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Developing an assessment framework for circularity in dike reinforcement projects



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Glossary

Directly reused materials: Reused material/object from the reinforced dike at a higher or equal level.

Disassembly potential: The possibilities for reuse of buildings and their components are dependent on the capacity of a building to be disassembled efficiently without damaging the components (Durmisevic, 2006).

Externally reused materials: reused material/object from outside the organisation through the utilisation of material banks or similar platforms.

Functional lifetime: the lifetime until the function of the material, components or element is not relevant anymore (e.g., due to changing environmental circumstances grass is not safe enough after 5 years so it needs to be replaced with stone plates).

Input materials: the materials used for the realisation and management & maintenance during the lifetime of a design.

Internally reused materials: reused material/object from other projects within the organisation.

Locally reused materials: Reused material/object from other projects near the dike.

Non-renewable materials: Materials not originating from a renewable source.

Output materials: the materials imbedded in a design at the end of the lifetime.

Primary resources: the raw materials extracted and used for production (European Commission, n.d.).

Recycled materials: Material from the processing and reuse of resources.

Refurbished materials: Material/object from the treatment of the resource to enable reuse in the DR project.

Regionally reused materials: Reused material/object from other projects located further from the dike.

Renewable & non-sustainable materials: Materials originating from a renewable source that is naturally replenished or cleansed on a human time scale, but the extraction rate exceeds the regeneration/cleansing rate.

Renewable & sustainable materials: Materials originating from a renewable source that is naturally replenished or cleansed on a human time scale & the extraction rate does not exceed the regeneration/cleansing rate.

Repurposed materials: Material/object gets a different (lower) function and application within the DR project.

Reused materials: material originating from a composed object that after use (and if needed after processing) is reused in the same function.

Secondary resources: the materials originating from previously used products or from residual streams of other systems. These inputs are used to replace primary or other secondary materials (Platform CB'23, 2020a).

Spatial-functional adaptivity: Design decisions are made to accommodate future interests by ensuring the adaptive capacity of objects (Platform CB'23, 2021).

Technical lifetime: the lifetime until the materials, components and elements are starting to break (e.g., grass on the side of a dike that dies after 10 years).

Technical-functional adaptivity: Design for an optimum between the technical and functional lifetime, where an object is designed to retain its performance under the expected changing circumstances (Kok et al., 2019).

Abstract

In the Netherlands, the objective of the Ministry of Infrastructure & Environment is to realise a full circular economy in 2050, where an intermediate goal of a 50% reduction in primary resource use in 2030 should be realised. In the coming thirty years, 1300 kilometres of dikes in the Netherlands must be reinforced to cope with rising sea levels caused by climate change. These dike reinforcement projects must conform with the circularity objectives of the government.

To support improved implementation of circularity in DR projects, this study conceptualised circularity in this context based on a literature review and interviews with practitioners in the sector. In this conceptualisation, circularity is considered a tool to maintain resource stocks, protect the environment and retain the value of objects/materials. This resulted in six categories that must be considered; the categories treat topics like the quantity of material use, the circular characteristics of input and output materials, the inclusion of future perspectives and interests in designs, the impact of material use, and the uncertainty of the data.

To track the progress of circular implementation in DR projects, an assessment framework was developed that compares different dike designs using the six categories from the conceptual framework. Each category has measurable aspects that can be used to determine a score for each category. To determine the final circularity score, each category is assessed and weighted depending on the perceived importance to circularity of an expert panel. In this way, circularity can be measured and assessed in DR project during the entire life cycle.

Introduction

The circular economy is defined by Geissdoerfer et al. (2016), p759, as “a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling.”. While multiple definitions exist (Figge et al., 2018; Korhonen et al., 2018; Saidani, 2018; Singh & Ordoñez, 2016), this definition integrates aspects found in different studies to display a complete perspective on the circular economy.

Circularity is considered a tool to achieve several objectives, namely: maintain resource stocks, protect the environment and retain the value of objects/materials (Korhonen et al., 2018; Platform CB’23, 2020a). To realise these goals, strategies like increasing the life-time/durability are prioritised over reuse, which gets priority over recycling etc. (Korhonen et al., 2018). The Ellen MacArthur Foundation has designed a comprehensive overview of this hierarchy of circular economy concepts; this is displayed in figure 1. In this diagram an additional distinction is made between the functioning of circularity of renewable/bio-based materials in consumer goods on the left and finite resources in user goods on the right. The overview provides a general perspective on the circular economy; however, depending on the context of implementation, some aspects can be irrelevant and can be omitted from the system. For example, circularity in food consumption exclusively considers the left wing, while the construction of dikes mostly considers the right wing.

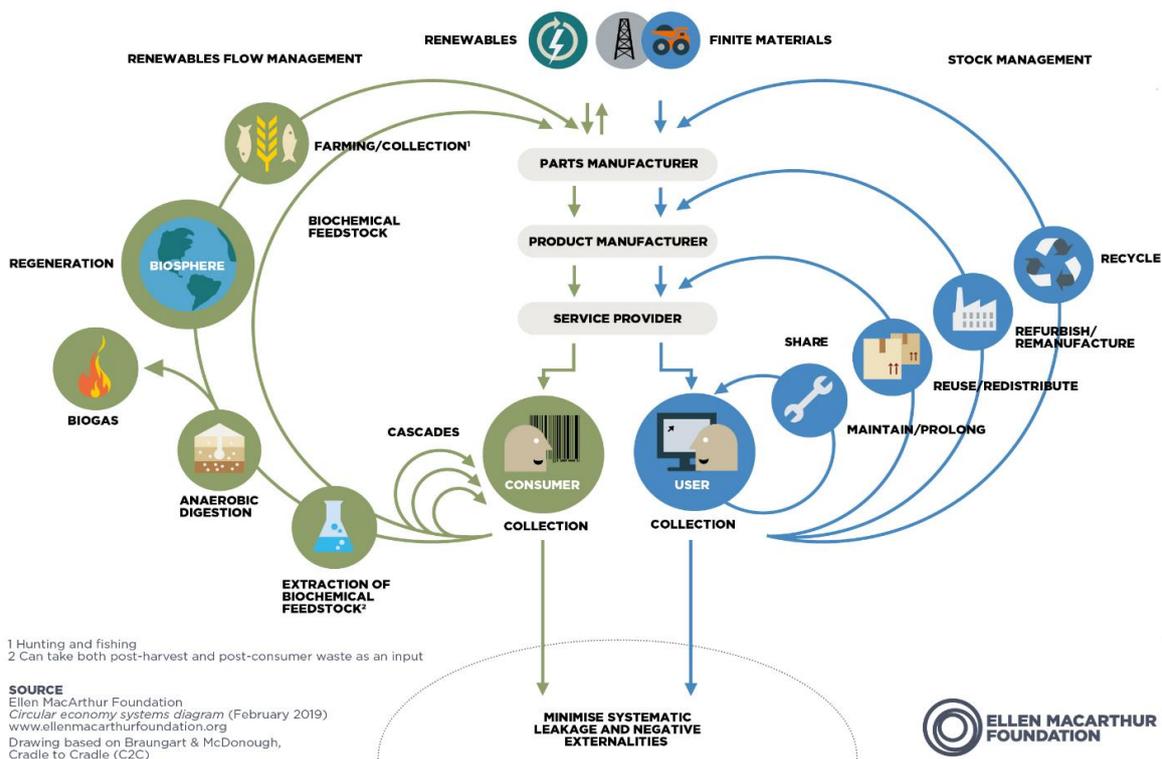


Figure 1: visual representation of the aspects of the circular economy and its hierarchal structure, also known as the 'Butterfly Diagram' (Ellen MacArthur Foundation, 2019).

Clear benefits of the circular economy approach compared to the current economic system are the increased resource use efficiency and the resulting independence from other countries/suppliers, the preservation of the value of products and resources and the limited environmental impact. Consequently, this resulted in the penetration of this concept in business strategies, as well as the policy-making of several countries, for example, China, Japan, the UK, France, Canada, the

Netherlands, Sweden and Finland (Geissdoerfer et al., 2016; Government of Canada, 2021; Heshmati, 2015; Korhonen et al., 2018; Koty, 2021; Zenbird, 2021).

In the Netherlands, the objective of the Ministry of Infrastructure & Environment is to realise a full circular economy in 2050, where an intermediate goal of a 50% reduction in primary resource use in 2030 should be realised (Rijksoverheid, 2016). To realise this, the government has established targets to pursue this objective: 1.) efficient resource use and reuse without harmful emissions into the environment, 2.) if primary resources are used, they must be extracted in a sustainable manner without harming public health and the environment, and 3.) product design must be adapted to reuse with minimal value-loss and without harmful emissions (Rijksoverheid, 2016). As part of their circular strategy, the Dutch government indicated 5 sectors that should become frontrunners in circular thinking, because of their large environmental impact and importance to the Dutch economy. These sectors are the biomass/food, plastic and manufacturing industries, as well as the civil engineering/construction and consumption goods sectors (Rijksoverheid, 2016).

The Dutch civil engineering sector is estimated to be responsible for 50% of all resource use, 40% of the energy use and 30% of water use in the country. Additionally, the sector produces an estimated 40% of the total waste stream through construction and demolition waste streams. Consequently, their operations produce an estimated 35% of the emitted CO₂ in the Netherlands (Rijksoverheid, 2016). These figures stress the necessity and the opportunity for the implementation, monitoring and improvement of circularity in this sector. To organise this, the sector can learn from the implementation, monitoring and improvement of sustainability, which has occurred in recent years through the 'Green Deal Duurzaam GWW' and 'Manifest Duurzaam GWW 2030' initiatives (Aanpak Duurzaam GWW, 2012; Manifest DGWW2030, 2021). Through these initiatives, circular aspects are partially included as components of sustainability. However, circularity is not specifically mentioned as a subject, which leaves the interpretation of the concept to the signatories of the initiatives. This results in the lack of a uniform perspective on what circularity is and what it entails in the civil engineering sector, which makes it difficult to structure circular developments and measure and assess the progress.

Since around 60% of the Netherlands is lying below sea level, an important component of circular implementation in civil engineering is in the construction/reinforcement of flood defence or 'wet' infrastructure. The range of possible measures required to protect the country from floods are quite variable in scale, e.g., digging a drainage ditch up to the construction of massive dikes. For dikes, very strict regulations are in place to ensure the safety of the inhabitants behind the dike. Unfortunately, climate change is causing significant sea level rise and increases the frequency of intense weather events (Dingman, 2015); both these developments contribute to a decrease in the safety levels of dikes. Therefore, many of the dikes in the Netherlands are scheduled to be reinforced in the coming thirty years; in total these projects amount to a length of 1300 kilometres of dike reinforcement (DR) (den Boer et al., 2021). These DR projects require large quantities of resources and the use of large machinery. Therefore, it is necessary to implement the principles of circularity to reduce resource use, limit the impact of the projects and retain the value of resources within the projects. In this way, DR projects can serve as an example of how to implement circularity in projects in the wider construction sector and eventually in other sectors. This could contribute significantly to achieving national targets on circularity.

'Rijkswaterstaat' is the executive branch of the Ministry of Infrastructure & Environment and a large contractor in the civil engineering sector. As a large contractor, they want to set a good example on how to implement circularity in their infrastructural designs (Rijksoverheid, 2016). Therefore, they formulated their own interpretation on how to implement circularity in infrastructural design through

their ‘circular design principles’ (Rijkswaterstaat, 2020). However, it is unknown how to quantitatively measure the implementation of these principles and if this differs for different types of infrastructure. The R-principles of Cramer provide a hierarchy of circular strategies, which can be used to provide a qualitative assessment (Waterschap Zuiderzeeland, 2021). However, the lack of quantitative methods for assessing circularity has been recognised as a key challenge in other studies as well (Avraamidou et al., 2020; Heshmati, 2015). Consequently, recent efforts focussed on determining an indicator framework and scoring system to measure and assess circularity, some examples are:

- 1) The implementation of circular practices and processes in dike reinforcement projects (Weersink & van Cuyk, 2020)
- 2) Circularity for projects in the wider construction sector (Platform CB’23, 2020a).
- 3) Circularity for design alternatives of dry infrastructural projects (e.g., bridges) (Meijer, 2018).

The previous research efforts (number 1-3 above) have several shortcomings. The first effort only scores the implementation of circular practices, which is only a proxy and not a measurement for actual circularity. The second effort attempts to quantitatively assess the value of the object/project, which is very difficult to determine for DR projects as most of the value of such a project comes from the protection it facilitates for the hinterland. In addition, large parts of the approach are still under development. For the last effort, the scoring criteria for some circular indicators were not easily workable and provided a shallow understanding of circular concepts like reuse and recycling. Furthermore, the author specifically mentions that specific requirements for ‘wet’ infrastructure were not considered in the design of the approach (Meijer, 2018). Hence, there is a lack of a uniform perspective on what circularity is and how it can be implemented in DR projects, as well as a lack of a quantitative, complete and workable methodology to assess circularity (not circular practices) in the context of DR projects.

Research goal and questions

A method to assess circularity in DR projects is necessary to get insight into the status of circularity in DR projects. Without it, it is impossible to track developments and improve the implementation of circularity and eventually achieve the national targets to become fully circular in 2050. Therefore, the following research question is formulated:

‘How can circularity be measured and assessed in dike reinforcement projects during the entire life cycle?’

To answer the main research question, two sub-questions have been determined:

(RQ1) What are aspects of circularity in DR projects that need to be measured?

To answer this question, it is important to know what the organisational and physical structure of DR project are, what frameworks for circular development already exist in the civil engineering/construction sector, and how circularity is currently incorporated in DR projects. This background information provides the foundation to explore what circularity means in DR projects and how it manifests itself in DR projects. The results from RQ1 provides the conceptual basis of this research and determine the aspects needed for a circularity assessment in DR projects.

(RQ2) How can these circular aspects be measured and scored to assess circularity in DR projects?

To answer this question, it is explored how circularity is quantitatively assessed in other sectors/projects and how (components of) these methodologies can be used to measure circular aspects in the context of DR projects. Additionally, it is researched how these measurements can be interpreted and scored to assess circularity.

In this way, this thesis contributes to the conceptualisation of circularity in DR projects, and predominantly addresses the gap on how to measure, score and assess circularity in DR projects.

Background information on dike reinforcements

Stakeholders

The executive responsibility for DR project lays with either Rijkswaterstaat or one of the 21 water boards, which are the regional water authorities in the Netherlands. This depends, however, on the jurisdiction of the region where the project is located. These organisations are thus also largely responsible for circular developments in these projects, which is often addressed and incorporated in their individual policy strategies (personal communication, Verschoor, appendix D). Another important stakeholder is the 'Hoogwaterbeschermingsprogramma' (HWBP), which is a cooperation between Rijkswaterstaat and the 21 water boards. The HWBP is responsible for a large part of the financing for these projects and thus can influence the implementation of circularity in DR projects (personal communication, Wolbers, appendix D). Together, these organisations share the responsibility to improve all important flood defence infrastructure to conform with the updated and more stringent safety regulations by 2050. They decided that these developments should be executed in a sustainable manner, which includes circularity as an important component (HWBP, 2021). For DR projects, a part of these developments is outsourced, and the relevant authority works together with an engineering firm and a construction contractor, which design and realise the DR project, respectively. In such a cooperation, Rijkswaterstaat or the relevant water board takes on a coordinative function (van Dijk, 2022; personal communication, Wolbers, appendix D).

Another important initiative concerning circularity in the construction sector, which includes the civil engineering sector, is 'Platform Circulair Bouwen 2023' or CB'23. This initiative includes different types of stakeholders within the sector that need to work with or are affected by circularity, for example contractors, designers, suppliers, constructors, recyclers, policy makers and scientists (Platform CB'23, 2021). This platform aims to conceptualise what circularity means in the context of the construction sector. Additionally, they provide general guidelines to assess circularity and how to structure the available information (Platform CB'23, 2020a, 2020b, 2021). By doing this they adopt a leading and exemplary role within the sector concerning the circular development. Since DR projects fall within this sector and CB'23 is a sector-wide cooperation, the current and future developments of the initiative will form an essential guideline/frame to develop a methodology to assess circularity in DR projects. If this research is not compatible with the current developments already published by the platform, it will most likely not be utilised in the sector. If a tool is developed that is compatible with the current developments of CB'23 it will contribute to the implementation of circularity in the sector and push the future developments of CB'23. Therefore, it can be stated that CB'23 bears a large responsibility for the conceptual development of circularity in the entire sector and thus DR projects.

Timeline

The lifecycle of objects within the construction sector can be structured into five phases. The first phase is the initiative phase, followed by the design, construction, maintenance and end-of-life phases. These phases often also apply to projects within the civil engineering sector (Platform CB'23, 2021). Historically, these phases followed linearly after one another as displayed on the left side of figure 2. In a circular system where material cycles are closed these phases will follow a cyclical pattern as displayed in figure 2 on the right side.

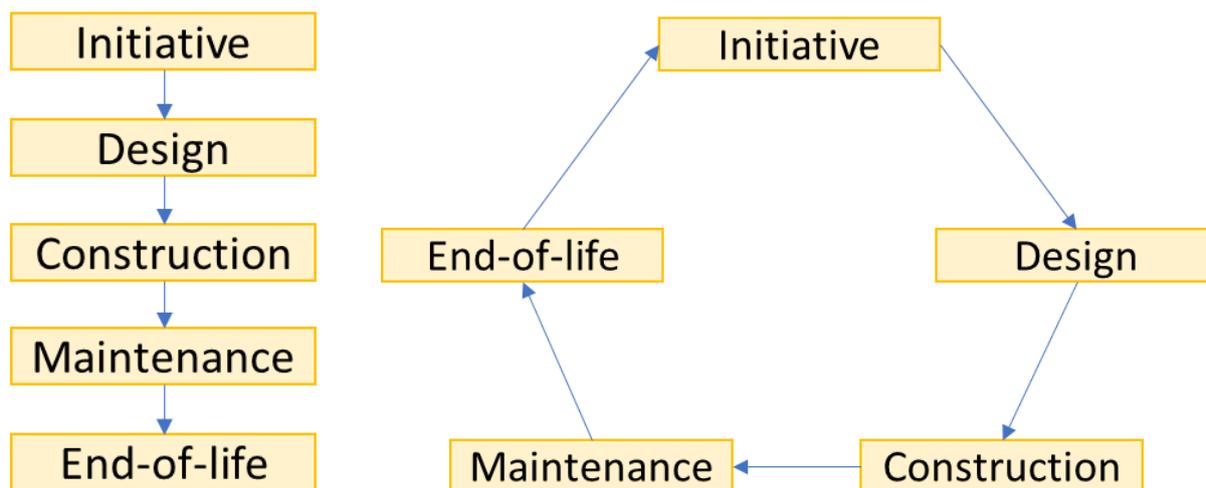


Figure 2: an overview of the phases in the life cycle of objects in a linear system (left) and in a circular system (right). Based on: (Platform CB'23, 2021).

DR projects follow a similar structure as described above; however, the phases are named differently, and some slight modifications are made. An overview of the structure can be found in table 1. It all starts in the initiative phase, where the scope of the project is determined and the situation in the social and natural environment is assessed. Secondly, the exploration phase occurs. In this phase, the direction of the solution is determined, so what option seems most feasible. Subsequently, in the design phase, this specific solution is detailed to get to a preliminary design and eventually to a definitive design. In the exploration and design phases, the project goes from having many, not fully developed alternatives towards one fully developed design. This process occurs through multiple design cycles where for each design cycle the remaining alternatives are assessed on many subjects (e.g., safety, sustainability, costs and environmental integration) to determine which alternatives are still relevant solutions for the project (van de Laar & Post, 2021). In the contract formation phase, agreements are drafted between all stakeholders. Often, no major changes occur in this phase. Afterwards, the realisation phase starts; this is when the project plans are executed. Changes made to the plan in this stage mainly occur to prevent nuisance and solve operational difficulties. Lastly, the management and maintenance (M&M) phase occurs, where it is ensured that the dike stays in a good condition to provide its function (den Boer et al., 2021; Waterschap Vallei en Veluwe, 2020).

Table 1: overview of the different phases in a DR project (den Boer et al., 2021; Waterschap Vallei en Veluwe, 2020).

Phase:	Description:	
1	Initiative	
2	Exploration	Exploration
3	Design	Design
4	Contract formation	
5	Realisation	Realisation
6	Management and maintenance	
Source:	(Waterschap Vallei en Veluwe, 2020)	(van Dijk, 2022)

The described phases indicate that DR projects still follow a linear structure since the project stops after either the M&M phase or the realisation phase and excludes the end-of-life phase. The exclusion of the end-of-life phase in the project structure is a major obstacle towards more circular projects (Platform CB'23, 2021).

Organisational structure

Rijkswaterstaat or the relevant water board is involved in every phase of a DR project. The involvement of the engineering firm and the construction contractor can differ depending on the organisational structure of the project. Traditionally, an engineering firm gets involved in the exploration phase of the project. It tenders for this phase only. For the design phase a new tender determines the engineering firm for that phase; it is possible that this is a different firm from the previous phase. After the design phase, the role for the engineering firm is generally over and a new tender determines the construction contractor for the project, which is assigned to execute the established plans. This results in a fractured process with hierarchical relations and the formation of isolated ‘islands’ of specialist knowledge without interaction between stakeholders (van Dijk, 2022). On the contrary, the two-phases approach tries to stimulate cooperation by structuring the process in an integrative way (van Dijk, 2022). In this approach, there is only one tender at the start of the exploration phase. Here you can register individually as an engineering firm or construction contractor or as a consortium. In this situation, the engineering firm is fully involved in the exploration and design phase and still partially involved during the realisation. The construction contractor gets involved earlier in the process starting from the design phase and has more sight on what happens in the exploration phase. In this way, the structure of the DR project promotes cooperation and the integration and sharing of knowledge.

