Master Thesis

Stimulating Circular Design in Wastewater Engineering

Formulating Interventions via Behavioural Insights

Source: AI-generated image by DALLE·3 based on prompt 'Circular Design in Wastewater Engineering'

By

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Preface

This thesis, "Stimulating Circular Design in Wastewater Engineering — Formulating Interventions via Behavioural Insights," marks the culmination of my journey in the Master's program in Engineering and Policy Analysis at TU Delft. It has been a pleasure to research and write this thesis from December 2023 to June 2024. The topic perfectly aligns with my background in Mechanical Engineering and my transition to the Faculty of Technology and Policy Management. It also reflects my ambition to pursue sustainable goals in a practical, realistic, and achievable manner. As Antoine de Saint-Exupéry famously stated, "A goal without a plan is just a wish," I strive to turn sustainability goals into reality through valuable insights and actionable strategies for implementing circular design practices within engineering firms.

I extend my sincere gratitude to my graduation committee for their constructive and encouraging support. To Lisa Scholten, my first supervisor, thank you for your invaluable guidance, feedback, and inspiration throughout this process. Your positive outlook and clear communication style have been instrumental in making my thesis both successful and enjoyable. To Gerdien, the second committee member, thank you for your kind and clear comments, which have elevated the quality of this thesis to new heights. To Jans, the company supervisor, I am grateful for the numerous hours we spent conversing on circularity and for the extensive information you graciously provided. Despite your busy schedule, you always made time for our conversations, providing support and insights. I would also like to extend my thanks to Peter Bervoets for his warm welcome and assistance in facilitating the case study opportunity.

Lastly, I want to thank my parents, whose unwavering faith in my ability to graduate has remained steadfast, even after eight years of university. Thank you, Ruben, for being so engaged and supportive throughout this journey. And to my housemates, I am thankful for the crucial daily morning coffee at 8:15. And thanks and glory be to God, whose love, wisdom, and serenity strengthen me every day.

In closing, dear reader, thank you for wading through this linguistic odyssey, rather than simply skipping it to reach the conclusion. Your attention span is truly impressive!

Jeanine de Jong
Delft, 18 June 2024

Abstract

This thesis investigates the adoption of circular design principles by engineers for the design of wastewater treatment plants for Water authorities, by exploring hindering and stimulating factors involved and applying the Behaviour Change Wheel (BCW) to develop strategic interventions for engineers at the case study consultancy firm Royal HaskoningDHV (RHDHV). The research problem addresses the challenge of integrating circular design principles into wastewater treatment plants, aiming to enhance circularity practices within engineering consultancy firms. The main research question is "*How can the adoption of circular design in wastewater engineering consultancy firms be enhanced using the Behavior Change Wheel?*" The objective is to gain insight into the key actors, the perception and engagement with circularity among RHDHV, the barriers and facilitators to the adoption of circular design and to propose strategic interventions using the Behaviour Change Wheel.

The research employs a qualitative research method, including a literature review, informal conversations, and semi-structured to open interviews with employees from the wastewater department of Royal HaskoningDHV. The collected data was analysed using thematic double coding, comprising an inductive explorative approach, and a deductive approach based on the Theoretical Domain Framework (TDF). The BCW framework was applied to identify behaviour change techniques (BCTs) and interventions that stimulate engineers to make more circular design choices in every phase of the project by considering and selecting materials and design choices that are reducing, reusable, recyclable, and demountable.

Key barriers to the adoption of circular design practices include limited knowledge, unclear principles, insufficient evidence of technical functionality, reluctance from clients, a preference for traditional design approaches, and budget constraints. On the other hand, facilitators include circularity workshops, partial integration into design processes, management ambition, and existing sustainability initiatives. Active client support and dedicated time for circular design are essential.

The BCW approach identified 43 behaviour change techniques beneficial for promoting circular design, from which a balanced selection addressing capability (knowledge and skills), opportunity (design routines and tools), and motivation (confidence in circular designs) is recommended. The recommended interventions for the specific case study are (i) comprehensive training sessions and educative materials on

circular design, (ii) establishing clear, achievable circular design goals, (iii) a focus on projects with clients committed to circular design, (iv) establishing a helpdesk or expert team for practical and social support, (v) incorporating circular prompts and cues into project planning, and (vi) monitoring progress while showcasing successes and providing feedback. Although tailored to Royal HaskoningDHV, these interventions can serve as a guideline for other firms, with necessary adjustments for different contexts and client relationships.

The study highlights the significance of targeted, practical interventions and raises new questions about the balance between sustainable and functional requirements, re-evaluating comfort and budgetary requirements and the need for further development of practical tools and guidelines.

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List of Abbreviations

AIDA — Awareness, Interest, Desire, Action

APEASE — Acceptability, Practicability, Effectiveness, Affordability, Side-effects, and Equity

BCW — Behaviour Change Wheel

BCT — Behaviour Change Techniques

C Engineer — Civil Engineer

CJM — Customer Journey Mapping

COM-B — Capability, Opportunity, Motivation - Behaviour

DuboCalc — Duurzaam bouwen calculator

ECI — Environmental Cost indicator

E Engineer — Electrical Engineer

GWW — Grond-, Weg- en Waterbouw (Civil, Road and Hydraulic Engineering)

H&S — Health and Safety

H Engineer — Hydraulic Engineer

IPM — Integraal Projectmanagement (Integrated project management)

KCAO — Klimaatneutraal & Circulair Assetmanagement en Opdrachtverlening

KCI — Klimaatneutrale en Circulaire Infrastructuur

MKI — Milieukostenindicator

P&ID — Piping and Instrumentation Diagram

PM — Project managers

PvE — Programma van Eisen (Programme of Requirements)

VO, DO, UO — Voor, Definitief, Uitvoerend ontwerp (Preliminary, Final, Implementation design)

RHDHV — Royal HaskoningDHV

RWZI — Rioolwaterzuiveringsinstallatie (Wastewater treatment plants)

TDF — Theoretical Domains Framework

UAV — Uniforme Administratieve Voorwaarden

WTB Engineer — Mechanical Engineer

Glossary

AIDA Model — A marketing framework describing the stages of consumer engagement: Awareness, Interest, Desire, and Action, applied to understanding how individuals move from awareness to taking action.

Behaviour Change Techniques (BCTs) — Specific interventions designed to alter behaviours by targeting components such as knowledge, skills, motivation, and environmental influences.

Behavior Change Wheel (BCW) — A framework used to analyse and guide the design of interventions for stimulating behaviour change. It incorporates theories from behaviour change literature into a coherent model.

Bestek — Dutch term referring to the specifications provided in a tender. It outlines detailed requirements, procedures, and guidelines that must be followed in the execution of a project.

Circular Design — Design practices that incorporate principles of the circular economy, focusing on minimising waste and making the most of resources. This includes designing products to be durable, reusable, recyclable, and upgradable.

Circular Economy — An economic system aimed at eliminating waste and the continual use of resources. Circular systems employ reuse, sharing, repair, refurbishment, remanufacturing, and recycling to create a closed-loop system.

COM-B Model — A framework within the Behavior Change Wheel that represents three essential conditions for behaviour, being Capability, Opportunity, and Motivation.

DuboCalc — A software tool to calculate the environmental impact of building materials throughout the life cycle of construction projects.

GWW Ambition Web — A tool used in the Dutch civil engineering sector to set and evaluate sustainability ambitions for infrastructure projects.

Implementation Design (UO) — The final detailed design phase in engineering projects, following approval of the preliminary (VO) and definitive (DO) designs, focusing on the practical aspects of construction and installation.

Offerte — Dutch for "quotation" or "bid," this term is used to describe the formal proposal submitted by a company in response to a request for tender. An offerte typically includes pricing, timelines, and the approach that the company will take to meet project specifications.

Preliminary Design (VO) and **Definitive Design (DO)** — Stages in the engineering design process where initial and final design solutions are formulated before proceeding to implementation.

Programma van Eisen (PvE) — Dutch for "Program of Requirements", it outlines the functional and performance requirements that a project must meet.

Theoretical Domains Framework (TDF) — A theory-based framework that identifies and categorises cognitive, affective, social, and environmental influences on behaviour, often used in conjunction with the BCW.

Verdygo — A design method for modular sewage treatment plants that allows for flexibility, scalability, and sustainability by facilitating easy upgrades and adjustments.

Water Framework Directive — A key piece of EU legislation that aims to improve and integrate water management across member states, focusing on long-term sustainable water usage.

1. Introduction

1.1 Relevance

Circularity is becoming increasingly relevant in light of countering climate change by implementing sustainability and resource use to move forward to a circular economy (Bashmakov et al., 2022). Because of the climate targets agreed upon in Paris in 2005, the Unie van Waterschappen has made it a policy that circularity be adopted in the Waterschappen as well (Unie van Waterschappen, 2022). As a result, study was performed on how contractors and water authorities could go about doing this, and it was a success: water authorities included it into their policy, while construction companies conducted pilot projects to demonstrate how circularity might be applied (Unie van Waterschappen, 2019). Despite this improvement, engineers' designs with circularity are still not on track, and circular design is not used as frequently as it could be (Platform CB'23, 2023). This is noteworthy, given that engineering consultancy firms seek to be at the forefront of creating and implementing innovations, particularly in the areas of sustainability and circularity. Therefore, in this master thesis, a descriptive qualitative problem-driven research will be conducted to apply an appropriate behavioural change model to a case study at Royal HaskoningDHV in order to formulate recommendations on how engineers in engineering consultancy firms can stimulate the adoption of circular design principles.

1.2 Problem Statement

Despite circular design in wastewater facilities receiving policy attention, literature research and framework approaches, the implementation still confronts the significant challenge that engineers are not adopting circular design methods and thus hindering reaching the circulatory goals. This problem emphasises the need of recognising and addressing the barriers that limit the efficient adoption of circular design within engineering firms. The disparity between conceptual literature studies and abstract frameworks for general firms, and on-the-ground engineering practices demands a thorough analysis in order to bridge this gap and stimulate sustainable circularity in wastewater design. This study's scope is centred on the design of wastewater treatment plants (RWZI) for water authorities by engineering consultancy firms, with Royal HaskoningDHV as the research case study. While the in-depth focus is on Royal HaskoningDHV, the insights gained are expected to be applicable to other engineering consultancy firms facing similar issues in circular design implementation. The scope ensures in-depth analysis of the subject while also providing significant insights for a broader audience, such as other engineering firms and policymakers who have the challenge of implementing circular design principles.

1.3 Conceptual Framework

The Behaviour Change Wheel (BCW) was selected as the framework for this study due to its comprehensive integration of behavioural science elements. The BCW is designed to support interventions with a solid theoretical basis. It incorporates behavioural analysis and change strategies, making it versatile and adaptable for application in the engineering sector for circular design implementation (Atkins et al., 2017; Michie, 2014; Michie et al., 2014). This framework has proven effective in similar studies in complex sectors where behaviour change is central (Barker et al., 2016, 2017; Cane et al., 2012; Cornish et al., 2019; Michie et al., 2011; Murphy et al., 2023; Ojo et al., 2019; Reid et al., 2022; Thompson et al., 2018; Whittal et al., 2020).

1.4 Case Study: Royal HaskoningDHV

The case study was conducted for the wastewater department of Royal HaskoningDHV (RHDHV), which is a global engineering consulting firm and a leader in circularity, assisting clients in capitalising on circular possibilities (HaskoningDHV, 2023). Together with other engineering firms, like TAUW, Arcadis, Witteveen+Bos, Fugro and WSP, and with Unie van Waterschappen, they are looking into KCAO for Flood Defences, Pumping Stations and Sewage Treatment Plants (RWZI) (Unie van Waterschappen, Fugro, et al., 2023; Unie van Waterschappen, TAUW, et al., 2023; Unie van Waterschappen, Witteveen+Bos, et al., 2023). During an exploratory interview with Royal HaskoningDHV, it was discussed that Royal HaskoningDHV aims to apply the Platform CB'23 framework, but that this cannot be implemented seamlessly.

1.5 Research Questions

The main research question is: "How can the adoption of circular design in wastewater engineering consultancy firms be enhanced using the Behaviour Change Wheel?" This will be investigated through the following sub-questions:

1. What are the existing practices and perceptions of circular design among the wastewater department at case study consultancy firm RHDHV?
2. What are the barriers and facilitators to adopting circular design at RHDHV?
3. How can the BCW framework be applied to design interventions that promote the adoption of circular design?

1.6 Significance of Study

The scientific relevance of this research lies in its contribution to the body of knowledge on sustainable engineering practices and behavioural change in professional settings. Practically, the study provides valuable insights for engineering consultancy firms and policymakers aiming to enhance the adoption of circular design. The findings can inform the development of effective strategies to overcome barriers and leverage facilitators, promoting a more sustainable approach to wastewater infrastructure design.

1.7 Structure of Report

This thesis is structured into multiple chapters. In Chapter 2, a detailed theoretical framework is provided, covering circular design, organisational culture and behaviour change, and the Behaviour Change Wheel. Chapter 3 outlines the methodology, including data collection and analysis methods. Chapter 4 presents the study's results through the lens of the Behaviour Change Wheel and systematically proposes interventions to promote circular design adoption. Chapter 5 discusses the findings, methodology, implications, limitations, and suggestions for future research. Finally, Chapter 6 concludes with recommendations for future research.

2. Theoretical Framework

This theoretical framework provides an overview of the concepts and theories employed in this thesis, emphasising relevant prior knowledge on the subject. It starts off with an introduction into circular economy, and then delves into circular design, including its concept, origins, and context, both for the broader societal implications and its specific application within engineering consultancy firms. Following that, behavioural and organisational culture change is discussed. In the final part, the framework Behaviour Change Wheel and origin, components and application are addressed.

2.1 Circular Design

Circular Economy and Design

Circular design, which is fundamental to sustainable engineering, is deeply rooted in the principles outlined by early pioneers in circular thinking. The cradle-to-cradle concept, as introduced by McDonough and Braungart, forms a foundational framework for reducing waste and optimising resource efficiency (McDonough & Braungart, 2010). Additionally, bio-mimicry principles, introduced by Benyus in 1995, contribute to aligning engineering practices with nature-inspired cyclical processes (Benyus, 2009). Although the circular economy and sustainability are closely related, circular economy places more of an emphasis on financial benefits for businesses and less on resource consumption and environmental damage, while sustainability is more concerned with stakeholder alignment of interests (Geissdoerfer, Savaget, Bocken, & Hultink, 2017).

Circular Design in Engineering Firms

This existing circular framework was elaborated on by defining strategies for circular design in engineering, being designs for circular supplies, resource conservation, multiple cycles, long life use of products and systems change, and by outlining circular business models, encompassing circular supplies based on industrial symbiosis, resource value recovery, product life extension, and extending product value through shared use, access and ownership on sharing platforms (Moreno, De Los Rios, Rowe, and Charnley, 2016). This way of designing has been implemented with innovative solutions, from material reclamation to modular design (Bocken, De Pauw, Bakker, & Van Der Grinten, 2016; Eberhardt, Birkved, & Birgisdóttir, 2020). However, the outcomes are ambiguous, with challenges persisting alongside success stories. Economic barriers, cultural resistance, legal feasibility and technological limitations continue to hinder effective implementation strategies, however circular design is maturing beyond theory-based concepts towards implementation tools, though typically neglecting social sustainability and requiring efforts from across and beyond manufacturing companies (Bjørnbet, Skaar, Fet, & Schulte, 2021; Dokter, Thuvander, & Rahe, 2021; Guerra & Leite, 2021).

Case studies for European engineering firms implementing circular design are few. Guldmann and Huulgaard (2020) did a study on twelve Danish companies that found barriers at all socio-technical levels, with most barriers at the organisational level, with no clear correlation to company size, industry and customers. The barriers encountered were in good correspondence with the literature, but four of the barriers, being investments in existing manufacturing facilities and value chain; reluctance to involve external stakeholders in CBMI activities; difficulty establishing cross-organisational collaboration; and a hesitant approach to promoting the circular economy agenda, were additions to those found in literature (Guldmann & Huulgaard, 2020). Another case study within a German manufacturing company indicated that more circular design had a lot of potential, but that it required collaboration with all consumer/supplier parties (Braun, Kleine-Möllhoff, Reichenberger, & Seiter, 2018). Hjaltadóttir and Hild (2021) studied companies in the region of Luxembourg and Gothenburg, Sweden and found that most were in an orientation process on defining the meaning and content of the circular economy, and that the main barriers were the lack of cooperation between actors, guidance from policymakers, fragmentation and lack of transparency. Mhatre, Panchal, Singh, and Bibyan (2021) found that the most used circular strategy in European companies is recycling and that the main initiatives originate from macro level initiatives by governments and/or regional administrative bodies and a further transition to circular design can be facilitated by government policies, infrastructure and technological availability, awareness, stakeholder collaboration and supply-chain integration. Bjørnbet et al. (2021) conducted a literature review on case studies for circular economy in manufacturing companies, and found that a holistic approach is needed to implement circular design.

Process of Circular Innovations in Wastewater Facilities

When the Netherlands committed to the Paris climate agreement, this resulted, among other things, in the Grondstoffenakkoord, an agreement of intent to develop transition agendas for the circular economy, and the Unie van Waterschappen committed itself to being 50% circular by 2030 and fully circular by 2050 (Ministerie van Infrastructuur en Waterstaat, 2017; Unie van Waterschappen, 2019). Following that, STOWA and Unie van Waterschappen (2022) conducted a study to clarify the path to the objective, and

Platform CB'23 released in 2021 a guideline for circular design and iterated to version 2.0 in July 2023, with the aim of providing concrete guidance and executable tools across a wide range of domains to establish circular design as standard practice. With the design teams as the target audience, it outlines how a design team can prepare itself for the design process and identifies the crucial technical, legal and financial aspects that require attention when translating the circular ambition into design strategies (Platform CB'23, 2023). In order to effectively coordinate with non-design responsibilities in the construction process, consideration is also given to the roles and collaboration both within and outward the design team, as well as how a design ecosystem should be established in this regard. Next, there are seven circular design strategies (see Figure 1) that, with the aid of a roadmap, can be implemented step-by-step in order to arrive at a customised approach that is unique to a project (Platform CB'23, 2023).

