and the production of CO_2 emissions from the production of building materials and products, see Figure 2.

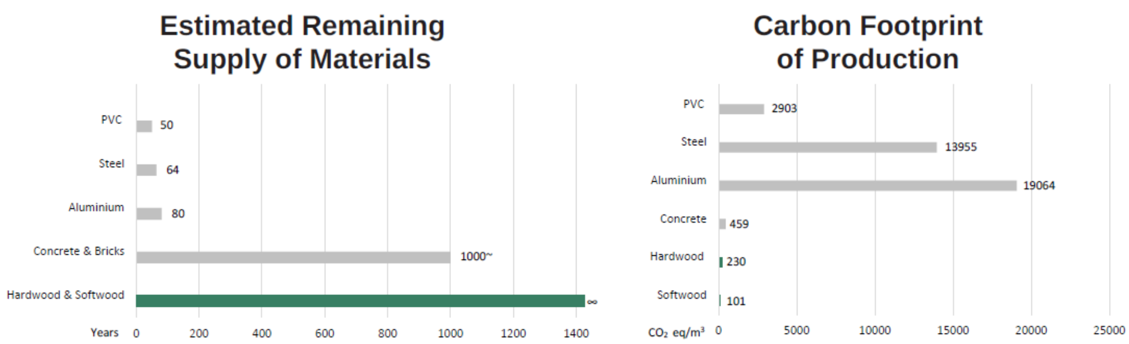


Figure 2: Usage and Pollution by the building sector, based on Lugt, P., & Harsta, A. (2020).

According to Schouten *(2016, P 13-14, 25, 87-89, 101 & 181)* , the concept of waste can only become a thing of the past by closing the cycles of fossil raw materials, ecological raw materials, and financial and social cycles. In short, working towards a transition from a linear to a circular system, as illustrated in Figure 3. When the government implements regulations on material use, the cycles of fossil and ecological raw materials can become manageable, through taxes, environmental accounting and market systems. This will then lead to new business models, employment, prosperity and growth in fields such as recycling, repair and collection. Through 'stimuli', or awareness, generated by the government, production sector and finally the consumer, the circular economy can become a reality, by working collectively towards solving issues.

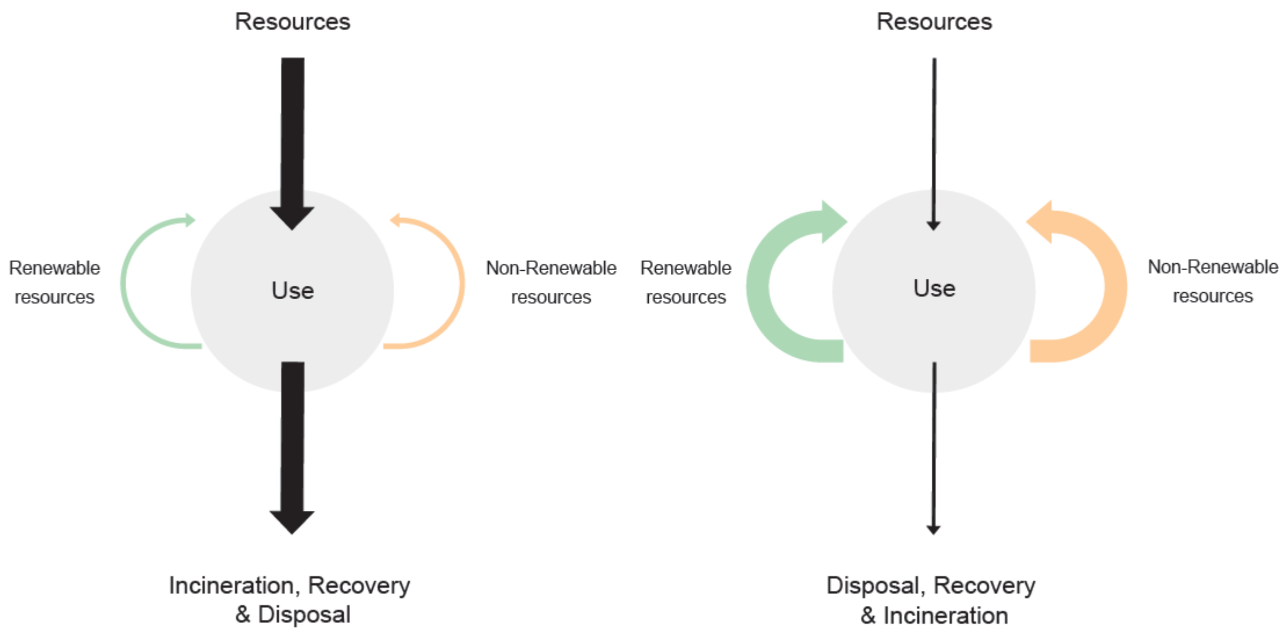


Figure 2: Linear system (left) & and circular system (right), based on Lugt, P., & Harsta, A. (2020).

2. Theoretical Framework

Within the construction industry, the awareness to apply circularity and solve issues needs to be raised in order to implement it. Currently, there are already circular initiatives such as some case studies covered in this paper, however, there are few actual projects where minimizing waste has become a reality, as researched by Rana Mahanta, N., Samuel, A. K., & Sachan, D. *(2021)*. As mentioned by Schouten *(2016)*, collective collaboration is important for circularity. Currently, the construction industry collaborates in a largely linear manner, see Figure 4, however, this needs to change to a collective system for the circular economy, see Figure 5.

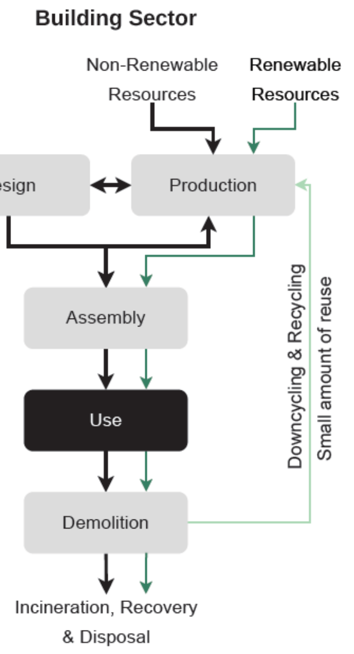


Figure 3: Current system, based on notes made during lecture by Rotor on 16-11-2022.

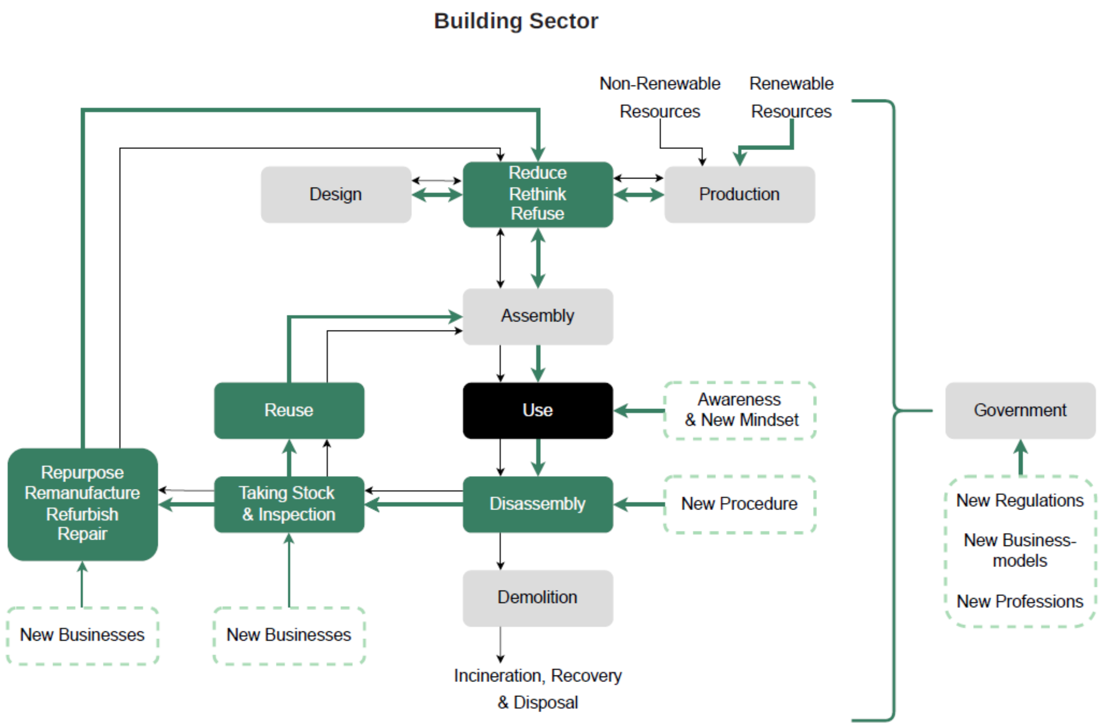


Figure 4: New system, based on notes made during lecture by Rotor on 16-11-2022.