	Fully involved
	Partially involved
	Not involved

Table 2: overview of the timing and duration of stakeholder involvement in DR projects (van Dijk, 2022; personal communication, Wolbers, appendix D).

Traditional organisation						
	Initiative	Exploration	Design	Realisation	Management and maintenance	End-of-life
Waterschap or Rijkswaterstaat						
Engineering firm						
Construction contractor						
Two phases approach						
	Initiative	Exploration	Design	Realisation	Management and maintenance	End-of-life
Waterschap or Rijkswaterstaat						
Engineering firm						
Construction contractor						

Physical structure

To be able to understand how circularity manifests itself in DR projects, some basic knowledge of the structure of a dike is necessary. A dike is always a unique solution for the problems in an area and therefore there is not really a standard dike. Nevertheless, in figure 3 a schematised overview of the standard flood-defensive elements of a dike is presented, below a short definition of all the elements is given. The size of each element can vary greatly, and sometimes specific elements are not present in the design of a dike. For a detailed description of the functions of each element consult van Asperen et al. (2001).

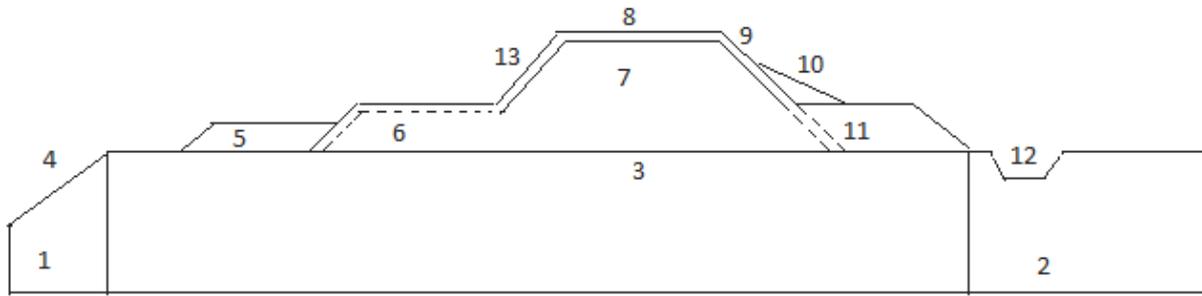


Figure 3: schematic representation of the structure of flood-defensive elements of a dike. Based on: (van Asperen et al., 2001). Definitions from: (TU Delft, n.d.).

1. Foreland	Terrain at the seaside of the dike.
2. Hinterland	Terrain behind the dike.
3. Dike base	Terrain forming the foundation of the dike.
4. Foreshore	Underwater part of the shore.
5. Stone revetment	Area at the toe of the dike below the high tide covered with stones.
6. Outer berm	Berm situated at the waterside.
7. Dike core	Inner part of a dike, usually consisting of rocks or sand.
8. Head	Top part of the dike.
9. Inner slope	Diagonal slope located at the inner side of the dike.
10. Transition slope	Extra slope to provide extra support and transition from the berm to inner slope.
11. Inner berm	Berm situated at the inner side to give extra support and prevent upwelling.
12. Dike ditch	Ditch at the inner side of a dike to catch seepage and discharge it.
13. Outer slope	Diagonal slope located at the waterside of the dike.

These standard elements of the dike mostly consist of sand, clay, rocks, stone and rubble. Beside these elements there are so-called special elements, which are elements that are not constituting of one of the previous mentioned materials (van Asperen et al., 2001). They are often used to support or replace certain standard elements of a dike while taking up less space in the process. There are many different types of special elements. Some examples are geotextiles or geogrids for extra reinforcement; vertical drainage; gravel, cement or chalk poles for extra stability; seepage screens; sheet piles and movable constructions (van Asperen et al., 2001). The use of special elements in the design has a large influence on the material use and thus the circularity of a dike. On the one hand, it can prevent the use of space and large quantities of ground, but it often introduces materials in the design that have a higher environmental impact, cost more, complicate maintenance practices and affect the reusability potential. Often, by slightly changing a design, large variations among a multitude of aspects must be considered to evaluate the circularity design (personal communication, Smeenge, appendix D). What these aspects are and how they can be measured is explored in this thesis. It must also be noted that this structure only includes flood-defensive elements. Therefore, elements like pipelines, cables, roads and their foundation are not included in the structure, while they are included in most DR projects.

Methods

The objective of this thesis is to develop a methodology for measuring and assessing circularity in DR projects throughout the entire lifecycle. Therefore, the results displayed in this thesis are descriptions of this methodology including justifications of the made choices. In this way, the main research question ***'How can circularity be measured and assessed in dike reinforcement projects during the entire life cycle?'*** is answered.

To formulate an answer to the main research question, a methodology is developed. This consists of a conceptual framework, which identifies multiple categories and aspects of circularity that must be measured and an assessment framework, which displays how these categories and aspects are measured and how these results can be interpreted and scored to assess circularity. To develop these frameworks, several sub-questions had to be answered. The results from these sub-questions are considered preliminary research. Therefore, these results are not directly included in the main results of this thesis and can be found in the previous 'background information' chapter and appendices A-D. Consequently, these appendices display a large part of the research process that resulted in the developed frameworks.

This research started with an explorative literature review where published scientific articles, research theses, white papers, policy briefs, regulations & guidelines, strategy reports and implementation reports were consulted to collect information on the organisation of DR projects including the involved stakeholders, the physical structure of dikes, conflicting definitions and scopes of circularity and sustainable & circular initiatives in both the civil engineering sector and DR projects specifically. This provided a foundation to answer three sub-questions [chapter: background information + appendix A]:

- What are the organisational and physical structure of DR projects?
- What frameworks for circular development already exist in the civil engineering/construction sector?
- How do dike reinforcement projects currently incorporate circularity?

The data from the literature review was complemented with four semi-structured interviews with two circularity advisors, a design manager and a technical manager in DR projects to collect the view of practitioners on circularity in the civil engineering sector and DR projects [appendix D]. Generally, the interviews followed a comparable structure, however, the discussed topics, initiated many follow-up questions and supported the exploration of new ideas. The general structure of an interview was:

1. Exploring the concept of circularity and its definitions.
2. Focussed discussion on a specific project/initiative the practitioner worked on.
3. Discuss the results from the literature review.
4. Discuss the possibilities to measure and assess the circular concepts.

This information was used to formulate a preliminary conceptual framework that consists of multiple categories relevant to circularity in DR projects, each with its own specific aspects. It displayed an early version of what circularity aspects had to be measured to assess circularity in DR projects.

This version was used as the foundation to start developing a preliminary assessment framework. The assessment framework addresses how the formulated circular aspects and categories can be measured in DR projects. Additionally, it provides an answer to how these measurements can be interpreted and scored to provide an assessment of circularity in DR projects. To develop this preliminary assessment framework published scientific articles, research theses, white papers, policy

briefs, regulations & guidelines, strategy reports, implementation reports and the conducted interviews were consulted to see how circularity is quantitatively assessed in other sectors/projects and how (components) of these methods can be used to develop an assessment framework.

Subsequently, both the preliminary conceptual and assessment framework were evaluated by three experts in either circularity or general assessments of DR projects during an interactive working session. This session followed a simple structure:

1. Explain the developed assessment framework, one category at a time.
2. Evaluate the completeness, applicability and value of the assessment framework for the category with targeted questions.
3. The targeted questions lead to discussion about limitations, examples and possible improvements.
4. Upgrade the scoring mechanism if necessary.
5. Summarise key findings from discussion on which participant agree.
6. Repeat step 1-5 for next category.

With the input from the working session, the preliminary conceptual and assessment framework were improved to get a final result. The final conceptual framework is formulated after careful analysis of three conceptual frameworks concerning circularity in the civil engineering sector (Kok et al., 2019; Meijer, 2018; Platform CB'23, 2021; Rijkswaterstaat, 2020) and four implementations of circular initiatives in recent DR projects (Halter & Stoop, 2021; HWBP, 2021; Jutte et al., 2020; Rijkswaterstaat, 2018; Waterschap Zuiderzeeland, 2021; Werkgroep emissieloos bouwen WOS, 2021). Additionally, input from the four interviews was used to integrate the current understanding of circularity in the sector into the conceptual framework (personal communication; Smeenge, Verschoor, Gaasbeek, van de Laar; appendix D). The resulting conceptual framework divides circularity in clearly defined and convenient blocks that improve the understanding of the concept. The development process of the conceptual framework is displayed in appendix A.

The final assessment framework is based on (components of) three assessment frameworks for circularity in the civil engineering sector (Meijer, 2018; Platform CB'23, 2020a; Weersink & van Cuyk, 2020), two assessment frameworks for circularity in the built environment (Durmisevic, 2006; Goddin et al., 2019; Verberne, 2016) and two tools already used in DR projects (Royal HaskoningDHV, 2021; Waterschap Zuiderzeeland, 2021). This is complemented with insights from five semi-structured interviews (personal communication, Smeenge, Verschoor, Gaasbeek, van de Laar, Wolbers; appendix D). A detailed analysis of the sources and their influence on the developed assessment framework can be found in appendix B.

As this research aims to measure circularity in DR projects, a circular perspective on the phases of the project is necessary. Therefore, the end-of-life phase is added to the scope of this research, while this is often excluded in DR projects. On the contrary, the contract formation phase is not expected to provide large changes concerning circularity in the project and is therefore placed outside the scope of this research. An overview of the phases of DR projects as used in this research can be found in table 3.

Table 3: the phases of a DR project within the scope of this research.

Phase:	Description:
1	Initiative
2	Exploration
3	Design
4	Realisation
5	Management and maintenance
6	End-of-life

Together, the conceptual and assessment frameworks provide an answer to the main research question: ***‘How can circularity be measured and assessed in dike reinforcement projects during the entire life cycle?’***

Results

This chapter provides the answer to RQ1 ‘What are aspects of circularity in DR projects that need to be measured?’ in the subchapter ‘Conceptual framework’ and RQ2 ‘How can these circular aspects be measured and scored to assess circularity in DR projects?’ in the subchapter ‘Assessment framework’.

Conceptual framework

Based on the literature review and interviews with practitioners, several categories were identified in this research, that provide a complete perspective on the concept of circularity in DR projects and that each correspond with at least one of the objectives of circularity. Following the developed definitions of categories, several aspects have been determined that specify and define these categories. The categories and aspects are displayed in table 4 and described in the following section.

1. ‘Minimal resource use’ is concerned with reducing material usage within dike designs.
2. ‘Input characteristics’ looks into the origins and production characteristics of the input material.
3. ‘Output characteristics’ looks into the potential function of the output materials in the next life cycle.
4. ‘Future proof’ investigates the capacity of the project/design to adapt to future changes.
5. ‘Impact’ identifies the environmental impact the design has during its life cycle.
6. ‘Uncertainty’ measures the quality of the data used to assess the other categories.

Table 4: the conceptual framework used as the foundation for the developed assessment framework.

Category	Phase	Aspect
1. Minimal resource use	Design	1.1 Prevention & reduction of scope and size
	Management and maintenance	1.2 Optimal management and maintenance
2. Input characteristics	Design & management and maintenance	2.1 Secondary resource use
		2.2 Primary resource use
3. Output characteristics	End-of-life	3.1 Potential for next life cycle
4. Future proof	Design	4.1 Spatial-functional adaptivity
		4.2 Technical-functional adaptivity
		4.3 Disassembly potential
5. Impact	All phases	5.1 Reduction of life cycle impact
6. Uncertainty	All phases	6.1 Documentation of circular information

1.1 Prevention & reduction of scope and size

Actively preventing something from being built or replaced if not essential or finding a solution with the minimal resource use is often mentioned as an important aspect of circularity in literature (HWBP, 2021; Meijer, 2018; Platform CB'23, 2021; Rijkswaterstaat, 2020). Additionally, it is a strategy already implemented in some DR projects (HWBP, 2021). Especially, in the early phases of a project the largest preventions and reductions in scope and size can be achieved (HWBP, 2021; personal communication, Smeenge [appendix D]). This aspect should document and give insight in all material usage during the initiative, exploration, design & realisation phases of design alternatives in a DR project. After comparison to the material usage in a reference design, the prevention and reduction of material usage can be assessed, which directly contributes to the goal of circularity to protect resource stocks.

1.2 Optimal management and maintenance

Optimising the material usage for the M&M of a design is mentioned in literature as an important aspect of circularity (Meijer, 2018; Platform CB'23, 2021; Rijkswaterstaat, 2020). Minimising the material quantities for this specific aspect is not per se the desired focus; it should be focussed on finding the right balance between this aspect and the prior one. This makes it possible to differentiate between designs with high realisation and low M&M material use versus lower realisation and higher M&M material use, and assess which design is more circular. The separation of these aspects enables fairer assessments of designs over their entire life cycle and supports better targeted improvements to designs.

2.1 Secondary resource use

Increasing the sustainable use of existing (secondary) resources through reuse and recycling is considered in almost all circularity literature as an essential component of circularity (Goddin et al., 2019; Heshmati, 2015; HWBP, 2021; Jutte et al., 2020; Kok et al., 2019; Meijer, 2018; Platform CB'23, 2021; Rijkswaterstaat, 2020; Royal HaskoningDHV, 2018; Waterschap Zuiderzeeland, 2021). Additionally, according to multiple interviewed experts in the DR sector, this aspect is the most recognisable characteristic of circularity (personal communication, Smeenge, Verschoor, Gaasbeek, appendix D). It contributes to all the goals of circularity by protecting resource stocks, retaining the value of resources and indirectly reducing the impact of resource use.

2.2 Primary resource use

This aspect differs from the previous aspect because it is only concerned with primary (new) inputs into the project. The use of primary materials is often considered to oppose circularity; however, some primary inputs can certainly contribute to circularity if they have some specific characteristics (Platform CB'23, 2021).

1. The use of renewable materials at a rate that allows natural replenishment contributes to the circular target to protect resource stocks (Platform CB'23, 2021).
2. Avoiding the use of scarce materials directly protects resource stocks (Platform CB'23, 2021).
3. The use of biobased materials helps reducing the environmental impact from resource use (Platform CB'23, 2021).
4. The use of local resources reduces the transport distances significantly, which reduces the environmental impact of the project (den Boer et al., 2021).
5. The use of sustainably produced resources reduces the environmental impact of the project (Platform CB'23, 2021).

This aspect should categorise primary inputs along these characteristics to assess whether they contribute or damage the circularity of a design. Thus, my results show that primary resource use is

concerned with designing around the sustainable use of materials, by avoiding scarce materials, using materials with a low environmental impact and use renewable instead of non-renewable resources.

3.1 Potential for next life cycle

Circularity is not only about the material inputs into a project. An important aspect to make circularity work for multiple life cycles is to investigate the future output flows, thus what is expected to happen with the materials at the end-of-life phase of the project. These considerations can significantly change the perspective when choosing input materials. Using resources in a design that can be reused or recycled in a next life cycle prevents the use of new resources in the future. Considering this future perspective of resource use is mentioned as a necessary change in mind-set necessary to achieve circularity (Meijer, 2018; Platform CB'23, 2021; Rijkswaterstaat, 2020).

So, for choosing between design alternatives at the start of a DR project, it is important to get insight into the future applications of the resources at the end of the life cycle. It is not realistic to expect all output material to be suitable for a next life cycle; some output will be lost. Since this is unpreventable, DR projects should strive to minimise the loss of output material by facilitating future reuse and recycling of the resources; this helps to retain as much value from these resources as possible and thus contribute to circularity. Examples of strategies are: choosing reusable input materials and the use of energy recovery systems at waste incineration plants to capture the imbedded energy of lost materials. To achieve this the resource outputs should be categorised according to their expected fate at the end of the life cycle.

4.1, 4.2 & 4.3 Future proof

Future proof design in the context of circularity has multiple definitions, which indicates the confusion around this concept. Therefore, it is decided to use 'future proof' as an overarching concept, where the aspects of this category reflect different definitions of future proof design. This leads to the following aspects and definitions:

- 4.1 Spatial-functional adaptivity: Design decisions are made to accommodate future interests by ensuring the adaptive capacity of objects (Platform CB'23, 2021).
- 4.2 Technical-functional adaptivity: Design for an optimum between the technical and functional lifetime, where an object is designed to retain its performance under the expected changing circumstances (Kok et al., 2019).
- 4.3 Disassembly potential: 'The sustainability of design in the future will rely strongly on the disassembly potential of building assemblies.' (Durmisevic, 2006).

5.1 Reduction of life cycle impact

From the perspective of sustainability, design decisions should be based on their consequence for the environmental impact and environmental performance of the object in the development, M&M and end-of-life phases (Platform CB'23, 2021). By minimising this environmental impact during the life cycle of a dike design a direct contribution is made to one of the core goals of circularity (Platform CB'23, 2020a; Rijksoverheid, 2016). All the reviewed frameworks include this as an aspect or indirect goal of circularity (Kok et al., 2019; Meijer, 2018; Platform CB'23, 2020a; Rijkswaterstaat, 2020). Additionally, an interviewed sustainability/circularity advisor in DR projects states that the environmental impact is often already assessed and part of the decision-making process (personal communication, Verschoor, appendix D). Through measuring the change in life cycle impact to the change in the other aspects, it is possible to assess the effectiveness of circular strategies.

6.1 Documentation of circular information

To facilitate circular development, it is essential to correctly collect and document the necessary data (Atta et al., 2021; Honic et al., 2019; Jutte et al., 2020; Meijer, 2018; Waterschap Zuiderzeeland, 2021). This is confirmed in the expert interviews. However, there is not yet an agreed upon system to do this in DR projects (personal communication, Verschoor, appendix D). Currently, a pilot project is running to address this problem (personal communication, Smeenge, appendix D). Furthermore, Platform CB'23 is currently working on a new version of their guidelines for material passports in the construction sector (personal communication, Gaasbeek, appendix D).

If the documentation of circular information is assessed and scored, it will incentivise further development of the process, which stimulates and improves the facilitating conditions for circularity. If it is not included as an aspect in this research, the documentation process is not scored and will be treated as a boundary condition and it will not be rewarded, which might lead to less focus on the aspect and consequently hinderance of circular development. Therefore, it is chosen to include this aspect in the conceptual framework of this research with the following definition: provide high quality documentation on important circular indicators that facilitate circular developments.

Assessment framework

In the previous sub-section, the concept of circularity in the context of DR projects was explored. The developed categories and aspects compartmentalise circularity into more easily measurable blocks. In this chapter, it is explained how these categories and aspect can be measured and scored to come to a circularity score.

Scope

The scope of the circularity assessment is set to include all applied measures; this means all removed and deposited materials. This excludes the part of the existing dike that is not subject to change and is used as the foundation of the new dike. If the existing dike were included, this would diminish the detail of the results of the assessment; relative differences in material use would be dampened, as well as the share of input and output materials classified as originating from and ending up as direct reuse would dominate these categories. Therefore, only the changed parts of the dike are included in the scope of this circularity assessment.

To provide structure to the assessment the dike is divided in elements. Initially, the structure from van Asperen et al. (2001) [background information] was proposed, but during the consultation of the expert panel this structure was regarded to be not applicable. Because dike designs are integral solutions, no clear separations between different ground-based elements are identifiable (e.g., between inner slope and dike core). It was suggested to base the division of elements on easy identifiable separations, e.g., changes in material. This led to the formulation of the elements in table 5. These elements are used in the assessment framework to get a detailed perspective on the assessed design alternative.

Table 5: overview of distinguishable elements of a dike based on material differences. Based on: (Bodemrichtlijn, n.d.; van Asperen et al., 2001).

Element:	Description:	Materials:
Ground solution	The continuous body of the dike consisting of ground materials, includes all non-distinguishable ground elements.	Sand, clay, peat
Distinguishable ground solution*	Clearly distinguishable ground elements receive their own category; for example, when an intermediate sealing layer between sand deposits is present.	Sand, clay, peat
Hard revetment	Hard cover of the dike to protect against erosion of high tide/waves.	Stone, rubble, concrete, asphalt
Soft revetment	Soft cover of the dike to protect against erosion of high tide/waves.	Grass & other vegetation
Fascine- & collar mattresses	Element that protects the shore and soil from erosion.	Brushwood, reeds
Geogrids/Geotextiles	Element that reinforces the stability of less supportive ground elements. Often used as the foundation of fascine- & collar mattresses.	Geosynthetics
Sheet pile wall	Supporting wall that increases the stability of the dike.	Steel, wood, reinforced concrete, other metals

Seepage screen	Water-resistant screen that prevents seepage from pipes or cables penetrating a sheet pile wall or other dike penetrations.	Neoprene
Pipelines and cables	This infrastructure is sometimes imbedded in the design of the dike.	Plastics, metals
Other infrastructure	e.g., roads, streetlights, crash barriers, fences etc.	

* The name of the element is depending on the description of the distinguishable layer.

Assessment mechanisms

To assess aspects 1.1 ‘prevention & reduction of scope and size’, 1.2 ‘optimal management and maintenance’ and 5.1 ‘reduction of life cycle impact’ a comparison to a reference design is necessary. This reference design functions as a benchmark where design alternatives can be compared to. The reference design should be established for each DR project, individually. However, it should always be determined in the same phase of a DR project. The reference design should be determined early in the project as it aims to track the development of these aspects throughout the project. This would result in a reference design originating from the initiative phase. However, if this moment is chosen, the engineering firm responsible for the dike designs is not yet involved and does not have access to the necessary information (personal communication, Wolbers). Contrarily, when a design in the earliest design cycle from the exploration phase is chosen as reference design, the involvement of the engineering firm is guaranteed. Additionally, this moment is still sufficiently early in the project to function as benchmark. Therefore, the first design in the exploration phase is used as the reference design in this assessment.