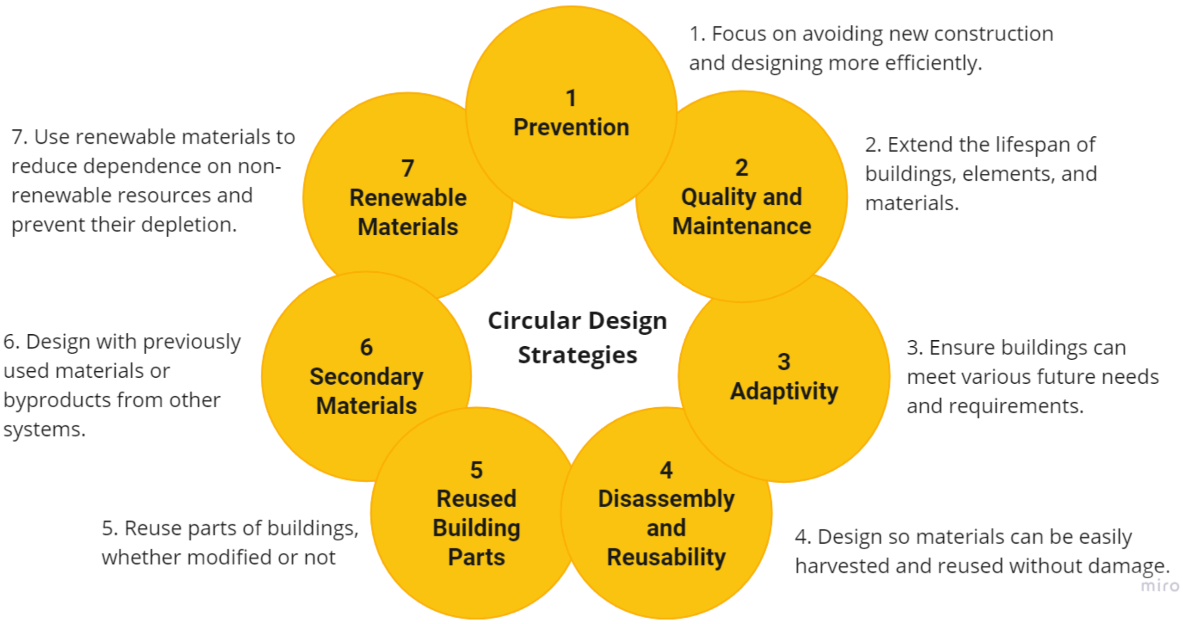

Figure 1. Seven Circular Design Strategies (edited and translated from Platform CB'23, 2023)

2.2 Behaviour Change in a Corporate Culture

The transition from a linear to a circular work process necessitates profound changes in how employees think, advise, communicate, and behave regarding circular design. This transition extends beyond merely implementing technical and procedural changes, requiring a fundamental shift in organisational culture (Boonstra et al., 2017; Burnes, 2017). Changing a work process within an organisational culture is inherently complex due to deeply ingrained daily practices and behaviours, which often result in resistance to change (Cameron & Quinn, 2011; Kotter, 2012; Schein, 2016). Resistance can arise from psychological concerns (fear of status loss or the unknown), organisational inertia (deep-seated traditions providing stability), group dynamics (conflicts with group norms), economic concerns (job loss, income reduction), misunderstandings about the change, and limited organisational capacity to implement changes due to a lack of resources or expertise (Piderit, 2000; Burnes, 2004; Oreg, 2006; Armenakis & Harris, 2009). Thus, adapting work processes requires not only technical modifications but also cultural adjustments, necessitating a reconsideration of the underlying values and norms that define the organisational culture (Burnes, 2004). Additionally, the success of implementation depends on the organisation's adaptability, as those with flexible cultures can more readily adopt new practices than those with rigid cultures (Burnes, 2004).

Changing corporate culture involves modifying fundamental values and norms and the collective mindset and interactions, making it a profound and protracted process essential for adapting to new external conditions (Cameron & Quinn, 2011; Schein, 2016). In contrast, behaviour change focuses on specific actions to achieve operational goals through altered routines and practices and is typically quicker to realise (Hagger et al., 2020). Culture change and behaviour change are interdependent, as effective behaviour change can drive cultural change and vice versa, and as Atkinson (2012) states, *"Behaviour change is central to any meaningful cultural change."*

2.3 Behaviour Change Wheel

Addressing behavioural change within an organisation requires selecting a robust model that is both theoretically grounded and practically identical, such as the Behaviour Change Wheel (BCW), to identify effective barriers to change, and to design and evaluate interventions that support these changes, which is crucial for achieving long-lasting and widely accepted changes (Michie et al., 2011, 2014). The BCW incorporates the COM-B model and Theoretical Domain Framework (TDF) and was introduced in 2011 as a synthesis of nineteen frameworks of behaviour change to aid designing interventions by selecting the appropriate intervention functions and policy categories that target the identified barriers and facilitators (Michie et al., 2011, 2014). COM-B is a framework and behaviour system involving the conditions capability, opportunity and motivation, see Figure 2 (Michie et al., 2011).

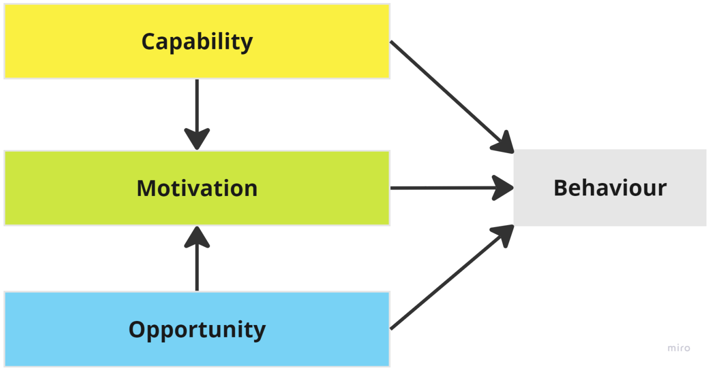

Figure 2. The COM-B model for behaviour change with the components Capability, Opportunity and Motivation. Source: Michie et al. (2014)

The BCW incorporates the Theoretical Domain Framework (TDF) which was first introduced in 2005 as a twelve-domain framework to identify the barriers and facilitators to behaviour change (Michie, 2005; Michie et al., 2014). Cane (2012) expanded this framework to fourteen domains by separating the domain Optimism from the domain Beliefs about capabilities and the domain Reinforcement from the domain Beliefs about consequences, and Atkins et al. (2017) wrote an extensive paper on the application process (Huijg et al., 2014).

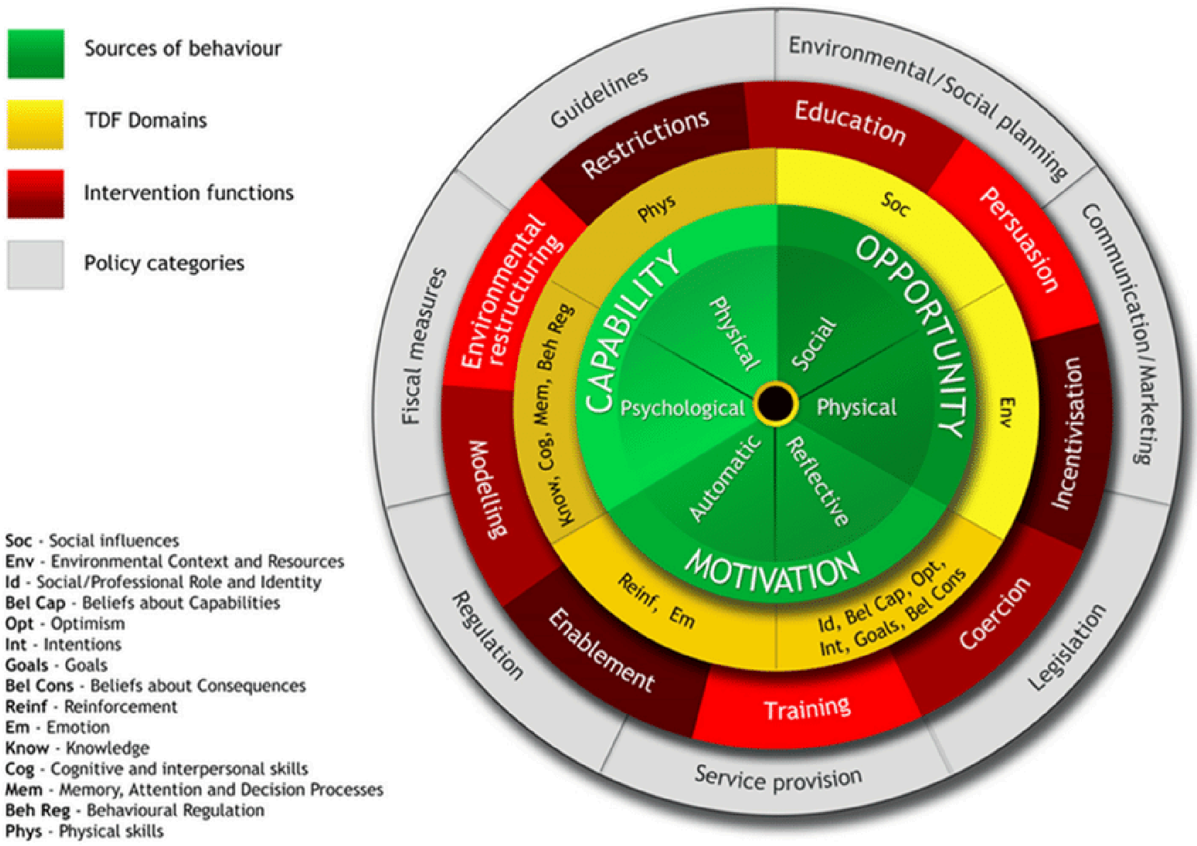

Figure 3. The Behaviour Change Wheel. Source: Michie et al. (2014)

The BCW is composed of three interconnected layers, as depicted in Figure 3. At its core is the COM-B model which includes the essential components for any behaviour to occur: Capability, Opportunity, and Motivation. Capability refers to the individual's psychological and physical capacity to perform the behaviour, such as necessary knowledge and skills. Opportunity refers to external factors that prompt or facilitate the behaviour, such as social and environmental influences. Motivation refers to mental processes that activate and direct behaviour, such as habits, emotional responses, and reflective decision-making (Michie et al., 2011, 2014). Behaviour change involves changing one or more of those components of COM-B to bring the system to a new state and minimise the likelihood of relapse.

Surrounding the COM-B model is the second layer, which consists of nine intervention functions directly aimed at influencing the three behaviour components: Education, Persuasion, Incentivisation, Coercion, Training, Restriction, Environmental Restructuring, Modelling, and Enablement. These interventions are directly applicable and aimed at changing specific behaviours by practical methods (Cane et al., 2012; Michie et al., 2011, 2014).

The outermost layer encompasses policy functions, which are broad strategies that create the context and environment for applying intervention functions. These include seven types of policy: Communication/Marketing, Guidelines, Fiscal Measures, Regulation, Legislation, Environmental/Social Planning, and Service Provision. These policies support and facilitate interventions by shaping the wider organisational, legal, and social context (Michie et al., 2014)

To operationalise the intervention functions and policy categories, the Behaviour Change Technique (BCT) Taxonomy outlines specific systematic procedures as the active components of behaviour change interventions, ensuring these interventions are grounded in practical, evidence-based methods (Michie et al., 2013). The interventions are evaluated using the APEASE criteria (Acceptability, Practicability, Effectiveness, Affordability, Side-effects, and Equity), which ensure that interventions are well-received by the target audience, feasible to implement, cost-effective, and equitable, while also accounting for potential negative side effects. This standardised and detailed evaluation technique ensures consistency, precision, transparency, and accountability in designing and implementing behaviour change interventions (Michie et al., 2014).

Furthermore, the integration of monitoring and feedback mechanisms within the BCT taxonomy enables real-time evaluation and adjustment of interventions, enhancing the effectiveness and sustainability of behaviour change (Michie et al., 2013). While the BCT specifies *what* should be done, the final step of the BCW focuses on *how* these interventions are implemented and delivered to the target audience by selecting an appropriate ‘mode of delivery’. This mode of delivery includes communication channels and interaction methods; the physical or virtual environment in which the intervention takes place; and the timing and frequency of intervention activities. An effective mode of delivery must align with the intervention’s nature and the target group’s needs to foster the desired behavioural change (Michie et al., 2014).

3. Methodology

This study has a qualitative approach due to its exploratory nature in which it aims to discover perceptions, behaviours, barriers, and facilitators to circular design and formulate interventions. Qualitative research provides the opportunity to delve deeper into human behaviour and the underlying motivations, as well as the social and organisational context in which these occur (Bryman, 2012). The study employs a case study approach and focuses on the wastewater department of Royal HaskoningDHV (RHDHV). Collected interview data was analysed systematically and, by applying the Behavior Change Wheel, behavioural insights were gained and relevant and effective interventions were designed in a structured three-stages approach.

3.1 Data Collection

The data collection comprised a combination of literature study, informal conversations, and semi-unstructured interviews with employees from the Wastewater Department at Royal HaskoningDHV (RHDHV). The interviews were preceded and paralleled by a literature review and informal conversations that provided in-depth understanding and valuable insights into the daily processes and specific jargon within the department.

Literature Study

A literature review of existing academic literature and sector-specific reports provided a theoretical foundation for the research. This included an extensive search on Google Scholar with keywords "circular design" AND "implementation" AND "engineering firms": 38 results; "challenges" AND "circular design" AND "engineering" AND "case study" AND "wastewater systems": 10 results; "circular design" AND "wastewater systems": 34 results. The first searches excluded publications prior to 2015 the Paris Agreements and papers without any citations. For the last search, "challenges" AND "implementation" AND "engineering firms" AND "circularity" AND "design" (99 results) excluded publications older than four years and, because of the rapid technological developments in the circular field and the aim to research the current implementation barriers. Additionally, all reports and documents on circularity from reputable entities Unie van Waterschappen, Water Test Network, STOWA, KWR, Platform CB'23, and circulairebouweconomie.nl were examined. This approach ensured a robust basis for further analysis.

To further be adequately informed on the research topic, books and articles on organisational culture change, behaviour change, and social research methods were studied, selected based on their prominence in their respective fields and the frequency of their quotations.

Informal Observations and Conversations

As a non-participating observer at RHDHV from February to June, three intern circularity workshops for different Engineer teams, one external circularity brainstorm session, a site visit on a wastewater facility, 18 weekly meetings from the Mechanical Engineering team and multiple standard workdays were attended, resulting in numerous informal conversations. These informal conversations laid a broader foundation for the interviews, enriching and deepening the understanding of barriers, potential interventions, and cultural contexts.. To avoid reactive effects, care was taken to minimise influencing participants' opinions on circular design.

Interviews

The methodology also included semi-structured interviews, which, due to the diversity in job functions, work experience, and circularity perspectives of the participants, evolved into more unstructured interviews. Ethical approval for the interviews was obtained from the Human Research Ethics Committee (HREC) of the Technical University Delft (Application number 3930).

Inclusion criteria focused on employees within the RHDHV Wastewater Department involved directly or indirectly in the design of wastewater treatment plants. This aimed to gather a wide range of experiences and perspectives across organisational levels, from junior to senior engineers, and from engineers to managers. This diversity was crucial to understanding the complex dynamics of circular design within an organisational context.

Interviews were conducted in private rooms at RHDHV offices in Amersfoort and Rotterdam, lasting between 30 and 50 minutes. With participants' consent, the interviews were audio-recorded using Microsoft Teams, transcribed verbatim, and sent to participants for review. This process enhanced the accuracy, reliability, and validity of the research, facilitating a precise coding and transcription analysis.

Interviews continued until data saturation was reached, which indicates that after three consecutive interviews, no new barriers or facilitators surfaced. In qualitative research, data saturation denotes that there is enough depth and breadth in the data to fully address the research questions (Bryman, 2012).

The interview questions were structured into three main sections. The first section focused on participants' job roles, experience, and influence on wastewater treatment plants. The second section explored the participants' definitions of circularity and circular design, followed by an analysis of their engagement with circular design principles and circular discussions with colleagues using the AIDA framework. The third section involved inquiries into the barriers and stimulators for circular design, followed by an explanation of the concepts behind behaviour influence and stimulation according to the COM-B and TDF models. This explanation aimed to inspire participants to further identify barriers and stimulators in their own context. Finally, there was an opportunity for participants to provide additional comments and questions. For the detailed interview guide, see the *Appendix: Interview Protocol.*

The study included 22 employees of RHDHV, of which 18 are engineers or have an engineering background, 6 are currently working in a management or project management position. 5 participants have junior level work experience, 4 medior and 13 senior, reference is made to Table 1. 3 declined the request to be interviewed stating reasons, too busy and not interested. 5 participants regularly fulfil several job functions, e.g. both Hydraulic and Mechanical engineer. Considering the department has 96 members, the quantitative results can also provide a certain level of reliability. D1-D22 refers to the specific interview transcriptions.

Table 1. Participant statistics with main job function and experience level.