Figure 5 shows that Design and Production will soon have to work and think differently toward circular solutions. Also, new companies are involved and the role of other stakeholders is transforming.

A field example where a similar new system of collaboration was applied is the interior renovation of two offices of Nationale Nederlanden by Fokkema and Partners. Here, the vision of 'Zero waste' was central to the design brief. According to the Zero Waste Europe *(2022)* , 'zero waste' is defined as:

> *"Zero waste is the conservation of all resources by means of responsible production, consumption, reuse and recovery of products, packaging and materials without burning, and with no discharges to land, water, or air that threaten the environment or human health"*

During the lecture of 22-11-2022, it was explained by the architect Dirk Zwaan, that by reusing materials from other locations, bio-based materials, and inventorying, storing, repairing, and reinstalling existing materials from the locations, 89% of the project is 'Zero Waste' *(Zwaan, 2022)*. When asked what happened to the remaining 11%, the answer was that these existing parts were damaged and could not be reused. This shows that in practice 'Zero Waste' rather than 'Minimal Waste' is achievable. The 89% was determined by calculating the Life Cycle Analyses (LCAs) of the new materials. These LCAs are registered within the National Environmental Database (NMD) *(Stichting Nationale Milieudatabase, 2023a)*. LCAs lead to Environmental Performance Costs (MKIs) of the materials, through eleven calculations it is determined what impact producing these materials in combination with their lifespan has on the environment, expressed in unit costs *(Rijksdienst voor Ondernemend Nederland, 2017)*. According to Zwaan, this was important in order to keep the project and the materials measurable and verifiable.

In order to gain insight into the use of materials that architects should be applying before 2050 and which criteria of these materials are normative for the circular economy, an assessment method is developed. By formulating an Overview that provides insight into the circularity of a building, an existing building can be assessed, a design or it can be used as a tool during the design process.

3. Method

The assessment consists of criteria, and the formulation of these criteria that are significant is in the method that collectively results in the Circularity Overview. The main research method within this study was desk research for drafting the criteria, also insights from lectures, workshops, and feedback from lecturers were used. The principle maintains that all criteria are measurable and verifiable, allowing the results to be verified and retrieved.

By filling in six case studies in the Overview, the resulting insights, the level of circularity of these case studies, and the functioning of the Overview tool are demonstrated. Circularity played a major role in these case studies, either by building as much as possible in a demountable form for reuse or by maintaining as much as possible of the material already present. By means of literature research, the case studies could be analyzed objectively. To this end, information collected and requested from recently completed buildings in the Netherlands was used. This was chosen so that the case studies could then be compared with each other, as they were located in the same climate and essentially the same building regulations applied to the projects, both of which influence material use.

3.1 Case Studies

The case studies consist of three newly built projects and three transformed churches, see Figure 6 below.

Name	Type	Completed in	Location	Architect
The Green House	Newly build	2018	Utrecht	cepezed
Triodos Bank	Newly build	2019	Driebergen-Rijsenburg	RAU Architecten
FOR	Newly build	2021	Rotterdam	Powerhouse Company
Grote Kerk	Transformed	2020	Hoorn	Hylkema Erfgoed Advies en Ontwerp
Laurentiuskerk	Transformed	2020	Weesp	Stork & Albrecht, arch. en Bouwad.
Baumannkerk	Transformed	2020	Rotterdam	HOYT

Figuur 5: The six case studies.

The new construction projects were specifically chosen because they all differ in part in how they approach circular construction and how the architects experience circularity themselves, one case study is explained as an example.

The Triodos Bank is an office building built largely of timber, steel, and glass which is demountable fixed, allowing it to be reused elsewhere after the building's lifetime *(Muis, 2018)*. The analysis showed that through slots in the floor construction, changes for future installations are possible and the high ceiling leads to spaces that allow for different types of programming. These aspects are consistent with a view from Cradle to Cradle, which describes that if a building is adaptable for different uses it becomes possible to be used by many generations, thus extending the life of the building *(Braungart & McDonough, 2007)*. Thomas Rau finds the following: *"The earth is a closed system and our stay is temporary"* *(Rau & Oberhuber, 2016, p. 11)*. By this, Rau means that we should consciously deal with the materials at our disposal to opt for a closed system, in which raw materials and materials are repeatedly reused and nothing will be lost *(p.79)*. However, Rau knows that nothing lasts forever, but limits can be stretched through careful design and craftsmanship *(p.49)*. Here, Rau opts for 'Building as a Material Bank', in which buildings function as banks for registered materials in order to make it easier to give them a new purpose after use, by means of 'urban mining' *(p. 117, 131)*.`

The three transformed churches are largely preserved, as revealed by the analyses. The image of the churches, and with it the existing material, can therefore largely be preserved. This approach is largely in line with Pottgeiser's *(Communication BK, 2020)* approach that 100% of the environment is heritage and should be preserved. This influences the view of buildings and materials, by determining the degree of value fullness of materials to then maintain them or reuse them in a way. This also keeps materials in the cycle, which is similar to Rau's new building approach. Through concrete and steel structures, the mid-aisles of these churches have been provided with more floor space and rooms. The two different approaches to construction make it interesting to compare and test these six projects for circularity.

3.2 Criteria
3.2.1 Layers
First, the elements of the case studies are divided using the Layers of Brand *(1994)* to make the Overview clear by separating the types and different expected lifespans of the elements. The layers 'stuff' and 'site' are omitted as no data was available for these and because they are not measurable and verifiable.

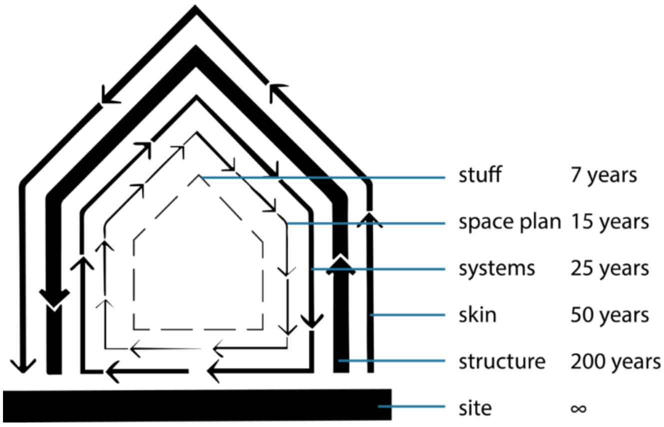


Figure 6: Layers of Brand, by Open Building.co (2020).

3.2.2 Elements, Materials & Amount
The elements are specified as materials and their quantity within the building. By studying the construction drawings, documentation, and photos, the materials are identified and categorized under renewable, fossil, and recycled. The quantities are based on digital post-measurement of the construction drawings to find out linear meters, areas, and quantities.

3.2.3 MPG Score
The materials and quantities are entered into 'GPR material' software which TU Delft has made available for this study. With this, the environmental impact of these materials can be determined, in this the quantity of the given material times the MKI of the material is done, and then the Environmental Performance Building (MPG) score per material is calculated which depends on the floor area of the building. Ultimately, all these scores of the materials within the building can be compiled into the total MPG of the building, which should not exceed 1.0 *(Rijksdienst voor Ondernemend Nederland, 2017)*. Through these MPG scores per material, it is possible to compare which material and its quantity are more applicable in terms of environmental impact. Besides the total MPG, the CO_2 emissions for producing all materials for the building can also be calculated, both of which are important measures within the Circular Economy.

3.2.4 Lifespan & Remaining Lifespan
Because the lifespan is included in the calculation of the MPG score, the lifespan per material is also added as a criterion. By subtracting the (expected) lifespan of the building in years from the lifespan of the applied material, it becomes clear how many years the material can survive in another location. The lifespan

per material is completed using NIBE's Environmental Classifications *(2023)* and SBR Lifespan of building products *(Vissering, 2011)*.