To assess aspects 2.1 ‘secondary resource use’, 2.2 ‘primary resource use’ and 3.1 ‘potential for next life cycle’ the characteristics of the input and output materials were provided with scores based on the importance of the characteristic towards circularity. This allowed to quantify the assessment of qualitative characteristics of materials. The scoring system, and how to use it, is explained in more detail in the relevant sections of these aspects.

To assess aspects 4.1 ‘spatial-functional adaptivity’, 4.2 ‘technical-functional adaptivity’, 4.3 ‘disassembly potential’ and 6.1 ‘documentation of circular information’ qualitative scoring criteria were formulated that represent different levels in the implementation of these circular considerations. The criteria are explained in more detail in the relevant sections of these aspects.

1.1 Prevention & reduction of scope and size

To measure this aspect, estimated/realised quantities of materials used in a design alternative needs to be compared to the reference design. The quantities of used materials should be catalogued per type of material at the level of each element. The collection of data at the element level and per type of material provides additional insights on a higher detail level, which can support targeted intervention to improve material use in the design. Subsequently, these quantities can be summed to obtain data for the entire dike [EQ1]. This has to be calculated for both the reference design and all design alternatives.

$$\text{Equation 1: } \text{Material quantity}_{DA} = \sum_{\text{element 1} - \text{element } n} \text{Material quantity}_{\text{element}}$$

To obtain a score for this aspect the relative difference between the total material quantity of the reference design and the relevant design alternative is calculated with EQ2.

- $Material\ quantity_{DA}$ = the total quantity of materials used in the realisation of the design alternative.
- $Material\ quantity_{ref}$ = the total quantity of materials used in the realisation of the reference design.
Both variables are calculated with EQ1 and in units of mass.

Equation 2: $Score_{aspect\ 1.1} = \frac{Material\ quantity_{DA} - Material\ quantity_{ref}}{Material\ quantity_{ref}}$

The calculated score indicates quantitatively the extent of the reduction of scope/size of the DR project. In the initiative, exploration and design phases, this is calculated with the expected material quantities, while the actual material quantities are used in the realisation phase.

Throughout all phases of a DR project and with each subsequent design cycle, it is expected that the accuracy and detail of the information will increase (personal communication, Verschoor, appendix D). Therefore, it is expected that the material quantities of the reference design will be based on coarse estimates, but the quantities of the design alternatives will become more accurate after several design cycles. The increased use and improvement of 3D-designing tools will further increase the accuracy and detail level of the designs.

1.2 Optimal management and maintenance

To determine the optimal strategy for M&M, a balance must be struck between the material use during realisation and the expected use for M&M. Therefore, the expected material use for M&M during the lifetime of the dike must be calculated per type of material at the level of each element with EQ3. The collection of data at the element level and per type of material provides additional insights in maintenance-intensive elements. Since elements can have different lifetimes compared to each other and the dike, the material quantity for M&M needs to be standardised over the entire lifetime of the dike. Therefore, the material quantity for one maintenance activity is multiplied with the lifetime component of the equation, which determines how many maintenance activities are required for the element during the entire lifetime of the dike.

- $Material\ quantity\ M\&M_{element}$ = the total quantity of materials used for M&M for an element during the entire lifetime of the dike.
- $Material\ quantity\ M\&M_{activity}$ = the total materials quantity used for M&M for an element for one maintenance activity.
Both variables are in units of mass.
- $Lifetime_{structure}$ = the expected lifetime of the structure.
- $Lifetime_{element}$ = the expected lifetime of an element before maintenance is required.
Both variables are in units of time.

Equation 3: $Material\ quantity\ M\&M_{element} = Material\ quantity\ M\&M_{activity} * \frac{Lifetime_{structure} - Lifetime_{element}}{Lifetime_{element}}$

Subsequently, the material quantities from EQ3 can be summed to obtain data for an entire design [EQ4]. This has to be calculated for both the reference design and all design alternatives.

Equation 4: $Material\ quantity\ M\&M_{DA} = \sum_{element\ 1 - element\ n} Material\ quantity\ M\&M_{element}$

To obtain a score for this aspect the relative difference between the total expected material quantity for M&M of the reference design and all relevant design alternatives is calculated with EQ4.

- $Material\ quantity\ M\&M_{DA}$ = the total quantity of materials used for M&M for a design during the entire lifetime of the dike [EQ4].

- *Material quantity $M\&M_{ref}$* = the total quantity of materials used for M&M for the reference design during the entire lifetime of the dike [EQ4].

$$\text{Equation 5: } Score_{aspect\ 1.2} = \frac{\text{Material quantity } M\&M_{DA} - \text{Material quantity } M\&M_{ref}}{\text{Material quantity } M\&M_{ref}}$$

The calculated score indicates the realised reduction in the M&M material use throughout the DR project.

Category 1: Minimal resource use

Based on the information collected and calculated for aspects 1.1 and 1.2, it is possible to determine what design alternative uses the least resources or realised the largest reduction in material use during both the entire project. The SKK 2018 methodology from Prins & Fillerup (2021) states that the total cost for a project is the sum of the investment costs and the M&M costs. In this way, the most cost-effective alternative can be determined. Applying similar logic to the data from aspect 1.1 & 1.2, the most resource-efficient alternative is the option that minimises the material use in the realisation [EQ1] and M&M [EQ4] phases together. This has to be calculated for both the reference design and all design alternatives. This is displayed in EQ6.

$$\text{Equation 6: } Total\ material\ quantity_{DA} = \text{Material quantity}_{DA} + \text{Material quantity } M\&M_{DA}$$

Subsequently, the total material quantities of the reference design and design alternatives [EQ6] are used to calculate the relative difference with EQ7.

$$\text{Equation 7: } Relative\ difference = \frac{Total\ material\ quantity_{DA} - Total\ material\ quantity_{ref}}{Total\ material\ quantity_{ref}}$$

To obtain the score for this category, a reduction objective is established for the DR project (e.g., -50%). By dividing the relative difference in material use between the design alternative and reference design [EQ7] with the reduction objective the score for this category is calculated [EQ8].

$$\text{Equation 8: } Score_{category\ 1} = \frac{Relative\ difference\ [EQ7]}{Reduction\ objective}$$

After consultation of the expert panel, it was indicated that $Score_{category\ 1}$ should be limited between -50% and +150% to penalise/reward differences in material use significantly even if the reduction objective is not achieved or substantially exceeded but to not let this score overrepresent itself in the total circularity score.

2.1 Secondary resource use

The assessment is of this aspect an adaptation to the 'kernmeetmethode' from Platform CB'23 (2020a). In aspect 1.1, 1.2 & category 1, a detailed overview of the material quantities and material types is established per element and per design. Beside that data, extra information must be collected on the characteristics of these input materials from producers and construction contractors to assess this aspect. This information allows the categorisation of these inputs into either primary or secondary resources. For this aspect, only the secondary inputs are relevant, while the primary inputs are relevant for the next aspect. The quantity of secondary input material is calculated with EQ9.

- $\%secondary_{material\ type}$ = the percentage of a material type that comes from a secondary source.
- $Material\ quantity_{material\ type}$ = the material quantity that is used in the design of a specific material type.

$$\text{Equation 9: } Input_{secondary} =$$

$$\sum_{material\ 1-material\ n} \%secondary_{material\ type} * Material\ quantity_{material\ type}$$

From this point, slight adaptations are made to the ‘kernmeetmethode’ to improve the categorisation of the secondary inputs; these are normally divided into reused and recycled inputs. These labels did not allow for a complete and correct categorisation of all secondary inputs. For this reason, the number of categories is expanded based on the R-principles for dike reinforcements as established by Waterschap Zuiderzeeland (2021) (table 6). Additionally, the labels ‘internal & external reuse’ were modified into ‘local and regional reuse’ based on the feedback from the expert panel, because the relevant differentiation factor is the transport distance and not the crossing of organisational boundaries.

Table 6: categorisations of the secondary inputs in a DR project.

Label:	Definition:	Score:
Direct reuse	Reused material/object from the reinforced dike at a higher or equal level.	2.0
Local reuse	Reused material/object from other projects near the dike.	1.9
Regional reuse	Reused material/object from other projects located further from the dike.	1.8
Refurbish	Material/object from the treatment of the resource to enable reuse in the DR project.	1.4
Repurpose	Material/object gets a different (lower) function and application within the DR project.	1.3
Recycle	Material from the processing and reuse of resources.	1.0

The existing hierarchy of these R-principles, where the first R-principle contributes more to circularity than the later R-principles, supports the evaluation of design alternatives. Therefore, based on this hierarchy and additional feedback from the expert panel each label receives a score relative to their importance for circularity. To calculate the score for this aspect EQ10 is used. The achieved scores (top term EQ10) are divided by twice the secondary input (bottom term EQ10), because the equation must reflect the achieved score/maximum score.

- $Input_{label}$ = the material quantity categorised under a specific label.
- $Score_{label}$ = the score given to the respective label.
- $Input_{secondary}$ = see EQ 9

Equation 10: $Score_{aspect\ 2.1} = \frac{\sum(Input_{label} * Score_{label})}{2 * Input_{secondary}}$

EQ10 results in a score between 50%-100%. This percentage measures how circular the secondary resource use in the design alternative is; the higher the percentage the more circular the secondary resource use is.

2.2 Primary resource use

First, the quantity of input material from primary sources is determined with EQ11.

- $\%primary_{material\ type}$ = the percentage of a material type that comes from a primary source.
- $Material\ quantity_{material\ type}$ = the material quantity that is used in the design of a specific material type.

Equation 11: $Input_{primary} =$

$$\sum_{\text{material } 1-\text{material } n} \%primary_{\text{material type}} * \text{Material quantity}_{\text{material type}}$$

Subsequently, the primary inputs are classified into three labels adapted from Platform CB'23 (2020a) (table 7). Non-renewable inputs do not contribute to circularity; therefore, these inputs should be minimised or eliminated. This label receives a score of 0. To determine how much a renewable input can contribute to circularity, it must be assessed whether the input is sustainably produced. Whether an input may be classified as sustainably produced is easily recognised if it bears an internationally recognised quality mark. Another approved way is by providing evidence that displays the extraction rate does not exceed the regeneration rate and that if the resource can be used for consumption it may not be used as a material. By using primary resources that are renewable and sustainably produced, no negative impact on the environment or negative consequences for the resource stocks should occur. After consultation of the expert panel, this label received a score of 1,8, while 'renewable & non-sustainable' label was scored at 0,5.

Table 7: categorisations of the primary inputs in a DR project.

Label:	Definition:	Score:
Renewable & sustainable	Originating from a renewable source that is naturally replenished or cleansed on a human time scale & the extraction rate does not exceed the regeneration/cleansing rate.	1.8
Renewable & non-sustainable	Originating from a renewable source that is naturally replenished or cleansed on a human time scale, but the extraction rate exceeds the regeneration/cleansing rate.	0.5
Non-renewable	Not originating from a renewable source.	0

To calculate the score for this aspect EQ12 is used. Again, the equation reflects the achieved score/maximum score.

- $Input_{label}$ = the material quantity categorised under a specific label.
- $Score_{label}$ = the score given to the respective label.
- $Input_{primary}$ = see EQ 11

$$\text{Equation 12: } Score_{\text{aspect 2.2}} = \frac{\sum(Input_{label} * Score_{label})}{2 * Input_{primary}}$$

For this aspect a score between 0%-90% can be achieved. This percentage can be considered the score of how circular the primary resource use is, the higher the percentage the more circular the primary resource use.

Category 2: Input characteristics

The detailed information provided in aspects 2.1 & 2.2 on the characteristics of the input of materials is used to determine a score for category 2 'input characteristics'. First, the percentage of secondary [EQ9] and primary [EQ11] input material relative to the total material input of the design [EQ6] is calculated with EQ13.

$$\text{Equation 13: } \%[secondary \text{ or } primary]_{DA} = \frac{Input_{[secondary \text{ or } primary]}}{Total \text{ material quantity}_{DA}}$$

To obtain the score for category 2 EQ14 is used.

$$\text{Equation 14: } Score_{\text{category 2}} =$$

$$(\%secondary_{DA} * Score_{\text{aspect 2.1}}) + (\%primary_{DA} * Score_{\text{aspect 2.2}})$$

This percentage is the score of how the total resource use of a design alternative complies with circular characteristics. This score has a range between 0%-100%, where the higher percentages mean more compliance with circular characteristics.

3.1 Potential for next life cycle

The first step to measure this aspect is to determine the quantity of output materials. It is assumed that the total output flow is equal to the initial input flow, thus conservation of mass. In reality, due to dikes being flood defence infrastructure, natural processes will act upon the dike, which will cause some mass loss during the lifetime of the structure. These are e.g., forces like wind erosion, water erosion and soil settling. For simplification purposes these losses are classified as losses at the end-of-life phase to sustain the conservation of mass.

For this aspect, the methodology of Platform CB'23 (2020a) is adapted. In that approach the output flows are separated into two categories: available for next life cycle and lost for next life cycle. However, based on the feedback from the expert panel it has been decided to combine these aspects into one for this assessment framework. Therefore, the output flows must be categorised into four labels (table 8).

Table 8: categorisations of the output flows in a DR project

Label:	Definition:	Score:
Reuse	Material/object is expected to be reused in the next life cycle.	2.0
Recycle	Material is expected to be reused in the next life cycle after processing of the resource.	1.0
Recover	The released energy after incineration of the material is captured and used.	0.25
Dumped	Material/object is ends up in a landfill site + other losses	0

Initially, the six labels from the aspect 'secondary resource use' were used here as well (to replace the simplified 'reuse' and 'recycle'). However, the feedback from the working session was that classifying the output flows is very uncertain, because it is a prediction of the future. Therefore, the detailed labels were considered not workable and changed back to the original labels from Platform CB'23 (2020a). The scores of these labels reflect their contribution towards circularity and are based on the feedback from the expert panel. To calculate the aspect score EQ15 is used.

- $Output_{label}$ = the output material quantity categorised under a specific label.
- $Score_{label}$ = the score given to the respective label.
- $Total\ output\ material_{DA} = Total\ material\ quantity_{DA} = EQ6$

$$\text{Equation 15: } Score_{aspect\ 3.1} = \frac{\sum(Output_{label} * Score_{label})}{2 * Total\ output\ material_{DA}}$$

This results in a score between 0%-100%. This percentage can be considered the circular potential of the resource use for the next life cycle, the higher the percentage the more circular potential there is for the next life cycle.

Category 3: Output characteristics

This category is fully determined by aspect 3.1 'potential for next life cycle'; therefore, no additional calculations are necessary to obtain the category score.

$$\text{Equation 16: } Score_{category\ 3} = Score_{aspect\ 3.1}$$

4.1 Spatial-functional adaptivity

This indicator is concerned with the level of inclusion of future considerations into the design of the DR project, for example, the reservation of space for solar energy generation in the future. The assessor classifies the design alternative into one of the five determined levels, each having its own qualitative assessment criteria. The criteria originate from the assessment of ‘adaptivity and future proofness’ formulated in the ‘Circulaire Peiler’ (Weersink & van Cuyk, 2020). The chosen classification must be supported with at least qualitative evidence stating how every part of the criteria is implemented. If possible quantitative evidence should be provided; this is, however, not made mandatory for it is expected that the availability of quantitative data is limited.

Table 9: overview of the scoring criteria for the assessment of the spatial-functional adaptivity. Based on: (Weersink & van Cuyk, 2020).

Score:	Criteria: Spatial-functional adaptivity
1.0	Ambitions from the larger area around the DR project are integrated; there is anticipation on possible social, spatial, climatological and natural development in the future.
0.75	Ambitions from the larger area around the DR project are integrated; there is room for future developments/climate change/ nature development.
0.5	Project targets are developed within the set cadres; environment participates actively; there is room for future developments/climate change/nature development.
0.25	Project targets are developed within the set cadres; there is room for future developments/climate change/nature development.
0	Project targets are only developed in the technical, spatial and policy cadres.

Equation 17: $Score_{aspect\ 4.1} = criteria\ score$

4.2 Technical-functional adaptivity:

The balance between the technical and functional lifetime of components and elements is an important aspect to ensure better adaptiveness to changing circumstances. When elements with long technical or functional life cycles are in the way of elements with short/medium technical or functional life cycles, it will increase the cost/effort to adapt the structure and thus reduces the technical-functional adaptivity. This indicator allows for four possible classifications, which tell something about the hierarchy of elements in the structure. This aspect must be evaluated for each element in the structure separately, where the average determines the aspect score. Again, the chosen classification must be supported with at least qualitative evidence or, if possible, quantitative evidence. This classification originates from Durmisevic (2006).

Table 10: overview of the scores and criteria for the assessment of the technical-functional adaptivity. Based on: (Durmisevic, 2006).

Score:	Criteria: Technical-functional adaptivity*
1.0	Long LC** (1) / long LC (2); short LC (1) / short LC (2); long LC (1) / short LC (2)
0.5	Medium LC (1) / long LC (2)
0.3	Short LC (1) / medium LC (2)
0.1	Short LC (1) / long LC (2)
0	Not considered

* When followed by (1) it means the element is assembled first, if followed by (2) it means the element is assembled second; consequently, the second element is in the way of the first element.

** LC = life cycle

From the consultation of the expert panel, major concerns about the applicability and value of this indicator came forward. It is difficult and time consuming to assess the life cycle of each element relative to each other. The main value it would have according to the experts was to actively familiarise

practitioners with the concept of this aspect. However, subconsciously or unknowingly, this perspective is often already applied to designs. Thus, the assessment would not result in drastic changes in circularity, while requiring extra time and effort. Therefore, it is chosen to not assess and score the ‘technical-functional adaptivity’ in this framework. However, it will still be included in the conceptual framework to inform practitioners of this concept.

4.3 Disassembly potential:

The original disassembly potential as proposed by Durmisevic (2006) had 17 indicators to determine the potential to disassemble materials, parts, components and elements of buildings. Since not all indicators in the framework are relevant for designs in DR projects two indicators are chosen that provide a simplified perspective on the disassembly potential in the context of DR projects.

1. Accessibility: elements should remain accessible for maintenance, replacements or disassembly with causing minimal damage to other elements.

Table 11: overview of the scores and criteria for the assessment of accessibility. Based on: (Durmisevic, 2006).

Score:	Criteria: Accessibility
1.0	Accessible without additional operation
0.8	Accessible with additional operation which causes no damage
0.6	Accessible with additional operation / causes reparable damage
0.4	Accessible with additional operation / causes partly reparable damage
0.1	Not accessible / total damage of elements
0	Not assessed

This indicator should be assessed for all non-ground solution elements in the DR project. Ground solution elements are excluded because it cannot be determined if damage to a ground element has occurred. The final score is equal to the average score of all the non-ground elements in the structure [EQ18]. The expert panel considered the criteria for ‘accessibility’ easily applicable and of significant value for the assessment of the disassembly potential during the working session.

$$\text{Equation 18: } Score_{accessibility} = \frac{\sum_n Score_{accessibility_{non-ground\ element\ n}}}{n}$$

2. Type of connection: the type of connection between elements determines if an element can be removed without affecting the structural integrity of the dike and with minimal damage to the element itself.

Table 12: overview of the score and criteria for the type of connection.

Score:	Criteria: Type of connection
1.0	Independent/detachable connection; structural integrity intact & element intact
0.7	Independent/non-detachable connection; structural integrity intact, but element damaged
0.2	Dependent/detachable connection; removal damages structural integrity & spares element
0.1	Dependent/non-detachable connection; removal damages structural integrity & damages the element
0.0	Not assessed

The original criteria from Durmisevic (2006) were considered not applicable by the expert panel; therefore, the criteria were adapted to better fit the context of DR projects. Again, this indicator only applies to the non-ground elements in a DR project. The final score is equal to the average score of all non-ground elements in the structure [EQ19].

$$\text{Equation 19: } Score_{type\ of\ connection} = \frac{\sum_n Score_{type\ of\ connection_{non-ground\ element\ n}}}{n}$$

The score for the disassembly potential is obtained with EQ20:

$$\text{Equation 20: } Score_{aspect\ 4.3} = \frac{Score_{accessibility} + Score_{type\ of\ connection}}{2}$$

Category 4: Future proof

To obtain the category score for ‘future proof’, the average between the spatial-functional adaptivity and disassembly potential must be calculated since the technical-functional adaptivity is excluded from the assessment framework.

$$\text{Equation 21: } Score_{category\ 4} = \frac{Score_{aspect\ 4.1} + Score_{aspect\ 4.3}}{2}$$

5.1 Reduction of life cycle impact

The assessment of the reduction of life cycle impact has been researched and implemented relatively well within the civil engineering sector compared to other circular aspects. With the standardisation of the Life Cycle Assessment (LCA) methodology by Stichting Bouwkwaliiteit (2019) (SBK), the resulting Environmental Cost Indicator (ECI) calculations and the subsequently developed DuboCalc programme (Royal HaskoningDHV, 2021), a well-established basis for the assessment of this aspect is present that is already regularly used in DR projects. Furthermore, the inclusion of LCA/ECI calculations in Platform CB’23 (2020a) indicates that the sector will obligate the use of these calculations in the future. Therefore, for the assessment of this aspect the SBK-methodology as implemented in DuboCalc is followed, as well as any updates to this methodology that become available in the future.

To obtain a score, the ECI value of the reference design and the design alternative must be determined with EQ22.

- ECI_{DA} = ECI result for the design alternative.
- ECI_{ref} = ECI result for the reference design.

$$\text{Equation 22: } Score_{aspect\ 5.1} = \frac{ECI_{DA} - ECI_{ref}}{ECI_{ref}}$$

Category 5: Impact

To obtain the score for this category, a reduction objective is established for the DR project (e.g., -50%). By dividing the score for aspect 5.1 [EQ22] with the reduction objective the score for this category is calculated [EQ23].

$$\text{Equation 23: } Score_{category\ 1} = \frac{Score_{aspect\ 5.1}}{Reduction\ objective}$$

The expert panel indicated that this score should also be limited between -50% and +150% to penalise/reward changes in life cycle impact significantly.