Job function -> / Experience level	Civil Engineer	Electrical Engineer	Hydraulic Engineer	Mechanical Engineer	Process Engineer	Projectmanagement	Management	Total
Junior/Medior	D1, D10	D20	D19, D22	D4, D14, D16	-	D17	-	**9**
Senior	D13, D21	D7, D12	D2	D8, D11	D15	D3, D18	D5, D6, D9	**13**
Total	**4**	**3**	**3**	**5**	**1**	**3**	**3**	**22**

Adapted AIDA model

To examine the engineers' cognitive and emotional engagement with circularity, the AIDA (Awareness, Interest, Desire, Action) model was selected. Initial research showed varied definitions and understandings of circularity, prompting questions about participants' awareness of circular design guidelines, interest in circular opportunities, willingness to apply this knowledge, and current engagement with circular practices. Although traditionally used to analyse purchasing behaviour, the adapted AIDA model is anticipated to effectively and successfully analyse the adoption behaviour of circular design. The model was redefined for this context: Awareness captures recognition of circular design and contributing sources; Interest is subdivided into Knowledge (understanding principles), Consideration (assessing feasibility), and Liking (appreciation); Desire is subdivided into Preference (desire to adopt) and Conviction (confidence in effectiveness); Action is subdivided into First Use (initial implementation), Satisfaction (outcome satisfaction), and Advocacy (promotion to others), see Figure 4 for a visualisation. This adapted AIDA model allows for a comprehensive analysis of engineers' perceptions and engagement, which is employed to define the target behaviours for the Behaviour Change Wheel, thus offering a robust approach to a contextual understanding of the problem.

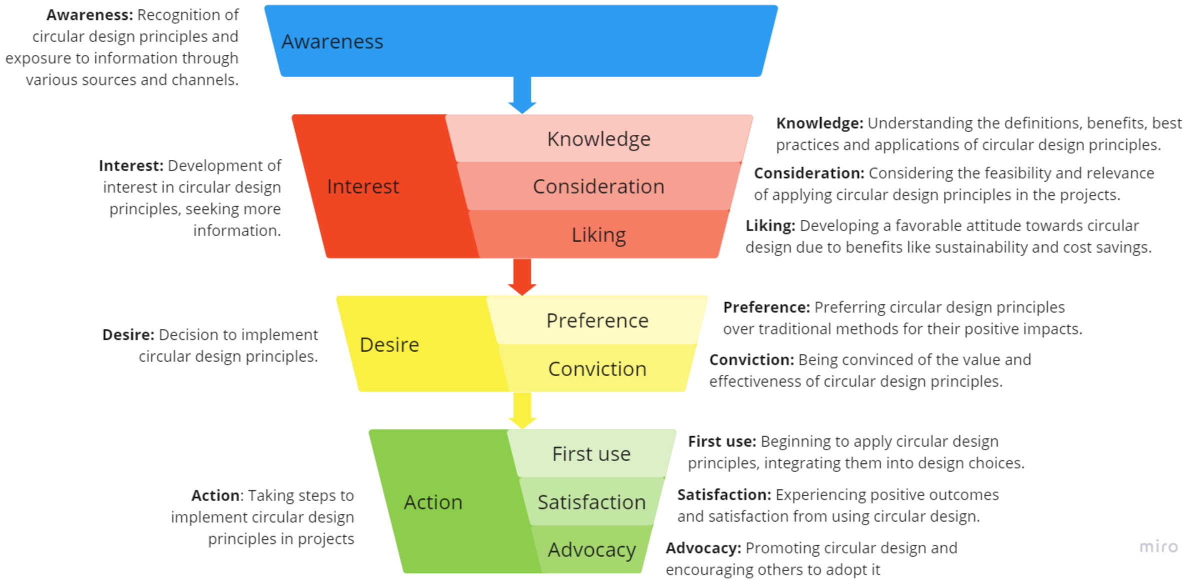

Figure 4. Adapted AIDA model for case study use, with description of various stages and subdivisions.

3.2 Data Coding

The data analysis involved several steps: thorough reading of all interviews for an overall understanding, followed by an exploratory inductive coding round, and finally, a deductive coding round based on the Theoretical Domains Framework (TDF). During the coding process, ATLAS.ti was utilised, an advanced software program for qualitative data analysis (Saldaña, 2015). By combining inductive and theory-driven coding processes, this research provided a deep insight into the factors affecting circular design adoption. Furthermore, this dual coding approach enhanced the practical relevance of the findings by ensuring that the recommendations are directly rooted in empirical data, making them applicable for real-world implementation.

- **Initial data familiarisation**
  The data was initially read thoroughly to gain a comprehensive understanding of the variety and breadth of the content, facilitating familiarisation and identification of preliminary themes.
- **Exploratory Coding**
  Next, the data was coded using an inductive and data-driven approach, where codes were derived from the data and the codebook evolved through the interviews. The aim was to openly and exploratively code the data, applying descriptive and categorical codes to accurately reflect the diversity within the data and mitigate research bias regarding patterns. The exploratory inductive coding round was based on the data, promoting the discovery of new and relevant themes without prior theoretical constraints.
- **Concept-driven Coding (TDF)**
  Subsequently, the data was a priori coded with a codebook consisting of the six COM-B components and the 15 domains from the Theoretical Domains Framework (TDF) for a Behaviour Change Wheel (BCW)-based analysis of the barriers (Michie et al., 2011). The concept-driven coding round ensured a systematic and theory-guided analysis, thereby creating a methodological link between the data and existing theoretical models. This contributed to both the scientific robustness and practical relevance of the research findings.

3.3 Data Analysis

The interview data was analysed by applying the Behaviour Change Wheel (BCW) aimed to understand the behaviours influencing the adoption of circular design principles and to formulate effective interventions. Furthermore, the results from the exploratory coding round were analysed by which additional insights were formulated on the context of the target behaviour and the barriers and facilitators of the adoption of circular design, aiding the first BCW Stage of understanding the behaviour. The BCW offers a structured approach for identifying and implementing interventions (Michie et al., 2014) and includes three stages, as visualised in Figure 5 and described in *The Behaviour Change Wheel: A Guide To Designing Interventions* by Michie et al. (2014). In the first stage, the selection of a target behaviour was —beside the deductive coding— aided by the explorative round and interviews. The second and third stage was aided by the interviews, the broad knowledge obtained from the observations and informal conversations.

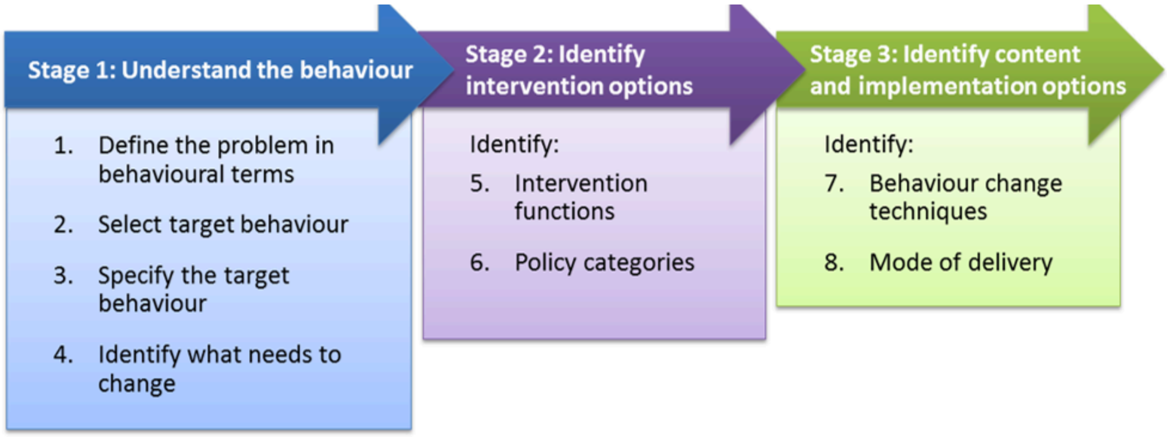

Figure 5. BCW method for designing behaviour change interventions. Source: Michie et al. (2014).

BCW Stage 1: Understand the Behaviour

The first stage of the BCW aims to provide a behavioural diagnosis of the situation by executing an initial analysis and the first four BCW steps, in order to identify which target behaviour can have an effective positive impact on the issue and what needs to change in the person or the environment to achieve this behaviour. Figure 6 provides an overview of the sub-goals and methods of stage 1.

This stage was kicked off with an initial analysis of the context of the problem, based on an exploratory analysis of the 22 interviews conducted. Then, the first step of the BCW was conducted by defining the problem of interest that requires intervention in behavioural terms, which was done by the integration of the interview results of AIDA-based questions, the observed barriers from the interview results and the initial analysis of the context of the problem. The second step addressed the list of behaviours that influence the target behaviour and was based on the results from the exploratory analysis, interviews and informal conversations. The target behaviour was selected by considering the likely impact of the behaviour, the ease of changing the behaviour, and the centrality and potential positive spill-over effect of the behaviour. The third BCW step aimed to specify the target behaviour by describing in detail the who, what, when, where, how and with whom of the behaviour. The fourth step identified what needs to change in the person or the environment to achieve the desired change in behaviour. This was accomplished by describing for each of the sub-components of the COM-B behaviour system which barriers are encountered to execute the target behaviour, and is based on the COM-B and TDF deductive coding of the interviews with codebook consisting of the 6 COM-B components and 15 TDF domains. Then, the most influential COM-B components were identified based on qualitative and quantitative results from the interviews.

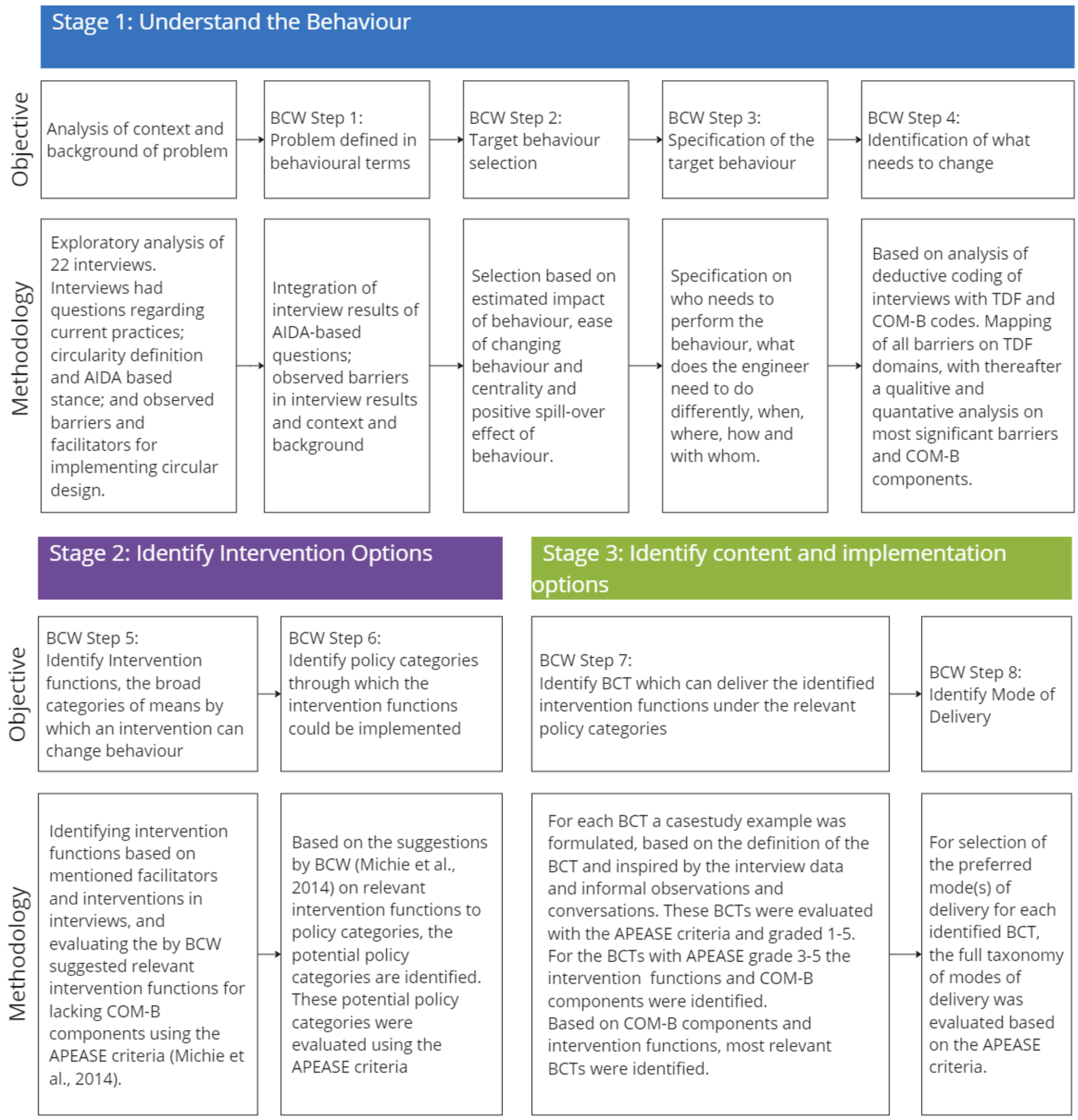

Figure 6. Overview of objectives and methodology for the steps of the three stage BCW approach.

BCW Stage 2: Identify Intervention Options

This stage links to the previous stage by adding intervention functions — broad categories of means by which an intervention can change behaviour — and policy categories through which the intervention functions could be implemented. Figure 6 provides an overview of the sub-goals and methods of stage 2.

The fifth step of the BCW was applied by evaluating the relevant intervention functions as suggested by Michie et al. (2014) and categorising the mentioned facilitators in the interviews to intervention functions, which were linked to COM-B components.

The candidate intervention functions were evaluated using the APEASE (Acceptability, Practicability, Effectiveness, Affordability, Side-effects, and Equity) criteria.

The BCW gives suggestions for which policy categories are likely to be appropriate and effective for each intervention function (Michie et al., 2014). These potential policy categories are then evaluated using the APEASE criteria.

BCW Stage 3: Identify Content and Implementation Options

The third stage of the Behaviour Change Wheel aims to identify Behaviour Change Techniques (BCTs) which can deliver the identified intervention functions under the relevant policy categories, including the medium through which the BCT can be delivered. For each BCT in the BCT Taxonomy version 1 a detailed example implementation was formulated, in line with the definition of the BCT, tailored to the specifics of the case study at RHDHV, and inspired by the interview data and informal observations and conversations. These BCTs were then evaluated by assessing their fit to the context and culture using the APEASE (Acceptability, Practicability, Effectiveness, Affordability, Side-effects, and Equity) criteria and the most promising BCTs were identified.

Where the BCTs specify *what* should be done, the mode of delivery specifies *how* the interventions could be implemented and brought to the target group. Selecting the preferred mode(s) of delivery was accomplished by evaluating the full taxonomy of modes of delivery with the APEASE criteria, to tailor the mode of delivery to the nature of the intervention and the needs of the target group, refer to Figure 7.

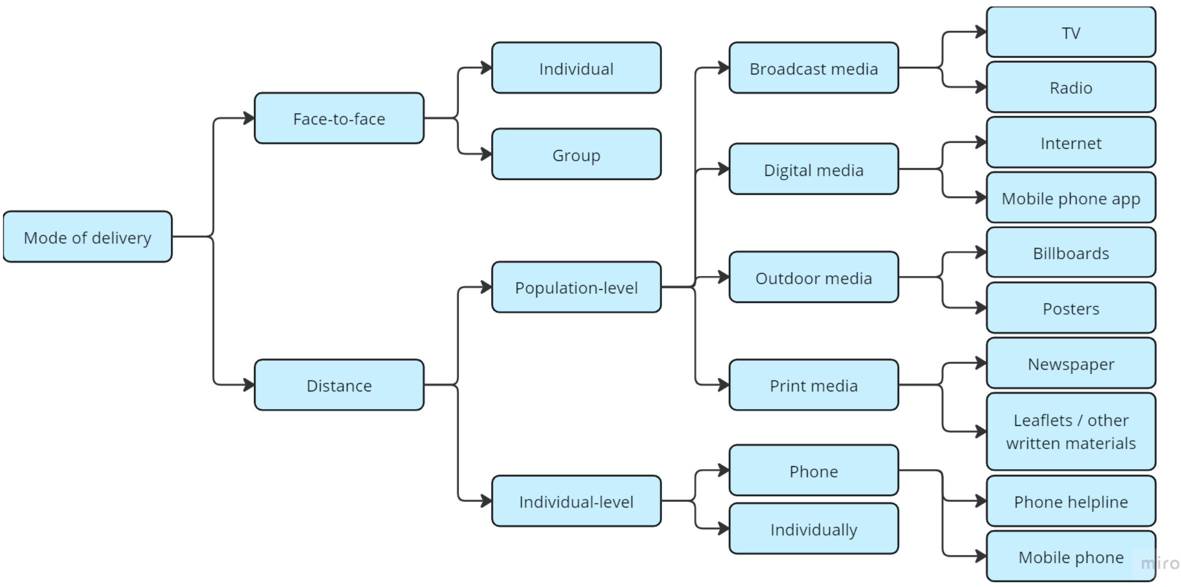

Figure 7. Taxonomy of modes of delivery for intervention functions. Source: Michie et al. (2014).

The research concludes with a list of additional observations, supplementing the general description of the situation from BCW stage 1 with analyses based on thorough exploratory analysis and extensive information from the interviews. These analyses highlight potential friction points or opportunities for the interventions. In BCW stage 1 an analysis is provided that aims to capture the core of the problem by identifying trends and simplifying them to create an insightful model, rather than reflecting the complete reality. This final step builds upon and deepens that initial analysis by providing detailed descriptions of the friction points with the goal of ensuring clear insights into where the interventions might encounter challenges. These descriptions are intended to ensure that, when implementing the interventions, potential challenges and weak points are thoroughly understood and anticipated.

4. Results

This section will commence by providing a background context based on the exploratory analysis, covering the design process, actors and interactions, and the definition, perception, and engagement with circularity. Subsequently, the interview data will be applied using the Behaviour Change Wheel, leading to the formulation of effective and strategic interventions to promote the adoption of circular design among engineers. The BCW approach follows a structured three-stage process: Understanding the behaviour, Identifying intervention options, and Identifying content and implementation options.