3.2.5 Maintenance

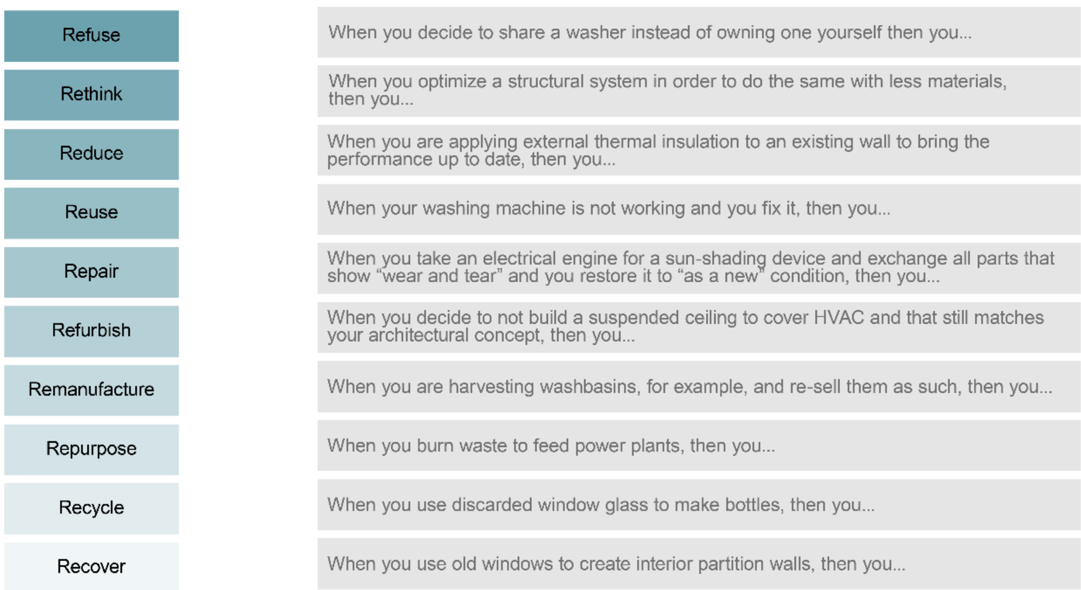
Maintenance which is necessary to maintain and/or extend the service life is added as criteria below, based on a comment by the Research Tutor after the P2 presentation on 25-01-2023 to include it in the Overview. This addition provides insight into which materials require maintenance during their lifespan, by then subdividing them into no, low, high maintenance and replacement, the degree of necessary maintenance becomes clear. Here, low maintenance means, for instance, painting a window frame and high maintenance means replacing some parts of the element. Maintenance may also be necessary periodically, in which case this is indicated. Information for these criteria is derived from Levensduur van bouwdelen en bouwmaterialen *(Niël et al.,1991)* and Bouwproducten *(Blaazer & Prins, 2012)*.

3.2.6 Remountable & Adaptive

Based on the documentation and detailed drawings, it can then be determined whether the materials are fixed in a demountable way, e.g. using screws, bolts or click systems. This shows whether a component is replaceable and reusable. Here it may be applicable that an element is adaptive, such as a timber frame element that can be taken apart to change or replace its structure. Adaptive has therefore been added as criteria, as an element that is adaptable can last longer.

3.2.7 R-Strategies

Using the previously mentioned criteria, it is then possible to determine which R-strategy or strategies are applicable to the elements. At the Circularity Workshop I on 15-12-2022, R-strategies were explained by Dr. Olga Loannou. Loannou conducted research on the R-strategies and these are shown in the figure below *(Loannou, O. & Tu Delft, n.d.)*. In this, the top three R's are not measurable and are not included in the Overview.



Figuur 7: R-strategies, by Loannou, O. & Tu Delft. (n.d.).

However, R9 to R3 are included in the Overview, as they can be demonstrated based on the previously completed criteria and literature applicable to the 'Services' layer. For the determination of R or R's per element, the criteria remaining lifetime and dismountable are particularly important, as they show whether the material can still last and whether it is movable.

3.2.8 Performance Explanation

Finally, the performance of the material will be explained after the life of the building has expired and the material has been detached. During a lecture organised by the studio on 16-03-2022, guest lecturer Anna Batallé Garcia told us that performance is the main measure to confirm the circularity of a material, or how long the material can last in the state it is in. Performance is an explanation based on the R or R's that apply and is the conclusion per element whether it can be retained within the cycle and is therefore circular.

4. Results

The result of the **Method** is the Circularity Overview. When filled in with data from the case studies, it can be tested, revealing how it works. Three completed examples of the Overview are shown below, to keep the explanation of the Overview simple, only the 'Facades' element under the 'Skin' layer of the case studies is shown. See the **Appendix** for the fully completed matrices of the six case studies.

Case Study: FOR, Roterdam
Architect: Powerhouse Company
Area: 3564 m²
Program: Offices & restaurant
Finished: 2021
Usage period: 50 years (assumption)
Assembly: largely dry & mechanical connections

Renewable resource / Fossil resource / Harvested / Existing resource / Low maintenance / High Maintenance / Replacement needed / P= Periodically recurring

Layer	Element	Material / Product (mm)	Amount	MPG	Lifespan in years	Remaining lifespan after 50 years of use	Maintenance	Remountable	Adaptive	Recover	Recycle	Repurpose	Remanufacture	Refurbish	Repair	Reuse	Performance Explanation
SKIN	Facades	Aluminium curtain wall	972 m²	0,024	≤75	≤25		■							■		Still has a long lifespan, used outside, will need maintenance.
		HR+++ safety glazing	972 m²	0,090	≤30	-20	■	■			■						Needs to be replaced, can be recycled.
		Prefab ins. timber wall-200	181 m²	0,002	≥75	≥25		■	■			■	■	■		■	Still has a long lifespan, can be reused and adapted.
		Spruce wall cladding-40	181 m²	0,002	≥50	0	■	■		■						■	Will reach end of life, needs to be recovered.
		CLT balconies-220	773 m²	0,002	≥75	≥25	P	■							■		Still has a long lifespan, used outside, will need maintenance.
		Steel barred balustrade	369 m	0,004	≥60	≥10		■							■		Still has a long lifespan, used outside, will need maintenance.

Case Study: The Green House, Utrecht
Architect: cepezed
Area: 680 m²
Program: Restaurant, greenhouse & meeting spaces
Finished: 2018
Usage period: 15 years
Assembly: Only dry & mechanical connections

Renewable resource / Fossil resource / Harvested / Existing resource / Low maintenance / High Maintenance / Replacement needed / P= Periodically recurring

Layer	Element	Material / Product (mm)	Amount	MPG	Lifespan in years	Remaining lifespan after 15 years of use	Maintenance	Remountable	Adaptive	Recover	Recycle	Repurpose	Remanufacture	Refurbish	Repair	Reuse	Performance Explanation
SKIN	Facades	Har. hardened glass panels	501 m²	0,000	≥40	-4	■	■			■						Produced in 1989, will reach the end of its lifespan.
		Cust. steel sup. structure-300	109 m²	0,020	≥100	≥85		■			■						Custom-made, can be recycled for other use.
		Prefab ins. timber wall-300	44 m²	0,008	≥75	≥60		■	■			■	■	■		■	Still has a long lifespan, can be reused and adapted.
		Aluminium curtain wall	272 m²	**0,116**	≤75	≤60		■								■	Still has a long lifespan, can be reused.
		HR+++ glazing	272 m²	0,012	≤30	≤15		■								■	Still has a long lifespan, can be reused.

Case Study: Grote Kerk, Hoorn
Architect: Hylkema Erfgoed Advies en Ontwerp
Area: 2620 m² (+ 2677 m² attic appartments)
Program: Hotel, restaurant & existing apartments
Finished: 2020
Usage period: 50 years (assumption)
Assembly: largely wet & mechanical connections

The neo-Renaissance P. Grote Kerk was built in: 1883
Was changed to apartments & store space in: 1983
A stand alone steel & concrete structure was added for this new program.