6.1 Documentation of circular information

The documentation of circular information is an important facilitating condition for circular development. Correctly handling the data in the project improves informed decision-making. To setup correct and useful documentation practices, the guidelines from Platform CB’23 (2022b), concerning material passports, are recommended to be followed [summary in appendix C]. This gives an indication of the structure and content of a material passport but still allows for documentation in different programmes and systems. For this aspect it is not assessed whether these guidelines are literally

followed, as alternative documentation systems can be suitable to achieve the same purpose. Instead, it is chosen to base the assessment on three quality requirements concerning data. Measuring these requirements can be used to indicate the accuracy or uncertainty of the other aspects in the circularity assessment. The data quality requirements are:

- 1) Actualisation: the data documentation must be up to date with the most recent situation of the DR project.
- 2) Traceability: the collector/publisher of the used data must be identifiable.
- 3) Level of detail: data must be as specific as possible. This can occur on three levels: **specific data** on products/materials from producers, contractors and specialists or through measurements and drillings; **general data** that is accepted in the sector (e.g., 'kengetallen'); and lastly, **assumptions**.

In the consultation of the expert panel, it came forward that the qualitative criteria for these indicators needed to be simplified, because it is expected that it is not possible to determine specific percentages of data considered traceable & reliable or belonging to a certain detail category. Additionally, the value of this category is to think about these data concerns and improve the quality of the data not to pinpoint specifically what percentage of data is of good quality. Therefore, simple and applicable criteria are chosen to improve workability.

Table 13: overview of the scoring criteria for the indicator 'actualisation'.

Score:	Actualisation:
1.0	Documented information is up-to-date to the most recent round of designs and executed for all remaining designs.
0.9	Documented information is up-to-date with the most recent round of designs, but not executed for all remaining designs.
0.8	Documented information is up-to-date with the previous round of designs and executed for all remaining designs
0.7	Documented information is up-to-date with the previous round of designs, but not executed for all remaining designs

Table 14: overview of the scoring criteria for the indicator 'verification'.

Score:	Traceability:
1.0	All data can be traced back to the collector/publisher.
0.9	Almost all data can be traced back to the collector/publisher.
0.75	A significant part of the data cannot be traced back to the collector/publisher.
0.6	Important data cannot be traced back to the collector/publisher.

Table 15: overview of the scoring criteria for the indicator 'level of detail'.

Score:	Level of detail:
1.0	Almost all data is considered general or specific data. Only a few assumptions are used.
0.9	Most data are considered general or specific data. Some assumptions are used.
0.8	A significant part of the data are assumptions. However, the impact on the results is estimated to be limited.
0.7	Assumptions are used for important data, that could significantly impact the results.

Category 6: Uncertainty

The scores from these indicators can be combined into the category score for uncertainty. Extra weight was attributed to the indicator level of detail, because the expert panel considered this to be the most influential factor for the quality of the assessment. It is calculated with EQ24.

$$\text{Equation 24: } Score_{category\ 6} = \frac{Score_{actualisation} + Score_{traceability} + (2 * Score_{detail})}{4}$$

Circularity score

To determine the circularity score, each category score must be evaluated and receive a weight dependent on the importance for circularity. It should be noted that different weights can be assigned to each category in the assessment, which presents a different perspective on circularity. Initially, the first five categories were weighed equally. Subsequently, this score would be multiplied with the uncertainty factor [EQ24] to obtain the final score [EQ25].

$$\text{Equation 25: } Circularity\ score_{initial} = Average\ score_{category\ 1-5} * Score_{category\ 6}$$

However, these weights were reconsidered with the expert panel. The group reached a consensus on the following statements:

1. The categories 'minimal resource use' & 'impact' assess partially the same, as 'minimal resource use' measures the quantity of material and 'impact' measures the quantity * impact.
2. Both categories provide valuable insights for circularity and thus must be included in scoring.
3. The weight of the 'impact' category must be increased as this is considered (by the experts) the most important goal of circularity, thus scoring well in this category must be rewarded.
4. In response to the increased weight of 'impact', the category 'minimal resources use' must be weighed less to prevent significant double counting due to statement 1.
5. The categories 'input characteristics' & 'output characteristics' must be rebalanced, because the 'input characteristics' score is based on data, while the 'output characteristics' score is based on 'educated' predictions of the future.
6. The category 'future proof' is scored with qualitative criteria instead of quantitative data. The concepts in this category are innovative and challenging, but not yet proven and applied in practice. Therefore, the weight of this category must be reduced; this limits the influence of this category on the circularity score, while still incentivising practitioners to implement and assess these concepts.
7. The uncertainty factor provides a valuable incentive to increase the data quality of the assessment and is included correctly.

After this discussion, every expert submitted their preferred weighing of the categories. Based on this information, the weights displayed in table 16 were assigned to each category. It should be noted that these weights are a subjective perspective of a select group of experts on circularity; others can disagree with these weights.

Table 16: overview of the initial and final weighing after consultation of an expert panel.

Category:	Initial weight:	Final weight:
1) Minimal resource use	20%	10%
2) Input characteristics	20%	25%
3) Output characteristics	20%	15%
4) Future proof	20%	10%
5) Impact	20%	40%
6) Uncertainty	Multiplication	Multiplication

The final circularity score is calculated with EQ26.

Equation 26: $Circularity\ score = \sum (Score_{category\ 1-5} * Weight_{category\ 1-5}) * Score_{category\ 6}$

Discussion

Place in literature

In the Netherlands, the decision-making for DR projects is approached from many different perspectives; examples of this can be water safety, life cycle costs, sustainability, circularity etc. (Maronier, 2018; van de Laar & Post, 2021; Waterschap Limburg, 2020). The complexity of a DR project calls for a structured approach to assess the situation and guide decision-making. Therefore, each project develops its own specific decision-making framework. This means that the content of this framework can differ per project. Naturally, these decision-making frameworks are developed within the established regulations at the national, regional and local level (Maronier, 2018; van de Laar & Post, 2021; Waterschap Limburg, 2020) and are, consequently, often structured similarly. The circularity assessment framework developed in this thesis should be integrated in these decision-making frameworks as best as possible to ensure its usefulness in practice.

In these decision-making frameworks, the method of including circularity as a consideration is variable. Where van de Laar & Post (2021) specifically include circularity as an individual consideration, Waterschap Limburg (2020) and Maronier (2018) include it as 'preference for reusable materials' and 'sustainable material use', respectively. It should be noted that this assessment framework is specifically developed to assess circularity and not to assess similar considerations like 'preference of reusable materials' and 'sustainable material use'. While these considerations share a similar goal, they differ significantly from each other in scope. While using this assessment framework could provide some valuable insights for these considerations as well, one should be careful with directly applying this methodology for these purposes. The implementation of the conceptual and assessment framework of this thesis could result in an improved shared understanding of circularity and thus make these decision-making frameworks more uniform in their inclusion of circularity as a consideration.

In addition to the decision-making framework, every DR project has a legal obligation to establish a 'Milieu Effect Rapportage' (MER), if it is expected to have a significant negative impact on the environmental quality. This MER describes and analyses the possible negative environmental impacts of the project to support the decision-making during the project (Maronier, 2018). Again, the included considerations in the MER are variable per project and often overlapping with some of the consideration in the decision-making framework. For example, the decision-making framework from van de Laar & Post (2021) for the IJsselmeerdijk project includes the investment & maintenance costs as well as the subsidising potential while these are excluded for the MER as these are not considered environmental impacts (personal communication, van de Laar, appendix D). However, in the decision-making framework and MER from Maronier (2018) these aspects are included. This displays the variability in setting up a decision-making framework and MER. Similar to what occurs in the decision-making framework the inclusion of circularity occurs in different forms (e.g., 'sustainable material use'), which have a slightly different scope. The developed assessment method for circularity in this thesis can also increase uniformity concerning circularity in MERs.

At the start of a project an intake session takes place, where the scope and targets of a project concerning sustainability are established; this is called an Ambition Web (Duurzaam GWW, n.d.). The developed assessment framework could be used to establish targets for the 'materials' theme in the Ambition Web. This would make it possible to monitor the Ambition Web targets for this theme using the assessment framework. However, it would be best if the theme could be changed to 'circularity', where the theme reflects the conceptual framework of this thesis, since this would directly connect the target development of a project to the aspects/categories used in this assessment. This would

create uniformity in the understanding, target setting, implementation and monitoring of circularity and thus standardise and simplify the process.

The proposed conceptual and assessment framework of this thesis are developed in the context of DR projects. However, this does not mean that the conceptual framework and some of the calculations cannot be applied in different contexts. When these frameworks are applied in different contexts a careful analysis to the applicability should be executed to prevent mistranslations.

The conceptual framework is developed to contribute towards providing a clear and structured definition of circularity in DR projects and hopefully in the wider civil engineering sector, which should result in a better understanding of this broad umbrella concept. The assessment framework is developed to reflect a balance between what circular indicators are currently quantitatively measurable (category 1-3 & 5) and what circular indicators are valuable and feasible to measure in the future (category 4). In this way, the conceptual and assessment frameworks provide a different perspective on circularity compared to the 'Circulaire Peiler', the 'kernmeetmethode', the circular indicators framework and their respective conceptual foundations (Meijer, 2018; Platform CB'23, 2020a; Weersink & van Cuyk, 2020). The 'Circulaire Peiler' is purely a process tool, while the 'kernmeetmethode' is designed to be purely quantitative (Platform CB'23, 2020a; Weersink & van Cuyk, 2020); the circular indicators framework from Meijer (2018) attempted to combine these functionalities, but this resulted in an incomplete, oversimplified and not easily workable methodology. The developed frameworks in this thesis tried to fill these gaps. In their current state, the developed frameworks provide a foundation on which future research can expand and improve. These efforts are necessary to improve the implementation of circularity and meet the objectives of the Dutch national government.

Limitations and future research

In the development of the assessment framework, many choices and assumptions were made to operationalise this methodology. For each of these choices and assumptions, a short reflection on their limitations and possible angles for future research are discussed.

To set the scope of the assessment, the 'old' parts of the dike were excluded from the circularity assessment, which results in higher variability in the circularity scores. Since large parts of the 'old' dike are not changed during a DR project, including them would dilute reductions in scope/size and include large quantities of input material originating from direct use. This would skew the results. Additionally, the division of the dike in specified elements approximates reality and will never perfectly reflect the dike design. It limits the scope of the assessment drastically as it only allows to assess the circularity at the project and element level. As a possibility for future research, the structure of the dike as proposed in this thesis requires improvement to ensure the workability of the assessment framework while increasing the detail level and thus the scope of the assessment.

Concerning the choice of the reference design, the first design in the exploration phase was deliberately chosen as reference point as it is the earliest design where the engineering firm is certainly involved. In this way it prevents difficult data transfer between different stakeholders in the initiative and exploration phase. However, if the use of material passports becomes more common in the future, the barrier of transferring the necessary data will be reduced or disappear, thus creating the possibility of choosing an earlier reference design. When this time comes the reference design options should be re-evaluated to choose the best option.

The use of several assessment mechanisms was necessary to develop assessments for all categories as some were not (yet) quantitatively assessable. This does, however, have some consequences for the

overall assessment. The use of reduction targets to score category 1 & 5 allows the coupling of the circularity score to the established targets of the project or the objectives from the government. If the reduction target is not centrally prescribed, it could be used to boost the circularity score by setting low targets. Therefore, the sector should agree upon a fixed reduction target for all assessments; for example, until 2030 a target of -50% and 2030 onwards -70%. This would improve the objectivity of the circularity score. Furthermore, the labels, their definitions and the corresponding scores provide a perspective on circularity based on the current understanding of circularity in literature and the views of a select group of practitioners. Since 'circularity assessments' are a rapidly evolving research field with many perspectives, it is advised to further research these labels, their definition and especially their scoring to keep up with these developments. This can, for example, be realised by repeatedly consulting an expert panel and significantly expanding the group of practitioners that were consulted to formulate these labels. Similarly, the weighing of categories in the circularity score is a perspective on circularity of a select group of practitioners and thus partially subjective. Still, the choice was made to use these weights to display what aspects and categories were considered important and to prioritise their improvement. However, by doing so, it compromises some of the objectivity of the circularity score. Again, additional research with an expanded group of experts would provide extra legitimisation for the weighing of the score.

The inclusion of the uncertainty factor as a category was considered to be valuable for this assessment framework. However, the category and its aspects are not yet complete, as more data concerns can affect the assessment. Additional research should be done to expand this category, improve the existing criteria and assign appropriate scores.

The previous section was concerned with the limitations of the parts that are included in the assessment framework. In addition, some parts were excluded, not considered or not executed, which provide some options for future research. For example, in the framework of Platform CB'23 (2020a), an indicator concerning the scarcity of materials is included. The concept of scarcity and its assessment is not yet present and could further enhance the assessment framework in this thesis. Additionally, the assessment framework has only been tested with the use of fictional data at this moment. Extra tests with real DR project data are required to evaluate the effect on the results and implement balancing and improvements.

Lastly, the main objective of this research was to conceptually define an assessment framework for circularity in DR projects. In addition to this, a tool has been developed to simplify the assessment process. However, only a demo version was developed in Microsoft Excel, due to time constraints and a lack of expertise in constructing such a tool. Additional effort and expertise are required to upgrade the tool into a final version. The upgrade could address the following points:

- a. The quantity of input fields should be minimised to prevent input errors.
- b. Dike designs are often developed in a 3D-design programme; the tool should be able to automatically read the output files of the most frequently used programmes to prevent transformation errors.
- c. Improved graphic representation of the assessment results would enhance the communication of the results and incentivise action.

Further research and development are necessary to improve the quality of circularity assessments in DR projects and the civil engineering sector. Therefore, the current version of the assessment framework should be regarded as a starting point/explorative effort for standardised circularity assessments in DR projects.

Conclusion

Circularity is often considered a broad and vague umbrella concept. Nevertheless, the Dutch government pushes for a more circular society by demanding a full circular economy in 2050 and an intermediate goal of 50% in 2030. This means that resource-intensive projects must start implementing circularity in their plans. In the coming thirty years, 1300 kilometres of dikes in the Netherlands must be reinforced to cope with rising sea levels caused by climate change. These dike reinforcement projects must conform with the circularity objectives of the government. However, there is currently no method to measure and assess circularity in DR projects. Therefore, the following research question is answered:

'How can circularity be measured and assessed in dike reinforcement projects during the entire life cycle?'

To identify what circularity means in DR projects and determine what aspects of circularity should be measured, this study conceptualised circularity in this specific context. In this conceptualisation, circularity is considered a tool to maintain resource stocks, protect the environment and retain the value of objects/materials. To become more circular six categories must be considered; the categories treat topics like the quantity of material use, the circular characteristics of input and output materials, the inclusion of future perspectives and interests in designs, the impact of material use, and the uncertainty of the data. This conceptualisation of circularity helps to create a shared understanding of the concept in DR projects. In this way, practitioners can more easily and more effectively implement measures that contribute towards more circular material use. Additionally, it also allows DR projects to set clear targets for circular development that can be monitored.

To be able to track the progress of circular implementations throughout a DR project an assessment methodology was developed that compares different dike designs using those six categories. Each category has measurable aspects that can be used to determine a score for each category. To determine the final circularity score, each category is assessed and weighted depending on the perceived importance to circularity of an expert panel. In this way, circularity can be measured and assessed in a DR project during the entire life cycle. The assessment framework helps the practitioners to easily compare different dike designs on circularity and track the progress of circular implementations throughout a project. The current version can be used to start assessing circularity immediately. However, it should be considered a foundation for additional research to improve the quality of the assessment. This is desired to support efficient implementation of circular ideas, to stay up to date with the latest developments concerning circularity and to ensure compliance with the objectives of the government.

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Appendices

Appendix A: Development of the conceptual framework

The confusion around the concept of the circular economy in general also manifests itself on the more detailed levels, for example the civil engineering sector or DR projects. The absence of a central definition and composition of circularity on these levels results in individual efforts per organisation or project and thus a chaotic mix of conceptualisations, implementations and assessment methodologies.

It should be noted that circularity in itself is not the goal, but only a tool to achieve several objectives, namely: maintain resource stocks, protect the environment and retain the value of objects (Korhonen et al., 2018; Platform CB'23, 2020a). It is also often seen as a tool to achieve sustainable development. It, therefore, treats many of the same topics as sustainability (personal communication, Verschoor & van de Laar, appendix D). Some aspects, commonly associated with circularity, have already been implemented, however often with a different motivation than to stimulate circularity. Examples of this are: 1.) the reduction of total material use and reuse of secondary materials to limit financial costs and 2.) the assessment of environmental impacts during the life cycle of a DR project, due to environmental concerns like pollution and climate change. When viewed in the perspective of circularity, this creates a set of unconnected indicators that do not assess all aspects of circularity. Firstly, this chapter investigates some existing frameworks for circular development in the civil engineering sectors. Secondly, it discusses current implementation efforts for circularity in DR projects. Afterwards, these different frameworks and implementation efforts are integrated into a conceptual framework, which reflects a complete perspective of circularity and its aspects in DR projects.

What frameworks for circular development already exist in the civil engineering/construction sector?

In the following section, three existing conceptual frameworks are discussed, which treat circularity in the civil engineering sector. These approaches are the circular design principles from Rijkswaterstaat, the guidelines for circular design from Platform CB'23 and a scientific article providing indicators for circularity from 2018 (Meijer, 2018; Platform CB'23, 2021; Rijkswaterstaat, 2020).

Circular design principles

The circular design principles (CDP) are formulated by Rijkswaterstaat to guide their infrastructural design towards more circular practices. The principles do not have to be used synchronously; it is recommended to implement the principles that, for a specific project, realise the largest benefits (Kok et al., 2019; Rijkswaterstaat, 2020). The principles pursue three goals that are necessary for circular design: prevention, value preservation and value creation. The definitions of these principles are derived from the explanations by Kok et al. from 2019 & Rijkswaterstaat from 2020. Figure 4 displays an overview of these goals and principles.

The first goal 'prevention' only includes one principle:

1. Prevent something from being built or replaced if not essential. However, when it is necessary, find a solution with the least amount of or no resource use.

The second goal 'value preservation' attempts to ensure that the maximum value of existing objects is preserved for future life cycles. Two principles are formulated to achieve this:

2. Prolong the lifetime of existing objects or individual components.
3. Make sustainable use of what is already there; this includes objects, materials, resources and natural processes.

The third goal 'value creation' is concerned with creating as much value as possible from an object while minimising resource use. To realise this objective, five principles are mentioned:

4. Design for multiple life cycles. Design adaptable, portable, reusable or suitable for multiple functions.
5. Design future proof. Design for an optimum between the technical and functional lifetime, where an object is designed to retain its performance under the expected changing circumstances.
6. Make designs that simplify and minimise management and maintenance.
7. Design around the sustainable use of materials, by avoiding scarce materials, using materials with a low environmental impact and use renewable instead of primary resources.
8. Design for minimal resource and energy consumption in development and utilisation.

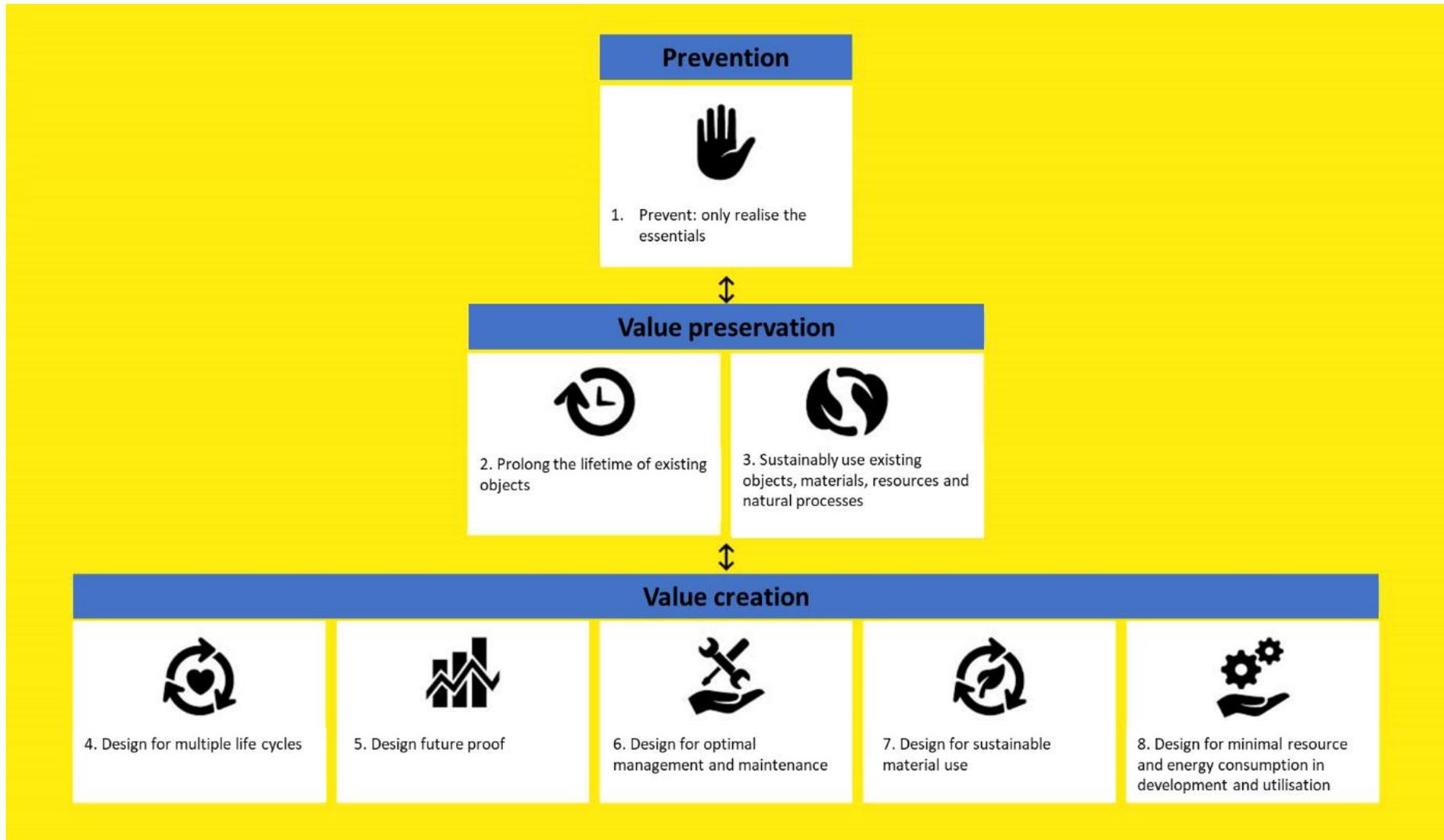


Figure 4: The eight circular design principles from Rijkswaterstaat categorised per goal. Translated from 'Circulaire ontwerpprincipes': Rijkswaterstaat, 2020

Guidelines for circular design

'Platform Circulair Bouwen 2023' developed the guidelines for circular design (GCD) to improve circular design in the construction sector. The definition of the six guidelines presented below are translated from the explanations given in Platform CB'23 (2021):

1. Design for prevention: prevent the use of products, elements or materials by put off the project, combine several functions or change solutions.
2. Design for reduction of life cycle impact: design decisions are based on their consequence on the environmental impact and environmental performance of the object in the development, utilisation and end-of-life phases.
3. Design for future proofing: design decisions are made to accommodate future interests by ensuring the adaptive capacity of objects.
4. Design with reused objects: in the design the reuse of existing products, components and elements are emphasised, if needed after some modifications.
5. Design with secondary resources: in this strategy designing with previously used resources or resources from waste streams is prioritised to minimise primary resource use.
6. Design with renewable resources: resources used in this design are from renewable sources and thus replenish or purify within the human time scale and should be inexhaustible if sustainably managed.

