Madaster Circularity Indicator Explained

Made for	Version	Date
Madaster users	1.0	25 February 2021

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1 Introduction

The Madaster Platform provides users with a time-saving depository for building-, material-, and product data, and facilitates circular management using the Madaster Circularity Indicator. The aim of the Madaster Circularity Indicator is to improve circular-oriented building design, and to increase the circular value of buildings.

In this document the functioning of the Madaster Circularity Indicator (CI) is explained, as well as the measurement methodology. The Madaster Circularity Indicator is under constant development. The latest version of the indicator (version 0.2) was published on 26 April 2018. This document will be updated and adjusted according to future developments.

Three factors played an important role in the development of the Madaster Circularity Indicator:

- Compatibility with the data uploaded to the Madaster Platform (e.g. BIM files), and the corresponding ease of use for its users;
- The Madaster Circularity Indicator offers an incentive for the owners, investors, architects and designers, suppliers, contractors, and waste management companies to improve the circularity of the design;
- The objective of the Madaster Circularity Indicator is to measure the circularity score of buildings based on the circular properties of materials and products used to construct those buildings.

Below, there is a brief description of the CI:

MADASTER CIRCULARITY INDICATOR (CI) FOR BUILDINGS
The Madaster Circularity Indicator is designed to assign circularity scores (ranging from 0-100%) to buildings. The calculated CI is based on the data recorded by the user in the Madaster database.

The CI measures the circularity level of buildings during 3 different phases:

- Construction phase: What is the ratio between the volume of “virgin” materials and the volume of “recycled, reused or renewable” materials?
- Use-phase: What is the expected functional lifecycle of the products used, as opposed to the average functional lifecycle of similar products?
- End-of-life: What is the ratio between the volume of "waste" , and the volume of "reusable and/or recyclable" materials and products derived from a building when it is refurbished or demolished?

Explanation of the CI Score:

- A building that is built entirely from virgin materials, with a shorter than average functional lifecycle, that ends primarily as waste, is a ‘linear’ building with a low CI-score of: 0-10%.
- A building that consists entirely of materials and/or products that can be reused in the future (as products or materials), is a ‘circular’ building with a maximum CI-score of 100%, even if its' functional lifecycle is shorter than average.

In practice, buildings will have scores ranging from 0-100%, since a mix of virgin, recycled and reused materials will be used, which can be partly be reused, and will partly end up as waste at the end of their technical lifecycle.

The Madaster CI for buildings is based on the Material Circularity Indicator developed by the Ellen MacArthur Foundation[1], which is consequently adapted for the functionality of the Madaster Platform.

[1] https://www.ellenmacarthurfoundation.org/programmes/insight/circularity-indicators.

2 Scope and basic principles

The Madaster Platform functions as a missing link in the transition to a circular economy: a central platform where the identity, quality, as well as the location of materials in buildings can be registered. The data stored in Madaster can only provide added value for the circular economy when the offered data is sufficiently detailed (both from a financial, and from a zero-waste perspective), and when buildings are designed in such a way that materials and products can be easily disassembled and collected for reuse and/or recycling at the end of their functional lifecycle. Additionally, the Madaster Platform can function as a data source for a 'marketplace' where the available materials are offered for sale in order to stimulate reuse.

In addition to the Materials Passport, which evolved from the Madaster Platform, a module is developed that offers owners, investors, architects and designers, suppliers, contractors and recycling businesses an incentive to improve the circularity of building designs. The Madaster CI-score measures the circularity level of buildings, and enables the partners involved to compare the different scores.

The Madaster CI-score is based on the following components:

1. **Construction phase (objective: 100% non-virgin materials):**
    - Product mass (kg)
    - Virgin materials used to manufacture a product (% of mass);
    - Recycled materials used to manufacture a product (% of mass);
    - Reused materials used to manufacture a product (% of mass);
    - Rapidly renewable materials used to manufacture a product (% of mass);
    - Efficiency of the recycling process resulting in the recycled materials (%);
    - Mass of waste generated by the recycling process that feeds the manufacturing process (kg).

2. **Use phase (objective: use > 100%):**
    - Functional lifecycle of the products and materials used (in years);
    - Industry-average functional lifecycle of the building layer (in years).