Layer	Element	Material / Product (mm)	Amount	MPG	Lifespan in years	Remaining lifespan after 50 years of use	Maintenance	Remountable	Adaptive	Recover	Recycle	Repurpose	Remanufacture	Refurbish	Repair	Reuse	Explanation
SKIN	Facades	Existing brick facade-560	1156 m³	0,000	≥75	-112	P		■					■	■		Is already 137y old, will continue to last with maintenance.
		Existing windows & doors	264 m²	0,000	≥40	-147	P	■						■	■		Is already 137y old, will continue to last with maintenance.
		Steel window & door frames	187 m²	0,007	≥100	≥50		■					■			■	Still has a long lifespan, can be reused or changed.
		HR++ glazing	67 m²	0,007	≤30	-20	■	■			■						Will reach end of life, needs to be recycled and replaced.
		Monument add-on glazing	120 m²	0,006	≤30	-20	■	■			■						Will reach end of life, needs to be recycled and replaced.

Figure 8: Screenshot of three Circularity Overviewes.

4.1 Example

By comparing the 'Prefab insulated timber wall' with the 'Existing brick facade', it becomes visible that the 'brick facade' has already lasted 137 years, and after using it for 50 years, it will be minus 112 years old while the 'timber wall' will last around 75 years. The 'timber wall' is demountable, adaptive, and therefore easily reusable. The brick facade, however, can only be improved, and repaired to retain its value and to even further increase its lifespan. Both are very different as well as favorable methods in terms of material use. As for fossil materials, glass is inevitable to apply in the facades, however the amount of glass determines the circularity of a facade. Due to the relatively short lifespan of glass, it needs to be replaced during its use, the complete glass façade of the Triodos Bank is therefore not a circular approach. The same can be said for concrete and other fossil materials, the amount of them should be kept to a minimum. The seal 'circularity' on both the Triodos Bank and the FOR can therefore be questioned, since both contain large amount of fossil materials. Finally, it is remarkable that the renewable materials score very low compared to fossil materials, although it is known from the **Introduction** that renewable raw materials have a lower environmental impact, it was not expected that these MPG scores would be so incredibly low.

4.2 Case Studies Results

After entering data from the six case studies each into a Circularity Overview, and comparing the results, the results below become visible in Figure 10.

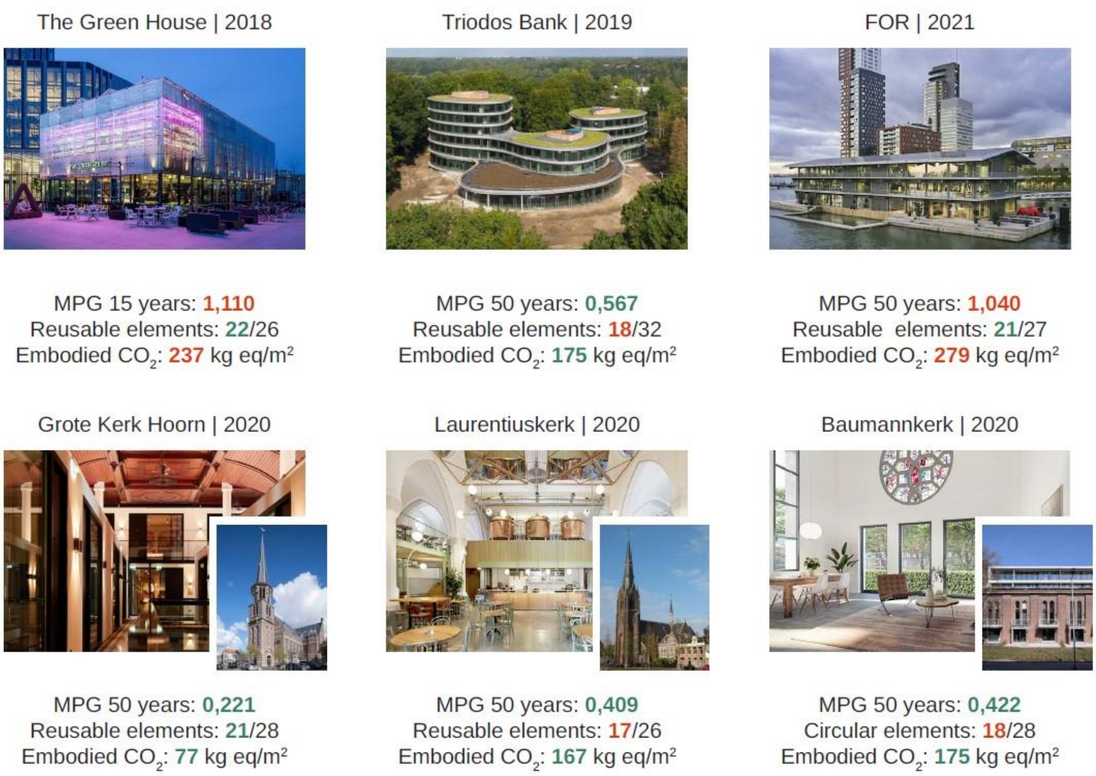


Figure 10: Result overview of the case studies.

From the overview, it becomes visible that the transformed churches score the best, this is because many materials of the 'Skin' and 'Structure' are largely preserved, so less material needs to be added which affects the MPG and CO_2 figures. However, it was found from the Circularity Matrices of these three case studies that mainly fossil materials were used. The Triodos bank has similar scores to the transformed churches, while the FOR has the lowest score. Partly due to the high use of concrete and solar panels. The Green House shows that with a short lifespan, the building itself does not score well on environmental impact, compared to those with a longer lifespan.

From this, it can be observed that a combination of reused materials from an existing or other building along with a high degree of use of renewable materials, optimal circularity, and low environmental impact can become possible for a building design. This shows that the Overview can lead to insights for determining an approach to the material used for a design.

5. Discussion

The Circularity Overview is a method to compare the material use of different projects and test them for circularity. The six case studies have been filled in as examples to a certain extent, so only the large numbers of materials used have been filled in and no details have been entered. However, the Overview can be supplemented to this level if desired. Here, the Overview can also function to find out the circularity of one project or even during the design process to make choices for materials and then be able to substantiate them.

It should not be forgotten that the Overview also falls short in certain areas. For instance, material properties can vary from one supplier to another; these properties are visible within the LCAs of materials registered in the NMD. However, this data could not be viewed at the time of this study, as the data viewer *(Stichting Nationale Milieudatabase, 2023b)*, using other material life cycle databases. As a result, there is a chance that results could be adversely affected by the use of different databases. Of note here is that the NMD currently has few materials and products, especially in the area of 'Services'. Based on these observations, it can be questioned whether adding the MPG to the Overview is measurable and verifiable. While this is true, it does give an indication that can be included in the consideration of materials, as the environmental impact of the material and its quantity then becomes clear as an indication.

A logical observation is that existing materials have an MPG score of 0.0 because the material already exists at the site. If used material from another site does have an MPG score since, removal, transport, and placement can have an impact on the environment. The NMD has reused materials with an EQI score, however, these were not yet available for the applied reused materials during the study so a score of 0.0 had to be maintained as well.

Finally, the R-strategies are difficult to distinguish which can lead to subjective results within the Overview. This is because no research was conducted into practical examples in which the materials were actually reused or, for instance, repaired. R-strategies were therefore only determined by means of the criteria filled in. Use and additional wear of materials were not included in the Overview, as this is not measurable. This has the greatest influence on the performance of the material during and after its use. When using the Overview, this should therefore be a point to be aware of.

6. Conclusion

Preliminary research into circularity enabled an objective analysis of the case studies in terms of circularity to gain insight into material use strategies. Through knowledge gained from these analyses, the literature and lectures, criteria were drawn up which resulted in a tool to measure the circularity of materials in buildings. The result is the Circularity Overview that can also be used to compare projects, to make choices between different materials during the design process of a building, or as an approach to the use of materials for a design.

This research has resulted in insights into how material handling of existing buildings in particular can be used in the future when designing buildings in the circular economy. In particular, the combination of new construction and transformation of an existing building such as reusing materials, applying detachable connections, and flexible layouts, and keeping existing structures intact as much as possible can lead to favorable outcomes in terms of circularity.

