TU DELFT CIRCULAR CAMPUS IN 2030

Interdisciplinary project group - MSc Industrial Ecology
February 2018

Carina Harpprecht- 1960717
Coen de Vos- 1262122
Leonardo Melo- 1940988
Micky Schepers - 1812203

Universiteit Leiden

INDUSTRIAL ECOLOGY
INNOVATIVE BY NATURE

TU Delft

Disclaimer and Policies

Table of contents

Contents

List of Abbreviations

BAU - Business as usual
CE - Circular Economy
CEI - Circular Economy Index
EC - European Commission
EPR - Extended Producer Responsibility
EoU - End-of-Use
EUR - Erasmus University Rotterdam
EWI - Elektrotechniek, Wiskunde en Informatica
IE - Industrial Ecology
FM - Facility Management of TU Delft
HEI - Higher Education Institutions
IPG - Interdisciplinary Project Group
LCA - Life Cycle Analysis
MFA - Material Flow Analysis
MIPS - Material Input Per unit Service
MLCM - Material Life Cycle Management
MSW - Municipal Solid Waste
PA - Priority Area
PMD - Plastic Metal Drinking cartons
PRM - Primary Raw Material
PSS - Product Service System
SRM - Secondary Raw Material
UBC - University of British Columbia
WF - Water Footprint
WtE - Waste-to-Energy
WUR - Wageningen University & Research

Table of Figures

List of Tables

About this Report

This report was commissioned by Dennis Meerburg, a project manager of the Campus and Real Estate department of TU Delft. It was supervised by Dr. Leendert Verhoef, Sustainability Innovation Program Developer at the Green Office of TU Delft. Additional guidance was provided by students from the TU Delft Green Office.

The work is executed by a multidisciplinary group of four Master students of “Industrial Ecology”: Coen de Vos (Dutch, B.Sc. Biology), Carina Harpprecht (German, B.Sc. Engineering Science), Leonardo Melo (Portuguese, MSc. Sustainable Energy - Thermal Energy) and Micky Schepers (Dutch, B.Sc. Industrial Design). It represents a 12 ECTS course called “IPG”, Interdisciplinary Project Group, which is a core course of the curriculum of Industrial Ecology, a joint programme by Leiden University and TU Delft, The Netherlands.

The project was commissioned due to a new waste tendering process for the TU Delft in 2020. Thus, its initial aim was to give guidance for future decisions regarding waste handling systems on campus. However, the overarching question was how TU Delft should approach their intention to become a “Circular Campus in 2030” as voiced in the TU Delft strategic framework 2016-2020. However, due to the fact that no general sustainability nor circular campus plan has been developed so far, we saw the necessity to create a holistic baseline taking into accounting both the whole system of TU Delft and the entire concept of Circular Economy. For the intrinsic approach of Circular Economy and of the field of Industrial Ecology is to consider whole life cycles instead of focusing solely on individual stages such as waste collection.

Hence this report aims at providing the baseline for future work towards a circular campus at TU Delft. It suggests a division of the complexity of the task into several Priority Areas, of which some selected ones are analyzed here, amongst others material based priority areas to support future decision-making of the waste tendering in 2020.
Furthermore, recommendations are given how to proceed or where to focus on in a continuation of the project.
Since the report aims at facilitating future work and at serving a broad range of stakeholders, it is organized and written with the goal of being accessible and communicative to people with different backgrounds and goals while still complying with scientific standards.

Ultimately, we would like to thank our supervisor Dr. Leendert Verhoef and our commissioner Dennis Meerburg for their invaluable inputs and interesting conversations reflecting our ideas. Additionally, we express our gratitude to Dr. E.G.M. Rene Kleijn, Director of Education M.Sc. Industrial Ecology, for his great guidance and support during our project. Finally, we would like to thank the Green Office of TU Delft and all our interviewees for their time, efforts and openness towards our questions. This applies especially for Michiel Faber, who spent several hours with us explaining the waste collection system of TU Delft.