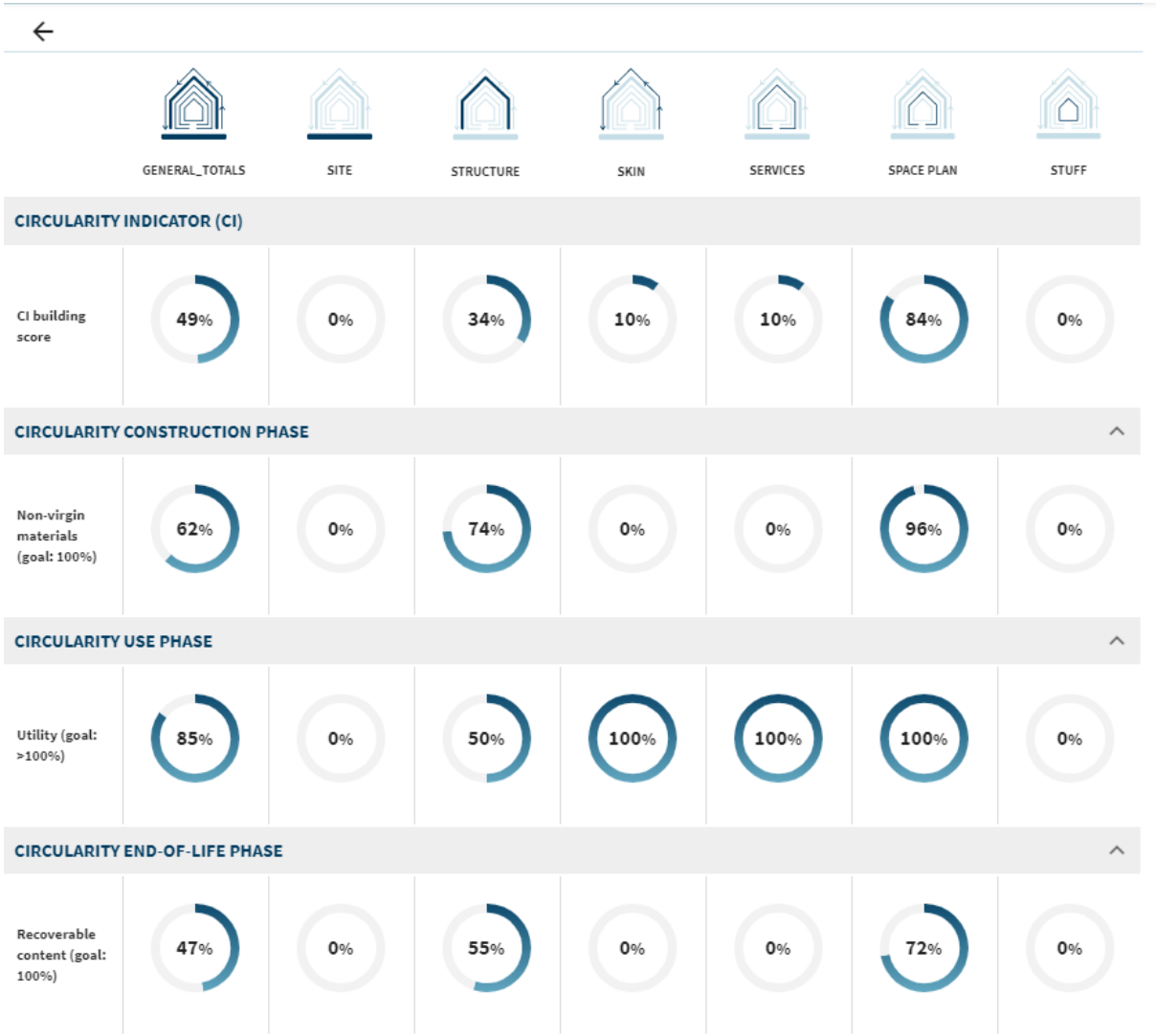
3. **End-of-life phase (objective: 100% of reusable materials):**
    - Materials suitable for recycling (% of mass);
    - Components suitable for reuse (% of mass);
    - Disassembly of products:
        - The assembly points are easily accessible, and the product can be easily removed without damaging other parts of the building (yes/no);
        - The product can be easily disassembled using standard tools without damaging the product or products to which it is attached (yes/no);
        - The product assembly points and the assembly methods are standardised and prefabricated (yes/no);
    - Mass of potential waste for landfill or incinerator (kg);
    - Efficiency of end-of-life recycling process (%);

- Mass of waste generated by the recycling process following the use-phase of the product (kg).