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Appendix
The Circularity Overviews of the six tested case studies

Case Study:	**The Green House, Utrecht**
Architect:	cepezed
Area:	680 m²
Program:	Restaurant, greenhouse & meeting spaces
Finished:	2018
Usage period:	15 years
Assembly:	Only dry & mechanical connections

Renewable resource
Fossil resource
Harvested / Existing resource
Low maintenance
High Maintenance
Replacement needed
P= Periodically recurring

Layer	Element	Material / Product (mm)	Amount	MPG	Lifespan in years	Remaining lifespan after 15 years of use	Maintenance	Remountable	Adaptive	Recover	Recycle	Repurpose	Remanufacture	Refurbish	Repair	Reuse	Performance Explanation
SKIN	Ground floor	XPS insulation-100	400 m²	0,127	≥75	≥60		■								■	Still has a long lifespan, can be reused.
		Sand layer-150	400 m²	0,012	≥100	≥100		■	■							■	Reuseable.
		Harvested pavement	400 m²	0,000	≥75	≥60		■	■							■	Still has a long lifespan, can be reused.
	Facades	Har. hardened glass panels	501 m²	0,000	≥40	**-4**		■			■						Produced in 1989, will reach the end of its lifespan.
		Cust. steel sup. structure-300	109 m²	0,020	≥100	≥85		■			■						Custom-made, can be recycled for other use.
		Prefab ins. timber wall-300	44 m²	0,008	≥75	≥60		■	■			■	■	■		■	Still has a long lifespan, can be reused and adapted.
		Aluminium curtain wall	272 m²	**0,116**	≤75	≤60		■								■	Still has a long lifespan, can be reused.
		HR+++ glazing	272 m²	0,012	≤30	≤15		■								■	Still has a long lifespan, can be reused.
	Roof	Harvested greenhouse roof	77 m²	0,000	≤40	**-4**		■			■						Produced in 1989, will reach the end of its lifespan.
		Steel profiled roofplates-50	321 m²	0,056	≥75	≥60		■								■	Still has a long lifespan, can be reused.
		PUR roof insulation-200	321 m²	**0,124**	≥75	≥60		■								■	Still has a long lifespan, can be reused.
		EPDM Roofing (mechanical)	321 m²	0,039	≤50	≤35	**P**	■								■	Still has a long lifespan, can be reused.
STRUCTURE	Foundation	Prefab concrete elements	119 m	0,115	≥75	≥60		■	■							■	Still has a long lifespan, can be reused.
	Support structure	Galvanised steel frames	16095 kg	**0,235**	≥75	≥60		■	■							■	Still has a long lifespan, can be reused.
	Floors	Timber casette floor-440	287 m²	0,069	≥75	≥60		■	■							■	Still has a long lifespan, can be reused.
SERVICES	Heating & Cooling	Floor Heating & Cooling	680 m²	0,017	≤50	≤35	**P**	■	■							■	Still has a long lifespan, can be reused.
	Heat generation	Waste heat inst., nearby office	680 m²	N/A	≤25	≤10									■		Lifespan can be improved by maintenance.
	Ventilation	Mechanical ventilation	680 m²	0,019	≥15	0	**P**	■	■						■		Lifespan can be improved by maintenance.
	Electricity	PV-panels	180 m²	0,078	25-	10-		■			■					■	Still has some lifespan, can be reused or recycled.
SPACE PLAN	Interior walls	Harvested glass walls	99 m²	0,000	≥75	≥29		■								■	Produced in 1989, can still be reused.
	Interior doors	Harvested glass doors	11 m²	0,000	≥75	≥29	**P**	■								■	Produced in 1989, can still be reused.
	Interior walls	Timber system walls-100	183 m²	0,046	≥25	≥10		■	■			■	■	■	■	■	Still has some lifespan, can be reused or adapted.
	Interior doors	Timber doors	9 p.	0,002	≥25	≥10	**P**	■			■					■	Still has some lifespan, can be reused.
	Ceiling finish	Har. custom timber panels	189 m²	0,000	≤50	≤35		■			■		■				Custom-made, can be remanufactured as cladding.
	Stairs	Steel & timber staircase	1 p.	0,012	≥100	≥85		■								■	Still has a long lifespan, can be reused.
	Balustrade	Steel barred balustrade	15 m	0,003	≥60	≥45		■								■	Still has a long lifespan, can be reused.

Total MPG score for 15 years of use:	**1,110**
Total MPG score for 50 years of use:	0,356
Total MPG score for 75 years of use:	0,259

Conclusion

Embodied CO_2 - 50 years: 237 kg eg/m2

The short 15-year usage results in a very high MPG score of 1,110 for the tested components, which is even higher than the maximum allowed of 1,0. Although many of the materials can be reused, they are largely produced from fossil resources, which also contributes to the high MPG score. If more elements had been made out of renewable or harvested materials, the MPG would be lower with no negative consequence for reusability, the same weight of the structure in timber alone leads to a score of 0.073 as opposed to the 0.235 of steel. In addition, increasing the years of use will contribute to a lower MPG & more efficient usage of the elements since they will be kept longer in their current state. On the other hand, is the MPG score difference between 50 - 100 years very minimal since many materials will not last for 100 years and need to be replaced.

Case Study:	**Triodos Bank, Driebergen-Rijsenburg**
Architect:	RAU Architecten
Area:	12.994 m²
Program:	Offices
Finished:	2019
Usage period:	50 years (assumption)
Assembly:	Largely dry & mechanical connections

- Renewable resource
- Fossil resource
- Harvested / Existing resource
- Low maintenance
- High Maintenance
- Replacement needed
- P= Periodically recurring

Layer	Element	Material / Product (mm)	Amount	MPG	Lifespan in years	Remaining lifespan after 15 years of use	Maintenance	Remountable	Adaptive	Recover	Recycle	Repurpose	Remanufacture	Refurbish	Repair	Reuse	Performance Explanation
SKIN	Ground floor	XPS insulation-190	3260 m²	0,016	≥75	≥25		■								■	Still has a long lifespan, can be reused.
		Concrete in situ floor-280	3260 m²	0,067	≥75	≥25					■						Will last longer then 75y, can be pulverised and recycled.
		Concrete substrate layer-70	3260 m²	0,016	≥75	≥25					■						Will last longer then 75y, can be pulverised and recycled.
	Facades	Aluminium curtain wall	4596 m²	0,031	≤75	≤25		■							■		Still has a long lifespan, used outside, will need maintenance.
		HR+++ safety glazing	4596 m²	**0,106**	≤30	**-20**	Replacement needed	■			■						Needs to be replaced, can be recycled.
		Sandwichpanel-100	551 m²	0,003	≤50	≤0		■		■	■						Will reach end of life, needs to be recycled and recoverd.
		Steel square facade beam	219861 kg	0,050	≥75	≥25		■	■		■					■	Still has a long lifespan, can be reused or recycled.
		Composite cladding-4	862 m²	0,014	≥50	**0**	P	■			■						Will reach end of life, needs to be recycled and replaced.
	Roof	CLT roof plate-120	3389 m²	0,002	≥75	≥25		■								■	Still has a long lifespan, can be reused.
		XPS insulation-200	3389 m²	0,017	≥75	≥25		■								■	Still has a long lifespan, can be reused.
		EPDM Roofing (glued)	3389 m²	0,006	≥70	≥20	P			■	■					■	last longer due to greenery, can be recycled or recoverd.
		Green roof drainage system	3050 m²	0,011	25-	**-25**	Replacement needed	■			■						Needs to be replaced, can be recycled.
STRUCTURE	Basement floor	Concrete in situ floor-280	2412 m²	0,020	≥75	≥25					■						Will last longer then 75y, can be pulverised and recycled.
	Basement walls	Hollow prefab concrete walls	1489 m²	0,018	≥75	≥25					■						Will last longer then 75y, can be pulverised and recycled.
	Basement column	Concrete in situ column-320	221 m	0,003	≥75	≥25					■						Will last longer then 75y, can be pulverised and recycled.
	Core	CLT walls-100	2912 m²	0,002	≥75	≥25		■								■	
	Beams	Laminated timber-90x300	2184 m	0,002	≥75	≥25		■								■	Still has a long lifespan, can be reused.
	Columns	Laminated timber-90x300	1092 m	0,001	≥75	≥25		■								■	Still has a long lifespan, can be reused.
	Floors	CLT floors-100	7695 m²	0,005	≥75	≥25		■								■	Still has a long lifespan, can be reused.
SERVICES	Heating & Cooling	Floor Heating & Cooling	3260 m²	0,004	≤50	≤0	P			■							Will reach end of life, is inside the situ floor finish.
	Heating & Cooling	H&C Climate ceiling	7695 m²	0,046	≤20	**-30**	Replacement needed	■	■		■						Needs to be replaced, can be recycled.
	Heat generation	Heat & Cold storage+Heatpump	N/A	N/A	≥20	**-30**	Replacement needed	■	■		■				■		Needs to be partly repaired, partly replaced & recycled.
	Ventilation	Mechanical ventilation install.	12.994 m²	0,016	≥15	**-35**	P	■	■		■				■		Needs to be partly repaired, partly replaced & recycled.
	Electricity	PV-panels on parkinglot	3300 m²	0,046	≤25	**-25**	Replacement needed			■	■						Will reach end of life, needs to be recovered & recycled.
SPACE PLAN	Floor finish	Anhydrite finish-40	7695 m²	0,008	≥75	≥25				■	■						Will last longer then 75y, can be partly recycled & recoverd.
	Floor finish	2xGypsumboard + insulation	7695 m²	0,011	≥75	≥25		■	■		■					■	Still has a long lifespan, can be recycled & reused.
	Interior walls	Steel frame glass walls & doors	482 m²	0,006	≤50	≤0	P	■	■		■				■		Will reach end of life, needs to be repaired & recycled.
	Interior walls	Harvested gypsum board-25	3408 m²	0,000	≥25	**-25**	Replacement needed	■			■						Will reach end of life, needs to be recycled.
	Interior walls	Gypsum drywall-100	1704 m²	0,019	≥25	**-25**	Replacement needed	■			■			■	■		Lifespan can be improved by maintenance, can be recycled.
	Stairs	Steel & timber staircase	39 p.	0,003	≥100	≥50		■								■	Still has a long lifespan, can be reused.
	Balustrade	Steel & glass balustrade	150 m	0,001	≥60	≥10		■								■	Still has a long lifespan, can be reused.
	Interior doors	Timber doors	285 p.	0,001	≥25	**-25**	Replacement needed	■			■				■		Will reach end of life, needs to recovered & recycled.