Circular indicators for comparing design alternatives

In the article from Meijer (2018), indicators were determined to compare infrastructural design alternatives on circularity. The indicators were divided in three categories: resource use, design characteristics and end-of-life. The definitions below are derived from the explanations given in Meijer in 2018.

In the category 'resource use' the following indicators are displayed:

1. Amounts of used materials: this indicates whether reductions in resource use occur for certain design alternatives.
2. Environmental impact of used materials: this indicator tracks whether changes in the design reduce or increase the stress on the environment.
3. CO₂-emission: this indicator tracks the CO₂-emission related to specific design alternative. It is separated from the previous indicator as this is common in literature.
4. Renewable energy use: this indicator is used to check whether finite energy resources are being exhausted and if emissions associated with these sources are prevented.
5. Reuse of existing objects, components & materials: closing material loops is an important target of circularity. This indicator checks the status of this process.
6. Transparency of the information of the used materials: this indicator is used to track the reliability of the material use information. If reliability is high, this would facilitate the implementation of circularity.

For the category 'design characteristics', the following indicators are formulated:

7. Modularity of the design alternative: this indicator scores design alternatives on the ability to disassemble or detach components and objects. This is partially dependent on how difficult it is to reach the components or objects and the quality of the disassembled/detached components.
8. Maintainability: this indicator measures the frequency, effort and nuisance related to maintenance activities. Good scores usually indicate longer lifespans of design alternatives and improve circularity.

9. Lifespan: this indicates the time an object can provide its function.

In the category 'end of life', the following indicators are used:

10. Reuse rate: this indicates the quantity of reusable materials after the life cycle of an object.

11. Recycling rate: this indicates the quantity of recyclable materials after the life cycle of an object.

12. Waste generation & energy recovery rate: this indicates the quantity of materials discarded as waste or used for energy recovery from waste.

The indicators in the framework were evaluated by a panel of experts; this led to the rejection of four indicators. The refuse principle is concerned with the prevention of projects if not necessary. This aspect was not considered in the indicator framework since it happens before issuing a project. Therefore, it is not suitable to be used in an assessment for design alternatives. The indicator concerning toxicity was rejected as this already is incorporated in the indicator for the environmental impact of used materials; similarly, reparability was incorporated in the indicator 'maintainability'. Economic costs were deemed a boundary condition and not an indicator of circularity.

Discussion

Each framework has its shortcomings, which disincentives their direct application as the conceptual foundation. An assessment framework based on the CDP has already been developed; however, this method is focussed on only a few indicators and therefore feels incomplete. The GCD focus only on the design phase, while the scope of this research is to incorporate all phases of a DR project. And Meijer's indicators are incomplete and oversimplified; this makes the indicators measurable but not accurate enough.

Each of the three approaches could individually provide a conceptual foundation for a circularity assessment framework in DR projects. However, for this research it is decided to integrate the approaches to incorporate their different perspectives in the best way possible.

How do dike reinforcement projects currently incorporate circularity?

The implementation of circularity in DR projects is often quite narrow and focusses on the reduction, reuse and recycling of materials. The HWBP acknowledges that a wider perspective on this subject is necessary in the future (HWBP, 2021). To create knowledge on this subject and develop this wider perspective several pilot projects were initiated where several aspects of circularity were researched. In the following paragraphs, four of these initiatives are discussed to explore the current efforts to implement circularity through a wider perspective in DR projects.

Prevention & scope and size reduction

Recently, revisions of several assessment methodologies for the safety levels of a dike (for example for failing mechanisms, piping, necessary height, macro stability and cover layers) resulted in the prevention or significant reduction of scope and size of several DR projects without compromising safety levels (HWBP, 2021; Weersink & van Cuyk, 2020). Through the loosening of existing regulations, implementation of innovations and implementation of real-time monitoring further reductions and thus more circular dike designs can be realised (Jutte et al., 2020).

Documentation of materials: 'oogstkalender'

In the construction sector, especially in the construction of buildings, it is recognised that a 'material passport' is an essential tool for the implementation of circularity (Atta et al., 2021; Honic et al., 2019). A material passport is a quantitative and qualitative inventory of the used materials in buildings. This includes: the type of material, the quantities used, the quality of the material, the reuse/recycling

potential, deconstruction & maintenance guidelines and the environmental impact (Atta et al., 2021; Honic et al., 2019). For DR projects the information on materials for current infrastructure often becomes available during the project, due to the lack of a material passport or an equivalent tool (Jutte et al., 2020).

The 'oogstkalender' as established by Waterschap Zuiderzeeland for the IJsselmeerdijk project is an inventory of materials that will become available during the project for some design alternatives. Additionally, an indication of the characteristics and quality of the materials is provided, as far as possible. This provides the information on what is already present and how it can be used in the future. It basically catalogues past efforts and coincides with the first four components of the material passport. Furthermore, it gave insight in the total material demand for several design alternatives and the expected use of salvaged materials to meet this demand (Waterschap Zuiderzeeland, 2021).

The goal of this inventory was to be able to support decision-making with insights in the circularity of different design alternatives. The 'oogstkalender' has been established during the exploration phase and it displayed that it was possible to improve circular decision-making in the project. Implementation in subsequent phases of a DR project should further improve this (Waterschap Zuiderzeeland, 2021).

This initial attempt provided valuable information on the difficulty of collecting accurate information for past projects. Therefore, it emphasises the importance of correctly documenting current and future developments as this facilitates better implementation of circularity in these projects (Waterschap Zuiderzeeland, 2021). Recently, Platform CB'23 (2022b) delivered an 80% version of their guidelines for the establishment of material passports in entire construction sector, with specifications for the civil engineering sector. An explanation of its content can be found in appendix C. The 'oogstkalender' and the efforts from Platform CB'23 (2022b) indicate the importance of accurate data collection and documentation for the implementation of circularity in DR projects.

Localisation of materials

Over the last century, regulations surrounding material requirements have become very stringent, which made the use of local materials in DR projects nearly impossible. This resulted in the import of materials with specific characteristics, which increased the environmental impact of the material use due to transport (HWBP, 2021). Lately, two DR projects (Gorinchem-Waardenburg & Grebbedijk) have attempted to increase the share of locally extracted materials as part of a pilot. These pilot projects showed that local material use reduced the emissions of transport and that it was often cheaper than imported materials (Halter & Stoop, 2021; HWBP, 2021; Weersink & van Cuyk, 2020). Based on these experiences stakeholders started to rethink the design process towards designing the project around the available local soil/material (soil from local extraction sites or salvaged from the dike). This change in design perspective could further enhance the implementation of local material use in DR projects. The use of local material does not seem to contribute to circularity directly, but it does limit the environmental impact of the project, which often is considered an objective of circularity (Platform CB'23, 2020a).

The implementation of both the use of local materials and the new design approach can be improved by slightly loosening the regulations concerning material quality without compromising safety levels, as this would make more materials viable for use (Jutte et al., 2020). Recently, after careful review, the strictness of the regulations on soil quality have been loosened in special cases (Rijkswaterstaat, 2018). This development allows some DR projects to use types of clay with slightly different characteristics after research has displayed the safety of the dike would not be compromised (Rijkswaterstaat, 2018).

Additionally, to stimulate reuse of local materials, a platform for material exchanges (material bank) should be developed. This platform should allow for material exchanges on multiple levels (e.g., intra

& inter project, intra & inter organisation) to support the maximisation of resource reuse (Jutte et al., 2020). To prevent unnecessary transport of materials, solutions on small scales should be prioritised. For example, reusing local materials within a project should have the preference before reusing the materials in other projects. To facilitate both the increased use of local materials and the material bank, an expansion of local storage and material processing capacity on or near project sites should be realised (Jutte et al., 2020). In addition, an integrative perspective on the project is needed where different ambitions are coupled to facilitate each other (e.g., nature development in the floodplains; the use of local soil from the construction of a side channel for the dike reinforcement). This should improve the implementation of local material use and make DR projects more circular.

Emission reduction

Currently, the DR project Wolferen-Sprok runs a pilot on how to catalogue the emissions of their construction and transport machinery and what is needed to bring the project to a zero-emission state or at least closer to this goal (HWBP, 2021; Werkgroep emissielooos bouwen WOS, 2021). To realise this, an inventory of the emissions of traditional machinery is produced, after which opportunities are formulated to eliminate or reduce these emissions. Elimination could be realised predominantly by switching from fossil-fuelled machinery to machinery fuelled by electricity from renewable energy or sustainably produced hydrogen. Because of this specific pilot project, electricity driven cranes and heavy soil-moving machinery have been developed; their use would not only significantly reduce emissions but also the nuisance of traffic from fuel-trucks and noise of construction machinery experienced by residents. Additionally, several large contractors in the Netherlands are starting to buy electric machinery, however, the actual utilisation of this machinery proves difficult as it encounters several obstacles. For example, the availability of charging infrastructure, determine charging scheduling and mechanisms and the limited battery capacity (personal communication, Wolbers). Besides non-fossil fuel machinery, significant emission reductions can be realised by optimising resource flows, transport routes and construction operations. For all these opportunities, a cost-benefit analysis is conducted to determine the best improvements for the DR project.

The pilot project in Wolferen-Sprok displays that the willingness to implement zero-emission initiatives is often present in both clients and contractors, however the initial financial investments are substantial and prove to be an obstacle for further implementation (Werkgroep emissielooos bouwen WOS, 2021). Therefore, financial assistance could assist in overcoming these initial costs and help mature the technologies/developments, which is needed achieve cost-effective solutions. The HWBP already has such an arrangement in place to support innovations (Jutte et al., 2020), however, this might be expanded. For this pilot, the target of a zero-emissions DR project was not yet feasible, however, the results should be further developed and implemented in other DR projects (Werkgroep emissielooos bouwen WOS, 2021).

Discussion

These four efforts can be considered the most important circular developments currently (being) implemented in DR projects. While often still in an early phase, they display what the focal points concerning circularity are for stakeholders in the sector at the moment.

- Prevention & scope and size reduction
- Documentation of materials and flows
- Localisation of materials
- Emission reduction

Appendix B: Development of the assessment framework

How is circularity quantitatively assessed in other sectors/projects

The three conceptual frameworks discussed in the previous chapter were used as foundation for three assessment frameworks for circularity. These different assessment frameworks are evaluated to observe different perspectives on circularity assessments in the civil engineering sector. Additionally, two frameworks used to assess circularity in buildings are discussed to evaluate developments in a related sector. Lastly, two tools are discussed that are currently used to assess (a part of) circularity in DR projects.

Table 17: overview of the discussed frameworks in this chapter.

Civil engineering sector	Built environment	Tools DR projects
'Circulaire Peiler'	Material, Product, System and Building Circularity Indices	DuboCalc
Guidelines for measuring circular design ('kernmeetmethode')	Disassembly potential	R-principles for DR projects
Circular indicators for comparing design alternatives		

The 'Circulaire Peiler'

This assessment framework assesses and compares the implementation of the CDP in design alternatives (HWBP, 2021; Waterschap Vallei en Veluwe, 2020). The tool was developed specifically for DR projects, but has also been used for water treatment systems (personal communication, Verschoor, appendix D). This is possible because the tool assesses the implementation of circular processes and strategies and not the impacts of these processes (personal communication, Verschoor & Gaasbeek, appendix D).

The 'Circulaire Peiler' is a multicriteria analysis, where each principle of the CDP is assessed through indicators. These indicators are scored through a 5-tiered ranking for which qualitative evidence must be provided; this ranking is based on the 10R strategies of Cramer, which provides a hierarchy of circular strategies (Waterschap Vallei en Veluwe, 2020). Some indicators require additional quantitative evidence in the form of Environmental Cost Indicator (ECI) or Material Circularity Index (MCI) calculations.

It is recognised that the scoring mechanisms in the 'Circulaire Peiler' are influenced by subjectivity, as ambiguities in the scoring criteria exist (personal communication, Verschoor, appendix D). Furthermore, there are no clear rules for determining the reference designs to which the improved designs should be compared to (personal communication, Verschoor, appendix D), which makes statements like 'a 20% size and scope reduction' questionable. However, the scores for the indicators are meant to track the progress of circular implementation and stimulate improvements rather than provide a quantitative figure of circularity (personal communication, Verschoor, appendix D). Therefore, the scoring system is designed to check if certain practices have been implemented or if certain calculations have been performed (personal communication, Verschoor, appendix D). Still the outcomes of these calculations do influence the score of certain indicators, however at this stage this is rather limited.

Guidelines for measuring circularity ('kernmeetmethode')

Platform CB'23 constructed a conceptual framework for circularity in construction, which was the aforementioned GCD. As a follow up study, the platform also created a preliminary methodology for the assessment of the GCD; this methodology is called the 'guidelines for measuring circularity' or

'kernmeetmethode' [translation: core measuring methodology]. This methodology is not yet completed and receives regular revisions, updates and expansions (Platform CB'23, 2020a).

The foundation of the assessment methodology is a material balance, which provides information on the in- and outflows of resources within the relevant context. After this material balance is set up, the 'kernmeetmethode' is applied, where with 7 indicators the circular characteristics of the system are determined. These indicators directly coincide with the three main targets of circularity: maintain resource stocks, protect the environment and retain the value of objects. Indicator 1-3 coincide with the first target, indicator 4 with the second and indicator 5-7 with the last.

1. Quantity of used materials (input)
2. Quantity of available material for next life cycle (output)
3. Quantity of lost material (output)
4. Impact on environment
5. Quantity of initial value (input)
6. Quantity of available value for next life cycle (output)
7. Lost quantity of existing value (output)

All these indicators are divided into sub-indicators, which provide more detail in the circular characteristics of the relevant context. In the next paragraphs the methodologies for indicators 1-4 and their sub-indicators are discussed as these provide a clear and intuitive approach to assess circularity in the context of DR projects. For indicator 1, the sub-indicators are displayed in figure 5 & 6. These figures display that the first indicator is divided into two dimensions: primary/secondary (1.1) & scarce/non-scarce (1.2). These sub-indicators are again further specified into multiple categories.

For indicator 1.1, all input flows included in the material balance are first classified according to the primary/secondary division. **Primary inputs** are defined as: materials produced by the earth and used by humans to manufacture products and other materials. **Secondary inputs** are defined as: material originating from previously used products or from residual streams of other systems. These inputs are used to replace primary or other secondary materials.

Subsequently, the more detailed categories are determined. **Renewable inputs** are originating from a renewable source that is naturally replenished or cleansed on a human time scale. These inputs can be biotic as well as abiotic. **Non-renewable inputs** are not originating from a renewable source. Whether an input may be classified as sustainably produced is easily determined if it bears an internationally recognised quality mark. Another approved way is by providing evidence that displays the extraction rate does not exceed the regeneration rate and that if the resource can be used for consumption it may not be used as a material.

The sub indicators concerning reused and recycled inputs use the following definitions. **Reused**: material originating from a composed object that after use (and if needed after processing) is reused in the same function. **Recycled**: material that underwent a recycling process and is again utilised in an object. For these two sub indicators it is recognised that these are insufficient to classify all secondary input flows (Platform CB'23, 2020a; personal communication, Verschoor, appendix D).

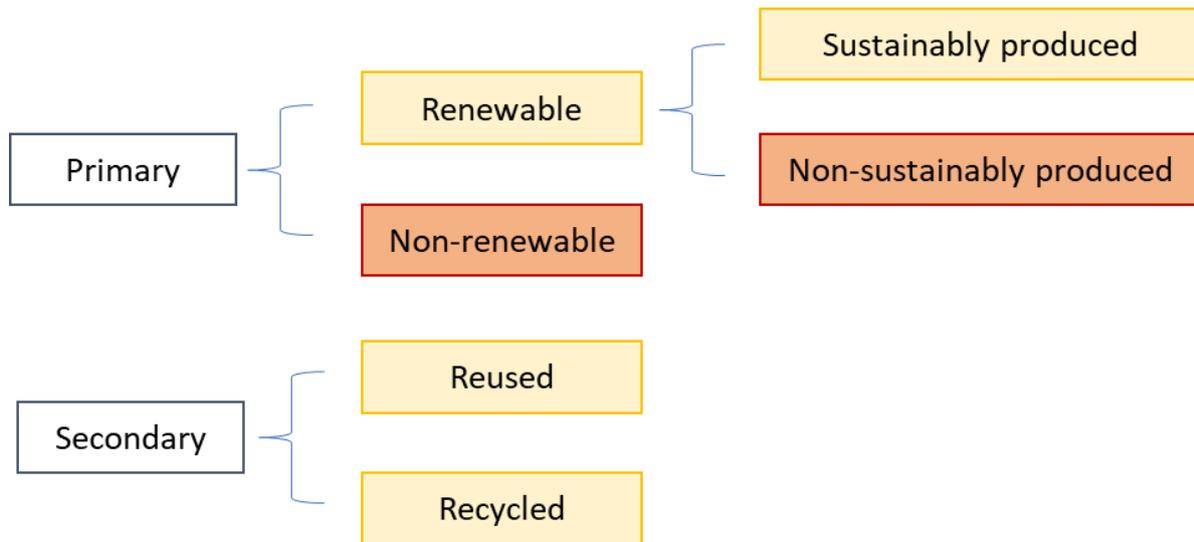


Figure 5: overview of sub-indicator 1.1 and its further specifications. Adapted from: (Platform CB'23, 2020a).

For indicator 1.2, the 'kernmeetmethode' first determines the physical scarcity of all input flows in the material balance. **Physical scarcity** is determined through the abiotic depletion potential, which is a methodology that is part of the Product Environmental Footprint Guidance. The use of the methodology is described in NEN-EN 15804:2012+A2:2019 (Platform CB'23, 2020a). A resource is classified as **socio-economic scarce** when it is included in the most recent Critical Raw Materials (CRM) list of the EU and is not already classified as physical scarce (European Commission, 2020; Platform CB'23, 2020a). The remaining resources are categorised as **non-scarce resources**. Thus, the categories should add up to 100 percent.

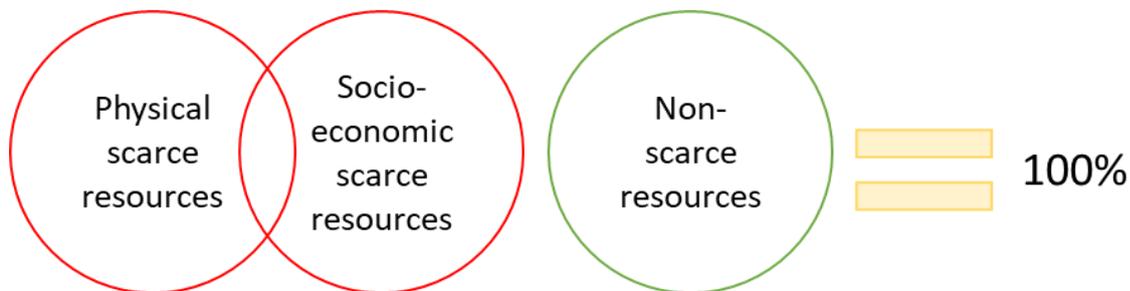


Figure 6: overview of sub-indicator 1.2 and its further specifications. Adapted from: (Platform CB'23, 2020a)

Indicators 2 and 3 are concerned with the available material for the next life cycle (2) and the lost material (3) and thus both consider the output flows of the material balance. An overview of indicator 2 & 3 and their sub indicators are displayed in figure 7. The output materials that are available for the next life cycle (2) are subdivided in two categories: **recyclable** and **reusable**. The definitions for these categories are the same as for indicator 1, except that this is concerned with the expected fate of the output materials. Furthermore, it is important that the output flows are classified according to realistic expectations of the end-of-life treatment and not according to the theoretical potential. In 2018, Royal HaskoningDHV set up guidelines to establish the realistic end of life treatment of materials. The following four questions should be answered to determine a realistic end of life scenario for materials, where the first question determines whether it qualifies as recyclable or reusable:

1. Technical: Are there applications for the material in the next life cycle when it is recycled or reused?
2. Demand: Is there sufficient demand for this application?