This method is designed to objectively measure the circularity level of both technical, and biological lifecycles, and to determine a single Madaster CI-score. Materials with biological lifecycles are materials that are biodegradable at the end of their useful life, whereas materials with a technical lifecycle, where the aim is to reuse and/or recycle these non-biological materials in a way that optimizes high-level reuse.

Basic principles:

i) Using as many recycled and/or reused materials as possible;
ii) Extending the functional lifecycle of products as long as possible;
iii) Collecting as many materials and products for recycling and reuse as possible.



On the Madaster Platform, the various components are displayed as follows:

Other sustainability indicators:

Although the CI method provides an indication of the circularity level of materials, products, and buildings, a number of sustainability indicators is not included in the calculation:

- Energy: the embedded energy of the materials used, and the energy consumption during the use-phase of the building;
- Water: the water consumption during the manufacturing and construction phases and during the use-phase of the building;
- Environmental footprint: climate change, ozone depletion, acidification, human toxicity, etcetera.
- Carbon footprint
- Odour nuisance and noise pollution, other risks, etc.

3 Determining the Madaster CI

The Madaster CI-score is automatically generated following a number of steps:

Step 1:
To generate a Madaster CI-score, a Madaster Platform user must first upload relevant building data using an IFC or Excel file. IFC is an open, standard format for the exchange of BIM data (Building Information Model) between various software packages. The Excel file enables you to import limited data sets, and to add data using a standard file format. There is no limit to the number of files you can upload to the Madaster Platform.

A reliable Madaster CI-score is only feasible for buildings whose products and materials have been fully recorded. Therefore, it is essential that Madaster users make sure that the source file meets the highest possible standards, and offers a complete, virtual representation of the building.

Madaster defines the following guidelines and requirements for setting up a BIM and the subsequent export of the IFC model:

- Prevent the use of the IFC entities 'Building element proxy' and 'Building element part';
- every GUID must be unique;
- Assign a material to all elements;
- Classify all elements using the NL/SfB classification system (4 digits);
- Always add the "Base Quantities" to your export;
- Include the "Renovation Status" or "Phasing" in the export in the identically named property set; use the English name if you assigned your own title, previously: Existing / Demolish / New
- Use the "2x3" export setting of a possible Madaster export" set

See the IFC export manuals and the Madaster Quick Reference Guide for detailed information on the ILS and IFC export options for the various software packages.

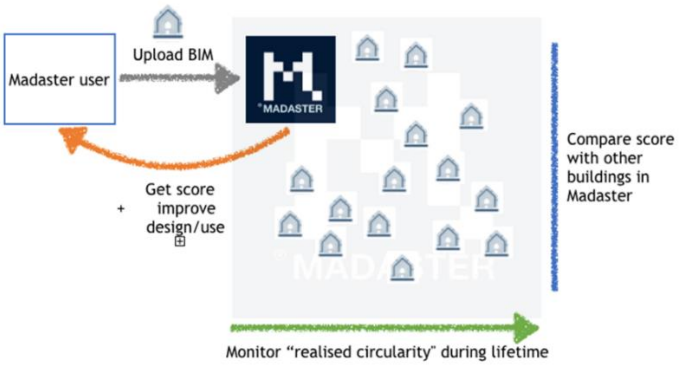
Step 2:
After the building data has been uploaded by the user, it is automatically mapped by the platform. The automatic mapping takes place as the current IFC files do not contain circular values, such as recycled content, and potential reuse. The data is enriched by linking materials and products from an IFC file to other databases. In the Madaster system environment, users can manually add information to the data from the BIM model.

With the automatic mapping, the amount of data increases, improving the comprehensiveness and reliability of the Madaster CI-score.

Step 3:
Subsequently, the 'first' Madaster CI-score is calculated from the uploaded building data, in accordance with the measurement methodology described in Chapter 4. In Madaster, the user can improve the design, add data, add further details, as well as upload newer versions in order to increase the CI-score.