Case Study:	**FOR, Roterdam**
Architect:	Powerhouse Company
Area:	3564 m²
Program:	Offices & restaurant
Finished:	2021
Usage period:	50 years (assumption)
Assembly:	largely dry & mechanical connections

Renewable resource
Fossil resource
Harvested / Existing resource
Low maintenance
High Maintenance
Replacement needed
P= Periodically recurring

Layer	Element	Material / Product (mm)	Amount	MPG	Lifespan in years	Remaining lifespan after 50 years of use	Maintenance	Remountable	Adaptive	Recover	Recycle	Repurpose	Remanufacture	Refurbish	Repair	Reuse	Performance Explanation
SKIN	Ground floor	Ins. ribbed concrete floor-280	2086 m²	0,052	≥75	≥25										■	Still has a long lifespan, reusable (part of floating foundation).
		XPS insulation-190	1188 m²	0,022	≥75	≥25		■								■	Still has a long lifespan, can be reused.
		Concrete substrate layer-70	1188 m²	0,011	≥75	≥25					■						Cast in situ, can be pulverised and recycled.
	Facades	Aluminium curtain wall	972 m²	0,024	≤75	≤25		■							■		Still has a long lifespan, used outside, will need maintenance.
		HR+++ safety glazing	972 m²	0,090	≤30	**-20**	■	■			■						Needs to be replaced, can be recycled.
		Prefab ins. timber wall-200	181 m²	0,002	≥75	≥25		■	■			■	■	■		■	Still has a long lifespan, can be reused and adapted.
		Spruce wall cladding-40	181 m²	0,002	≥50	0	■	■		■						■	Will reach end of life, needs to be recovered.
		CLT balconies-220	773 m²	0,002	≥75	≥25	P	■							■		Still has a long lifespan, used outside, will need maintenance.
		Steel barred balustrade	369 m	0,004	≥60	≥10		■							■		Still has a long lifespan, used outside, will need maintenance.
	Roof	CLT roof plate-120	1842 m²	0,004	≥75	≥25		■								■	Still has a long lifespan, can be reused.
		XPS insulation-200	1842 m²	0,040	≥75	≥25		■								■	Still has a long lifespan, can be reused.
		EPDM Roofing (glued)	1842 m²	0,013	≥70	≥20	P			■	■					■	last longer due to greenery, can be recycled or recoverd.
		Green roof drainage system	1842 m²	0,012	25-	**-25**	■	■			■						Needs to be replaced, can be recycled.
STRUCTURE	Foundation	Concrete floating foundation	4512 m²	**0,227**	≥75	≥25									■	■	Still has a long lifespan, reusable, will need maintenance.
	Support structure	Timber laminated structure	2967 m	0,002	≥75	≥25		■								■	Still has a long lifespan, can be reused.
	Core	CLT walls-220	339 m²	0,001	≥75	≥25		■								■	Still has a long lifespan, can be reused.
	Floors	CLT floors-190	2376 m²	0,012	≥75	≥25		■								■	Still has a long lifespan, can be reused.
SERVICES	Heating & Cooling	Floor H&C	3564 m²	0,017	≤50	≤0	P			■							Will reach end of life, is inside the situ floor finish.
	Heating & Cooling	H&C Climate ceiling	3564 m²	**0,078**	≤20	**-30**	■	■	■		■						Needs to be replaced, can be recycled.
	Heat generation	Water heat exchange	3564 m²	N/A	≤15	**-35**	■				■				■		Needs to be partly repaired, partly replaced & recycled.
	Ventilation	Mechanical ventilation	3564 m²	**0,180**	≥15	**-35**	■	■	■		■				■		Needs to be partly repaired, partly replaced & recycled.
	Electricity	PV-panels	870 m²	**0,438**	≤25	**-25**	■			■	■						Will reach end of life, needs to be recovered & recycled.
SPACE PLAN	Interior walls	Steel frame glass walls & doors	502 m²	0,024	≤50	≤0	P	■			■				■		Will reach end of life, needs to be repaired & recycled.
	Interior walls	Timber system walls-100	697 m²	0,019	≥25	**-25**	■	■	■			■	■	■	■		Lifespan can be improved by maintenance, adaptable.
	Interior doors	Timber doors	52 p.	0,001	≥25	**-25**	■	■			■				■		Will reach end of life, needs to recovered & recycled.
	Stairs	Steel & timber staircase	9 p.	0,002	≥100	≥50		■								■	Still has a long lifespan, can be reused.
	Balustrade	Steel sheet balustrade	33 m	0,001	≥60	≥10		■								■	Still has a long lifespan, can be reused.

Renewable resource
Fossil resource
Harvested / Existing resource

Total MPG score for 15 years of use:	2,452
Total MPG score for 50 years of use:	**1,040**
Total MPG score for 75 years of use:	0,908

Conclusion

Embodied CO2 - 50 years: 279 kg eg/m2

The MPG at an assumed lifespan of 50 years is 1,040 which is higher than the currently permitted score of 1,0, a longer lifespan would be appropriate. Partly due to the amount of concrete and all the PV panels, ventilation units and air conditioning units that need to be replaced during use, the score is so high. Perhaps replacing the air-conditioning ceilings with air heating and cooling, since mechanical ventilation is used anyway, will ensure less replacement of components. Noteworthy are the very low scores of the applied materials in timber, this is due to its renewable raw material and long lifespan. Much of the material is remountable and has a long lifespan, leading to many possibilities for reuse. Without the concrete floating foundation and the PV-panels is the MPG score 0f 0,375, which clearly shows the potential of building with a lot of timber has on the climate impact of this building.

Case Study:	**Grote Kerk, Hoorn**
Architect:	Hylkema Erfgoed Advies en Ontwerp
Area:	2620 m² (+ 2677 m² attic appartments)
Program:	Hotel, restaurant & existing apartments
Finished:	2020
Usage period:	50 years (assumption)
Assembly:	largely wet & mechanical connections

The neo-Renaissance P. Grote Kerk was built in: 1883
Was changed to apartments & store space in: 1983
A stand alone steel & concrete structure was added for this new program.