3. Value preservation: Can the specific characteristics of the material be utilised in the next life cycle?
4. Impact: Is there no negative impact with the application of this material on the reusability of other resources in the appliance?

Surprisingly, Platform CB'23 does not specifically recognise that the sub indicators 'recyclable' and 'reusable' are insufficient to classify all output flows that are available for the next life cycle (this was the case for input flows at indicator 1. Therefore, it is expected that this might lead to unclassified or wrongly classified outputs.

The lost output materials (3) are also subdivided into two categories. The first category is concerned with output materials where it is expected that the imbedded **energy** is **recovered** after incineration. The second category includes materials that are expected to be **dumped** at landfill sites. To assess what fate can be expected for different types of materials the estimations from Stichting Bouwkwaliiteit (2019) are used.

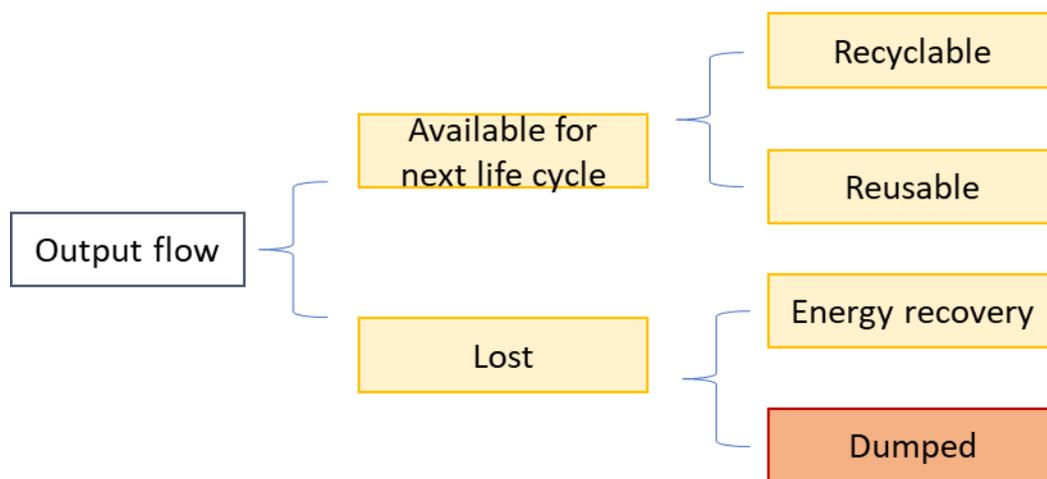


Figure 7: overview of sub-indicator 2 & 3 and their specifications. Based on: (Platform CB'23, 2020a)

For indicator 4 concerning the impact on the environment the 'kernmeetmethode' uses the SBK-methodology. This methodology is a translation/adaptation of the European regulations into the Dutch context to develop environmental product declarations on the product level (EN 15804) (Stichting Bouwkwaliiteit, 2019). The SBK-methodology measures 19 different impact categories. to assess the total impact on the environment. These categories are used to form a weighted score for indicator 4; the weighing is again executed according to SBK-methodology (Platform CB'23, 2020a; Stichting Bouwkwaliiteit, 2019). The 19 impact categories are:

1. Climate change – total
2. Climate change – fossil
3. Climate change – biogenic
4. Climate change – land use (change)
5. Ozon layer depletion
6. Acidification
7. Eutrophication freshwater
8. Eutrophication seawater
9. Eutrophication land
10. Smog formation
11. Depletion of abiotic resources – minerals and metals

12. Depletion of abiotic resources – fossil energy carriers
13. Water use
14. Particulate matter emissions
15. ionising radiation
16. Ecotoxicity (freshwater)
17. Human toxicity, carcinogenic
18. Human toxicity, non-carcinogenic
19. Land use related impact/soil quality

Indicator 5-7 are concerned with determining the value of the input flows (5), available output flows for the next life cycle (6) and the lost value of output flows (7). For all indicators, a calculation for the technical-functional and economic value is required. However, a methodology for calculating the technical-functional value is not yet developed. For economic value a detailed methodology is provided for determining the value in every phase of a life cycle. However, it is acknowledged that collecting data on the costs for the demolition/processing phase and on the benefits outside the project boundaries is very difficult, which results in an incomplete assessment on the economic value. These arguments display why at this moment this methodology for determining the value of input and output flows is not feasible; however, it might be in the future when the methodology for the technical-functional value is developed, and further implementation of the circular economy will expand the data availability.

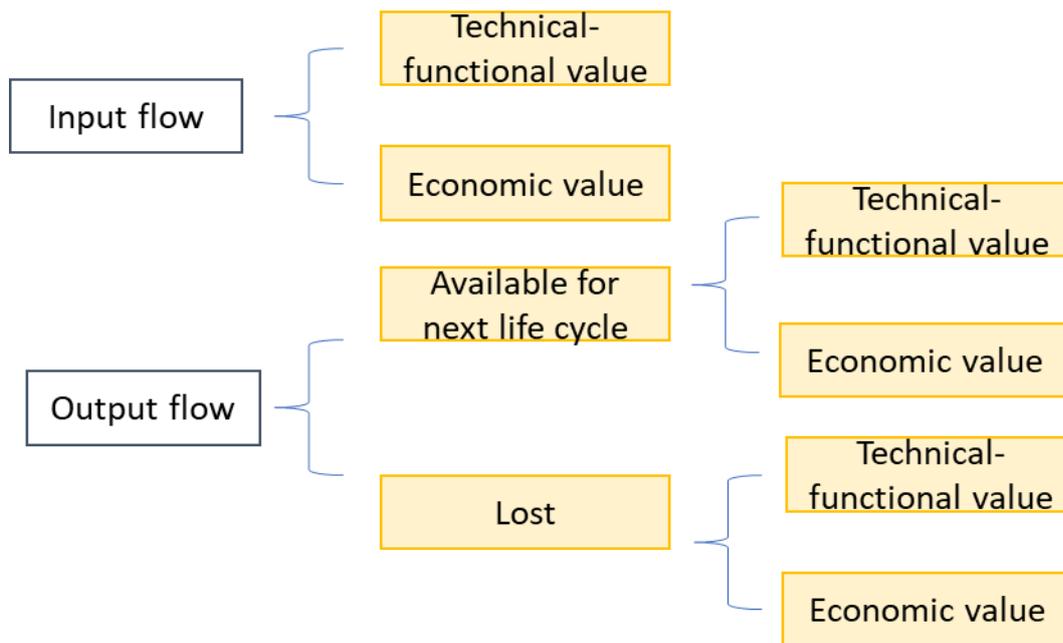


Figure 8: overview of indicator 5-7 and their sub indicators. Based on: (Platform CB'23, 2020a).

Circular indicators for comparing design alternatives

This framework assesses circularity in dry infrastructural projects (e.g., bridges). Almost all indicators are scored through a 5-tiered system of qualitative criteria similar to the scoring system of the 'Circulaire Peiler'. In addition, the criteria have a quantitative component where it is assessed if a percentage of the object's material input complies with the indicator, an example is provided in table 18.

Meijer states that: 1.) the reuse of components in the same function is more circular than reuse in a lower function or recycling; this is called downcycling and 2.) transportation of the components and materials is an important factor for determining the circularity of a design alternative (Meijer, 2018).

However, these statements are poorly included in the criteria and therefore are not considered in the scoring of this indicator.

Table 18: the 5-tiered scoring system for the indicator 'reuse of existing objects, components and materials in new objects' (Meijer, 2018).

Score	Description
Excellent	Most or all parts of the object (80-100%) are made of reused components and/or objects; additionally, a small part can be made of recycled materials.
Very good	A large part of the object (60-80%) is constructed with recycled materials and/or reused components.
Good	About half of the object (40-60%) is constructed with recycled materials and reused components.
Fair	A small amount of the object (20-40%) consists of recycled materials or reused components.
Poor	No reuse or barely any reuse at all in the object (0-20%).

The aspects in the framework of Meijer are generally well-structured and well-defined, however, this was not translated into complete, detailed and applicable scoring criteria. From this should be concluded that scoring criteria should have a balance between completeness, detail and applicability, which should be checked with practitioners.

There are two indicators that do not follow the 5-tiered structure, which are the 'amount of used materials' and 'environmental impact of used materials' indicators. The first determines the quantity of each type of material in the preferred unit of weight/volume. Lower quantities are considered more circular. This weight/volume is not compared to a benchmark, which results in a ranking of what design alternatives is more circular and not an objective assessment of circularity. The second indicator 'environmental impact of used materials' can be determined either by using DuboCalc or an LCA, dependent on the preference of the user. This is very similar to the methodology and scoring used in the 'kernmeetmethode' and is the most common approach in the sector for environmental impact assessment. Again, this results in a ranking of what design alternative is more circular, so a comparison with a benchmark could assist in a more objective circularity score.

Material, Product, System and Building Circularity Index

The Material Circularity Indicator is a methodology to assess the circularity of the flows of products and materials in a company (Goddin et al., 2019). It was initially developed to operate on two different scales. If calculated at the product level, it functions to compare different versions of products and assess improvements in product design. Additionally, it can be used to set a circularity standard to your products. If calculated at the company level, it can internally function to get insight in the circularity of product ranges and departments within the company. Externally, this could function as a measure to compare your circularity to competitors.

The MCI is concerned with calculating the technical aspect of circularity, thus the flows and circulation of materials. However, it should be noted that information about the types of materials and their characteristics is not included, which makes steering for improvement more difficult. Additionally, information on the environmental impact is not included.

The MCI already included the possibility to calculate on the product and company scales. However, Verberne (2016) expanded the methodology with the Product Circularity Index (PCI), System Circularity Indicator (SCI) and the Building Circularity Indicator (BCI), where he adapts the methodology for the built environment. His expansion assumes that the circularity of a product is not simply the sum of the circularity of its materials. It is also dependent on the interfaces and connections between materials. Therefore, the Design for Disassembly Factor (DDF) was included for determining the PCI. The DDF originates from the research of Durmisevic (2006) on the disassembly potential of buildings. Subsequently, for the SCI it is assumed that the circularity of a system is the sum of its constituents, in this case its products and thus materials (Verberne, 2016). Lastly, to calculate the BCI a building is divided according to Brand (1995) his Shearing layers of Change. Based on this division Verberne (2016) argues that the aspects of a building with a shorter life cycle exert more influence on the circularity of the building and thus receive extra weight in the score.

In this framework, each level is constructed as the sum of the previous level while including more circular conditions each level (DDF & Shearing layers of Change). Through this method a detailed and workable approach was developed to calculate the technical aspects of circularity of a building, which might be translated to the context of DR projects. However, this approach does not include the broader definition of circularity that incorporates the characteristics of the materials and the life cycle impact, which makes it incomplete.

Disassembly potential

The possibilities for reuse of buildings and their components are dependent on the capacity of a building to be disassembled efficiently without damaging the components (Durmisevic, 2006). This problem has been conceptualised specifically in this context, which resulted in the formation of 8 aspects for disassembly and 17 disassembly determining factors (DDFs), which should reflect all aspects that influence the disassembly potential of a building (Durmisevic, 2006; Durmisevic et al., 2003). The first statement is also applicable to DR projects; however, the aspects and factors that are of importance in that context can differ drastically. Additionally, dikes often do not consist of many components that require disassembly as the designs are largely based on ground solutions. However, some DDFs do apply to components like power lines and other cables, drainage and other piping, culverts and anchors. Thus, a selection is required to apply the DDFs in DR projects. An overview of these aspects and DDFs is provided in figure 9.

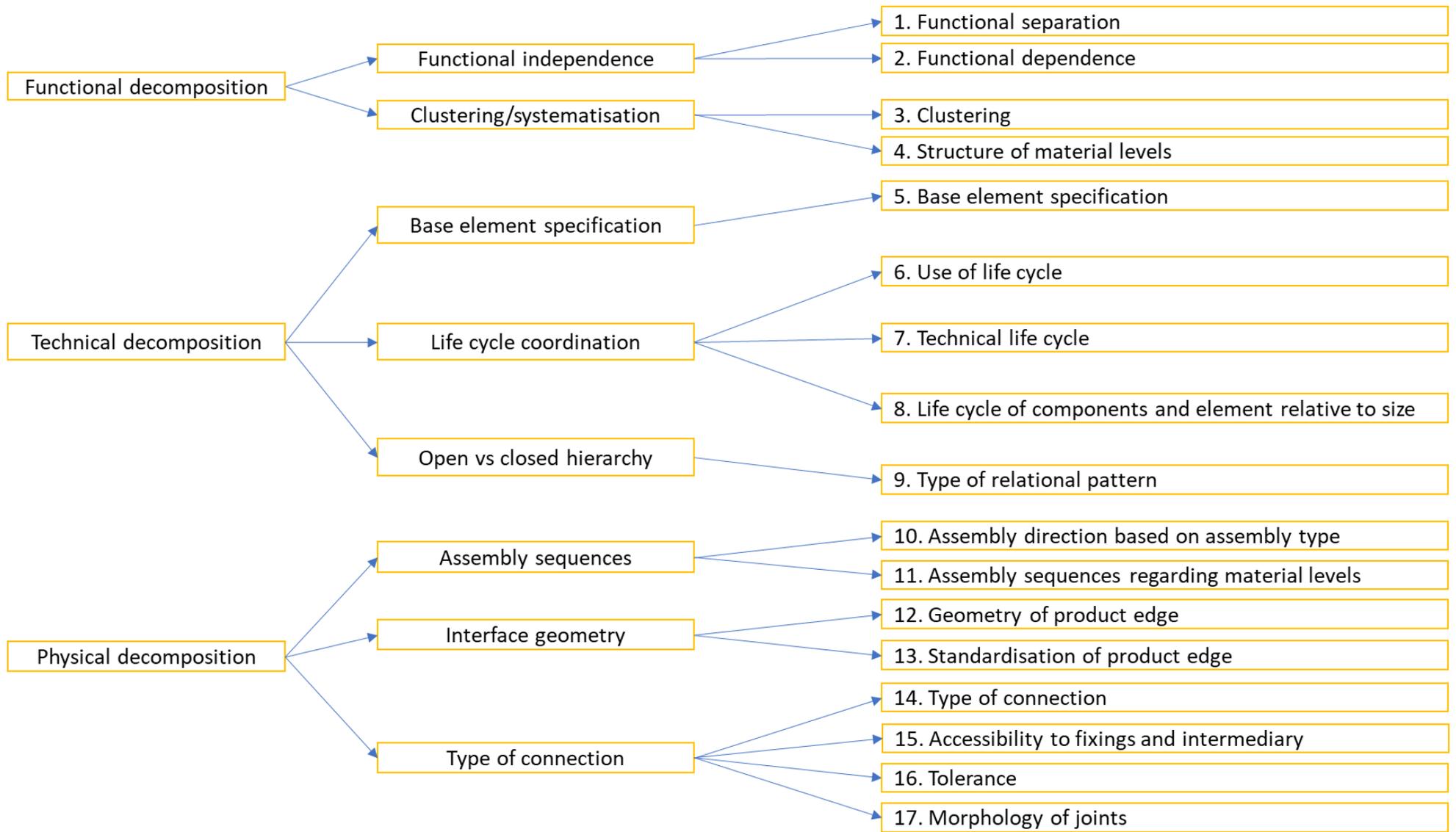


Figure 9: overview of the factors determining the disassembly potential (Durmisevic, 2006; Durmisevic et al., 2003).

R-principles, R-model and R-ladder frameworks

The concept of the R-principles, R-model or R-ladder is widely used when circularity is discussed. The framework has many variations where the number of included strategies/aspects is variable between 3-10 (Vermeulen et al., 2018). Examples of this are the simple reduce, reuse, recycle or the 10-R model of Cramer, which was used in the 'Circulaire Peiler'. Additionally, in the 'oogstkalender' another adaptation of the R-framework is developed (table 19), but specifically in the context of DR projects (Waterschap Zuiderzeeland, 2021).

Table 19: adaptation of the R-framework for DR projects (Waterschap Zuiderzeeland, 2021).

Direct reuse	Direct reuse in the same DR project at a higher or equal level.
Internal reuse	Indirect reuse in other projects within the organization.
External reuse	Indirect reuse outside the organisation through the utilisation of material banks or similar platforms.
Refurbish	Treatment of the resource to enable reuse in the DR project.
Repurpose	Resource gets a different function and application within the DR project.
Recycle	Processing and reuse of resources.
Recover	disposal of resources with energy recovery.
(Re)deposit	deposit resources in a depot.

While there are a lot of similarities between all the different frameworks, it is possible that similar aspects in two different frameworks have different definitions. This creates a lot of confusion about the definitions and hierarchy of the different Rs (Vermeulen et al., 2018). This emphasises the difficulty of including the Rs in an assessment tool in a manner that is understandable for all stakeholders, since most are familiar with at least one version of this framework and the corresponding definitions. Therefore, if a version of the Rs is used in this assessment tool under development, the concepts must be clearly distinguishable from one another by providing workable definitions.

DuboCalc

In some of the previously discussed assessment frameworks, DuboCalc was mentioned as a tool to assess the environmental impact of civil engineering infrastructure. This tool is based on the calculation methodology of the LCA and the SBK-methodology and therefore uses the same impact categories as the 'kernmeetmethode' (DuboCalc, n.d.). However, DuboCalc is currently only using the first 11 impact categories; implementation of the latter 8 is under development (personal communication, Wolbers). Through the use of these impact categories, the Environmental Cost Indicator (ECI) [Dutch: Milieukostenindicator (MKI)] was created, which expresses these environmental impact categories in euros. This includes all environmental impacts of the material and energy use up to the end-of-life phase; the end-of-life phase is thus excluded (Royal HaskoningDHV, 2021). The tool is connected to the Nationale Milieudatabase (NMD), which provides factsheets with general information on products, like lifetime and functional unit, as well as any LCA information which is available (Royal HaskoningDHV, 2021).

DuboCalc divides DR projects into 9 categories for which information must be delivered. Below all the categories in DR projects used in DuboCalc are listed with a short explanation of their contents.

1. Ground displacement: includes the transport, application and disposal of different types of ground.
2. Hard cover: includes the removal and application of hard cover, for example setting stone, rubble stone, hydraulic engineering asphalt and open stone asphalt.
3. Soft cover: includes the creation and management of grass cover of the dike.
4. Sheet piling: includes constructions that function to improve the macro stability of the dike.

5. Heave screen: includes two options, a steel sheet pile or a recycled plastic heave screen.
6. Filter screen: includes several options for filter screens
7. Drainage infrastructure: functions to reduce the hydraulic pressure
8. Bank protection: includes the installation of soil and bank protection, e.g., brushwood mats.
9. Road infrastructure: includes the removal and installation of road infrastructure; these are for example, access roads, bicycle paths and maintenance roads.

For each of these categories some assumptions are made based on reference projects, regulations and experiences from experts. For extra information about these assumptions consult the ‘Handreiking DuboCalc in dijkversterkingen’ from Royal HaskoningDHV (2021). For each category, standard objects are designed based on these assumptions. These standard objects can be considered packages of building blocks used to design a standard dike. By adapting these standard objects or assembling a specific set of building blocks relevant to the situation in your DR project, ECI results are produced (personal communication, Wolbers). Standard objects can be imported from DuboCalc object library or project/product specific information can be delivered by stakeholders and subsequently imported to DuboCalc. Information from LCAs can be imported from the NMD database (Royal HaskoningDHV, 2021). In this way, DuboCalc provides a structured and standardised methodology to combine multiple sets of environmental impact information and link this to specific design aspects.

In the Aanpak Duurzaam GWW, DuboCalc is proposed as the preferable tool to determine the environmental impact costs in the Dutch civil engineering; this includes DR projects (Aanpak Duurzaam GWW, 2012). A monitoring effort from the HWBP in 2020 showed that DuboCalc was already used by a third of all projects in the exploration phase. Furthermore, the tool was used for almost 75% in the design phase to assess some design alternatives and a fifth of the projects for all design alternatives (HWBP, n.d.). The already frequent use and prescription as ‘preferable tool’ makes the inclusion of DuboCalc in the assessment tool a justified choice.

Discussion

From the previous paragraphs some key findings can be concluded:

1. When quantitative data is used to measure an indicator, a reference measurement is necessary to compare the design alternative to a fixed benchmark (→ objective scoring) and not only to another alternative (→ ranking).
2. When qualitative criteria are used to score an indicator, clear and workable definitions must be used to prevent too much subjectivity and inaccuracy during the assessment.
3. The labels ‘reuse & recycling’ in the ‘kernmeetmethode’ do not cover the input and output flows entirely. More detailed labels could increase accuracy and completeness. The R-framework from Waterschap Zuiderzeeland (2021) could provide a solution.
4. A quantitative assessment of ‘value’ as proposed in the ‘kernmeetmethode’ is not yet feasible; a qualitative assessment as displayed in the ‘Circulaire Peiler’ is incomplete but currently more applicable.
5. DuboCalc is used to standardise the measurements of environmental impacts and is imbedded in the strategy for more sustainable infrastructure projects; therefore, this tool and methodology can be directly applied to provide the same assessment of environmental impact in the context of DR projects.
6. Assessments of circularity require large quantities of data. This data must be presented in a structured manner through a material passport to increase transparency and workability. Additionally, the data must be of reasonable quality to produce a reliable score.

7. Circularity manifests on multiple scales. The layering of the MCI, PCI, SCI and BCI can be used as inspiration on how these scales interact and how they provide different levels of detail to a circularity assessment.