Step 4:
The circularity level can be monitored during the use-phase of the building. During the use-phase of the building, circular values can change. Also, maintenance and repair activities can be included

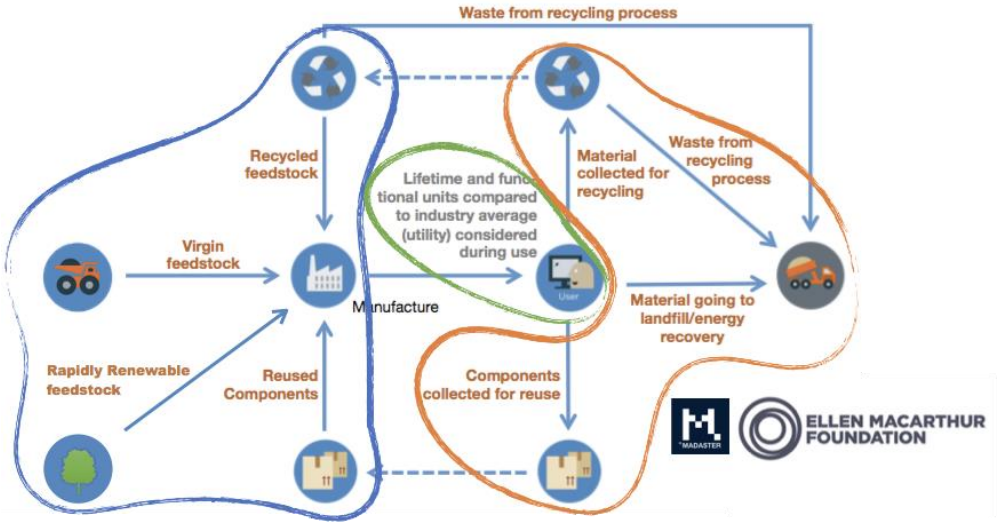
in the data. This way, the score stays up-to-date and accurate. It is the user who determines when a new CI-score is calculated.



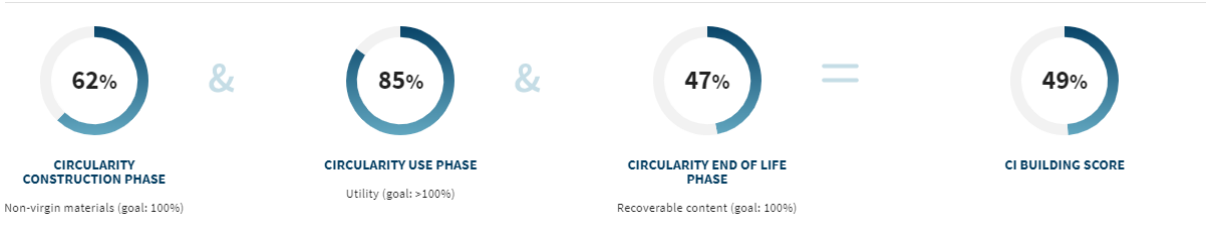
Note on the quality of the data:
The quality of the BIM data uploaded to Madaster is a determining factor for the usefulness of the data for the calculation of the Madaster CI-score. To realize a good CI-score, it is important that the BIM-model is sufficiently detailed and contains enough information.

4 Madaster CI-score Measurement Method

After extensive analysis of the available methods and tools used to measure circularity, Madaster decided to choose the 'Material Circularity Indicator' measurement method of the Ellen MacArthur Foundation (EMF) as a basis for developing the Madaster Circularity Indicator. For the remainder of this document, the EMF method is treated as a matter of course. A detailed description and additional information on the Material Circularity Indicator, which is open-source, can be found on the website of the Ellen MacArthur Foundation[2]. The visualisation below, in which the existing EMF model can be clearly recognised, is the result of several expert sessions.



The measurement method of the Madaster CI has three different phases: the construction phase (blue), the use phase (green), and the end-of-life phase (orange). This enables users to compare products and buildings by comparing the various components and to easily assign circularity ambitions and objectives.



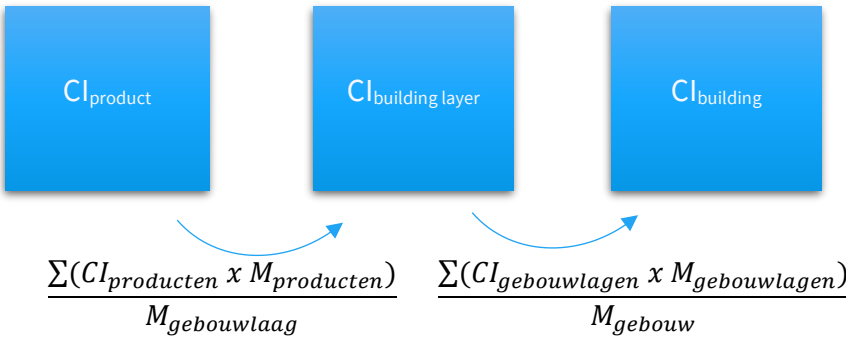
The circularity objectives for each phase are:

1. Construction Phase: 100% use of non-virgin materials (recycled and/or reused) or the use of rapidly renewable materials, whereby the use of recycled materials are considered less attractive, as the recycling process generates its own waste streams.