4.1 Stage 1: Understand the Behaviour

To gain insights into the behaviour associated with circular design, the following section begins by presenting the outcomes of the context in which this behaviour arises. This includes the design process, the involved actors and their interrelationships, and the perception of circularity, all of which are based on the exploratory examination of the interviews. From this contextual background, the focus then turns to the target behaviour, which is defined in behavioural terms as engineers making more circular design choices at every phase of the project. Furthermore, the section identifies the essential changes required in both the individual person and the environment to facilitate the occurrence of this behaviour.

4.1.1 Behaviour Context: Design Process

According to interviews D1, D2, D7–D19, D21, as well as informal conversations, the design process in which circular design should take place is tailored to the specific characteristics of each project. However, the interviewees identified the following general process steps in the typical design process from tender to execution: Tender publication, quotation submission, quotation selection, development of system choice design, preliminary design (voorontwerp — VO), final design (definitief ontwerp — DO) and tendering specifications (bestek), tender for contractors, selection of contractor, development of the implementation design (uitvoeringsontwerp — UO), and the implementation phase under supervision and management.

The water authority, acting as a client, initiates a tender for a design project, such as constructing a new building, restoring, or expanding a treatment plant. This tender is made available through Mercell, a European platform for online tendering and bidding (D5–D7, D16, D17, D19; J. Kruit, personal communication, May 13, 2024). The notice includes a detailed project description and a Programme of Requirements (Programma van Eisen — PvE) (Poppelaars, 2016). Subsequently, various engineering consulting firms assess the tender and decide whether to submit a quote. This process involves analysing the requirements and estimating the necessary resources and time (D5, D9). The client then selects the most suitable quote, and the chosen engineering firm starts the design process (Poppelaars, 2016).

At RHDHV, this design process begins with a system choice phase, which includes all necessary research and calculations to advance to the preliminary design phase, also known as the "variantenstudie". In this phase, a system is chosen, and its functionality, such as volume, is defined in the design (D2, D11, D13, D16, D21). This is accomplished by mapping the existing system, problem, options, restrictions, wishes, and objectives of the client (D1, D2, D13, D18, D21). The process technologist and hydraulic engineer compare different technologies, identify bottlenecks (such as available surface area on the site), and develop appropriate solutions (D1, D2, D7, D8, D11, D15, D19). Using this information, the process technologist creates several design options and presents each variant to the client with a sketch showing what will be newly built, removed, and where each element will be located (D1, D2, D7, D8, D11, D15, D19). Ultimately, the client selects a system using a multi-criteria analysis (MCA) and the recommendations and explanations provided by the process technologist (D5, D10, D11, D14, D15).

In the following stage of preliminary design (VO), all design decisions are brought together in a spatial elaboration of the sketch design. Civil, mechanical, and electrical engineers contribute to the design during this phase. Upon completion of the preliminary design, it is submitted to the client for approval and feedback (D5–D11, D13, D14, D16, D17, D21). The mechanical engineer utilises the sketch design criteria, such as pump capacity, to identify the required equipment (D4, D8, D15, D21, D22). The civil engineer designs the housing for the equipment and tanks, ensuring they fit within the site, while the electrical engineer designs all electrical components (D7, D10, D12, D13, D20, D21). At this stage, a rough cost estimate can be generated based on potential materials and construction methods (D1, D11, D15, D21)

The final design (DO) is a more detailed version of the preliminary design, with a higher level of specificity (D1, D7, D10, D12, D14, D15, D17, D21). After completion of the final design, it is submitted to the client for approval and feedback (D12, D14, D15-D18). In the final phase, the tendering specifications (NL: het bestek) are prepared, which include a detailed description of the design, along with the associated drawings and conditions set for the project (D9, D14, D18, D21; Bodemrichtlijn, n.d.).

The water authority, acting as the client, publishes a tender for an implementation project, and contractors make calculations based on the specifications (D5, D7, D10, D14). The water authority then selects a contractor based on price, quality, and ideas for circularity, sustainability, and shortening the construction phase (D21, Poppelaars, 2016). The selected contractor then creates an implementation design (UO), which includes working drawings and supplier drawings (D5, D7, D10, D14, D15, D20).

The last stage of the project is the execution stage, during which the water authority has the option to engage the engineering firm as a supervisor and project manager. In this role, the engineering firm is responsible for overseeing the project's execution and ensuring that it adheres to the contract and design specifications (D4, D6, D8, D10,; Bodemrichtlijn, n.d.).

4.1.1.1 Design and Construction Team and Market Demand

The use of Design & Construction teams (*NL: Bouwteam*) has become more prevalent in recent years, indicating that the contractor is involved in the project earlier than in the process described above (GMB, 2023; Onderwater, 2024). The involvement of the contractor has enhanced mutual trust between the contractor, the water authority, and the engineering consulting firm, with the goal of achieving a more effective design process and higher-quality project outcomes (D11, D21, GMB, 2023; Onderwater, 2024). In a construction team's design process, which progresses from sketch design to final design, the engineering firm's phase of tendering specifications and the constructor's phase of the implementation design become increasingly intertwined (Waterschap HDSR, 2024; informal conversations). Due to a significant increase in projects related to sewage treatment plants in connection with the more rigorous requirements of the Water Framework Directive, market demand is high, and there is a strong focus on efficient design, to which construction teams make a substantial contribution (Onderwater, 2024).

4.1.1.2 Current Circularity Practices in Design Process

The incorporation of circularity within the design process is not standardised and varies depending on the water authority involved, the specific project's circular ambition , and whether a member of the design or construction team raises the issue. Interviewee D16 noticed this variation in an implemented circular design choice, stating (translated), "*I've noticed that it is not done by default. It stems more from the water authority itself*" (D1, D3–D5, D7–D9, D11–D14, D16–D18, D20). Despite this lack of standardisation, an increasing number of projects are employing process elements that promote circularity. These elements include discussing sustainability goals at kick-off meetings, adhering to the principle of reusing the current system, utilising multicriteria analysis (MCA) with a circularity requirement, and holding sustainability meetings to concretize ambitions (D2, D3, D18, D19, D21). During kick-off meetings at the start of a project, the client's circular ambitions and vision are clarified using tools such as the GWW ambition web (see Figure 8) or an equivalent method, and the commitment to circularity is explicitly stated (D5, D12, D15, D19). Another common practice in the sketch design phase is to identify elements for potential reuse, motivated in part by financial benefits and a desire to avoid unnecessary constructions (D1-5, D7, D8, D13-15, D17, D19-D22). Furthermore, several projects have held “sustainability sessions” in various formats for meetings between the client’s project team and RHDHV, ranging from expressing ambition, concretising circular ambitions, brainstorming possibilities, and developing circular applications (D2, D3, D5, D12, D15, D18, D19, D21). While interviews D2, D3, D18, D19, and D21 suggested that these sessions increased the degree of circular choices in the final design, interviewees D3, D19, and D22 also mentioned that the sessions were not very fruitful and did not reach their full potential due to the incorrect timing and the client’s decision not to elaborate or implement the circular possibilities.

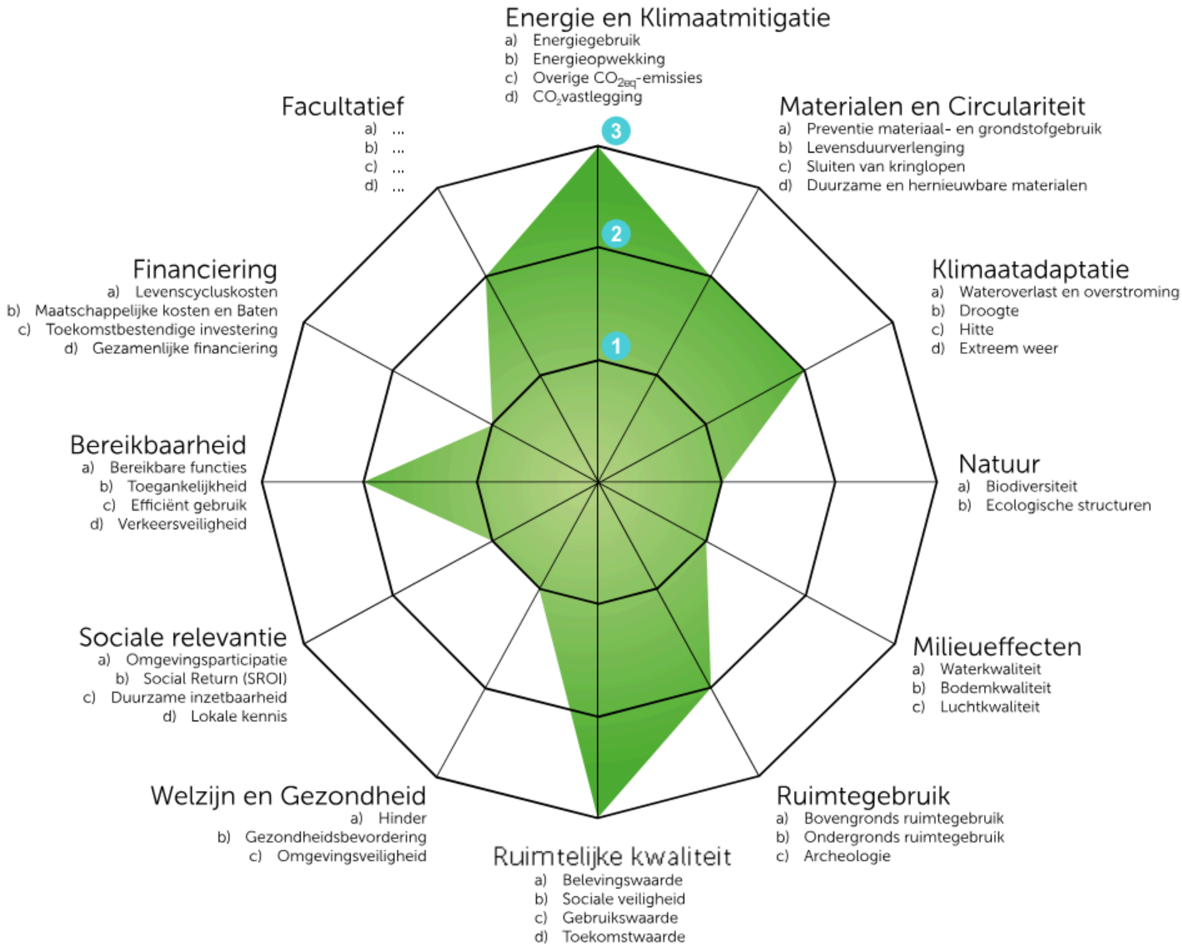

Figure 8. Dutch example of a GWW ambition web, aims to provide clarity regarding the ambitions for a particular project. Source: Duurzaam GWW, 2024.

4.1.1.3 Current Circular Design Choices

Interviewees D1–D5 and D7–D22 discussed several practicable and successful design choices that have been previously implemented to enhance the circularity of a design. These choices are listed in the order of their occurrence within the project phases:

- At the start of the project, sustainable market options can be explored and the GWW object tree and ambition web can be used to systematically determine and apply sustainability ambitions.
- In the sketch design phase, opportunities for reusing elements and modular systems can be identified, driven by the incentive to minimise costs and environmental impact. Additionally, convincing the client to limit reserve capacity in treatment plants to reduce material and energy use and considering CO_2 impact in decision-making can be considered.

- The suggested options for the preliminary design phase include making design choices that preserve materials and structures without unnecessary modification, using round tanks with reusable wall elements and data busses, repurposing buildings and tanks, planning for future expansions, and integrating circularity considerations into the project, similar to the structural safety and health assessment.
- For the final design phase, the suggested options are replacing traditional steel pipeline bridges with wooden versions, using plastic valves with PTFE seals, making a well-considered choice between steel and plastic pipes, using lifting straps instead of steel chains for pump installations, using prefabricated instead of on-site construction, using modular Verdygo constructions, and reusing large structures like scraper bridges by relocating them to a different wastewater treatment plant.
- Furthermore, overarching the phases, implementing electrical standards to increase the option of reuse and modularity, using the circularity calculator tool DuboCalc or an ECI calculator, and conducting work sessions to concretise circularity ambitions into applicable design choices were mentioned.

4.1.1.4 Influence of Project Type on Circularity

The circular ambition varies depending on the project type, as perceived by interviewees D5–D7, D16, D17 and D19. Several key factors influence this variation. Projects can be categorised into renovations, new constructions, and minor modifications (D5, D16, D17, D19). Renovations often allow for significant reuse of existing materials, whereas new constructions frequently aim for state-of-the-art, showpiece, highly visible, and sustainable designs (D5, D7, D16, D17). Additionally, projects may focus on optimising existing processes or adding new treatment steps to enhance capabilities (D6, D16). Larger projects typically incorporate more comprehensive sustainability measures and circular principles (D5, D16, D17). The visibility of infrastructure components, such as above-ground pumping stations, also influences design, with an emphasis on aesthetics and circularity as showcase elements (D16, D19). Centralization efforts may involve constructing new facilities or expanding existing ones to handle increased capacity, while new projects can be entirely new facilities or expansions focusing on future growth and technological advancements (D5, D6, D11). Both the project type and the water authority's circularity mindset have a significant impact on the circularity ambition for a specific project (D3–D7, D11, D12, D15–D20).

4.1.2 Behaviour Context: Actors and Interactions

The interviewees (D1–D22) identified four main actors involved in the creation and approval of a circular design: RHDHV wastewater department, the water authority, the contractor, and the supplier, as illustrated in Figure 9. The water authority is responsible for requesting a circular design, while RHDHV is tasked with designing the circular design. The contractor assist in the development and implementation of the circular design, and the supplier provides circular materials or modular elements (D1–D5, D7, D9, D12–D17, D19–D22). For a comprehensive overview of each actor's responsibilities, goals, tasks, and the timing of their involvement in the design project, please refer to *Appendix: Actors*.

The **water authority**, responsible for requesting circular designs, comprises several subgroups. The board holds the overall final responsibility and shows a high interest in circular design due to moral and upcoming legal obligations (D3, D9, D12–D15). This interest influences the project team, which handles the project design and realisation, and is tasked with ensuring alignment with circular objectives (D1, D5, D9, D15, D19, D21). The maintenance subgroup oversees the daily management and upkeep of wastewater facilities (D2, D12–D15, D17, D21). Although maintenance does not actively participate in the design process, their input is critical due to their practical concerns over reliability and ease of maintenance, which often conflict with circular goals (D12–D15). Their influence can significantly impact the acceptance and selection of circular measures, making their power substantial but inconsistent across different water authorities (D12, D14, D17, D21). RHDHV refers to the water authority as a whole as 'the client'.

The **Royal HaskoningDHV Wastewater Department** consists of management, project managers, technical managers, process technologists, and civil, electrical, hydraulic, and mechanical engineers. Management is responsible for the long-term strategy and overall departmental performance, showing a significant interest in circularity to align with industry trends and strategic goals (D6, D9). However, the extent of their active involvement in promoting circular designs is somewhat unclear (D13). Project managers, who bear final responsibility for project outcomes, exhibit a strong interest in circularity due to both RHDHV and the water authority's goals (D3–D6, D17, D18). They influence the project by collaborating and communicating with clients and coordinating the design process, although they are constrained by budget and time limitations. Engineers, who are responsible for developing the designs, display varied levels of interest and influence in circularity, depending on their perception of feasibility and the support they receive from other actors (D1, D2, D4, D7–D16, D19–D22).

The **contractor** holds a pivotal role and wields significant influence, particularly when the design process involves a construction team (D11, D21). They assist in the practical implementation of circular measures and are responsible for executing the project according to the design specifications (D10, D11, D14, D17, D21). Contractors select materials and components based on circular criteria and possess the expertise to estimate lifespans and potential for reuse (D3, D11, D19, D22). Their involvement ensures that theoretical designs are effectively translated into practical implementations (D4, D7, D14). Contractors have substantial power in realising circular designs due to their control over material selection and construction methods, and their interest is generally aligned with meeting client specifications and achieving sustainable and affordable outcomes (D4–D7, D16, D21, D22).

Suppliers are vital for circular design due to the dependence on their materials and modular elements. While they do not directly influence the design process, they indirectly shape circular design by introducing new possibilities such as the Verdygo principle (D1, D7, D8, D14). Suppliers deliver components with environmental process descriptions (EPD) and material passports, which are essential for maintaining circular standards (Platform CB'23, 2023; Rockpanel, n.d.; D11, D14, D21). Modular elements like the Verdygo principle also contribute to standardisation and circular design (D1, D4, D7, D8). Early contractor involvement indirectly causes suppliers to work more closely to ensure material compatibility and sustainability (D12, D19). Suppliers have significant power in the success of circular designs by providing compliant materials and aligning with industry trends and client demands for sustainability (D1, D11, D19).