Layer	Element	Material / Product (mm)	Amount	MPG	Lifespan in years	Remaining lifespan after 50 years of use	Maintenance	Remountable	Adaptive	Recover	Recycle	Repurpose	Remanufacture	Refurbish	Repair	Reuse	Explanation
SKIN	Ground floor	Existing concrete floor-300	1025 m²	0,000	≥75	**-17**					■						Will last longer then 75y, can be pulverised and recycled.
		E. concrete substrate layer-70	1025 m²	0,000	≥75	**-17**					■						Will last longer then 75y, can be pulverised and recycled.
	Facades	Existing brick facade-560	1156 m³	0,000	≥75	**-112**	P		■					■	■		Is already 137y old, will continue to last with maintenance.
		Existing windows & doors	264 m²	0,000	≥40	**-147**	P	■						■	■		Is already 137y old, will continue to last with maintenance.
		Steel window & door frames	187 m²	0,007	≥100	≥50	P	■					■			■	Still has a long lifespan, can be reused or changed.
		HR++ glazing	67 m²	0,007	≤30	**-20**	■	■			■						Will reach end of life, needs to be recycled and replaced.
		Monument add-on glazing	120 m²	0,006	≤30	**-20**	■	■			■						Will reach end of life, needs to be recycled and replaced.
	Roof	Existing slate roofing-4	3166 m²	0,000	≥75	**-112**	P	■	■						■		Is already 137y old, will continue to last with maintenance.
		Existing timberboard-22	2558 m²	0,000	≥75	**-112**	P	■	■					■	■		Is already 137y old, will continue to last with maintenance.
		Aluminium window frame	190 m²	0,000	≤75	**-38**	■	■			■						Will reach end of life, needs to be recycled and replaced.
		HR glazing	190 m²	0,000	≤30	**-57**	■	■			■						Will reach end of life, needs to be recycled and replaced.
STRUCTURE	Foundation	Ex. brick & conc. Found. & struc.	N/A	0,000	≥75	**-112**									■		Is already 137y old, will continue to last with maintenance.
	Support structure	Existing steel structure-400	476 m	0,000	≥50	**-37**		■							■		is 37y old, will last significantly longer than 50y, maintenance.
	Floors	Existing concrete floor-350	880 m²	0,000	≥50	**-37**									■		is 37y old, will last significantly longer than 50y, maintenance.
	Floors	Steel deck concrete floor-50	636 m²	0,014	≥50	**0**	P								■		lasts longer than 50y, maintenance, can be recycled.
	Walkway	Steel walkway structure-200	324 m²	0,016	≥50	**0**	P	■							■		Will last significantly longer than 50y, maintenance.
SERVICES	Heating & Cooling	Floor H&C	271 m²	0,001	≤50	0	P			■							Will reach end of life, is inside the situ floor finish.
	Heating & Cooling	H&C Climate units	799 m²	0,003	≥15	**-35**	■	■	■		■				■		Needs to be partly repaired, partly replaced & recycled.
	Heat generation	Air-Air heat pump	799 m²	0,004	≥20	**-30**	■	■	■		■				■		Needs to be partly repaired, partly replaced & recycled.
	Heat generation	Existing heat gen. Installation	1550 m²	0,000	≥20	**-30**	■	■	■		■				■		Revised in 2020, will need maintenance.
	Ventilation	Existing mech. ventilation	1550 m²	0,000	≥15	**-35**	P	■	■		■				■		Revised in 2020, will need maintenance.
	Ventilation	Balanced ventilation install.	1 pc.	0,008	≥30	**-15**	P	■	■		■				■		Needs to be partly repaired, partly replaced & recycled.
SPACE PLAN	Interior walls	Steel frame glass walls & doors	484 m²	0,047	≤50	≤0	P	■			■				■		Will reach end of life, needs to be repaired & recycled.
	Interior walls	Gypsum drywall-125	2229 m²	0,034	≥25	**-25**	■	■			■				■		Lifespan can be improved by maintenance, can be recycled.
	Interior doors	Custom arched timber doors	86 m²	0.001	≥25	**-25**	■	■			■				■		Will reach end of life, needs to recovered & recycled.
	Ceilings	Dubble gypsum board-125	1070 m²	0,012	≥25	**-25**	■	■			■				■		Lifespan can be improved by maintenance, can be recycled.
	Stairs	Steel & timber staircase	7 p.	0,006	≥100	≥50		■								■	Still has a long lifespan, can be reused.
	Balustrade	Steel & glass balustrade	91 m	0,056	≥60	≥10		■								■	Still has a long lifespan, can be reused.

Renewable resource	Total MPG score for 15 years of use:	0,639
Fossil resource	**Total MPG score for 50 years of use:**	**0,221**
Harvested / Existing resource	Total MPG score for 75 years of use:	0,178

Conclusion

Embodied CO2 - 50 years: 77 kg eg/m2

The MPG at an assumed lifespan of 50 years is 0,221, which is a beneficial low score. The score is so low because relatively little material has been added to the existing church of which almost everything has been preserved. An important choice is that the inside of the church is not insulated, but rather just the rooms as 'boxes'. Although a lot of maintenance and replacement of elements will be required over the 50-year period of use, the MPG is so low because the relatively few materials provide utility to the large floor area. Using long-lasting natural materials could have made the MPG even lower.

Case Study:	**R.K. Laurentiuskerk, Weesp**
Architect:	Stork & Albrecht, arch. en Bouwad.
Area:	1905 m²
Program:	Offices, bruwery, hotelroom, Yoga & app.
Finished:	2020
Usage period:	50 years (assumption)
Assembly:	largely wet & mechanical connections

The neo-Gothic R.K. Laurentiuskerk was built in: 1876

- Renewable resource
- Fossil resource
- Harvested / Existing resource
- Low maintenance
- High Maintenance
- Replacement needed
- P= Periodically recurring

Layer	Element	Material / Product (mm)	Amount	MPG	Lifespan in years	Remaining lifespan after 50 years of use	Maintenance	Remountable	Adaptive	Recover	Recycle	Repurpose	Remanufacture	Refurbish	Repair	Reuse	Performance Explanation
SKIN	Ground floor	Concrete in situ floor-400 (Fossil)	706 m²	0,027	≥75	≥25					■						Will last longer then 75y, can be pulverised and recycled.
SKIN	Ground floor	EPS Insulation-170 (Fossil)	706 m²	0,009	≥75	≥25					■						Will last longer then 75y, can be pulverised and recycled.
SKIN	Ground floor	Concrete substrate layer-160 (Fossil)	706 m²	0,013	≥75	≥25					■						Will last longer then 75y, can be pulverised and recycled.
SKIN	Facades	Existing brick facade-600 (Existing)	1085 m³	0,000	≥75	**-119**			■					■	■		Is already 144y old, will continue to last with maintenance.
SKIN	Facades	Existing windows & doors (Existing)	161 m²	0,000	≥40	**-154**		■						■	■		Is already 144y old, will continue to last with maintenance.
SKIN	Facades	Steel window & door frames (Fossil)	62 m²	0,005	≥100	≥50	P	■					■			■	Still has a long lifespan, can be reused or changed.
SKIN	Facades	HR++ glazing (Fossil)	62 m²	0,008	≤30	**-20**	Replacement needed	■			■						Will reach end of life, needs to be recycled and replaced.
SKIN	Facades	Monument add-on glazing (Fossil)	161 m²	0,011	≤30	**-20**	Replacement needed	■			■						Will reach end of life, needs to be recycled and replaced.
SKIN	Roof	Existing slate roofing-4 (Existing)	1805 m²	0,000	≥75	**-119**	P	■	■						■		Is already 144y old, will continue to last with maintenance.
SKIN	Roof	Existing timberboard-22 (Existing)	1805 m²	0,000	≥75	**-119**	P	■	■					■	■		Is already 144y old, will continue to last with maintenance.
SKIN	Roof	Stone wool ceiling ins.-240 (Fossil)	213 m²	0,002	≥100	≥50		■	■		■		■			■	Has a very long lifespan, can be reused in multiple ways.
STRUCTURE	Foundation	Ex. brick structure & foundation (Existing)	N/A	0,000	≥75	**-119**									■		Is already 144y old, will continue to last with maintenance.
STRUCTURE	Support structure	Concrete beams-400 (Fossil)	417 m	0,061	≥50	**0**	P				■				■		lasts longer than 50y, maintenance, can be recycled.
STRUCTURE	Support structure	Sand lime bricks-214 (Fossil)	1211 m²	0,038	≥75	≥25					■						Wet fixed, can be pulverised and recycled.
STRUCTURE	Floors	Concrete in situ floor-150 (Fossil)	1136 m²	**0,106**	≥50	**0**	P				■				■		lasts longer than 50y, maintenance, can be recycled.
STRUCTURE	Floors	Concrete substrate layer-70 (Fossil)	1136 m²	0,021	≥75	≥25					■						Cast in situ, can be pulverised and recycled.
SERVICES	Heating & Cooling	Floor H&C (Fossil)	1863 m²	0,005	≤50	0	P			■							Will reach end of life, is inside the situ floor finish.
SERVICES	Heat generation	Air-Water heat pump (Fossil)	3 pc.	0,047	≥20	**-30**	Replacement needed	■	■		■				■		Needs to be partly repaired, partly replaced & recycled.
SERVICES	Ventilation, H&C	Balanced ventilation install. (Fossil)	3 pc.	0,022	≥30	**-20**	P (High maintenance)	■	■		■				■		Needs to be partly repaired, partly replaced & recycled.
SPACE PLAN	Interior walls	Aerated concrete wall-75 (Fossil)	160 m²	0,003	≥60	≥10					■						Will last a long time, wet fixed, can be recycled.
SPACE PLAN	Interior walls	Gypsum drywall-100 (Fossil)	422 m²	0,009	≥25	**-25**	Replacement needed	■			■				■		Lifespan can be improved by maintenance, can be recycled.
SPACE PLAN	Interior walls	Moveable panel wall (Fossil)	27 m²	0,001	≥25	**-25**	Replacement needed	■	■		■				■		Lifespan can be improved by maintenance, can be recycled.
SPACE PLAN	Interior doors	Timber doors (Renewable)	42 p.	0,001	≥25	**-25**	Replacement needed	■			■				■		Will reach end of life, needs to recovered & recycled.
SPACE PLAN	Ceilings	Dubble gypsum ins.-125 (Fossil)	140 m²	0,002	≥25	**-25**	Replacement needed	■			■				■		Lifespan can be improved by maintenance, can be recycled.
SPACE PLAN	Stairs	Steel & timber staircase (Fossil)	12 p.	0,013	≥100	≥50		■								■	Still has a long lifespan, can be reused.
SPACE PLAN	Balustrade	Steel barred balustrade (Fossil)	38 m	0,001	≥60	≥10		■							■	■	Still has a long lifespan, can be reused, will need maintenance.