[2] https://www.ellenmacarthurfoundation.org/programmes/insight/circularity-indicators.

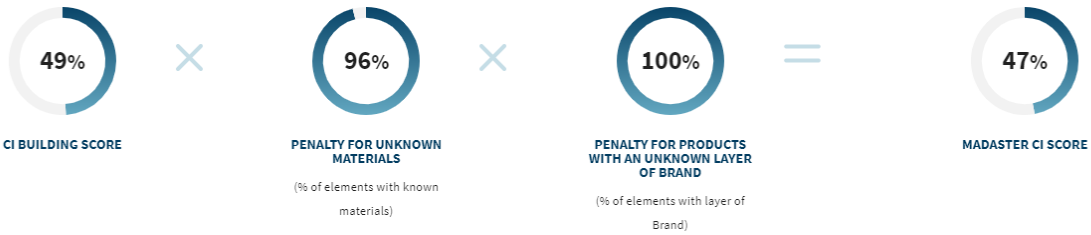
2. Use-Phase: products with a functional lifecycle that exceeds the industry-average . Here, the ideal situation would be one of infinite reusability, with an infinite number of lifecycles.
3. End-of-Life Phase: Materials/products with 100% reusability, on the highest level possible. Here, the ideal situation would be one of immediate reuse.

To calculate the Madaster CI-score, the measurement method uses the weighted average. The weighted average is based on the mass of the materials and products used. Subsequently the scores are calculated, both for the different building layers (Brand, 1994)[3], and for the building as a whole.



The Madaster CI measurement method consists of two levels:

1. Building Circularity Indicator: The CI-score of the building based on the available data;
2. Madaster Circularity Indicator: The Building CI-score adjusted by two correction factors. By applying these correction factors, the comprehensiveness of the dataset in the Madaster database is taken into account. A circular building and the corresponding Materials Passport can only be effective if the products and materials in the building have been properly recorded. The applied correction is based on the comprehensiveness of the model in terms of the percentage of the mass for which the materials are known, and the comprehensiveness of the model in terms of the percentage of the mass for which the NL-SfB coding is available.



[3] Brand, S. (1994). How Buildings Learn; What happens after they're built. Penguin Publishing Group

5 Calculating the Building CI-score

This chapter contains additional information on the circularity indicators for the Construction Phase (Section 1), the Use-Phase (Section 2), and the End-of-Life Phase (Section 3). Subsequently, the calculation of the Building CI-Score is explained (Section 4), using EMF's Material Circularity Indicator as a basis.

5.1 Construction Phase Circularity Indicator

To calculate the Circularity Indicator for the construction phase, the user must be able to provide insight into the materials a product or building has been constructed from (see Chapter 6). This can be done using data from the existing Madaster database or by manually entering the required data on material and product level. At this point, a distinction is made between the percentage of virgin and non-virgin materials. For reused materials, the Madaster CI-score distinguishes between recycled, reused, and rapidly renewable materials.

The formula for the Construction Phase Circularity Indicator is:

$$CI_{Constructie} = F_R + F_{RR} + F_U$$

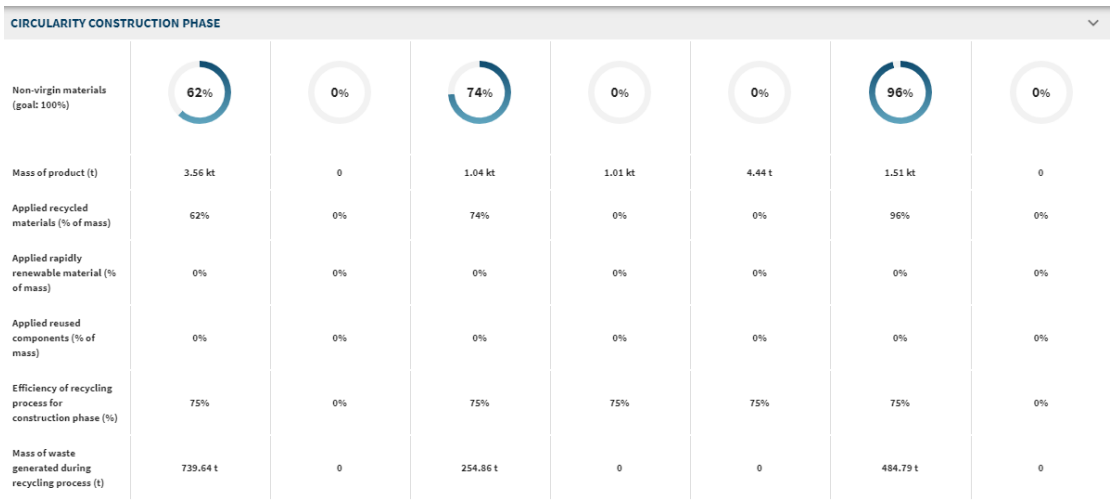
F_R Fraction of recycled materials (as a % of the product mass);
F_{RR} Fraction of rapidly renewable materials (as a % of the product mass);
F_U Fraction of reused products and/or components (as a % of the product mass).