Appendix C: Passports for the construction sector

To assess circularity in the civil engineering sector it is recognised that a lot of data is necessary. To determine the specific data demand and provide a clear structure of all data a working group was developed by Platform CB'23. This working group has recently delivered an 80 percent version of their guidelines for the establishment of passports in the construction sector, where also specifications were included for the civil engineering sector (Platform CB'23, 2022b). This version includes a quick start guide to start a material passport, which will be discussed below.

1. Determine the relevant sector where the object is used.

Here the choice is between two options: the civil engineering sector & the civilian and utility sector. The sector determines for a large part what the information demand for the passport will be.

2. Determine the phase and scale/level in which the passport is established.

The necessary information differs per phase in the life cycle of an object and also on which detail level should the information be collected and structured. The quick start guide indicates four phases: production, realisation, utilisation and demolishing phases. The options for scale/level of the passport are from small to large: resource → material → part → component → element building/structure/object.

3. Determine the target for the use of the passport.

A passport has to be coupled to a use or target to optimise the collected information to the goal and determine the user of the passport. The quick start guide indicates seven different targets:

- Minimal Viable Product (MVP): the minimal information provision every project should have.
- General registration: a general overview of all materials/products/components an object consists of.
- Measuring circularity: data needed to utilise the 'kernmeetmethode' and assess the level of circularity of an object.
- Acquisition: information that can be requested during circular acquisition processes.
- Subsidy requests: includes the information needed for specific subsidy requests.
- Maintenance: passport focussed on the registration of changes to the object due to maintenance activities.
- Tenders: provide the structure to stimulate 'smart' proposals during tenders.

4. Insert the previous steps into the shortlist.

As part of the quick start guide the working group developed a 'short list' in which the input of the previous steps gives a list of information that should be collected, thus the foundation of your material passport. The shortlist can be found in Platform CB'23 (2022a).

5. Determine gaps in the available information.

In this step the necessary data must be collected through the use of databases with product information or through consultation with stakeholders (e.g., contractors, producers etc.).

6. Complement the shortlist.

In this step the foundation established with the shortlist can be complemented with project specific requirements.

7. Determine the output format.

In this step it should be determined in what programme or system the passport must be built. This is dependent on the desires of the user and/or existing efforts of a material passport.

Appendix D: Summarised recap of interviews (Dutch)

David-Jan Smeenge – 08-02-2022

Oogstkalender IJsselmeerdijk voortgang

Kleine veranderingen in het berekenen van het benodigde ontwerp kan voor grote veranderingen zorgen van het referentie ontwerp naar een kansrijk alternatief. Dit zorgt daarvoor ook voor enorme schommelingen in de benodigde materialen.

In de eerste ontwerploop van de verkenningsfase van het IJsselmeerdijk versterkingsproject zijn de ambities niet behaald. De ambities zijn:

1. 50% primair grondstofgebruik verminderen.
2. Zoveel mogelijk materialen hergeruiken.
3. Alle materialen die we toepassen moeten in de toekomst herbruikbaar zijn.

In een volgende ontwerploop zijn best veel optimalisaties doorgevoerd, waardoor de ambities langzaam weer binnen handbereik kwamen.

Ambitietoets vermindering van het gebruik van primaire grondstoffen met 50%	Alternatief Vooroever OL2 [ton/m ³]	Referentieontwerp [ton/m ³]	Vermindering primaire grondstoffen vooroever OL2 [%]	Vermindering primaire grondstoffen vooroever OL1 [%]
Dijkvak 1	1.061.106	874.117	-21%	-174%
Dijkvak 2	1.159.284	1.652.821	30%	-195%
Dijkvak 3	429.184	639.808	33%	-13%
Totaal	2.649.575	3.166.747	16%	-151%

Te verwijderen materiaal voor vooroever alternatief OL2:	Hoeveelheid materiaal voor hergebruik [ton/m ³]	Hoeveelheid materiaal voor recycling [ton/m ³]	Hoeveelheid materiaal naar energiewinning [ton/m ³]	Hoeveelheid materiaal naar stort [ton/m ³]
Dijkvak 1	572.822	96.447	1.488	18.674
Dijkvak 2	444.481	73.853	1.519	16.089
Dijkvak 3	255.937	42.830	665	8.278
Totaal	1.273.240	213.130	3.671	43.041
Percentage van totaal	83%	14%	0%	3%
Percentage van totaal waarvoor hergebruik binnen dijkversterking is voorzien	83%	9%	0%	0%

Voor de laatste ambitie is qua gewicht de herbruikbaarheid ongeveer 99.8%, wat echt wel veel is. Die overige 0.2% komt vanuit de kraagstukken, geotextiel en palen rij met rijshout, die veel al worden gestort. Echter voor er verwacht dat dit wel nog geoptimaliseerd kan worden in de planuitwerkingsfase.

Informatievoorziening

Informatie voor het opstellen van de oogstkalender was relatief makkelijk te verkrijgen, maar niet per se op een gedetailleerd niveau. De dijken in zuidelijk Flevoland zijn 1986 opgeleverd. De opbouw van de dijk is goed bekend omdat er niet op de basis van een oude dijk gebouwd hoefde te worden, daardoor is alle informatie uit die tijd omtrent het ontwerp redelijk accuraat (in ieder geval accurater dan op veel plekken in Nederland). Op basis daarvan is het vrij goed mogelijk om een oogstkalender op te stellen. Maar natuurlijk ziet de werkelijkheid er altijd anders uit dan op de tekeningen en moet je rekening houden met de heterogeniteit van de ondergrond, dit is voornamelijk het geval bij oudere dijken die niet van scratch zijn opgebouwd. Dit hoeft echter niet veel gevolgen te hebben op het gebied van circulariteit, omdat je toch niet de hele dijk zal afgraven of een versterkingsproject uit te voeren, dus die informatie is ook niet op super gedetailleerd nodig.

Door middel van boringen en sonderingen wordt verdere informatie verworven over welke materialen zijn gebruikt in de dijk en die mogelijk vrij kunnen komen. Verder bestaat een groot deel van de dijk

uit steenbekleding wat relatief vaak vervangen wordt. Bij het vervangen kun je weer informatie over de onderliggende materialen verkrijgen. Doordat de IJsselmeer dijk vaak wordt aangevallen is er dus veel herstelwerk verricht, waardoor er ook veel informatie is door observatie en dat lijkt redelijk over een te komen met de tekeningen van vroeger.

De informatievoorziening van andere dijken in Nederland loopt over het algemeen achter in de digitalisering van de informatie, maar in principe moet er voor het beoordelen van de dijken veel informatie beschikbaar zijn over hoe de dijken zijn opgebouwd. Wat betreft de bekledingslaag zou dit bij veel Waterschappen wel aanwezig moeten zijn aangezien deze veel bloot gesteld wordt aan golven en dus vaak als eerste een obstakel is in de beoordeling, dus er wordt ook veel onderzoek naar gedaan. Om de macrostabiliteit van de dijk te beoordelen moet er gewoon veel grondonderzoek verricht worden, waarbij je dus ook goed kan zien uit wat voor materialen een dijk is opgebouwd. Of dat je er in ieder geval een redelijke inschatting van kan maken. In principe, uitzonderingen daargelaten, zou de informatie die nodig is voor het beoordelen een dijk (op het gebied van veiligheid) genoeg moeten zijn om een document als de oogstkalender op te stellen.

Technisch verhaal

De oogstkalender laat eigenlijk alleen maar het technische verhaal van circulariteit zien. Voor een dijkversterkingsproject zal dit ook het belangrijkste aspect zijn wat ze zelf gemakkelijk kunnen beoordelen. Indien je een bredere definitie van circulariteit neemt, waarbij je ook met de impact gaat werken, valt dit misschien snel buiten het straatje van de betrokkenen in zo'n project. Je moet een balans vinden tussen het complete verhaal en aspecten die daadwerkelijk gaan helpen om je doel te bereiken. Hierbij moet je er goed voor zorgen dat je alleen informatie voorziet waarop ontwerpkeuzes gemaakt kunnen worden of andere veranderingen mee doorgevoerd kunnen worden.

Afstemmen op een ambitieweb

Om goed af te stellen wat een dijkversterkingsproject wil bereiken op het gebied van circulariteit kan het goed zijn om de beoordeling te koppelen aan het Ambitieweb dat van tevoren is opgesteld.

Vergelijken inter- en intraproject en ontwerpen

Het vergelijken van ontwerpen tussen projecten is moeilijk omdat ieder project een unieke oplossing is voor een uniek probleem. Om binnen een project te vergelijken moet je al gauw uitwijken naar het vergelijken met een referentieontwerp, dit zou mogelijk moeten zijn, maar het vaststellen van een referentieontwerp is niet een gestandaardiseerd proces (je bent er best wel vrij in, maar het moet wel een reële schatting zijn), waardoor er verschillen in je benchmark kunnen ontstaan. Het maken van een referentieontwerp is verplicht om je project te kunnen aandragen bij het HWBP, maar in dit proces zullen nog wel dingen omgerekend en aangepast moeten worden om het ook bruikbaar te maken als benchmark voor je circulariteitsberekening.

De laatste optie is om alleen mogelijke ontwerpen met elkaar te vergelijken en kijken welke meer circulair is.

Kritiek circulaire peiler

De circulaire peiler is een goede tool om te kijken of je proces circulair ingericht is en welke opties er zijn om snel meer circulair te worden. Maar de circulaire peiler mist wel het kwantitatieve aspect om echt te kunnen finetunen in je ontwerpen en je circulaire implementaties, daarvoor is de oogstkalender bijvoorbeeld opgezet.

Opbouw dijkversterkingsproject

Verkenningfase:	Planuitwerkingsfase:	Realisatiefase:
Referentieontwerp	Schetsontwerp	Uitvoeringsontwerp

Alternatieven	Voorlopig ontwerp	
Kansrijke alternatieven	Definitief ontwerp	
Voorkeursalternatief		
Beslissingsalternatief		

Materialenpaspoort

Marten Hoeksema is technisch manager bij de Grebbedijk en zij focussen volledig op circulariteit. Zij zijn volgens mij ook bezig met het opstellen van een materialenpaspoort voor dijksversterkingsprojecten. Het detailniveau van een materialenpaspoort moet zinvol zijn en dus gebaseerd zijn op wat je in de toekomst nodig denkt te hebben.

Commentaar op mijn aspecten

De eerste twee aspecten gebeuren in het begin van de verkenningsfase; bij deze aspecten valt ook verreweg de meeste winst te behalen. Hier is al expliciet veel aandacht voor.

Bij het aspect future proof zou ik ook zeker robuustheid en uitbreidbaarheid gaan overwegen, aangezien dit belangrijke concepten zijn voor dijkversterkingen.

Ik krijg het gevoel dat het detailniveau van al deze aspecten al vrij snel heel hoog zal worden waardoor een beoordeling misschien erg veel tijd kan gaan kosten.

Veel van de aspecten hebben al een groot raakvlak met bestaande testen/criteria die gebruikt worden om dijkversterkingen te beoordelen. Op welke criteria een beoordeling wordt gemaakt wordt beschreven in het afweegkader.

Jörgen Verschoor – 08-02-2022

Circulaire Peiler - scoring

Per deelvraag/indicator zijn er 5 scores mogelijk. In hoeverre je voldoet aan een optie is inderdaad onderworpen aan subjectiviteit. Op dat vlak is de circulaire peiler geen 'harde' meter, maar echt een peiler. Het is bedoeld om een indicatie te geven van welke circulaire overwegingen je gedaan hebt en hoe je dit zou kunnen verbeteren.

De absolute waarde van de peiler maakt niet heel erg uit, maar het gaat vooral om de verbetering die een project doormaakt in de score door de fases heen behaald worden.

Naarmate je verder komt in het project, wordt het detail van de informatie hoger, waardoor je naast alleen denken aan een circulair aspect je er ook mee kan gaan rekenen. Dit zorgt ervoor dat de score ook door de fases heen zal stijgen. Verder doordat de weging van bepaalde aspecten veranderd door de fases heen omdat sommige aspecten belangrijker worden dan anderen en dit zie je ook terug in de score.

De circulaire peiler beoordeelt voornamelijk of je bepaalde berekeningen hebt gedaan of niet, maar de peiler wordt wel onderbouwd met kwantitatieve berekeningen zoals een MKI LCA en zelfs de MCI en kan deze ook inzichtelijk maken.

De wegingen van de circulaire peiler zijn niet gebaseerd op harde rekenregels, maar er is gekeken om een balans te vinden. Hierbij is wel echt uitgegaan van expert beoordelingen en gebruik gemaakt van trial and error. Dit is niet per se objectief, maar het tot nu toe het beste wat we kunnen doen. Over de wegingen kan je misschien het beste even gaan spreken met Heike Gaasbeek van Lievense/WSP, zij weet hier meer van af.

Het gebruik van een referentieniveau voor de bepaling van circulariteit is nog niet gebruikelijk op dit moment. Het is natuurlijk lastig om van een oude dijk te bepalen wat het precieze ontwerp is en hoe circulair dat was op dat moment. Je zou dan eigenlijk geheel opnieuw dat ontwerptraject door moeten en daar is de tijd en het geld vaak niet voor. Met name ook omdat zo'n referentieontwerp op zichzelf niks oplevert qua duurzaamheid en circulariteit. Dat het bepalen van een referentieniveau moeilijk is komt omdat de informatievoorziening vroeger niet zo gedetailleerd was en al zeker niet online beschikbaar. Dus het vergelijken van het nieuwe ontwerp met de huidige dijk is niet rendabel. Dit probleem gaat in de toekomst wel opgelost worden omdat we nu alles aan het documenteren zijn wat later als referentiepunt gebruikt kan worden, maar uiteindelijk is dat alleen om voortgang te bepalen. Je moet uiteindelijk toch 100 procent circulair zijn dus dan maakt dat referentiepunt niet zoveel meer uit. Maar om te kunnen sturen is de voortgang fijn om inzichtelijk te hebben.

De circulaire peiler is voor de komende 5 jaar denk ik wel goed genoeg om circulariteit te meten, maar ik hoop dat we dan wel zoiets hebben van het moet scherper, strakker en meer. De transitie is tweeledig: technisch en cultureel. Technisch hebben we de stap wel aardig gezet, maar ook de culturele verandering moet gemeten worden.

Gunningcriteria

In de sector beginnen er ook al initiatieven te ontstaan waarbij circulariteit een onderdeel wordt van de aanbesteding en gunningscriteria, dit wordt meestal gedaan vanuit MKI-berekeningen. Nu is dat voornamelijk nog in de vorm van: is er een MKI-berekening uitgevoerd dan is het goed, maar ik zou graag zien dat in de toekomst ook de MKI-score zelf de gunning bepaald. Omdat er naast circulariteit nog meer belangen een rol spelen in de gunning, kan het af en toe een ingewikkelde puzzel worden.

Om hier een weg in te banen kan het nuttig zijn om voor het project een Ambitieweb in te vullen, waarin de doelen voor een project wordt bepaald. Hiermee kan je dus op een gestructureerde manier deze belangen een plekje en aandacht geven. En ook kijken hoe belangrijk circulariteit is als gunningscriterium in dit project.

Duurzaamheid vs circulariteit

Duurzaamheid en circulariteit verschillen in de zin dat duurzaamheid een doel is en circulariteit een middel is om een bepaald doel te bereiken.

Circulariteit wordt gebruikt als tool voor meerdere doelen: dat kan zijn het beschermen van bestaande grondstofvoorraden, maar ook om het milieu zo min mogelijk te belasten. In deze gevallen werkt circulariteit toe naar duurzaamheid. In die zin kan je zeggen dat circulariteit vergelijkbaar is met de duurzaamheid van materialen.

Echter is er niet echt een harde scheiding tussen de begrippen. Bijvoorbeeld energie grondstoffen zoals olie en kool zouden volgens deze definitie ook onder circulariteit vallen, maar in werkelijkheid is dat meer een onderwerp van de energietransitie. Ik ben van mening dat we die scheiding wat meer los moet laten omdat het uiteindelijk toch allemaal naar hetzelfde doel werkt.

Klimaatpositief worden

Waterschap Vallei en Veluwe wil in 2050 klimaatpositief zijn, zodat ze de opwarming van aarde kunnen terugdringen. Dit helpt ook bij het compenseren van processen en projecten die niet klimaatneutraal gemaakt kunnen worden.

Obstakels bij implementatie

De pioniers zijn al echt goed bezig. Deze voorlopers lopen nu tegen veel obstakels aan en zijn deze aan het oplossen zodat daarna de volgers gemakkelijk de verandering naar circulariteit kunnen

doormaken. Een praktisch voorbeeld is het hergebruik van materiaal. Bij de Grebbedijk komt veel materiaal vrij, wat ga je daarmee doen? Dan moet je dus een grondbank hebben, deze bestaan al wel, maar voor andere materialen is dit een stuk moeilijker. Wat je ziet is dat aannemers vaak wel een adres hebben waar ze bepaalde materialen kwijt kunnen, maar dan kan je vaak niet waarborgen dat het materiaal op de hoogst mogelijke manier hergebruikt wordt. Dit soort obstakels loop je nu tegen aan en ga je oplossen zodat dat later niet meer hoeft.

Voor materialen is een ander obstakel de inkoop en verkoop. Deze sluit nog niet op elkaar aan. Je ziet nu wel dat er online marktplaatsen ontstaan die dit oplossen, maar het is zo'n grote en waardevolle sector dat hier wel goed toezicht op moet komen. Dus ik zou het liefst zien dat dit gecentraliseerd wordt. Dit kan door een private partij gedaan worden als je dit snel en goed wil laten gebeuren. Het risico is dat er veel geld mee gemoeid gaat en om dat goed te reguleren moet de overheid dit op zich nemen. De overheid koopt zelf 60 miljard in waarvan een groot deel door de GWW komt, dus ze hebben ook wel erg veel baat bij dit zelf goed regelen. Je moet dan wel ook voor opslagcapaciteit zorgen, hiervoor kunnen bijvoorbeeld oude gemeentewerven gebruikt worden, deze vervulde deze functie vroeger, maar deze zijn bijna allemaal verdwenen. Je mist de verbinding tussen vraag en aanbod waardoor circulaire kansen onbenut blijven.

Het opnieuw leren ontwerpen met hergebruikte materialen moet ook weer opnieuw geleerd worden, vroeger deden we dit al wel, maar daar zijn we mee gestopt.

Financiering

In principe worden dit soort projecten gefinancierd met belasting, deze zal niet van de ene op de andere dag hoger worden, dus je werkt altijd binnen hetzelfde budget om alle belangen te realiseren. Dit kan aangevuld worden met subsidiegeld van het rijk, maar dat is ook een eindige bron van financiering. Als het investering plafond is bereikt, dan wordt een project gewoon niet tot nauwelijks duurzaam of circulair uitgevoerd indien dit meer geld zou kosten. Dan gaat het budget naar de kerndoelen die bereikt moeten worden zoals bijvoorbeeld waterveiligheid.

Wat je ziet is dat soms circulaire en duurzame maatregelen ook kostenwinst kan opleveren. Ik zou dan graag zien dat dit ook aan verdere ontwikkeling op die gebieden gespendeerd wordt, maar dit is uiteindelijk aan het bestuur. Je ziet nu bij sommige projecten dat je deze besparingen na een beetje gelobby ook echt aan duurzame of circulaire doelen kan spenderen.

Materiaal gestuurd ontwerpen

Het ontwerpen vanuit de materialen die je beschikbaar hebt is een belangrijke cultuurshift die gemaakt moet worden om uiteindelijk verder te komen met circulariteit. Blue City in Rotterdam heeft hier al een mooi project mee gedaan, maar ook zeker in de dijken wereld komt dit steeds meer naar voren.

Bij Noorderzelve is een project uitgevoerd waarbij ze een dijk ontwerp hebben gemaakt met relatief slappe grond, die normaal als ongeschikt wordt geacht. Maar door materiaal gestuurd te ontwerpen hebben ze toch een manier gevonden door die dijk iets hoger en breder te maken, dit kostte meer grond maar de MKI wees uit dat het wel voordeliger was qua milieu impact.

Kritiek op mijn aspecten

Qua documentatie is natuurlijk het materialenpaspoort een belangrijke tool. CB'23 geeft hier wel handvatten voor, maar die zijn nog lang niet voldoende. Er is een NEN-norm (NEN ISO 19650) die dit wel behandelt, maar volgens mij is dit wel specifiek voor BIM.

Uitbreidbaarheid is denk ik een heel belangrijk onderdeel van het future proof aspect dat jij omschrijft.

Zorg dat als je bepaalde dingen meetbaar gaat maken, dat je de huidige standaarden daarin betreft, dus alle NEN ISO's. Want dit zijn regels waar men zich al aan moet houden. Het moet daar gewoon direct op aansluiten.

Jouw idee om wat meer detailniveau (R-ladder gedetailleerder verwerken) aan te brengen in het technische stuk is zeker goed om een completer beeld te krijgen.

Wat ik wel graag nog wil zien als dit binnen je onderzoekscope valt is dat je die cultuurverandering probeert te stimuleren met je tool. Hoe ga je zorgen dat mensen in het vakgebied dit gaan gebruiken en niet gewoon hun oude manier gaan uitvoeren. Hoe verleid je ze? Dit kan door ze te belonen voor circulaire ideeën tijdens de gunning van projecten. Maar die gunningscriteria worden ook opgesteld door mensen, dus hoe zorg je ervoor dat duurzaamheid en circulariteit een grotere weging in dat proces gaan krijgen.