- Renewable resource
- Fossil resource
- Harvested / Existing resource

Total MPG score for 15 years of use:	1,176
Total MPG score for 50 years of use:	**0,409**
Total MPG score for 75 years of use:	0,306

Conclusion

Embodied CO2 - 50 years: 167 kg eg/m2

The MPG at an assumed lifespan of 50 years is 0,409, which is a high score compared to the Grote Kerk. The score is almost twice as high because of the use of a large amount of concrete. The use of concrete is not beneficial for the circularity of the building as well. Although concrete has a very long lifespan, which can be extended with inspections and maintenance what is sustainable if it remains as it is, the structure cannot be changed or taken apart without demolition. Using long-lasting natural materials could have made the MPG even lower.

Case Study:	**Baumannkerk, Rotterdam**
Architect:	HOYT
Area:	4205 m² (+ 492 annex)
Program:	Appartments & retail
Finished:	2020
Usage period:	50 years (assumption)
Assembly:	largely wet & mechanical connections

Was built in 1953,

- Renewable resource
- Fossil resource
- Harvested / Existing resource
- Low maintenance
- High Maintenance
- Replacement needed
- P= Periodically recurring

Layer	Element	Material / Product (mm)	Amount	MPG	Lifespan in years	Remaining lifespan after 50 years of use		Remountable	Adaptive	Recover	Recycle	Repurpose	Remanufacture	Refurbish	Repair	Reuse	Performance Explanation
		Refurbishment PUR ins.-200	1305 m²	0,024	≥75	≥25				■							Will last longer then 75y, cannot be recycled.
	Ground floor	Existing concrete floor-160	1305 m²	0,000	≥75	≥25					■						Will last longer then 67y, can be pulverised and recycled.
		Concrete substrate layer-110	1305 m²	0,024	≥75	≥25					■					■	Will last longer then 75y, cannot be recycled.
		Existing brick facade-500	631 m³	0,000	≥75	**-58**			■					■	■		Is already 67y old, will continue to last with maintenance.
		Existing windows & doors	58 m²	0,000	≥40	**-177**	P	■						■	■		Is already 67y old, will continue to last with maintenance.
		Refurbishment insulation-160	1262m²	0,017	≥25	**-25**		■	■		■						Will last longer then 25y, can be pulverised and recycled.
SKIN	Facades	Prefab ins. timber wall-200	194 m²	0,002	≥75	≥25		■	■			■	■	■		■	Still has a long lifespan, can be reused and adapted.
		Micro concrete cladding-15	188 m²	0,001	≥75	≥25	P	■	■			■	■	■		■	Will last longer then 75y, can be reused or recycled.
		Aluminium window & door frames	447 m²	0,012	≥100	≥50	P	■							■		Still has a long lifespan, used outside, will need maintenance.
		HR++ glazing	447 m²	0,026	≤30	**-20**		■			■						Will reach end of life, needs to be recycled and replaced.
		Monument add-on glazing	7 m²	0,000	≤30	**-20**		■			■						Will reach end of life, needs to be recycled and replaced.
		Existing roof tiles-12	325 m²	0,000	≥75	**-58**	P	■	■						■		Is already 67y old, will continue to last with maintenance.
	Roof	Existing timberboard-22	325 m²	0,000	≥75	**-58**	P	■	■						■		Is already 67y old, will continue to last with maintenance.
		PUR roof insulation-180	861 m²	0,016	≥75	≥25				■							Will last longer then 75y, cannot be recycled.
		EPDM Roofing (glued)	425 m²	0,003	≤50	0	P			■	■					■	Will reach end of life, needs to be recycled and replaced.
	Foundation	Ex. brick structure & foundation	N/A	0,000	≥75	**-58**			■					■	■		Is already 67y old, will continue to last with maintenance.
	Support structure	Sand lime bricks-214	1225 m²	0,022	≥75	≥25					■						Wet fixed, can be pulverised and recycled.
STRUCTURE	Walkway	Steel walkway structure-200	47 m²	0,001	≥50	**0**		■							■		Will last significantly longer than 50y, maintenance.
	Floors	Concrete in situ floor-250	2900 m²	**0,117**	≥50	**0**					■				■		lasts longer than 50y, maintenance, can be recycled.
	Floors	Concrete substrate layer-70	2900 m²	0,025	≥75	≥25					■						Cast in situ, can be pulverised and recycled.
	Heating & Cooling	Floor H&C	3562 m²	0,004	≤50	0	P			■							Will reach end of life, is inside the situ floor finish.
SERVICES	Heat generation	Water heat pump	38 p.	0,057	≥20	**-30**		■	■		■				■		Needs to be partly repaired, partly replaced & recycled.
	Ventilation, H&C	Mechanical ventilation	3562 m²	0,015	≥15	**-35**	P	■	■						■		Lifespan can be improved by maintenance.
	Interior walls	Gypsum drywall-100	1021 m²	0,010	≥25	**-25**		■			■				■		Lifespan can be improved by maintenance, can be recycled.
	Interior walls	Sand lime bricks-100	167 m²	0,001	≥75	≥25					■						Wet fixed, can be pulverised and recycled.
	Interior doors	Timber doors	223 p.	0,002	≥25	**-25**		■			■				■		Will reach end of life, needs to recovered & recycled.
	Stairs	Steel & timber staircase	9 p.	0,002	≥100	≥50		■								■	Still has a long lifespan, can be reused.
	Balustrade	Steel & glass balustrade	84 m	0,002	≥60	≥10		■								■	Still has a long lifespan, can be reused.

- Renewable resource
- Fossil resource
- Harvested / Existing resource

Total MPG score for 15 years of use:	1,268
Total MPG score for 50 years of use:	**0,422**
Total MPG score for 75 years of use:	0,331

Conclusion

Embodied CO2 - 50 years: 175 kg eg/m2

The MPG at an assumed lifespan of 50 years is 0,422, which is a high score compared to the Grote Kerk but similar to the Laurentiuskerk. The use of a large amount of concrete mainly contributes to this score. Although concrete has a very long lifespan, which can be extended with inspections and maintenance what is sustainable if it remains as it is, the structure cannot be changed or taken apart without demolition. Using long-lasting natural materials could have made the MPG even lower. The structure could have easily be made out of timber to replace the concrete and sand lime stone.