Leiden, June 13, 2018

Executive Summary

Circular Economy (CE) has been gaining traction as an alternative for the traditional produce-use-dispose economic system, with the potential of alleviating virgin material use and environmental impacts. TU Delft recognizes the potential for this concept, and has articulated the ambition for a circular campus by 2030 in the TU Delft Strategic Framework 2018-2024. This report discusses the findings of research into how this ambition could take shape and addresses the following question:

How can TU Delft as an educational institution implement the principles of CE in order to reach its circularity target by 2030?

In order to answer this question, a number of sub questions were posited. These were:

What are the principles of CE, and how do they apply to the TU Delft as a system?
What is the CE context and what does a vision for TU Delft look like?
Into which Priority Areas can future work for a circular campus be structured in order to facilitate a CE transition?
What is the current situation of selected Priority Areas, what are best practices of other universities for them, and which measures are required to realize the implementation of those within TU Delft's roadmap to circularity?
How can the circularity performance of investigated material based Priority Areas, Priority Area I and II, be measured in order to include them in a monitoring system?

A four-step framework was developed to answer the sub questions and develop a roadmap towards a circular campus by 2030. The first step consisted of desk research, in which the concept of CE is explored further in depth and the TU Delft is defined as a system and context variables were compared to those of frontrunner universities. Then, as a second step, the larger CE context of The Netherlands and EU was explored. On the basis of this and conducted interviews nine Priority Areas (PA) were formulated to split up the larger concept of a circular campus. These PAs were: Operational End-of-Use (EoU) Material, Non-Operational Material, Construction & Demolition Material, Energy, Water, Land Use, Transport, Leadership and Communication.

Not all of these PAs were addressed. The third step assessed the current situation of Operational EoU Material both quantitatively and qualitatively, while Non-Operational Material, Leadership and Communication were assessed qualitatively. The results of this step were combined in step four in a roadmap with milestones towards a circular campus by 2030.

Step one clarified that the concept of CE entails extracting maximum value from resources and minimizing input of resources into the economic system, through an overarching waste hierarchy of Reduce, Reuse and Recycle. It also includes using renewable energy, since the ultimate aim is to balance regeneration of natural resources with yields. After that, the system of TU Delft was defined as consisting of two layers, the productive (which produces research and education) and supportive (which provides services such as cleaning and catering), with

the supportive layer producing most material input and output. Analyzing and comparing the context variables of TU Delft and frontrunners Wageningen University and Research center (WUR) and University of British Columbia (UBC) revealed that timing and opportunity, strategic vision & governance and waste logistics were the most influential differences between these universities and TU Delft.

Analyzing the larger CE context of The Netherlands and EU in the second step showed how the ultimate goals of TU Delft and these institutions align, providing opportunity for synergistic cooperation. As mentioned before, combined with stakeholder interviews this lead into the definition of PAs. From this, we established a vision for the TU Delft, in which it uses its strengths to take the lead in the transition to CE, and sets an example for other universities with regards to campus circularity.

Having performed step one and two, the report goes on to describe the current situation of Operational Material in TU Delft. Operational Material is defined as consisting of paper & cardboard, plastic, metal & drinking carton (PMD), coffee cups, organic waste, swill and residual waste. It was established through interviews that residual waste can only be incinerated, and is thus per definition not a potentially circular flow. From the data emerged that Operational Material is the largest material flow through the TU Delft system, and that currently only paper & cardboard and residual waste make up significant shares of this flow because of current separate collection.

The relative fraction of paper & cardboard seems to have dropped significantly (ca. 10%) between 2010 and 2017, while the relative fraction of residual waste has increased with about the same percentage. Whether this is due to less paper use or less efficient paper collection is currently not entirely clear. The per Full Time Equivalent (FTE, including students and staff) paper waste generation has decreased from 18 kg to 11 kg, possibly explaining the relative decrease. However, less efficient paper collection might also explain the corresponding relative increase in residual waste.

A Living Lab study by Jan Henk Welink at the faculty of 3mE, combined with the achievements of WUR revealed the potential of separate organic waste and swill collection to increase from 0% to 32%, thereby decreasing the relative share of residual waste. From the best practices it further emerged that large scale on-site composting is frequently done by other universities, and from an interview with compost experts it became clear that this presents a strong economic opportunity. PMD, however, presents a tougher challenge as the Afvalfonds Verpakkingen forces private waste processors to charge higher prices for separate processing.