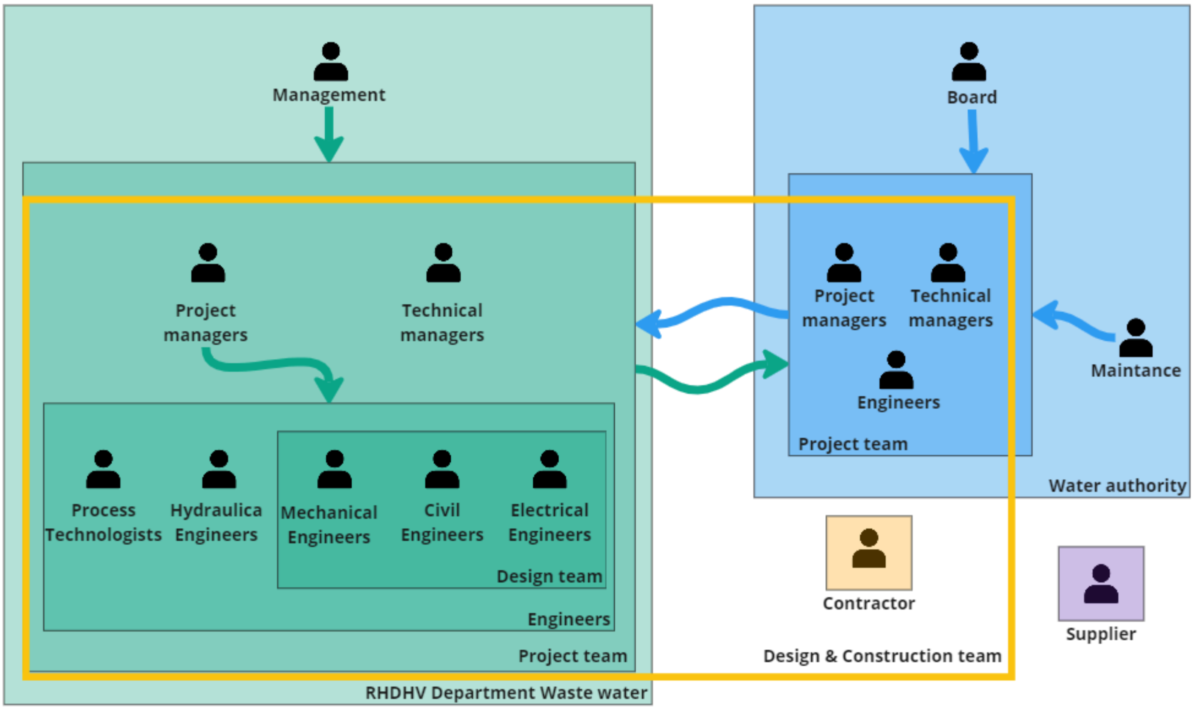

Figure 9. Key actors and subgroups within a wastewater design project. Arrows indicate relations where one actor has a significant influential impact on the functioning of the other.

Power and Interest of Water Authority and RHDHV

The water authority plays a crucial role in incorporating circular design because RHDHV, as a commercial entity, tailors its deliverables to meet client demands. When the water authority initiates circular implementations, there is a very high likelihood of successful implementation. However, the ambition among and within the water authorities differ significantly.

Based on the mentioned results on actors and interactions, it can be inferred that the power and interest in circular design among these actors differ considerably. The water authority's board and project team exhibit high interest in circularity due to moral and legal obligations, while maintenance often resists due to practical concerns. However, the position for both the power and interest of maintenance is ambiguous. Interviews and informal conversations suggest that their stance varies per water authority and project, as illustrated in Figure 10: Power/Interest-Grid.

RHDHV's management demonstrates strategic interest in circularity, aligning with long-term goals, but their active involvement in promoting circular designs is somewhat unclear. Project managers have a strong interest in circularity driven by both RHDHV's and the water authority's goals. They influence the project through client communication and coordination but are constrained by budget and time limitations.

Engineers, responsible for developing the designs, display varying levels of interest and power, ranging from minimal influence due to reliance on other actors for approval, to significant influence as they directly incorporate circular elements into their designs. This variability is depicted in Figure 11: Map visualisation of stakeholder engagement.

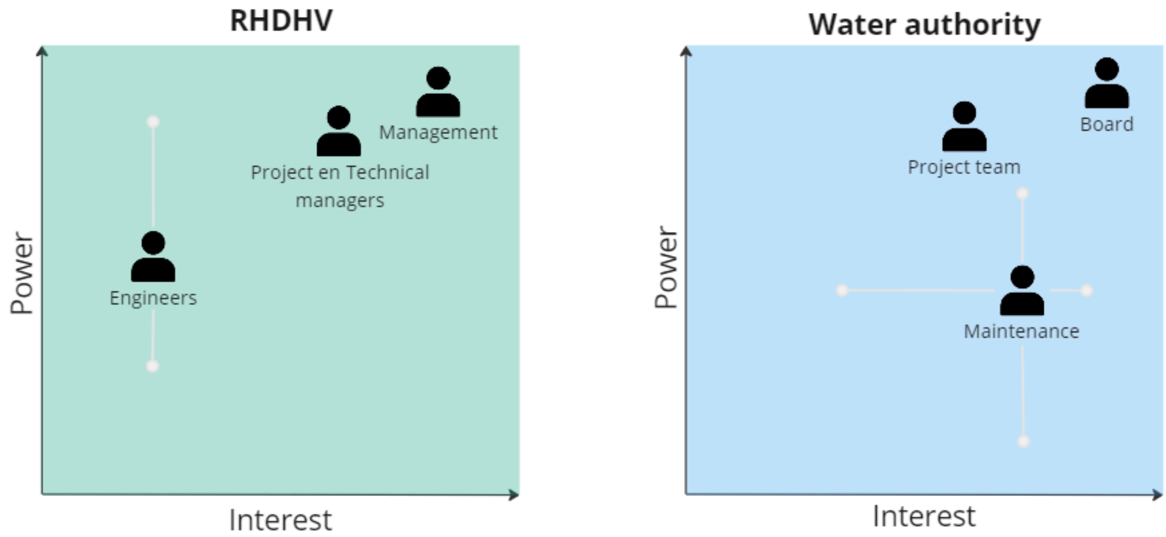

Figure 10. Power/Interest-Grid for the realisation and acceptance of a circular design for a wastewater facility with ambiguous positions for actor Maintenance and actor Engineers.

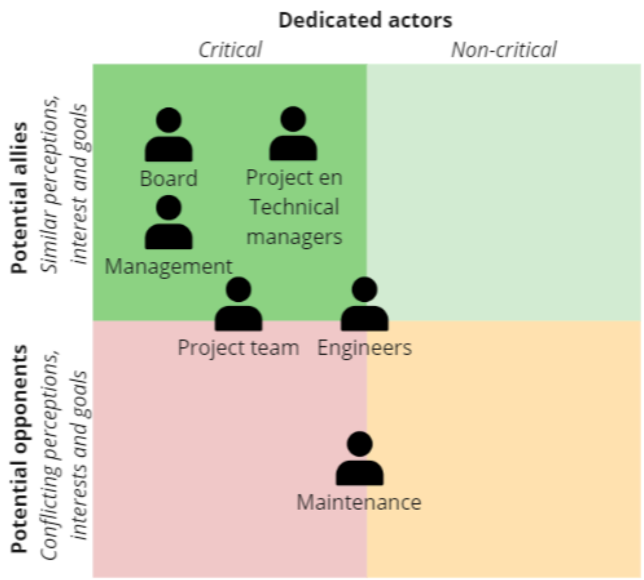

Figure 11. Map visualisation of stakeholder engagement for the actors engaged in creating and accepting circular design, with three of the actors falling into multiple categories due to inconclusive results.

Maintenance, a key actor, is often excluded from the design process despite having a significant influence on the final design choice. This partly explains why initial ambitions set by the management and design team are often not realised in the final design. Under the influence of maintenance, traditional solutions are frequently chosen over circular ones. This suggests that, in addition to facilitating circular design by engineers, barriers on the client side also need to be addressed. Although the realisation of construction projects is beyond the scope of this thesis, it is relevant because engineers' negative expectations about the realisation process hinder the adoption of circular principles for the design process.

4.1.3 Behaviour Context: Perception on Circularity

The exploratory analysis on the interviews revealed that the definitions of circularity and its principles, as well as the self-evaluated progress on the use of circular design concepts, differed among the engineers, project managers, and management at RHDHV's wastewater department.

Circularity Definition among Participants

The control question in the interview, which aimed to check the participants' definition of circularity, showed that the knowledge of the term's definition varied in range and depth among the interviewees. All 22 interviewees believed that circularity encompassed the reuse of components and materials and was either a part of or strongly connected to sustainability. Four interviewees mentioned that the term is somewhat abstract and can encompass many aspects, with the word 'circle' in circularity leading them to think of the cycle of components in which existing parts are to be recycled (D13, D14, D19, D20). Nine interviewees expanded this definition to include minimising the use of raw materials (D1, D2, D4, D9, D11, D14, D15, D21, D22), three interviewees included building modularly, robustly, or demountably with a foresight to future reuse (D3, D6, D21), and four included making conscious material choices (D1, D15, D18, D21). It was also observed that circularity is sometimes confused or strongly linked with sustainability or energy efficiency (D3, D5, D11, D14, D18), without a clear distinction between these different concepts.

These results suggest that employees in the RHDHV wastewater department are aware of the concept of circularity and its strong link to sustainability, reuse, and recycling, but have a limited understanding of the broader definition of circularity. As a result, their knowledge of circular design is also limited, as they are primarily familiar with principles focused on reuse and recycling, and less with principles focused on material prevention and the use of renewable raw materials.

Cognitive Perception and Engagement

The results of the interview questions related to the AIDA model are presented in the *Appendix: AIDA Model*. These findings indicate that all 22 participants are familiar with the term circularity, are aware of the water authorities' goal and ambition to incorporate more circularity in their designs, and are open to acquiring more knowledge on circular design. However, only 10 of them are willing to actively invest time and effort to obtain this knowledge, while the remaining 12 indicate that they only acquire new information when exposed to it.

Eleven participants expressed a desire to apply circular design principles: nine participants expressed a moderate desire, and two participants a low desire. Although the desire among participants varies, all participants favour sustainable designs over non-sustainable ones, provided the designs meet functional, financial, and comfort requirements. Moreover, no one opposed incorporating circularity into designs, although the cost to the project team and the willingness to compromise on criteria differed. Participants expressed a high or low desire to apply circular design, depending on their confidence in and acceptance of circular possibilities and the client's ambitions and choices. Fifteen participants with a moderate or high desire claimed to lack interest or knowledge to act on it. Only two of 22 participants (D2, D22) mentioned incorporating circular design practices, although three other participants recognized the design strategies in their current design practices and thus incorporated circular design unintentionally (D8, D12, D20)

The terms *awareness of, interest in* and *knowledge of* were used interchangeably by the participants (D1—D14, D16—D18, D20—D22). Awareness was interpreted in different ways, namely awareness of the existence of the definition of circularity; of the need for circularity; of the existence of circular design strategies; and of RHDHV's objectives and ambitions . For interest and knowledge, this applied to having interest or knowledge in the definition of circularity, the existence of the seven circular design strategies and how RHDHV wants to achieve its objectives and ambitions and implement the concrete, practical possibilities of circularity.

An analysis of these results suggests that despite an awareness of the importance of circularity, a preference for circular design, and a desire to apply it, actual implementation is generally low, revealing a discrepancy between motivation and practical application. The interest in actively developing the knowledge and skills necessary for circular design is moderate, resulting in many feeling incompetent to apply it. Furthermore, there is a perceived lack of ability and resources to implement circular design. Considering this general trend, it can be assumed that everyone is at or beyond the Awareness phase, and efforts should concentrate on enhancing the phases of Interest, Desire, and Action. Based on the results, it can be expected that the Desire phase can be quickly traversed, as there is already a preference for circular design, albeit perceived as impractical or inadequate. Once these barriers are removed and individuals are competent, the transition to Action is likely to occur swiftly.

Step 1: Problem Definition in Behavioural Terms

The engineering consultancy firm RHDHV is facing a problem where circular design is not being implemented despite the presence of several facilitators, such as the client's ambitions, the availability of circular alternatives, a circular design guideline (*Leidraad Circulair Ontwerpen 2.0)* written by Circular Bouwen '23, and RHDHV offering one workshop session per team. Regarding the factors hindering employees from applying circular design, the interviewees identified a wide range of barriers, which are quantified and elaborated on in *Appendix: Explorative analysis*. The most frequently mentioned reasons included lack of knowledge and skills (20 interviews), client reluctance (22 interviews), conservatism and routine (18 interviews), insufficient client budget (17 interviews), inadequacy of functional requirements (17 interviews), and higher time investment (14 interviews). All interviews highlighted the client as a crucial factor in the success or failure of implementing a circular design. In 18 interviews, the client was identified as a barrier, with the cost of the design and the client's budget mentioned in 14 of these 18 interviews, and the demands of the Maintenance actor cited in 11 of these 18 interviews as reasons for the client's reluctance.

Integration of AIDA-deduced results and mentioned barriers in interviews

The barriers mentioned during the interviews were integrated with the results obtained from the AIDA model, resulting in the categorisation presented in Table 2. This categorisation allowed deducing the target behaviour, which was then analysed using the BCW. The classification of the barriers mentioned in the interviews, based on the results from the AIDA model—(i) the lack of interest and knowledge and (ii) the gap between desire and action—indicates that the issue faced by RHDHV, namely the lack of delivery of circular designs, can be divided into three main issues of RHDHV and their engineers.

1. Engineers not learning circular design principles, resulting in lack of knowledge on how to design circularly.
2. Engineers not implementing the available circularity knowledge in the designs.
3. The client's choice and implementation of a circular final design (DO) to a realised building project.

The first issue relates to the feasibility of applying circular design principles due to the lack of knowledge and skills, making engineers unable to implement circularity in designs, and their lack of active participation in learning circular design principles. The second issue is that the existing knowledge, either possessed by engineers or available to them, is not applied in projects. These two issues concern the creation of circular designs by engineers. However, all interviews highlighted a third issue for the success of circular design, which is the client's role (D1–D22). The third issue is the client's choice for and implementation of a circular final design (DO) to a realised building project. If engineers create a functionally adequate circular design, it is the client who must act and opt for the circular design and realise it. Since RHDHV and their engineers consider a design successful if the client is satisfied and chooses to realise it, this third issue is a crucial factor for the success of circular design. However, as RHDHV and their engineers are not the main stakeholders of this issue, addressing this realisation issue with the Behaviour Change Wheel is beyond the scope of this thesis.

Table 2. Main issues hindering circular designs, based on derived results from the AIDA model, with classification of barriers obtained from interviews.

Identified issue	Barrier	Remark on the internal or externality of the barrier
Issue of lack of learning and knowing circular design principles	Lack of experience	External barrier to engineer, potentially in sphere of influence of RHDHV
	Lack of clarity and knowledge	Within sphere of influence of engineer and RHDHV
Issue of lack of implementation of circular design choices	Costs (Budgetary requirements)	External barrier
	Time constraints	Internal barrier to engineer; to some degree within sphere of influence for RHDHV but linked to external barrier Costs
	Functional requirements	External barrier
	Process within organisation	Within sphere of influence for RHDHV
	Cultural aspects	Within sphere of influence for RHDHV
Issue of lack of realisation of circular designs	Clients preference	External barrier

The first two issues identified, being the lack of learning circular design principles and the lack of implementing and applying available knowledge on circular options and principles, can be analysed with the Behavioural Change Wheel. Despite ongoing workshops at RHDHV to increase the knowledge of circular design principles, and the existence of some circularity knowledge among their interviewees (as described in *Behaviour Context: Design Process*), this knowledge is not being effectively or successfully translated into practice. Moreover, even the two participants D2 and D22 who have taken courses on circular design and consider themselves experienced in this area are not effectively implementing circularity. Based on these observations, it is determined that the most effective approach for circular design is to adopt a target behaviour centred on implementation.

Step 2: Target Behaviour Selection

The target behaviour that is most likely to have a considerable impact on resolving the implementation problem highlighted in step 1 is for **engineers to make more circular design choices in every phase of the project,** aiming to achieve the 50% circularity ambition by considering and selecting reducing, reusable, recyclable, and demountable materials and design choices. The target population for this behaviour is the engineers within the wastewater department of RHDHV. This target behaviour was found to have the most favourable combination of estimated impact of behaviour, ease of behaviour change, and centrality and positive spill-over effect of behaviour, compared to other potential target behaviours. Other potential target behaviours considered included project managers persuading the client to select a circular design, project managers leading the team in the application of circular design, management facilitating and stimulating engineers in circular design, and engineers learning circular design practices.

Step 3: Target Behaviour Specification

The detailed target behaviour entails that **engineers, in every phase of the design process, review their design with the seven circular design strategies and apply these strategies to their design where possible**, with the subsequent detailed specifications.

Who needs to perform the behaviour — Engineers are the primary designers, and their behaviour changes are crucial for achieving more circular designs. Engineers entail all Civil, Electrical, Hydraulic, Mechanical and Process Engineers from the Wastewater department at RHDHV (Personal observation; 2024).

What does the engineer need to do differently — Engineers need to alter their design behaviour by systematically reviewing, considering, and applying the strategies of the Leidraad Circulair Bouwen '23 to their projects (Platform CB'23, 2023). This requires them to be aware of these strategies, understand how and where to apply it in their designs, and reserve time to evaluate and integrate these strategies.

When — Different strategies can be applied at various phases of a design project. By considering circular choices at each step, engineers can make more sustainable decisions throughout the project lifecycle (D1—2, D7—19, D21). The minimum requirement is to review these strategies once per project phase, although more frequent reviews are beneficial.

Where — Design work can occur in the office, at home, or at the client's site. The location where circular strategies are reviewed and applied is not critical (Personal observation; 2024). However, for smoother implementation, it is recommended to engage with clients or discuss strategies with colleagues in the office. Nevertheless, the target behaviour should be location-independent, allowing engineers to perform these activities at any work location.

How — Engineers should review the seven design strategies from the Leidraad Circulair Bouwen ‘23 for each component they design, questioning whether and how the relevant strategy can be applied. They should assess the benefits and drawbacks concerning other client requirements and integrate the circular options into the design. In cases of uncertainty or if the disadvantages of a circular choice outweigh the benefits for the client, this should be discussed in client meetings.

With whom — Circular design is a collaborative effort involving other engineers and is supported by project managers (for recurring reviews and time allocation), management (for approval to allocate time), and clients (for funding additional time), as indicated by the exploratory analysis (D3, D5, D9, D17, D19).

Step 4: Identification of What Needs to Change

This step identifies the type of barriers encountered to execute the target behaviour for each sub-component of the COM-B behaviour system, and analyses which COM-B components are lacking, based on the COM-B and Theoretical Domain Framework (TDF) coding of the interviews. The barriers and facilitators were categorised into the six components of the COM-B framework, as shown in Table 3 and Figure 12.

The quantitative results show that Psychological Capability (19 participants) and Physical Opportunities (20 participants) are the main hindering COM-B components. Additionally, a dual outcome for Reflective Motivation is measured with 13 instances mentioned as lacking and 14 instances as stimulating for applying circular design principles (D1–D12, D14–D21).