For the Building CI-score (Section 4) the following data and ratios from the construction phase is taken into account:

- The product mass (M) (kg);
- The efficiency of the recycling process preceding the construction phase* (E_F) (%);
- The mass of waste generated during the recycling process (W_F) (kg).

* This applies to the recycling process preceding the production of the product. E.g., it is possible that it takes two discarded floor tiles to manufacture one new floor tile that completely consists of recycled materials (a 50% efficiency).

Display on the Madaster Platform:



5.2 Use Phase Circularity Indicator

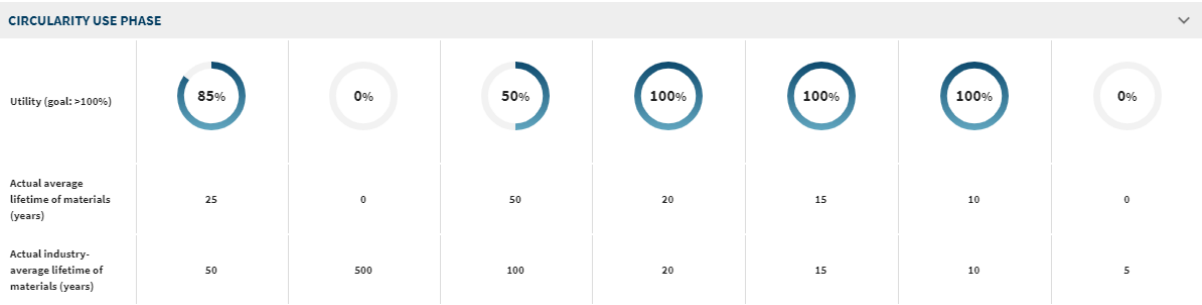
To generate the Use-Phase Circularity Indicator, the user must be able to provide insight into the potential functional lifecycle of a product, including its potential reuse (See Chapter 6). Should the potential functional lifecycle be unknown, then the lifecycle of the relevant building layer is used, instead. Subsequently, the potential functional lifecycle is compared to the industry-average lifecycle in accordance with Stewart Brand's 'Building Layers' theory[4].

The formula for the Use-Phase Circularity Indicator is:

$$CI_{Gebruik} = \frac{L}{L_{av}}$$

L Potential functional lifecycle of a product, in years;
L_{av} Industry-average lifecycle of a building layer, in years.

Display from the Madaster Platform:



Please note: The total score cannot be generated by simply dividing 49 by 50. The actual score of 53% is determined by calculating the weighted average of all products from the various system layers. See Chapter 4 for more information.

5.3 End-of-Life Phase Circularity Indicator

To generate the End-of-Life Phase Circularity Indicator, the user must be able to provide insight into the potential reuse scenario for each material and/or product (see Chapter 5). The calculation distinguishes material reuse (recycling), component and/or product reuse (reuse) and waste

[4] Brand, S. (1994). How Buildings Learn; What happens after they're built. Penguin Publishing Group

disposal (landfill sites + incineration). The efficiency of the recycling process, i.e., the additional waste generated by this process is also taken into account.