A set of potentially useful indicators was then proposed, consisting of Material output per unit of science (MOUS), Material output per graduate student (MOGS), Product-level circularity metric, Net recycled content (NRC), Material Circularity Indicator (MCI), Operational EoU material footprint, Organic EoU material footprint, Residual EoU material footprint, PMD fraction footprint and Paper footprint. Three scenarios (Business as usual, Best practices and

Frontrunner) were sketched along these indicators on the basis of potential interventions, and an extensive list of Living Lab experiments was proposed to achieve these scenarios.

The next PA that was discussed is Non-Operational Material. This was defined as material with a longer lifespan that is owned by the TU Delft, such as furniture and electronics. The stakeholders throughout the life cycle were analyzed and turned out to be Commissioning, Procurement, Users, Facility Management & EoU collection, Waste management on campus and Waste contractor, chronologically. It became clear how Commissioning is bound by EU tendering regulations and how this prevents using innovation developed on campus and limits choice in circular products or services. Furthermore, the fragmented stakeholder networks appeared to result in a lack of common vision and results in gaps in responsibility. Another bottleneck, for waste management on campus, turned out to be the amount of dedicated space for waste storage and the issue of ownership. Concluding, four main issues were uncovered, the first being a lack of communication and organization due to departmental structure, second being a lack of dedicated departments for CE principles, third being obstacles in the form of regulations and fourth being a lack of guidance and decision support.

Having observed these issues, our proposal was to establish a Material Life Cycle Management department, with its main tasks being facilitation of communication & collaboration between departments, provision of top-down guidelines, management of CE dedicated departments, coordination of bottom-up projects on campus, monitoring of performances with the help of indicators and allocation of financial assets. We further observed from best practices of other universities that the Warp-It platform has been well established as a sharing platform for used material, to promote reuse. We thus recommended to implement this.

The last two analyzed PAs were Leadership and Communication. These were analyzed in less detail and still need deeper research. Leadership was argued to consist of Research, Education and Valorisation. Research on CE is already well established at TU Delft, but for Education we argued that TU Delft could take Kolb's experiential learning styles more into account, by involving students in CE measures or by setting up challenges. For Communication we encountered some difficulty in finding communication with regards to sustainability in general in the TU Delft, and therefore recommended to create a general communication strategy for CE throughout the TU Delft.

The recommendations per PA can be found at the end of each PA chapter. These shall serve as guidance, how the results of the analyses can be implemented in the future, and where future research can build on.

Ultimately, we concluded that the PAs which could not be investigated as part of this project should be analyzed by future project groups or can serve as thesis topics, i.e. Construction & Demolition Material, Energy, Water, Land Use, and Transport. Generally, more research is needed to bring about a transition towards a circular campus. There is a high potential to apply the Living Lab approach as well, for instance in the planned Echo building, to facilitate further implementations of circular practices. Thus, we recommend to actively promote these opportunities for further student projects on the topic of a circular TU Delft, to support a transition.

Introduction

In the last decades, the rapidly increasing anthropogenic impacts on the environment through industries and current lifestyles have been moved to the centre of our attention by not only organizations (e.g. the United Nations Environment Programme) and labels (e.g. cradle to cradle (Braungart, McDonough, & Bollinger, 2007)) but also by scientific research (Frosch & Gallopoulos, 1989). Focus has especially put on damages caused by emissions or pollutants such as CO2 (Solomon et al., 2009), Phosphorus (Childers et al., 2011) or plastic waste (Derraik, 2002), as well as on the exploitation of depletable resources (Wellmer, & Becker-Platen, 2002), e.g. of fossil fuels or of scarce metals.

One approach to tackle sustainability issues is the concept of Circular Economy (CE) which aims at minimizing negative impacts of human activity on the environment by optimizing energy and resource systems (Lonca et al., 2018). In the last years, a lot of research has been done in the field of CE by academia (Geissdoerfer et al., 2017) as well as by initiatives such as the Ellen MacArthur Foundation, which focuses on the implementation aspects. However, no consensus has been reached so far in terms of specific targets, definitions (Kircher et al., 2017) or assessment tools (Su et al., 2013). While governments continuously set new targets (EC, 2015), the field is rather diverging then converging (Homrich et al., 2017).