Table 3. Quantified categorisation of the count of participants affected by barriers associated with each COM-B component. For further details, refer to *Appendix: BCW Analysis*.

	Barrier identified Amount of interviewees	**Facilitator identified** Amount of interviewees
Physical Capability	0	0
Psychological Capability	19	6
Reflective Motivation	13	14
Automatic Motivation	6	1
Social Opportunity	12	6
Physical Opportunity	20	4

The qualitative results are summarised in Figure 12, highlighting the main barriers for the relevant COM-B components. The qualitative analysis of the interrelationships between the barriers indicates that positive reflective motivation is inherently present, while negative reflective motivation predominantly arises from lacking Physical Opportunity and Physical Capability. Overall, participants mentioned Psychological Capability and Physical Opportunities as the main barriers, but the interviews also revealed Automatic and Reflective Motivation as important barriers. However, many interviews implied— both indirectly and directly—that the Motivation barrier is mostly caused by the demotivating effect of a lack of Psychological Capability and Physical Opportunities (D1–D12, D14–D21).

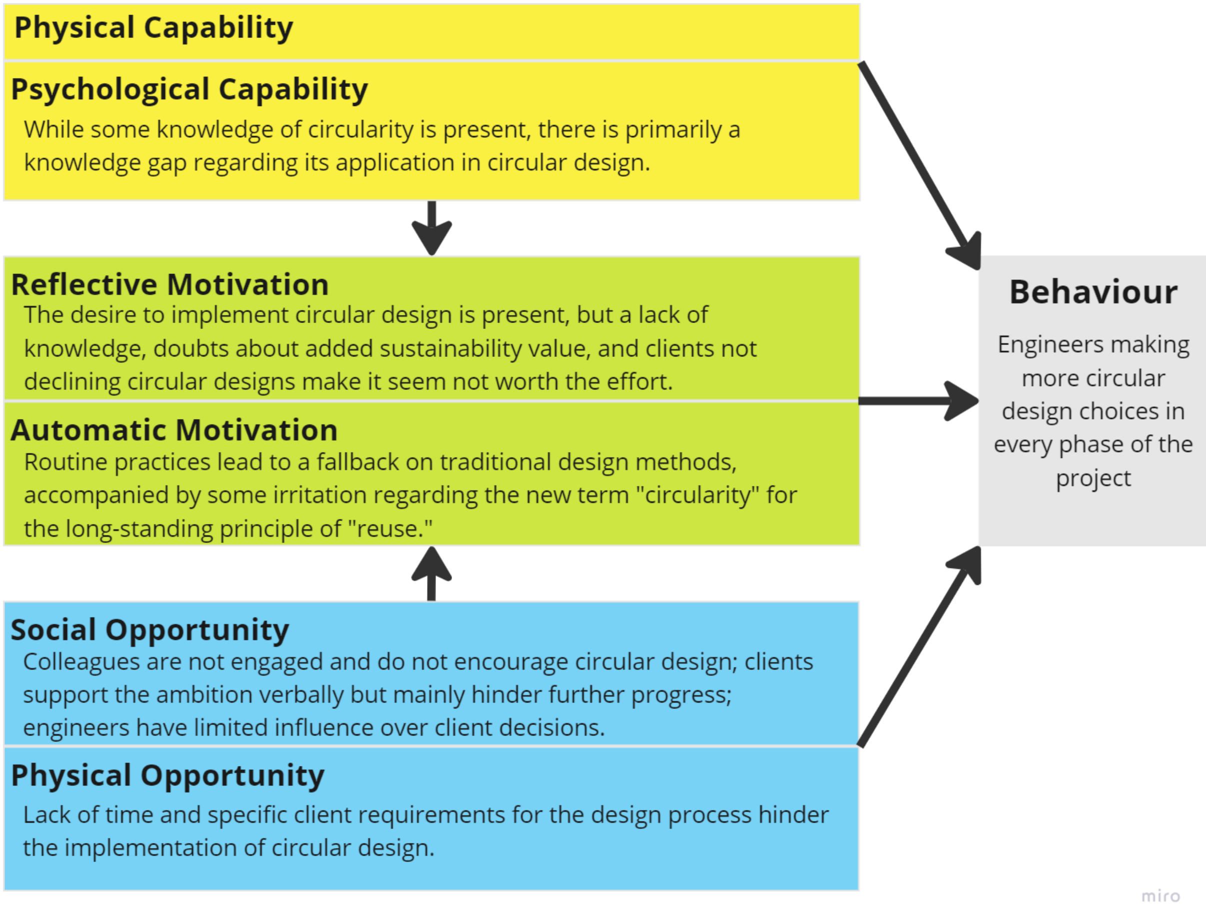

Figure 12. Overview of COM-B components with hindering barriers on target behaviour

The TDF domains were qualitatively analysed, of which the detailed barriers are described in Table 4, and the domains which predominantly (>20 participants) hinder the implementation of circular design to be Knowledge; Beliefs about Capabilities; Beliefs about Consequences; Environmental Context and Resources and Social influences. Domains which hinder the adoption little to none (<3 participants) are Social/Professional and Identity, Intentions, Behavioural Regulation and Physical skills. Due to the low level of Knowledge, Beliefs about Capabilities are also low, and as Environmental Context and Resources and Social Influences are low, Beliefs about Consequences are affected similarly. Because functional requirements and the client diminish the possibilities within circular design, there is little confidence in the utility of designing circularly, and it is generally expected that the client will reject the circular design. Logically, it is more practical to focus on Domains Knowledge, Environmental Context and Resources, and Social Influences, as inherently, Beliefs about Capabilities and Beliefs about Consequences are also enhanced.

Table 4. Identified implicit and explicit barriers based on COM-B components and TDF domains, see *Appendix: BCW Analysis* for elaboration.

COM-B components		TDF domains	Identified barriers per TDF domain
Capability	Physical	Physical skills	None. All necessary physical capabilities are present for applying traditional, circular, and combined design methods.
Capability	Psychological	Knowledge	Significant lack of understanding of circularity and its application. Many are unaware of the broader definition, including material reduction and limit it to reuse of components and materials. Misunderstandings lead to beliefs that circular design is not feasible.
Capability	Psychological	Cognitive and interpersonal skills	Individuals lack specific skills and creativity for circular design. Have not received training in methods, techniques, or life cycle analysis. Unknown how to apply life cycle analysis and MKI calculations.
Capability	Psychological	Memory, Attention & Decision Processes	Habits cause reverting to traditional design practices. No structural reminders to apply circular design principles.
Capability	Psychological	Behavioural Regulation	No self-monitoring or breaking old habits. Lack of feedback and support to improve practices.
Motivation	Reflective	Social/Professional Role and Identity	Roles tied to technical expertise and practical solutions. Some see the introduction of circular design as a challenge to their competence. For others, it's part of being a good client advisor.
Motivation	Reflective	Beliefs about Capabilities	Doubts about ability to successfully apply circular design, which are exacerbated by lack of examples showing feasibility and effectiveness.
Motivation	Reflective	Optimism	Low optimism about feasibility and benefits, with pessimism fueled by negative experiences, misunderstandings and unclarity on benefits.
Motivation	Reflective	Intentions	Positive towards idea of circular design, but low intention to apply circular principles. Not motivated without incentives or recognition. Prefer meeting traditional standards and client expectations.
Motivation	Reflective	Goals	No clear goals for implementing circular design, which causes circular design to remain an abstract ambition without concrete application.
Motivation	Reflective	Beliefs about Consequences	Beliefs on circular design being costly and needing more maintenance. Scepticism about durability of circular materials. Widespread belief that clients, despite circular ambitions, often revert to traditional choices
Motivation	Automatic	Emotion	Reluctance to change and uncertainty about new methods. Familiar, traditional approaches feel comfortable. Distrust in quality and durability of circular solutions and thus fear of mistakes and uncertainty with new methods.
Motivation	Automatic	Reinforcement	Unconscious preference for traditional methods. Existing procedures are carried out automatically and instinctively. Clients' preference for traditional designs reinforces engineers' hesitation.
Opportunity	Social	Social influences	Lack of support and encouragement from colleagues and supervisors. Discouragement by contradictory requirements and unwillingness of client. Organisation culture focused on quick, cost-effective solutions.
Opportunity	Physical	Environmental Context and Resources	Lack of tools, software, and access to reusable components for circular design. Tight deadlines and limited budgets hinder implementation. Unfamiliarity with existing circular solutions.

4.2 Stage 2: Identify Intervention Options

Step 5: Identification of Intervention Functions

In Step 4, several COM-B components were identified as needing change, leading to the identification of seven relevant and viable intervention functions for achieving the desired change. However, each intervention function only effectively addresses a subset of the COM-B components, refer to Table 5. Therefore, a combination of the intervention functions is necessary to successfully achieve the required change in the identified COM-B components. An APEASE (Acceptability, Practicability, Effectiveness, Affordability, Side-effects, and Equity) evaluation of these intervention functions resulted in the finding that all intervention functions could be useful, except Coercion and Restriction which were deemed both undesired and ineffective (D5, D6, D17, D21)

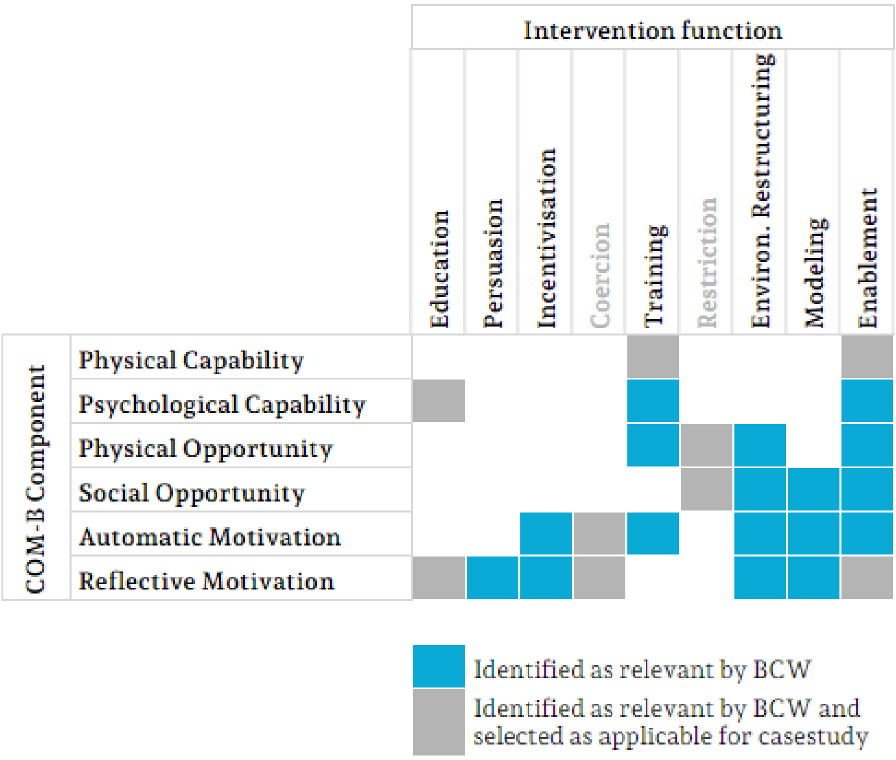

Table 5. Intervention functions relevant for COM-B components. (Derived from Michie et all, 2014)

To address the two main problematic COM-B components, Psychological Capability and Physical Opportunity, the most suitable intervention functions identified were **Education**, which focuses on increasing knowledge and understanding, **Training** which aims to improve skills, **Environmental Restructuring** which involves changing the physical or social context, and **Enablement** which seeks to increase capability or opportunity.

To intervene on the low motivation to design circularly, despite the demotivating lack of capability and opportunity factors, additional intervention functions can be implemented. These include **Persuasion**, which uses communication to stimulate or change positive or negative feelings; **Incentivisation**, which creates expectations of reward; and **Modelling**, which demonstrates examples of the desired behaviour. Coercion and Restriction were excluded due to participants expressing negative opinions about these methods. Furthermore, alternatives such as Persuasion and Incentivisation offer a more positive approach to increasing motivation and do not directly address the core issues of low motivation. Given the existing positive motivation, which is countered by the demotivating effects of low Psychological Capability and Physical Opportunity, the intervention functions Coercion and Restriction would not effectively change the inability or lack of opportunity to design circularly. Instead, Incentivisation and Persuasion can better stimulate efforts to overcome these barriers. The COM-B component Social Opportunity can be addressed through the previously mentioned intervention functions.

Step 6: Identification of Policy Categories

Five policy categories were identified as viable and effective for applying the seven identified intervention functions, with several policy categories encompassing a subset of these functions, refer to Table 6 and *Appendix: BCW Analysis*. However, a combination of these policy categories is necessary to effectively address all lacking COM-B components through the intervention functions. An APEASE evaluation of these policy categories is provided in *Appendix: BCW Analysis*.

Communication/Marketing is effective for the intervention function of Education, as it spreads awareness and knowledge about circular design across the department. Campaigns and information sessions can inform engineers about the benefits and practical applications of circular design. For Persuasion, it can highlight the advantages of circular design and motivate engineers to adopt these practices by showcasing inspiring case studies and experiences.

Guidelines support Education by providing clear, structured information on integrating circular design into projects, helping engineers understand and apply the necessary steps. For Training, Guidelines serve as the foundation for programs, ensuring consistent learning and equipping engineers with required skills. It also assists in planning and implementing Environmental Restructuring to promote circular design.

Service Provision enhances Training by offering specific sessions and workshops focused on circular design, improving engineers' skills and knowledge. For Enablement, it provides resources and support, such as access to a database of recycled materials or design tools, facilitating the integration of circular principles into projects. For Modelling, services demonstrating successful circular design examples can inspire and encourage similar practices.

Environmental/Social Planning supports Environmental Restructuring by strategically planning to create environments that foster circular practices, requiring careful coordination among stakeholders. Regarding Enablement, strategic planning reduces barriers and makes resources more accessible, promoting circular design practices through a systematic approach and involving various parties.

Regulation supports Education through mandatory circular design programs , ensuring engineers possess basic knowledge and awareness. For Training, compulsory programs equip engineers with necessary skills, although they may require significant resources and face potential resistance. Concerning Enablement, regulations that facilitate access to resources and support aid in implementing circular design practices, while considering compliance costs.

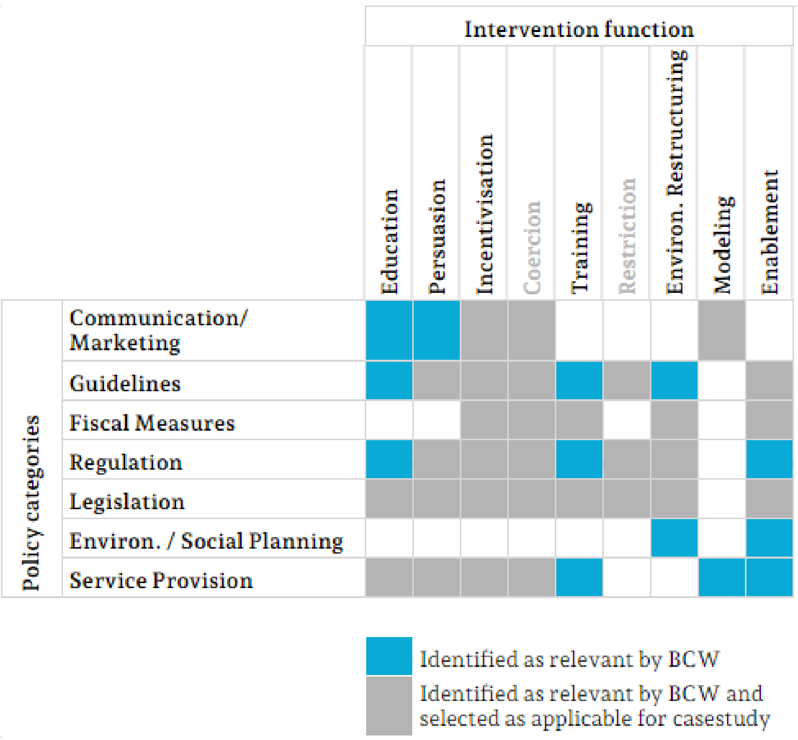

Table 6. Policy categories relevant for identified intervention functions.

4.3 Stage 3: Identify Content and Implementation Options

Step 7: Identify Behaviour Change Techniques

The Behaviour Change Techniques (BCTs) are the active components of behaviour change interventions, which were selected by assessing their fit to the context and culture using the APEASE criteria. This process resulted in 10 promising, 15 probable, and 18 possible relevant BCTs out of a total of 93 BCTs from 10 of the 16 categories of the BCT taxonomy version 1.

The top scoring BCTs with the best APEASE scores are presented in Table 7, while the complete scoring table is provided in the *Appendix: BCTs.*

Table 7. List of BCTs with the best combined score (5) on APEASE-criteria, ordered on taxonomy numbering.

Nr	Label	Acceptabili ty	Practica-bi lity	Effective-n ess	Affordabi-l ity	Side-effect s	Equity
1.1	**Goal Setting (behaviour)**	High	High	High	High	Low	High
1.4	**Action Planning**	High	High	High	High	Low	High
3.2	**Social support (practical)**	High	High	High	Medium	Low	High
4.1	**Instruction on how to perform a behaviour**	High	High	Very High	Low	Low	High
8.3	**Habit formation**	High	High	High	High	Low	High
8.4	**Habit reversal**	High	High	High	Medium	Low	High
8.7	**Graded tasks**	High	High	High	High	Low	High

Considering that Physical Opportunity and Psychological Capability should be the main focus of the behaviour change intervention, Table 8 displays the high-scoring BCTs (APEASE score ≥ 3) for Physical Opportunity and Psychological Capability. It is noteworthy that there are relatively many opportunities for enhancing Psychological Capability and few for Physical Opportunity. Both quantitatively and in terms of the content of the BCTs, this suggests that Psychological Capability can be more readily adjusted, while Physical Opportunity may be more challenging to address. As a result, engineers may have higher Capability and thus Motivation, but Physical Opportunity might still be lacking, leading to a potential demotivating effect. This could either result in engineers who are capable and seek out the few available opportunities, engaging in as much circular design as Physical Opportunity permits, or engineers who are capable but remain demotivated due to the low Physical Opportunity. If this trend would be observed or is expected, this could be countered by focussing on BCTs that intervene for a higher Motivation.