The formula for the End-of-Life Phase Circularity Indicator is:

$$CI_{End-of-Life} = C_R \cdot E_C + C_U$$

C_R Fraction of materials that can be potentially recycled at the end of its useful life (as a % of the product mass);

E_C Efficiency of the recycling process in the end-of-life phase (%);

C_R Fraction of components and/or products that can be potentially reused at the end of its useful life (as a % of the product mass);

The fraction of components and/or products to be entered must fulfil several conditions (Design for Disassembly). These conditions must be met, because the reuse of components and/or products is only possible when these can be successfully extracted from a building. The conditions to be fulfilled at product level, which can be found on the 'Administration' tab, are:

1. The assembly points are easily accessible, and the product can be easily removed without damaging other parts of the building (yes/no).
2. The product can be easily disassembled using standard tools without damaging the object or objects to which the product is attached.
3. The assembly points and assembly methods used to install the product are standardized and prefabricated.

Display from the Madaster Platform

CIRCULARITY END-OF-LIFE PHASE

Recoverable content (goal: 100%)	47%	0%	55%	0%	0%	72%	0%
Materials for recycling which are going to be collected (% of mass)	62%	0%	74%	0%	0%	96%	0%
Components for reuse which are going to be collected (% of mass)	0%	0%	0%	0%	0%	0%	0%
Mass of potential landfill & energy incineration (t)	1.34 kt	0	275.08 t	1.01 kt	4.44 t	53.41 t	0
Efficiency of recycling process for end of life phase (%)	75%	0%	75%	75%	75%	75%	0%
Mass of potential landfill & energy incineration of the recycling process (t)	554.8 t	0	191.14 t	65.62 kg	0	363.59 t	0

Please note: The total score of 13% cannot be generated from the displayed values, since this score is determined by calculating the weighted average of all products from the various system layers. See Chapter 4 for more information.

5.4 Building Circularity Indicator

5.4.1 Circularity Indicator

The Circularity Indicator is calculated taking into account the material flows and the utility factor.

To calculate the Circularity Indicator (CI), the following formula is used:

$$CI = 1 - LFI \cdot F(X)$$

5.4.2 Linear Flow Index (LFI)

The Linear Flow Index (LFI) is used to calculate the linear part of the material flow, starting with 100% of virgin materials, with 100% ending up in an incinerator or on landfill. The LFI has a range from 0 (completely circular) to 1 (completely linear).

The formula for the LFI is as follows:

$$LFI = \frac{V + W}{2M + \frac{W_F - W_C}{2}}$$

It consists of the following sub-formulas:

$$V = M\ (1 - F_R - F_{RR} - F_u)$$

M	Product mass (kg)
V	Mass of virgin material used in manufacturing a product (kg)
F_R	Fraction of recycled materials (as a % of the product mass);
F_{RR}	Fraction of rapidly renewable materials (as a % of the product mass);
F_U	Fraction of reused products and/or components (as a % of the product mass);

$$W = W_0 + \frac{W_F + W_C}{2}$$

W	Mass of waste (kg)
Wo	Mass of waste (kg) that ends up on landfill or incinerators after the useful life of a product.
Wf	Mass of waste (kg) generated by the recycling process that provides the materials used to manufacture a product.
Wc	Mass of waste (kg) generated by the recycling process after the useful life of the product.

$$W_0 = M(1 - C_R - C_U)$$

Cr	Fraction of materials with a waste recycling scenario (as a % of the product mass);

Cu Fraction of materials with a waste reuse scenario (as a % of the product mass);

$$W_F = M\ \frac{(1 - E_F)F_R}{E_F}$$

Ef Efficiency of the recycling process (%) supplying the materials to manufacture a product. The default value of 75% can be changed manually, since the required data is not available.

$$W_C = M\ (1 - E_C) \cdot C_R$$

Ec Efficiency of the recycling process (%) for a product with a waste recycling scenario. The default value of 75% can be changed manually, since the required data is not available.

5.4.3 Utility Factor - F(X)

The F(X) utility Factor calculates the impact of the length of the useful life of a product. This impact decreases by improvements in the design, repairs, upgrades, and preventive maintenance.

The formula for the utility factor[5] is:

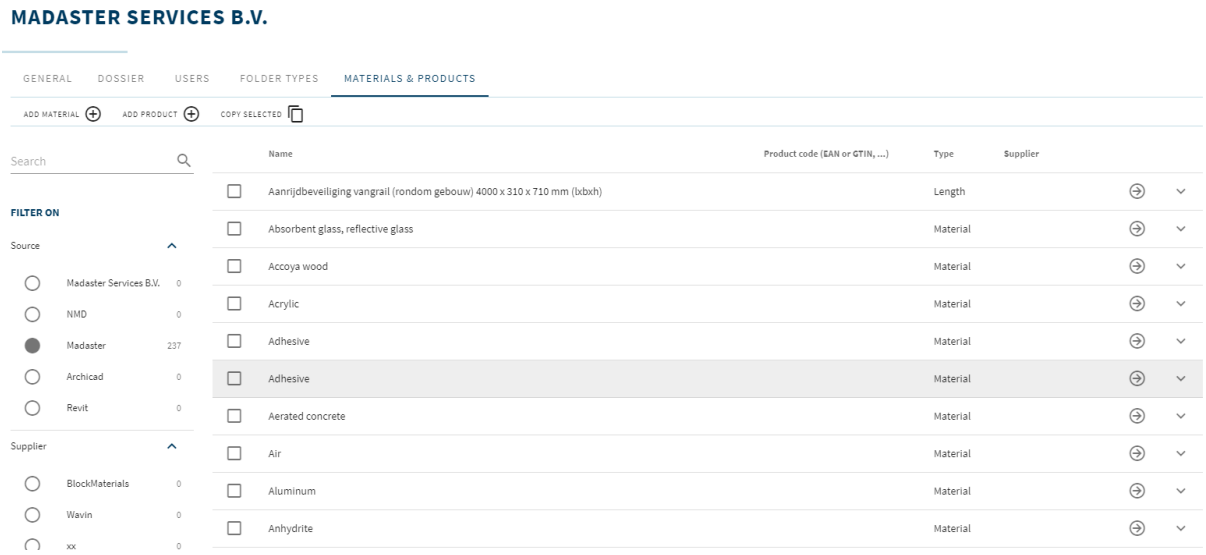
$$F(X) = \frac{0{,}9}{X} \quad \& \quad X = \frac{L}{L_{av}}$$

0,9 Utility constant[6];
L Potential functional lifecycle of the product (years);
L_{av} Industry-average functional lifecycle of the product (years).

[5] Please note that the Madaster CI-score methodology does not take into account the EMF U/UAV component.
[6]The utility constant ensures that fully linear products, with a potential functional lifecycle equal to the industry-average lifecycle, receive a score of 0.1 – 1. Products that are fully linear, with a lower potential functional lifecycle than the industry-average lifecycle, receive a score < 0.1(https://www.ellenmacarthurfoundation.org/programmes/insight/circularity-indicators.)

6 Madaster Database for Materials & Products

To enrich IFC files and to record the required circularity data, the Madaster database can be used for both materials, and products. This database, which already contains data on well-known materials and products, can be extended with new materials and products. The databases available for enrichment can be found under the tab databases



Which materials and products are displayed here?

This page provides an overview of all materials and products in the Madaster database and aother globally available databases for your country and the platform as well as all databases added under your account. In the filter column (‘Source’) you can see the database the product is registered in. The Madaster database can be viewed by every user. You cannot modify this data. It depends on a user's privileges, whether or not they can edit the materials and products they added to the database themselves.

How can you change the circularity data of materials?

1. Click the ‘Edit’ button for the material or product you would like to change.
2. Edit the data you would like to change (e.g. recycled content, reuse scenario, disassembly).
3. Click the ‘Save material’ or ‘Save product’ button.

How can you add new materials or products?

You can add a new material or product for a source file from the ‘Enrichment’ tab. To open the ‘Enrichment’ tab, you click the ‘View status’ button (which is displayed next to a source file on the 'Dossiers' tab) or, if you are an account administrator, you can use the ‘Administration’ menu.

After you have added a new material or product, you can use this menu to display the material or product, and enter the available fields.

1. You can create a product in one of your account databases by clicking the ‘Add material’ or ‘Add product’ button. You can find the products and materials you added on the ‘Materials’ and ‘Products’ tabs of your account. There, you can subsequently add details for the material or product you just entered.
2. To enter additional data, you can click the ‘Edit’ button (behind the material or product you have just created), and add data on the available tabs, such as materials or circularity data, or search criteria.

7 Current developments

The Madaster CI-score is in constant development, and it is Madaster's aim to continuously play a leading role in developing and providing circularity measurement methodologies. To enrich the input of the Madaster Platform, and to increase its reliability, it is necessary to establish links to external databases with reliable data (preferably from the suppliers themselves). It is also important to use a 'Circularity BIM Information Development Manual' (IDM) with guidelines and a fixed set of rules for the implementation of IFC files.

Madaster is constantly talking to partners who can supply the platform with data on applied materials, functional lifecycles versus technical lifecycles, durable versus non-durable reuse, and the impact of materials on mankind and nature.