In order to support teaching and research on CE, the Ellen MacArthur Foundation cooperates with institutions of higher education, which are so called pioneer universities. Those address CE with respect to four disciplines: business, education, design and engineering (Ellen MacArthur Foundation, 2018b). TU Delft is one of those eight pioneer universities (Ellen MacArthur Foundation, 2018a), and focuses on the area of technical solutions for a transition towards CE.

Besides providing society with scientific studies and with knowledgeable students, universities also play a role in pioneering change by applying novel and innovative principles within their own operations. Thus, in the ideal case, being a leading educational institution includes demonstrating society how to successfully implement results and strategies identified by research into their own daily processes.

In the beginning of 2018 the Technical University of Delft (TU Delft) presented a new strategic framework, formulating its intentions for the coming 6 years. Amongst others, it states:
"*We align our facilities and services to the University's objective of making a [...] sustainable [...] contribution to society, by [...] developing and execute a sustainability plan for a CO2 neutral and Circular Campus in 2030.*"
(TU Delft, 2018b, p.45).

This reveals TU Delft's intention to become a circular campus by 2030, though no sustainability plan has been designed for the campus yet. One main obstacle, why CE principles are currently still at a very low implementation level in case of both governments, and businesses is the multitude of stakeholders needed to collaborate (Lonca et al., 2018). This drastically increases the complexity of the already rather manifold problem.

Some campuses, such as University of Wageningen, Edinburgh or British Columbia are already actively working on the goal of improving their resource efficiencies e.g. through advanced waste collections, zero waste plans or product sharing platforms. However, no university so far has an elaborate plan for a transition to a CE in the near future. In case of TU Delft, the main focus lies on energy technology, specifically on becoming zero energy. Other aspects such as primary material inputs or closing material cycles have not been addressed yet within campus operations despite a wide range of research being done by TU Delft scientists regarding these topics.

This report represents the first of its kind dealing with the issue of TU Delft becoming a circular campus. It addresses the need of developing a plan for TU Delft's strategy to apply CE principles with the aim of being a circularity pioneer. Therefore, the main research question is as follows:

How can TU Delft as an educational institution implement the principles of CE in order to reach its circularity target by 2030?

The following sub-research questions will guide the way towards the main research question:
What are the principles of CE, and how do they apply to the TU Delft as a system?
What is the CE context and what does a vision for TU Delft look like?
Into which Priority Areas can future work for a circular campus be structured in order to facilitate a CE transition?
What is the current situation of selected Priority Areas, what are best practices of other universities for them, and which measures are required to realize the implementation of those within TU Delft's roadmap to circularity?
How can the circularity performance of investigated material based Priority Areas, Priority Area I and II, be measured in order to include them in a monitoring system?

The report is divided into several parts. The methodology explains the method applied for the analysis from Part 1 - 3. Part 1 provides a theoretical background in terms of CE theory, the system definition of TU Delft, and university dependent context variables. This information is then combined in Part 2, which describes how the task of a circular campus can be broken down into nine Priority Areas (PAs). Subsequently, selected PAs are analyzed in Part 3. Per PA this analysis is structured into a description of the current situation, best practices from other universities and recommendations for the future. Lastly, a roadmap suggests measures to take for a transition towards a circular campus. The report finishes with a discussion and conclusion.It is important to note, that not all suggested nine PAs could be discussed within the scope of this report. Therefore, it focuses especially on operational EoU materials via a quantitative analysis and on non-operational materials via a qualitative analysis. Other areas, land-use, leadership and communication are investigated in less detail. This report is aimed at lying a foundation for future projects on circular campuses, therefore, the remaining PAs are to be covered by prospective studies.

Methodology

In order to answer the main research question, how TU Delft can implement CE principles in order to reach its circularity targets, we define a specific framework which is explained in this chapter. Furthermore, we elucidate upon the methods applied within this framework to tackle different analyses.