Table 8. List of high-scoring BCTs for Physical Opportunity and Psychological Capability

	Label	Definition of BCT	APEASE score
Physical Opportunity and Psychological Capability:			
7.1	Prompts/cues	Introduce or define environmental or social stimulus with the purpose of prompting or cueing the behavior	4
7.6	Satiation	Advise or arrange repeated exposure to a stimulus that reduces or extinguishes a drive for the unwanted behavior	4
Physical Opportunity:			
7.5	Remove aversive stimulus	Advise or arrange for the removal of an aversive stimulus to facilitate behavior change (includes 'Escape learning')	4
3.2	Social support (practical)	Advise on, arrange, or provide practical help for performance of the behavior.	5
7.4	Remove access to the reward	Advise or arrange for the person to be separated from situations in which unwanted behavior can be rewarded in order to reduce the behavior (includes 'Time out')	3
Psychological Capability:			
11.3	Goal Setting (behaviour)	Set or agree on a goal defined in terms of the behaviour to be achieved	5
11.2	Problem Solving	Analyse, or prompt the person to analyse, factors influencing the behaviour and generate or select strategies that include overcoming barriers and/or increasing facilitator	4
1.1	Goal Setting (outcome)	Set or agree on a goal defined in terms of a positive outcome of wanted behaviour	4
2.1	Action Planning	Prompt detailed planning of performance of the behaviour	5
2.4	Review behaviour Goal(s)	Review behaviour goal(s) jointly with the person and consider modifying goal(s) or behaviour change strategy in light of achievement.	4
2.5	Discrepancy between current behaviour and goal	Draw attention to discrepancies between a person's current behaviour and the person's previously set goals	3
2.7	Monitoring of behaviour by others without feedback	Observe or record behaviour with the person's knowledge as part of a behaviour change strategy	3
2.2	Feedback on behaviour	Monitor and provide informative or evaluative feedback on performance of the behaviour	3
1.6	Self-monitoring of outcome(s) of behaviour	Establish a method for the person to monitor and record the outcome(s) of their behaviour as part of a behaviour change strategy	3
9.1	Monitoring outcome(s) of behaviour by others without feedback	Observe or record outcomes of behaviour with the person's knowledge as part of a behaviour change strategy	3
7.8	Feedback on outcome(s) of behaviour	Monitor and provide feedback on the outcome of performance of the behaviour	3
4.1	Instruction on how to	Advise or agree on how to perform the behaviour (includes 'Skills	5

	perform a behaviour	training')	
7.7	**Information about social and environmental consequences**	Provide information (e.g. written, verbal, visual) about social and environmental consequences of performing the behaviour	*4*
8.3	**Demonstration of the behaviour**	Provide an observable sample of the performance of the behaviour, directly in person or indirectly e.g. via film, pictures, for the person to aspire to or imitate	*4*
1.2	**Exposure**	Provide systematic confrontation with a feared stimulus to reduce the response to a later encounter	*4*
8.1	**Associative learning**	Present a neutral stimulus jointly with a stimulus that already elicits the behaviour repeatedly until the neutral stimulus elicits that behaviour	*3*
8.4	**behavioural practice/rehearsal**	Prompt practice or rehearsal of the performance of the behaviour one or more times in a context or at a time when the performance may not be necessary, in order to increase habit and skill	*4*
6.1	**Habit formation**	Prompt rehearsal and repetition of the behaviour in the same context repeatedly so that the context elicits the behaviour	*5*
15.2	**Generalisation of a target behaviour**	Advise to perform the wanted behaviour, which is already performed in a particular situation, in another situation	*4*
8.7	**Graded tasks**	Set easy-to-perform tasks, making them increasingly difficult, but achievable, until behaviour is performed	*5*
1.3	**Credible source**	Present verbal or visual communication from a credible source in favour of or against the behaviour	*4*
1.5	**Pros and cons**	Advise the person to identify and compare reasons for wanting (pros) and not wanting to (cons) change the behaviour (includes 'Decisional balance')	*4*
8.6	**Comparative imagining of future outcomes**	Prompt or advise the imagining and comparing of future outcomes of changed versus unchanged behaviour	*4*
1.4	**Reduce negative emotions**	Advise on ways of reducing negative emotions to facilitate performance of the behaviour (includes 'Stress Management')	*3*
5.3	**Conserving mental resources**	Advise on ways of minimising demands on mental resources to facilitate behaviour change	*4*
13.2	**Framing/reframing**	Suggest the deliberate adoption of a perspective or new perspective on behaviour (e.g. its purpose) in order to change cognitions or emotions about performing the behaviour (includes 'Cognitive structuring')	*3*
9.3	**Mental rehearsal of successful performance**	Advise to practise imagining performing the behaviour successfully in relevant contexts	*4*

To stimulate the adoption of circular design methods at Royal HaskoningDHV, the following combinations of BCTs could be applied, resulting from the previous BCW steps and an APEASE evaluation based on interviews, personal observation and communication. These combinations aim to enhance the capability and opportunity of engineers and provide incentives to translate existing motivation into action.

1. **Practical Training and Instruction**

Inform, educate and instruct through practical training sessions and materials; educate on an action plan for performing circular design behaviour; inform how and where to find guidelines, information and support (BCT 1.4, 4.1, 8.1, 8.7, 9.1).

2. **Collaborative Goal Setting**
   Set or agree on a circular behavioural goal (e.g., applying guidelines from Leidraad Circulair to one design meticulously) and circular project goal (e.g., "deliver at least one design with five innovative circular design options each month") in collaboration with the engineers, rather than imposing goals solely on their behalf (BCT 1.1, 1.3).
3. **Focusing on Committed Clients**
   Prioritise design projects with clients committed to circular designs, who are open to higher-cost solutions or are dissatisfied with traditional designs, thus providing more time, opportunity, open-mindedness, and support for making circular choices (BCT 7.4, 7.5).
4. **Building Expert Support Systems**
   Establish a helpdesk, expert team, or information centre where engineers can obtain practical support for a variety of challenges and questions, and which organises regular in-depth sessions with open invitations, addressing challenging cases in applying circular design methods (BCT 3.2, 6.1, 7.6, 7.7).
5. **Integrating Circular Design Habits**
   Create habits and routine by adding several prompts/cues in the planning and process of projects to prompt circular design and replace traditional design (e.g., circular ambition and brainstorm meetings, document deliverables) (BCT 7.1, 8.3, 8.4).
6. **Sharing Success Stories and Feedback**
   Showcase success stories or give instructive feedback by monitoring and reviewing behavioural goals, project goals and realisations of circular designs (BCT 1.5, 1.6, 2.1, 2.2, 2.5, 2.7).

Practical Training and Instruction increase the Capability, **Collaborative Goal Setting** and **Sharing Success Stories and Feedback** increase the commitment and motivates engineers to apply circular design choices when Capability and Opportunity allow them to, and **Focusing on Committed Clients** improves Physical and Social Opportunity, thereby boosting Motivation to make circular design choices. **Building Expert Support Systems** expands Social Opportunity and aids in developing Capability, and **Integrating Circular Design Habits** changes the environment, thus aiding Opportunity and Reflective

Motivation. Collectively, this approach provides a balanced strategy for enhancing and promoting behaviour across all components of the COM-B framework.
Engineers vary in their roles, work experiences, and personal beliefs. Consequently, in practice, certain components of the six interventions may resonate better than others. It is advisable to implement all six interventions to engage the entire breadth of the department.

Step 8: Identify Mode of delivery

Where the BCTs specify *what* should be done, the mode of delivery specifies *how* these interventions could be implemented and presented to the target group by selecting the appropriate 'mode of delivery' and *who* is responsible or involved, considering the nature of the intervention and the needs of the target group. Reference is made to Table 9 for a briefly described content - delivery mode overview.

Practical Training and Instruction
Interactive seminars and hands-on workshops, featuring initial extended training sessions followed by semi-annual refresher courses, enable engineers to learn through practice, receive immediate feedback, and benefit from peer-to-peer learning. This training should be combined with offering educational material such as online courses, webinars, manuals, guides, and checklists that allow engineers to learn at their own pace and time, and serve as ongoing reference tools during project execution. Expert trainers and experienced colleagues should deliver these interventions, providing credible and relatable insights that enhance the practical training sessions.

Collaborative Goal Setting
To promote commitment and alignment, collaborative goal-setting workshops and team meetings can be organized. These interactive sessions allow engineers to discuss and set clear, achievable circular design goals. The use of printed materials such as manuals, guidelines, and goal-setting templates ensures that these goals are well-documented and accessible. Team leads play a crucial role in this process, guiding the discussions and ensuring that all team members are committed to the established goals.

Focusing on Committed Clients
This objective can be accomplished in two primary ways: first, by strategically seeking out and acquiring more circular projects; and second, by encouraging existing clients to shift their perspective towards a more circular approach. Management is responsible for the

first approach, strategically selecting projects from clients who are already inclined towards circular practices, providing more opportunities for circular design. The second approach can be achieved by circular experts and client relationship managers, who can organise one-on-one meetings and interactive group sessions with clients to discuss the benefits and strategies of circular design. Educational promotional materials, including case studies and detailed explanations of circular design principles, can reinforce client understanding and support decision-making.

Building Expert Support Systems

Establishing a helpdesk or expert team is vital for providing engineers with practical and social support, ensuring immediate access to support and high-level expertise. This expert team could organise weekly online and in-depth sessions for the entire engineering department to discuss challenging cases related to circular design methods, offering supporting engineers through reminders and expertise. Additionally, online helpdesk and support chat platforms (such as those available on Teams), provide convenient access to expert advice and resources. Informational brochures and FAQs can provide quick reference materials.

Integrating Circular Design Habits

To create sustainable circular design habits, it is crucial to integrate several prompts and cues into project planning and processes, which must be supported by management, implemented by project managers, and followed up by engineers. Project management can incorporate these cues and prompts to the planning and process, by adding standard agenda items to discuss circularity, giving frequent reminders to consult the circular guidelines, or expecting a circular deliverable document where engineers outline their circular choices and options. Additionally, organising ambition meetings, strategically planned brainstorm sessions, and ensuring the follow-up and integration of these brainstorm sessions into the design process can help engineers in routinising and integrating circular design methods.

Sharing Success Stories and Feedback

Collaborative goal setting should be accompanied by monitoring and reviewing results, showcasing success stories, and providing constructive feedback on less successful cases to maintain motivation and guide engineers. Team leads and circular experts can monitor progress; team leads can discuss the commitment and set goals in team discussion sessions, while circular experts can review unsuccessful cases and provide individual instruction or address common mistakes and common missed opportunities in training sessions. Newsletters and case study reports highlighting successful realisations of circular design can further inspire and provide practical examples of circular design in practice.

Table 9. Recommended interventions for RHDHV wastewater department with content, delivery mode and involved actors of intervention.

Intervention	BCTs	Content	Mode of Delivery	Involved actors
Practical Training and Instruction	1.4, 4.1, 8.1, 8.7, 9.1	Inform, educate, and instruct engineers on circular design behaviour and provide practical support and resources	Interactive seminars, hands-on workshops, online courses, webinars, manuals, guides, checklists	Expert trainers, experienced colleagues
Collaborative Goal Setting	1.1, 1.3	Set or agree on clear, achievable circular design goals collaboratively with engineers	Goal-setting workshops, team meetings, manuals, guidelines, templates	Team leads
Focusing on Committed Clients	7.4, 7.5	Prioritise and motivate clients committed to circular designs by discussing benefits and strategies	One-on-one meetings, group sessions, educational promo materials, case studies	Management, circular experts, client relationship managers
Building Expert Support Systems	3.2, 6.1, 7.6, 7.7	Provide practical support through a helpdesk or expert team, organising regular sessions to address challenges	Weekly online in-depth sessions, helpdesk, support chat platforms, informational brochures, FAQs	Helpdesk staff, expert teams
Integrating Circular Design Habits	7.1, 8.3, 8.4	Create sustainable habits by integrating prompts and cues into project planning and processes	Project planning prompts, standard agenda items, reminders, deliverable documents	Management, project managers
Sharing Success Stories and Feedback	1.5, 1.6, 2.1, 2.2, 2.5, 2.7	Showcase success stories and provide feedback to maintain motivation and guide engineers	Feedback sessions, review meetings, newsletters, case study reports	Team leads, circular experts, colleagues

4.4 Additional Observations

The above analysis touched upon RHDHV's situation regarding the implementation of circular design. To explore the potential challenges and opportunities for the implementation of interventions in more detail, the following list has been created. This list includes additional observations from the interviews, selected based on their positive or negative impact on the implementation of circular interventions, with potential solutions also derived from the interviews where applicable.

- **Paradox of offering circular design to a paying client requesting a traditional design.**

Royal HaskoningDHV is a profit-driven consultancy firm commited to deliver what clients request. This creates a paradox when RHDHV aims to deliver time-intensive circular designs instead of the traditional low-cost designs clients ask for. This paradox is also evident in the expectations placed on engineers, who are encouraged to use time-consuming circular design methods but are only allowed to log the working hours typical of a traditional design process.

The challenging implications of this paradox are evident in management's approach. Although circularity is a key element of their long-term strategy, they prioritise a profitable, time-efficient, client-driven approach in the short term. However, learning and applying circular design takes more time than calculated, meaning strict monitoring of hours spent seriously hinders the adoption of circularity. Because circular design requires more time initially and remains more time-consuming even once established, spending more time on design is inevitable. Thus, a solution must be found to reconcile the profit motive and the company's sustainable ambitions. Expecting engineers to add extra hours from their spare time contradicts RHDHV's commitment to work-life balance. Standardising circular design to a level that takes the same or less time is not yet feasible. However, given the growing market demand, the ambitions of the Unie van Waterschappen, and the interest from water authorities aiming to implement circular design, it is more likely that clients will pay for circular designs. Alternatively, RHDHV may continue to aspire to design circularly, but full implementation may only happen once it becomes financially profitable.

- **Critical seniors unintentionally discourage juniors from implementing circularity**

  Senior employees, while supportive of circularity, prioritise functional requirements over circular alternatives. This critical stance unintentionally discourages motivated junior employees from advocating for circular solutions to their seniors. Junior employees feel limited in their ability to influence circularity due to their limited responsibilities and client contact. Juniors, motivated by sustainability but inexperienced in incorporating circularity into designs, lack guidance from seniors on effectively applying circular principles and are often taught the design profession traditionally by their circular-critical seniors. This dynamic can significantly inhibit juniors, who start with enthusiasm but become increasingly sceptical and less motivated for circular design due to negative and critical reactions from seniors.
- **Circular Development Team**

The current intention to form a Circular Development Team (NL: Circular Kernteam) consisting of motivated and interested employees who can promote circularity within the department presents a challenge. Seniors possess the necessary skills but lack optimism and motivation, whereas juniors have the motivation but lack the knowledge and experience. If the team cannot be entirely composed of invested, motivated, and skilled seniors, a possible solution could be to include project managers and juniors tasked with integrating circularity into the process, supported by seniors who can provide content expertise when needed.

- **Complex client attitude**
  Clients often express a desire or demand for circular solutions due to legislative pressure but are unwilling to pay extra and do not want to compromise on other requirements. Furthermore, the client's decision is not solely objective but also subjectively influenced by a preference for familiar, conservative choices and the needs of the Maintenance department. Other reluctance stems from higher costs, unnecessarily high functional requirements, and a preference for new over second-hand items. Recycling and material prevention lack prestige for water authorities, and biodegradable materials are seen as costly. The only real undisputed advantage of circular design is sustainability, but the extent to which this is prioritised varies among and within water authorities.
- **Clients are essential, but may be strategically selected and influenced**
  In projects where circularity has been successfully implemented, the water authority initiated the effort. RHDHV generally follows a client-driven approach, delivering what the client wants and pays for. Currently, in a supply-demand-driven market with more projects than employees, there is an opportunity for selective client choices. If selecting clients with a circular mindset is not possible, efforts should focus on engaging clients with circularity through active education, promotion, and tactical advice during the Multi-Criteria Analysis (MCA), while also addressing any objections from the Maintenance department.
  Clients are free to make subjective choices that may not rank highest in the MCA, which means they might opt for a more circular design, even if it seems illogical compared to the initial Programme of Requirements (PoR). However, engineers typically aim to create designs that perform well according to the PoR and the MCA, leading to unnecessary compromises on circularity without consulting the client on their openness to modifying the MCA or incorporating subjectivity into the design selection.

By recognizing that clients do not always make rational decisions and incorporating both the consequences and opportunities of this behaviour into the process, an approach can be adopted that aims to ensure the client ultimately opts for and pays for a more circular design.