Hoe deze tool in te passen in het bestaande beoordelingskader

Als je wilt zorgen dat een tool als deze geïmplementeerd wordt, dan is de beste manier om mensen over te halen door successen te delen. Wat heb je bereikt en verbeterd door het gebruik van deze tool. Daarbij moet je misschien ook zorgen dat het gebruik van de tool en de winst die ermee te behalen valt gekoppeld wordt aan de ambities, doelen en interesses van alle potentiële gebruikers. Het liefst wil je dat de tool al door de projectleiders en ontwerpers direct gebruikt worden en niet pas wanneer er een duurzaamheids/circulariteits adviseur aanhaakt.

De kennis van veel mensen in het werkveld is op individueel vlak best aardig, maar in het algemeen valt het nog best wel tegen. Zeker als je kijkt of mensen er ook daadwerkelijk wat mee doen. Mensen zijn voornamelijk met taken bezig en niet met doelen, wat niet gek is want we zijn een taakgerichte organisatie. Dit maakt wel dat soms bepaalde doelen niet vanzelf nagestreefd worden. Nu koppelen we voornamelijk de taken die we doen aan bepaalde doelen. In de toekomst hoop ik dat we vanuit bepaalde doelen alle taken binnen de organisatie kunnen bepalen, maar dit vraagt om een enorme cultuurveranderingen.

Veel mensen in het werkveld zijn onbewust al best wel bezig met circulariteit en duurzaamheid, maar hebben experts nodig om dit te structureren. Verder is er tot nu toe nog best wel gelimiteerde uitwisseling tussen projecten en organisaties op dit gebied. Dat kan door corona komen, maar dat denk ik eigenlijk niet.

Heike Gaasbeek – 08-03-2022

Circulariteit en CB'23

In deze technische sector is er een groep die graag wil bijdragen aan het implementeren van duurzaamheid en circulariteit, maar een groot deel doet het liever zoals het altijd al ging en hebben veel weerstand tegen deze veranderingen.

Ik vind dat duurzaamheid is niet CO2 impact. Je moet het onderwerp veel breder zien. Als je circulariteit niet meerekent voor duurzaamheid kom je er simpelweg gewoon niet. Daarom moet je echt het hele plaatje mee pakken, wat circulariteit op een bepaalde manier doet.

Maar wat is circulariteit dan. Als iedereen zijn eigen tool ontwerpt dan meten we allemaal weer wat anders. Dus we moeten gaan afstemmen waar we het over hebben. Een voorbeeld van deze standaardisatie is wat CB'23 aan het doen is.

Bij CB'23 mist het disassembly potential nog wel heel erg, dit kan een goede toevoeging zijn.

CB'23 is nu bezig met het door ontwikkelen waarbij ze ook het verschil tussen hoog- en laagwaardig hergebruik implementeren en onder welke stromen grond behoort. (leidraad meten 3.0 wordt verwacht eind april)

Circulaire Peiler

Samengewerkt met waterschap Vallei Veluwe om deze te ontwikkelen. Er is inmiddels een nieuwe versie deze zal ik even doorsturen. De nieuwste tool van de circulaire peiler is online beschikbaar gemaakt.

Je hebt de schil met de eerste 8 onderdelen die zijn bedoeld om je proces circulair in te richten. Mochten er nieuwe meetmethoden komen dan kan je in principe gewoon de MCI vervangen door de nieuwe methode. Dus echt een proces methode.

Hoe je bijvoorbeeld kan meten of je preventie en reductie hebt toegepast is door aan de start van een project een referentie berekening te maken. Dit kan bijvoorbeeld door een MKI berekening op basis van basis bouwblokken die in DuboCalc beschikbaar zijn. Binnen de circulaire peiler is ervoor gekozen om de opgaveverkleining te beoordelen op basis van de MKI (dus referentie = bouwblokken; door project heen meet je relatief de verbetering).

Op de basis van de informatievoorziening die je krijgt door de afkeuringsonderzoeken en het aanvragen van een DR project bij het HWBP zou je via de bouwstenen in Dubocalc een referentiepunt kunnen maken voor ieder project. Dit zou een goede verbetering zijn omdat je dan enigszins je referentieberekening standaardiseert.

Voor ieder project moet al een SSK-raming gemaakt worden die gebaseerd is op LCC-berekeningen en dit zou eigenlijk direct gelinkt moeten worden aan een invoertabel voor Dubocalc. Een voorwaarde hiervoor is wel dat de elementen die je als input gebruikt voor je LCC-berekening ook in Dubocalc aangemaakt moeten kunnen worden. Dus je moet er uiteindelijk voor zorgen dat de methodieken als LCC en MKI en andere methodes op elkaar aangesloten worden of in ieder geval van vergelijkbare informatie gebruik maken. Dit zou het een stuk gemakkelijker maken om alle onderzoeken te doen.

Een voorbeeld van dit probleem is dat bijvoorbeeld de CO2 impact. In een SSK-raming zijn al de uitstoot van graafmachines opgenomen en de draaiuren die de machines draaien. Het is dan nog een kwestie van het vermenigvuldigen en dan weet je je CO2 impact. Dat dit niet gebeurt komt omdat het niet de prioriteit is van de verantwoordelijke personen. Daaraan merk je nog dat er weerstand/onwil is bij sommige personen in de sector.

De verdeling van je project in fases wat in Dubocalc wordt gebruikt (A-D) is ideaal om over de gehele levenscyclus te kijken naar je impact. Zorg ervoor dat jouw tool hier ook op aansluit, dit verbetert namelijk je integratie met de rest van de sector.

Voor de circulaire peiler hebben we destijds een referentieberekening gedaan op basis van KOSWAT, ik heb hier zelf niet echt mee gewerkt, dat heeft mijn collega destijds gedaan, maar het dient uiteindelijk hetzelfde doel.

De MKI-berekening wordt twee keer meegewogen in de Circulaire Peiler. Dit is niet per se erg want aan de start van je project zul je bij het eerste aspect punten gaan verdienen, maar de weging van die punten wordt in latere fasen steeds lager, dus heeft minder invloed op de score. Voor die latere die gaat steeds meer meewegen in latere fasen. Het toekennen van veel punten aan de MKI-berekening

is in de circulaire Peiler gedaan met het doel om mensen aan te sporen om die berekening ook daadwerkelijk te gaan doen. Dit komt omdat het echt bedoeld is als processtool.

Bij de technisch manager van een project waar ik aan werk, merk ik echt dat er nog veel weerstand is om bijvoorbeeld zo'n MKI-berekening te doen.

Materialenpaspoort

CB'23 geeft hier wel een handreiking voor. Deze is echter heel erg gericht op gebouwen. Maar in de komende versie wordt de GWW beter behandeld. Deze wordt 11 maart beschikbaar gemaakt.

Wat ik uiteindelijk zou willen is dat je een tool krijgt waarbij je een afstand kan selecteren, laten we zeggen 30 km, en dat je dan te zien krijgt:

- Dit zit erin
- Wat komt er vrij en wanneer
- Op wat voor manier
- En wat kan je ermee

Nu worden verschillende materialenbanken aan elkaar gekoppeld, maar het moet echt beter geïntegreerd worden, maar dit is een kwestie van datamanagement.

Verschillende lagen in DR-versterkingen die in het materialenpaspoort terug moet komen: Materiaal → onderdeel → Blokniveau.

Observaties

Dat iets goed uit de MKI-berekeningen komt betekent niet dat het ook bijdraagt aan circulariteit. Een betonmengsel waarin polymeren worden toegevoegd, omdat het anders afval wordt, zorgt voor hergebruik en dus minder afval. Hierdoor komt het ook erg goed uit de MKI-berekening, maar uiteindelijk na de levenscyclus van het beton zorgt het alleen maar voor meer afval omdat nu ook het beton onbruikbaar voor reuse is.

Een ander voorbeeld zijn staalslakken, dit is een restproduct vanuit de staalindustrie. Deze worden ook gebruikt in dijken. In een project hadden ze deze staalslakken niet goed ingepakt, waardoor er contaminatie veroorzaakt werd. Nu zeiden ze dat zolang je deze dingen goed inpakt is er niks aan de hand. Dan moet je je toch afvragen of je dat wilt.

Deze voorbeelden laten goed zien dat je wel kritisch moet blijven omtrent de keuzes die je maakt en welk risico je wilt nemen. (Discussie punt)

In een LCA wordt de uitloging van materialen (bijv. Staalslakken) wel meegenomen in de bouwfase, maar tijdens de gebruiksfase wordt dit helemaal niet meer meegerekend als mogelijke impact. Wat best raar is omdat dit toch wel degelijk een risico is.

Bij project Grebbedijk gaan ze volgens mij nu met materiaal paspoorten aan de slag dit kan best een interessante ontwikkeling zijn voor jouw onderzoek.

Commentaar op mijn framework

Jouw aspecten lijken heel erg op de ontwerpprincipes van het MIRT, dus dat is goed.

Ik zou nog wel even naar de volgorde kijken van je aspecten; het is denk ik beter als je ook enigszins de volgorde aanhoudt die je tegenkomt in een DR-project. Het is belangrijk om die volgorde goed te doen, omdat het ene aspect uit de andere volgt en er toch altijd wel enige overlap is tussen alle aspecten.

Als je echt wilt gaan meten wat de impact is en niet zo erg de procesmatige kant op wilt, moet je ook even kijken naar LCC-berekeningen, dit is namelijk een van de eerste dingen die gevraagd wordt als je circulaire ideeën wilt implementeren, want iedereen wilt weten wat dat nou uiteindelijk kost. Dit gaat om investeringskosten en om life cycle kosten.

LCC is misschien ook wel een tool om de afweging te maken tussen het vraagstuk tussen robuustheid en functionele levensduur van een dijk. Dmv. het vergelijken van investeringskosten + instandhoudingskosten + beheer en onderhoudskosten over een tijdsduur van 100 jaar.

Roel van de Laar – 09-03-2022

Huidige implementatie circulariteit

Mijn rol bij dijkversterkingsprojecten zit hem meestal in de procedures. Bij de IJsselmeerdijk werk ik aan het Milieueffectenrapport (MER) en de vergunningen. Dus ik ziet niet direct aan de duurzaamheidsknoppen. In andere projecten heb ik wel aansluiting met deze duurzaamheid aspecten.

In het MER is duurzaamheid 1 van de criteria. Dit wordt in kaart gebracht voor ieder project. Andere aspecten in het MER zijn bijvoorbeeld waterveiligheid, natuur, bodem, archeologie en cultuurhistorie. Het onderdeel duurzaamheid is in dit rapport uitgesplitst in 3 categorieën, namelijk:

1. Milieu impact en broeikaseffect (MKI en CO2 berekening)
2. Circulariteit
3. Biodiversiteit

Wat we qua circulariteit hebben gedaan bij het IJsselmeerdijk project bestaat uit verschillende dingen. We zijn begonnen met het maken van een referentieontwerp. Dit is een ontwerp van een standaard dijkversterking, dit gebeurde in de verkenningsfase. Op basis van dit ontwerp hebben we ambities en doelstellingen voor duurzaamheid gemaakt, dus ook van circulariteit. In dit project ging dat om een doelstelling van we willen graag x% aan herbruikbaar materiaal gebruiken en genereren. Daarna zijn we bij iedere stap in het ontwerpproces weer gaan meten hoe we nou eigenlijk presteren tegenover deze doelstellingen. De bewijslast die achter deze doelstellingen zit is dus een document als de 'oogstkalender'. Uiteindelijk hoe het werkt is dat voor het opstellen van het MER worden cijfers aangeleverd. In het geval van dit project werd circulariteit beoordeelt aan de hand van cijfers omtrent de hoeveelheden van materiaalgebruik en de mate van circulariteit dmv. input/output. In het MER wordt een kwalitatieve beoordeling gemaakt door experts op basis van deze cijfers per ontwerp. Dat geeft een beoordeling voor circulariteit.

Natuurlijk is dit maar een van de beoordelingscriteria in het MER, dus circulariteit is niet een allesbepalende categorie. Aan de hand van deze beoordeling wordt er natuurlijk wel gestuurd op circulariteit. Daarbij ligt op dit moment een focus op het sluiten van de grondbalans en zoveel mogelijk hergebruikt materiaal introduceren.

In het dijkversterkingsproject Gorinchem-Waardenburg (GOWA) zijn ze een dijkversterkingsproject gaan combineren met een uiterwaard verlaging, waarbij ze de grond van het uitgraven van de uiterwaard kunnen gebruiken in het dijkversterkingsproject. Dan zie je dat binnen een omgevingsvisie van zo'n project gezocht wordt naar een totale oplossing, waarbij circulariteit van die grond een van de puzzelstukjes is; dit opent heel veel mogelijkheden voor zo'n project. Het scoren van dit soort acties is op dit moment afhankelijk van de ambities die gesteld zijn aan het begin van het project.

Eerder werden dit soort acties ondernomen vanwege het positieve kostenplaatje dat het oplevert. Terwijl je nu langzaam ziet dat bij sommige projecten juist de circulariteit overwegingen meer mee gaan spelen. Al is GOWA wel een front runner op het implementeren van duurzaamheid en circulariteit

in vergelijking tot veel andere projecten. In de dijkversterkingen wereld is pas de afgelopen 2 jaar dit echt een aandachtspunt geworden, dus er is nog veel te behalen.

Verskil afwegingskader vs MER

Voor IJsselmeerdijk hebben wij een document gemaakt waarin het afwegingskader voor een dijkversterking wordt omschreven. Hierbij komen ook aspecten zoals kosten ed. ook in voor. Voor het MER is dit er bijvoorbeeld uitgelaten omdat het niet een 'milieueffect' is. Daarin kan je dus stellen dat het afwegingskader een stuk breder is dan een MER.

Bespreken van mijn aspecten

IK: uit de gesprekken die ik gevoerd heb met mensen binnen het vakgebied merk je dat er twee stromingen zijn omtrent de definitie van circulariteit in dijkversterkingsprojecten. Aan de ene kant heb je een smalle definitie, waarin je eigenlijk alleen kijkt naar de technische aspecten van circulariteit, dus de hoeveelheden, het hergebruik. Aan de andere kant heb je ook de brede definitie waarin dus ook de ruimtelijke inpassing en de impact meegenomen worden. Die bredere definitie heeft mijn aspecten grotendeels bepaald. Maar deze bredere definitie heeft veel overlap met andere criteria in het MER en het afwegingskader. Is dit erg en hoe kijk jij hiertegen aan?

Als er overlap tussen het andere criteria in het afwegingskader ontstaat, is het erg belangrijk dat je goed definieert wat dan die bijvoorbeeld die technische robuustheid is en wat robuustheid onder circulariteit inhoudt.

Er staan best veel aspecten en dus indicators in jouw methodologie. Je moet er wel rekening mee houden dat het maar een klein onderdeel van een MER is en dat het niet kan zijn dat circulariteit opeens onevenredig veel indicators heeft, want dan lijkt het dat circulariteit belangrijker wordt bevonden dan andere beoordelingscriteria. Dus zorg dat je gaat onderzoeken hoe je er wel uitgebreid naar kan kijken, maar dat het wel in verhouding blijft tot de andere beoordelingscriteria die in het MER staan.

Bij andere MERs hebben we wel eens gewerkt met uitgebreide achtergrondrapporten voor bijv. duurzaamheid waarin je dus het brede beoordelingskader kan gebruiken zoals jij nu ontwikkeld, maar voor het MER zelf moet het wel behapbaar blijven dus moet je wat meer gecompriemd werken. Je kan nog steeds wel een uitgebreide beoordeling doen zoals jij nu schetst, maar dit moet samengevat kunnen worden tot een concrete beoordeling binnen het MER.

IK: als je voor meerdere criteria binnen het MER een kwantitatieve beoordeling doet dmv bijvoorbeeld een MKI-berekening, komt er dan niet teveel weging op een MKI berekening te liggen?

Uhm ja dat is een goede vraag. Uiteindelijk wordt aan de hand van al die kwantitatieve data een kwalitatieve beoordeling gemaakt door een expert. Deze expert zou in de stap naar een kwalitatieve beoordeling dit eruit moeten kunnen halen en zorgen dat het geen probleem is.

Uiteindelijk is een MER geen rekenkundige exercitie waarbij je alle criteria optelt en tot een voorkeursalternatief komt. Het is het bijeenbrengen van alle benodigde informatie om een integrale afweging te maken en dat is niet een rekensom uiteindelijk. Nog een tip is dat het navolgbaar moet zijn voor eenieder. Dus ook bestuurders enzo, de beoordeling die jij geeft moet gericht zijn opdat zij het kunnen begrijpen.

Het niet op een hoog ambitieniveau implementeren van circulariteit en duurzaamheid is denk ik niet vanuit onwil van stakeholders, maar ligt meer bij het ontbreken van de kennis om het te kunnen doen. Veel komt terug op, 'wij zijn gewend om dit te doen', dus daar gaan we mee door. Door het inbrengen van duurzaamheid en circulariteit adviseurs proberen we eerste de ambities wat scherper te zetten en

duidelijk te krijgen wat de mogelijkheden zijn. Verder helpt een adviseur mee om echt een vinger aan de pols te houden tijdens het hele traject om duurzaamheid en circulariteit niet op de achtergrond te laten verdwijnen.

Data

Voor het MER maak je een team van specialisten. Deze specialisten zorgen in principe zelf voor hun data en beoordeling van hun expertise gebied. Een kwantitatieve beoordeling wordt wel zoveel mogelijk nagestreefd, maar dit is niet voor ieder project mogelijk. Bij kleinere projecten is er dus vaker echt een kwalitatieve beoordeling op basis van de beschikbare informatie.

Het wordt natuurlijk steeds makkelijker om kwantitatieve data te krijgen doordat ontwikkelingen als 3D tekenen steeds makkelijker worden. Waar dat nu voornamelijk voor de grotere projecten is, gaat dat denk ik ook steeds vaker voor kleinere projecten gebeuren. Want hiermee maak je gewoon de nauwkeurigheid van de besluiten beter.

We weten nu eigenlijk niet super veel van de dijken die in de jaren 70 – 90 zijn uitgevoerd. Op basis van die tekeningen kan je weinig zeggen over wat herbruikbaar is. Die informatie wordt nu wel op slimme manieren verkregen door werkzaamheden in het veld, maar zal nooit super accuraat worden dan zoals je het nu in nieuwe projecten goed vast zou leggen.

Hoe informatie nu vastgelegd wordt moet echter wel nog veel aandacht krijgen. Want bij veel projecten is het nog steeds niet super goed. Sommigen werken nog met de ‘oude’ methodiek waarbij het uitgangspunt is dat zolang het veilig is, je niet precies hoeft te weten waar welke grondsoort in de dijk terugkomt. Hier zie je zeker wel een verschil tussen de ambities en de praktijk. Je ziet bijvoorbeeld ook dat voor aannemers dit niet heel fijn is, omdat ze hierdoor een deel van hun flexibiliteit kwijtraken. Als alles precies en gedetailleerd moet opgebouwd zijn dan kan je niet makkelijk optimaliseren om kosten te besparen.

Punt voor discussie

Als je alleen focust op Nederland kan je er vanuit gaan dat veel data wel beschikbaar komt om kwantitatieve berekeningen te doen. Als je ook wilt dat je tool internationaal gebruikt gaan worden, dan is een kwalitatieve beoordeling het enige haalbare. Dus dan moet je echt wel aanpassingen maken.

Michiel Wolbers – 19-03-2022

Bepalen referentieontwerp

Wanneer zijn de eerste tekeningen tot stand gekomen tijdens een dijkversterkingsproject, waaraan je circulaire informatie hebt toe kunnen kennen?

We hebben voorafgaand aan de verkenningsfase al een opdracht gehad voor het DR-project GOWA. Hiervoor moesten we inventariseren aan welke voorwaarden de dijk niet meer voldeed. Hierdoor hadden we al aardig wat informatie en een schetsontwerp beschikbaar waarop we dus MKI-bouwstenen konden toepassen. Dit zou in principe ook voor andere projecten moeten kunnen.

Als deze informatie niet beschikbaar is, dan zul je dit moeten doen aan het begin van de verkenningsfase. Ik zou dit eigenlijk sowieso doen, want in het begin van de verkenningsfase is er pas een verbintenis tussen opdrachtgever en opdrachtnemer, dus dan kun je je uitgangspunten op elkaar afstemmen.

Organisatie

Hoe ziet de organisatiestructuur eruit bij een dijkversterkingsproject?

Bij dijkversterkingen zijn of Rijkswaterstaat of de Waterschappen verantwoordelijk. Het HWBP is meer een achterliggend orgaan dat een groot deel van de financiering verzorgt. Het HWBP is dus niet direct betrokken met een ingehuurd ingenieursbureau of aannemer, dat gebeurt door Rijkswaterstaat of het Waterschap zelf.

In de verkenningsfase wordt over het algemeen een ingenieursbureau gevraagd om een inschrijving te doen, dit bureau werkt aan een voorkeursalternatief. Daarna start de planfase. Je hebt twee opties:

- De conventionele aanpak, dan wordt er opnieuw gekeken welk ingenieursbureau voor deze fase het project verder mag brengen. Dit kan hetzelfde bureau zijn maar dat hoeft niet. In deze fase wordt het ontwerp dan verder uitgewerkt. Dan in de realisatiefase wordt er een aannemer gezocht om deze plannen uit te gaan voeren.
- De twee fasen aanpak, dan wordt de aanbesteding van de planuitwerkingsfase en realisatiefase tegelijk gedaan. Dus dan wordt er tegelijkertijd een ingenieursbureau en aannemer gezocht. Soms kan je je inschrijven in een consortium van een ingenieursbureau en aannemer paar, maar het komt ook voor dat dit op individuele basis wordt gedaan. Op deze manier wordt een extra ronde aan aanbestedingen voorkomen.

Bij beide aanpakken heeft Rijkswaterstaat of het Waterschap een coördinerende functie.

Het ingenieursbureau heeft tijdens de realisatiefase ook nog wel een rol, maar deze is wel een stuk kleiner.