- **Varying perception on MKI-tool.**
  The level of detail required in MKI calculations and their perceived value varies among employees. Some interviewees find detailed MKI insights motivating, others believe it enhances their capability, and still others see them as a way to overcome client-related obstacles. Currently, the MKI tool is not used by engineers, and the assumption that an MKI calculation tool would save time is incorrect since engineers are not investing any time in these calculations at present. Consequently, introducing a tool would actually increase the time spent on MKI calculations, and structural time-investment is considered a drawback. Therefore, before developing an MKI tool, it is crucial to determine the purpose of the MKI calculations, the necessary level of detail, whether the tool should be used by a single expert or all engineers, and its usability and comprehensiveness.
- **Irritation and confusion on old practices rebranded as new**
  The perception that circularity is merely old practices repackaged as new creates scepticism. This is especially true when traditional resource management practices are promoted as innovative circular solutions. The terminology also causes confusion as some engineers are proficient in reuse but lack skills in material prevention or biodegradable materials. This makes it challenging for them to identify whether they are unconsciously competent or consciously incompetent in circular design principles. A possible solution is to distinguish between two types of circularity: old-fashioned circularity, encompassing well-known practices such as reuse and recycling, and innovative circularity, which involves new practices like designs incorporating second-hand parts and biodegradable materials.
- **Misunderstandings about the term 'circularity'**: The term 'circularity' is often misunderstood to mean only recycling. Many employees are unaware that it also includes reducing material use and using biodegradable materials. A comprehensive training program should therefore cover everything from the basic definition and philosophy of circularity to advanced design principles, in order to adequately train engineers in circular design. This thorough training could be very time-consuming and may take several sessions to complete.
- **Costs as a double-edged factor**: Costs can act both as a driver and a barrier to circularity. While initial investments in circular designs might be higher due to the

necessary research and development, the long-term potential for cost savings through reuse and material reduction can be significant.

- **Lack of internal discussion on circularity**
  Although circularity is a management priority, it is rarely discussed among engineers and project managers. This lack of frequent questioning and discussion on the work floor hampers widespread adoption and action, leaving the definition and philosophy of circularity, ambition of RHDHV, and the status, implementation, adoption, and feasibility of circular design open to interpretation among employees. Clear communication can help correct assumptions and eliminate unspoken misunderstandings.

5. Discussion

This thesis focused on the challenge of integrating circular design principles within wastewater engineering consultancy firms, specifically focusing on enhancing circularity practices within these firms, with a specific case study on consultancy firm Royal HaskoningDHV. The research uncovered barriers and facilitators to implementing circular design and recommended strategic interventions. This discussion encompasses the study's findings and interventions, methodology, implications, limitations, and suggestions for future research.

5.1 Interpretation of Results

The study found that while engineers at RHDHV possess a general awareness of circular design, a significant gap exists between this awareness and the actual implementation of circular design principles. Primary barriers identified include insufficient knowledge and clarity about circular design, conflicting technical and functional requirements, lack of client support, conservative preferences for traditional designs, and perceived higher costs associated with circular options. Conversely, facilitators encompass the positive moral perception on circular design, client ambition to be sustainable, recent internal circularity workshops, and the heightened emphasis on integrating sustainability ambition sessions within projects.

An interesting pattern in the data reveals that while there is a desire to incorporate more circularity in design, there is a lack of confidence in its feasibility or the ability to apply it. Awareness of circular design and moral motivation are high, but practical action and implementation are low. This pattern is confirmed by the BCW analysis using the TDF framework, which highlighted low psychological capability and physical opportunity, alongside dual reflective motivations: high moral motivation, but low confidence and optimism. Interview data suggest that engineers are willing to design circularly but lack the necessary knowledge, skills, resources, and support. This conforms to the COM-B model's assertion that without sufficient opportunity and capability, both motivation and execution of target behaviour are low as well. Alternative explanations for the findings regarding positive motivation include the possibility that engineers might overstate their willingness to adopt circular design due to the organisation's recent emphasis on circularity and sustainability. Moreover, the perception and engagement regarding circularity has been extensively questioned in the interview by using the adapted AIDA model which effectively inspired participants and provided them with the vocabulary to articulate their positions on circular design, leading to more detailed, accurate and specific insights.

A significant barrier in the application of circular design principles is the lack of knowledge and clarity about what circularity entails and how it can be applied. Interviews consistently underscore that engineers are not sufficiently familiar with the principles and practical applications of circular design. The cruciality of this barrier is in line with the perspective of Bransford et al. (1999) that expertise cannot develop without a deep understanding and the ability to flexibly apply knowledge in new situations. RHDHV's decision to organise educational workshops is commendable. However, from an outside perspective, it seems that other significant barriers are receiving insufficient attention.

Another substantial barrier is the difficulty of combining highly technical, functional, and budgetary requirements, comfort and conservative preferences with circular design principles. Both clients and engineers highly value well-proven, reliable, and functional wastewater treatment systems, which can be challenging to achieve with circular components and materials. This raises serious doubts and scepticism among engineers about whether circular designs can convincingly meet the same high standards as traditional designs, demotivating engineers to either persuade the client to re-evaluate the comfort and budgetary demands or invest time and effort into developing viable circular designs. Given RHDHV's ambition to deliver more circular designs and the efforts already put into organising workshops, it is advisable to persevere and address other aspects recommended by the COM-B model. Intervening on the opportunity component is crucial, as engineers, despite gaining knowledge and skills from workshops, will remain constrained and demotivated in applying them. This could result in the workshops fall short of achieving their intended effect, leading to minimal adoption of circular design practices.

The BCW framework was successfully applied to identify effective interventions, such as education and training to enhance Psychological Capability, environmental restructuring to improve Physical Opportunity, and using persuasion and incentivization to boost motivation. The proposed interventions—such as practical training, collaborative goal setting, focusing on committed clients, building expert support systems, integrating circular design habits, and sharing success stories—are designed to address these barriers comprehensively. In practice, given the diverse roles, work experience, and personal beliefs among engineers, some interventions may resonate more than others. Nevertheless, the combination of these six interventions covers a wide spectrum and can effectively engage the entire department.

5.2 Implications

The findings of this research hold significant implications for engineering firms and policymakers striving to enhance circular design practices. The study confirms the efficacy of the Behaviour Change Wheel (BCW) in formulating interventions and reinforces existing knowledge on behaviour change in the context of circular design. This highlights the crucial role of targeted interventions in promoting circular practices. Furthermore, practical insights gleaned from applying the BCW framework in engineering contexts offer a deeper understanding of internal and external factors affecting circular design adoption.

5.2.1 Theoretical Implications

This research represents a substantial contribution to the field of circular design within engineering consultancy firms by addressing a notable gap in applying the Behaviour Change Wheel (BCW) framework to formulate effective interventions. Beyond validating BCW's efficacy in formulating interventions, the study enhances understanding of behaviour change principles within engineering contexts. It underscores the importance of integrating circular design principles at every stage of the design process, from initial project planning to final implementation. Moreover, this research highlights the critical role of client engagement, emphasising the necessity for engineers and project managers to be equipped with persuasive tools and training to guide clients toward circular design choices. This resonates with existing literature on sustainability, which advocates for comprehensive and integrated approaches to overcome barriers and promote circular design adoption. The findings also validate the relevance of the COM-B model in understanding behaviour change within professional settings, providing empirical evidence for tailored interventions in various organisational contexts.

5.2.2 Practical Implications

The practical implications of this study are highly relevant for engineering firms and policymakers because identified barriers are addressed through targeted interventions, enabling engineering consultancy firms to more effectively integrate circular design principles into their projects, aligning with sustainability goals and complying with regulatory and client demands. This study highlighted the critical need for creating an enabling environment characterized by clear guidelines, incentives, and robust educational frameworks, thereby enhancing the capability and opportunity for circular design practices.

Moreover, this study contributes to the existing literature on circular design methodologies, as outlined in the "Leidraad Circulair Ontwerpen 2.0" by Circulair Bouwen '23. By utilising the BCW framework to develop various interventions that stimulate circular design adoption, the comprehensive approach helps prevent one-sided and "it seemed like a good idea at the time" type of interventions and ensures that strategies are well-rounded and sustainable. Key recommendations include setting behavioural goals, conducting training workshops, providing practical study materials, and the integrating circularity into project budgets and planning processes. By adopting these strategies, consultancy firms can empower their engineers to adopt circular design methods instead of traditional design methods, thereby enhancing their circular design deliverables and overall sustainability impact.

5.3 Limitations and Future Research

5.3.1 Limitations

While this thesis offers valuable behavioural insights, there are limitations to its generalisability that require further research. Firstly, the research focused exclusively on a single engineering consultancy firm in its case study, limiting the generalizability of the findings. The unique organisational culture, management practices, and client relationships specific to RHDHV may not fully reflect the challenges and opportunities in other firms or sectors. Future research could involve a more diverse range of firms and contexts to validate and refine the proposed interventions.

Secondly, the study relied on qualitative methods such as interviews and thematic analysis, which inherently introduces subjectivity and potential bias. Despite efforts to ensure data triangulation and achieve data saturation, the qualitative nature of data collection and analysis can influence outcomes. Interviewees' awareness of the research' focus might have led to more favourable responses toward circular practices, thereby introducing positive bias. Triangulating these findings with quantitative data or additional case studies would enhance the robustness of understanding and strengthen the conclusions.

Thirdly, while engineers were central to the study given their role in implementing circular solutions, broader organisational factors which facilitate engineers in their work may have been overlooked. The roles of project managers and general management were not extensively explored. Future research with a broader scope could involve applying the Behaviour Change Wheel in analysing management's facilitating behavioural role in providing resources and support for developing circular knowledge and skills, and the project managers' role in actively incorporating circular principles into their projects and client relations. This research could further enhance the effectiveness of intervening to aid circular design implementation.

Fourth, the strong sustainability focus of the firm may have influenced interview responses, by eliciting more favourable answers due to the company's sustainability goals, thus overestimating the actual commitment to circular practices and causing positive bias. Despite efforts to mitigate this effect by applying the adapted AIDA model, prolonged discussions on circularity could have increased participants' awareness and familiarity with the concept, affecting their responses.

Fifth, the study did not address the significant role of technology and digital tools in facilitating circular design and knowledge reuse within the firm. The impact of technological advancements, software platforms, and other digital aids on promoting and applying circular practices was not explored, but could be considered in future research.

Despite these limitations, the findings are deemed to be relevant and valid for addressing the research question on interventions to promote the adoption of circular design. The findings offer detailed insights and a solid foundation for understanding barriers and facilitators to adopting circular design, and offer practical interventions for engineering firms, though implementing these findings in other firms with their unique cultures and contexts requires tailored adjustments. Nonetheless, this research serves as a robust framework and guideline for such interventions. The outcomes offer RHDHV a dependable overview of the situation, barriers, facilitators, and effective interventions, as the methodology and sample size, data saturation, and triangulation, ensures the robustness and reliability of the findings.

Future Research

The findings of this research propose several new research directions in circular design and its integration within engineering consultancy firms. This research showed a need among engineers for proven, functionally adequate circular materials, practical tools and guidelines, a comprehensive overview of viable circular alternatives, and a simplified calculation formula to assess the superiority of circular and sustainable options. Academic research can significantly contribute in developing this knowledge and providing insights and transparency in these areas.

Furthermore, the role of technology and digital tools in promoting and simplifying circular design practices can be investigated, as these aspects were not thoroughly explored and beyond this study’s scope. Future studies should also delve into the roles of project managers and leadership in fostering a circular design environment, ensuring that not merely the engineer exhibits circular behaviour, but the surrounding and facilitating stakeholders as well. Additionally, exploring strategies to enhance client commitment to circularity are also crucial areas for further research to increase overall adoption of circular practices.

To enhance the generalizability of these findings, future research could broaden its scope to encompass a wider range of firms and sectors beyond singular case studies, thereby validating and refining proposed interventions across diverse organisational contexts. Finally, incorporating quantitative data and employing mixed methods would provide a more robust understanding, reducing subjectivity and potential biases present in qualitative research methodologies.

6. Conclusion

6.1 Answering Research Questions

The main research question in this thesis was: *"How can the adoption of circular design in wastewater engineering consultancy firms be enhanced using the Behavior Change Wheel?"* This study identified key findings through sub-questions (i) *What are the existing practices and perceptions of circular design among the wastewater department at case study consultancy firm RHDHV?*; (ii) *What are the barriers and facilitators to adopting circular design at RHDHV?*; and (iii) *How can the BCW framework be applied to design interventions that promote the adoption of circular design?*

Current practices and perceptions within RHDHV's wastewater department vary among engineers, project managers, and management. Circular design is inconsistently integrated into design processes and is often dependent on the ambitions of involved water authorities and the initiative of project teams. Engineers generally acknowledge the importance of circular design and prefer sustainable solutions if those convincingly meet all technical and functional requirements. Yet, the motivation to actively seek out knowledge and apply circular design principles remains low.

Several key barriers impede the adoption of circular design, including a lack of knowledge and clarity about circular design principles, insufficient conviction of technical and functional requirements, client hesitancy, conservative preference for traditional designs, and budgetary constraints. Identified facilitators include circularity workshops, current but limited incorporation of circularity in standard design processes, management ambition, and existing sustainability initiatives. Active client support and creating dedicated time and opportunities for circular design are also critical factors.

The Behavior Change Wheel (BCW) was employed to design targeted interventions aimed at promoting the adoption of circular design principles. This process identified 43 behaviour change techniques (BCTs) with potential positive effects, focusing on the key BCTs deemed to be potentially most effective. Recommended interventions based on the BCW framework include investments in education, training, and study material, creating time and space for circular design, integrating circular design principles into current processes, and providing tools and training for engineers and project managers to effectively advocate circular choices to clients.

The approach utilized in this research effectively addressed the core research question. By combining qualitative methods such as interviews with the application of the

BCW framework, the study provided in-depth insights into barriers and facilitators, resulting in the formulation of strategic interventions. Despite these valuable insights, the study has some limitations, such as the focus on a single consulting firm, potentially limiting the generalizability of the results. Furthermore, this research raised new questions about the balance between sustainable and functional requirements, highlighting the need for further development of practical tools and guidelines.

In conclusion, strategic interventions based on the BCW framework addressing the barriers to adopting circular design in wastewater engineering consultancy firms are effectively formulated. By focusing on education, structural process integration, and client persuasion, firms can stimulate their circularity design practices and contribute substantially to a circular economy. This study underscores the importance of targeted, practical interventions to overcome barriers and enhancing the adoption of circular design, thereby paving the way for more sustainable engineering practices in the wastewater sector.

6.2 Recommended Interventions

The BCW approach identified 43 BCTs with positive effects, however, implementing all 43 BCTs could reduce the feasibility of successful execution. Therefore, it is recommended to prioritise a balanced selection between a realistically achievable selection of BCTs that covers a wide array of barriers. This recommendation to cover a wide array of barriers aligns with the research outcomes and the COM-B model's philosophy, which suggests that capability (investing in knowledge and skills), opportunity (routine in design processes, tools and guidelines, reserved time and space), and motivation (optimism in the feasibility of circular, functionally-adequate designs) all need to be addressed for the target behaviour to occur. Therefore, to stimulate the adoption of circular design methods at Royal HaskoningDHV, the following interventions are recommended.

- **Practical Training and Instruction** - Provide comprehensive training sessions and materials to educate engineers on circular design practices, including hands-on workshops, online courses, webinars, manuals, guides, and checklists, led by seasoned trainers and experienced colleagues to ensure thorough understanding.
- **Collaborative Goal Setting** - Host collaborative goal-setting workshops where engineers can establish clear, achievable circular design goals, using printed materials such as manuals and guidelines to ensure these goals are well-documented and accessible, guided by team leads.

- **Focusing on Committed Clients** - Strategically prioritise projects from clients committed to embracing circular design principles, even if they involve higher costs. Encourage current clients to adopt a circular perspective through personalised one-on-one meetings and group sessions led by circular experts and client relationship management.
- **Building Expert Support Systems** - Establish a helpdesk or expert team to provide engineers with practical and social support. This includes offering immediate assistance and organising weekly online sessions to address challenges in applying circular design methods, complemented by online helpdesk platforms and informational brochures.
- **Integrating Circular Design Habits** - Foster sustainable circular design habits by integrating prompts and cues into project planning. Management and project managers can add these prompts during planning stages, such as standard agenda items for circularity discussions and reminders to consult circular guidelines, supported by regular ambition meetings and brainstorming sessions.
- **Sharing Success Stories and Feedback** - Monitor and review the progress toward circular design goals, showcasing success stories and providing constructive feedback, with team leads and circular experts tracking progress. Review commitments in team meetings, and review unsuccessful cases to offer tailored guidance, enhanced by newsletters and case study reports highlighting successful circular design implementations.

The interventions have been specifically designed for the Royal HaskoningDHV case study; they offer a robust foundation and guideline for circular design implementation interventions in other firms; however, tailored adjustments are required due to each company's unique culture, context and client relations.

6.3 Limitations and Future Research

The methodology employed in this research effectively addressed the research question. The combination of qualitative methods, including interviews and the application of the BCW framework, provided insights into barriers and facilitators, and effectively led to the formulation of strategic interventions. Despite the valuable insights, this study has some limitations, such as the focus on one consulting firm, which limits the generalizability of the results due to Royal HaskoningDHV's specific culture and client relationships. The reliance on qualitative methods introduces subjectivity and potential bias, despite efforts for data triangulation. The focus on engineers may overlook broader organisational factors; future research should include the roles of management and project managers. Additionally, the firm's strong sustainability focus might have influenced interview responses, overestimating commitment to circular practices. Despite these limitations, the findings offer relevant insights into promoting circular design adoption at RHDHV.

This research also raised new research direction regarding the balance between sustainable and functional requirements and highlighted the need for proven circular materials, practical tools, guidelines, a comprehensive overview of viable alternatives, and simplified calculation formulas for assessing circularity and sustainability. Future studies should explore the role of technology and digital tools, and the influence of project managers and leadership on fostering circular environments. Investigating strategies to enhance client commitment to circularity is also essential. To improve generalizability, research should include diverse firms and sectors, and use quantitative and mixed methods to provide a robust understanding and reduce subjectivity.

In conclusion, this thesis has successfully formulated strategic interventions to address barriers hindering the adoption of circular design in wastewater engineering consultancy firms, guided by the BCW framework. By focusing on education, integrating structural processes, and influencing client perspectives, organisations can foster their circularity design practices and contribute to a circular economy. This study underscores the importance of targeted, practical interventions in overcoming barriers and promoting the adoption of circular design, thereby paving the way for more sustainable engineering practices in the wastewater sector.

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