Framework description

Because of the fact that there are is not existent framework for implementing Circular Economy thinking at a university a framework we developed a framework which is partially based on the backcasting framework by Quist & Vergragt (2006). However, for the sake of ensuring accessibility for a broad spectrum of readers, we purposely chose to make use of our own terminology, and use of a roadmap instead of the transition pathway. Besides, what is new about our approach is the division of the problem at hand into the Priority Areas, suitable for university implementation of Circular Economy, to be tackled independently.

It is important to point out that being an educational institution leads to special conditions and university dependent context variables which need to be considered. Therefore, we define a framework which allows to account for TU Delft's specific situation.

The developed framework is depicted in Figure 1. It divides the report into different parts starting from the left and going to the right: the research phase, the definition of the CE context for TU Delft and a respective CE vision, the analysis of the current situation of each priority area and the strategy for the future and lastly the design of a roadmap to circularity.

In the research phase, three aspects are investigated; firstly the theory of CE, i.e. common definitions and principles of CE used in both academic literature and in business reports such as the Ellen MacArthur Foundation. This knowledge lights the way, in general, on what CE comprises and which principles need to be realized.
Secondly, the system of TU Delft is examined through the lenses of Industrial Ecology system theory and in terms of its functionality as an educational institution. The generally defined CE principles are not directly designed for universities but rather for businesses. Therefore, they cannot simply be copied to any system. To support the translation from general CE theory to the TU Delft, the third aspect, current examples of frontrunner universities with similar goals, serves as a bridge. There are examples of universities that are already working at improving their sustainability performance, which can provide a base from which to work on circularity.

We will research their approaches and results to learn from their experiences to increase the efficiency of TU Delft's transition.

Taking those three aspects in the research phase allows us to proceed to the next phase, part 2, the definition of the CE context specifically for TU Delft. Based on this context we create a vision for the future. The vision illustrates what an ideal circular TU Delft would look like to generate a goal which everyone involved can work towards. For the aim of this project we derive so called Priority Areas (PAs) in order to deconstruct and break down the complexity and broadness of implementing CE. These PAs result from the findings on CE theory, the TU Delft context but also from declarations of the European Commission and the Dutch government. Thus, they can be seen as a recommended categorization for starting and managing the transition process towards a circular campus. However, they should not be seen as the only aspects of a CE transition, but rather as the ones to focus on at the beginning. At a more advanced stage of the transition, they might need to be complemented. Yet, from the current state, they should serve as a guideline to initiate a transition.

The overall aim of the report is to develop a roadmap to a circular TU Delft by 2030, which is the last part. To do so, in part 3, the current status and practices of several priority areas at TU Delft will be analyzed and regarded through the lenses of Industrial Ecology and CE. This implies the consideration of the university dependent context variables and tools from the CE theory, i.e. life cycle thinking and the principle of the circularity ladder. Comparing the current status with the goals of CE and best practices from frontrunner universities, we identify obstacles and aspects which need to be changed for a transition to CE and thus derive recommendations for a future CE strategy. This also includes investigations of organizational and management structures in case of PA II.

Since analyzing all Priority Areas would be out of the scope of this project we focus mainly on the following Priority Areas:

PA I: Operational EoU material
PA II: Non-operational material
PA VIII: Leadership
PA IX: Communication

We decided on these Priority Areas based on both the initial project proposal and our own backgrounds and expertise. Dependent on data and information available these will be analyzed accordingly. The methods applied in this analysis are explained more in detail in the next section.
One goal is to develop a monitoring system using indicators for PA I - VII, however, due to the complexity of this task and time constraints, this will be discussed for only PA I. This monitoring system allows to measure change and thereby encouraging actors to take action. Moreover, it serves as an example for developing monitoring systems for the other PAs.

Using the results from Part 3, Part 4 summarizes the recommendations per PA discussed and combines them into one roadmap. This roadmap provides recommended intermediate milestones per PA which stakeholders in the university can use to guide their steps towards a transition to CE. The purpose of showing the broadness of PAs necessary while only discussing five PAs, is to set the base of future work towards a circular campus. Thus, it shall open the field for future projects on CE at TU Delft.

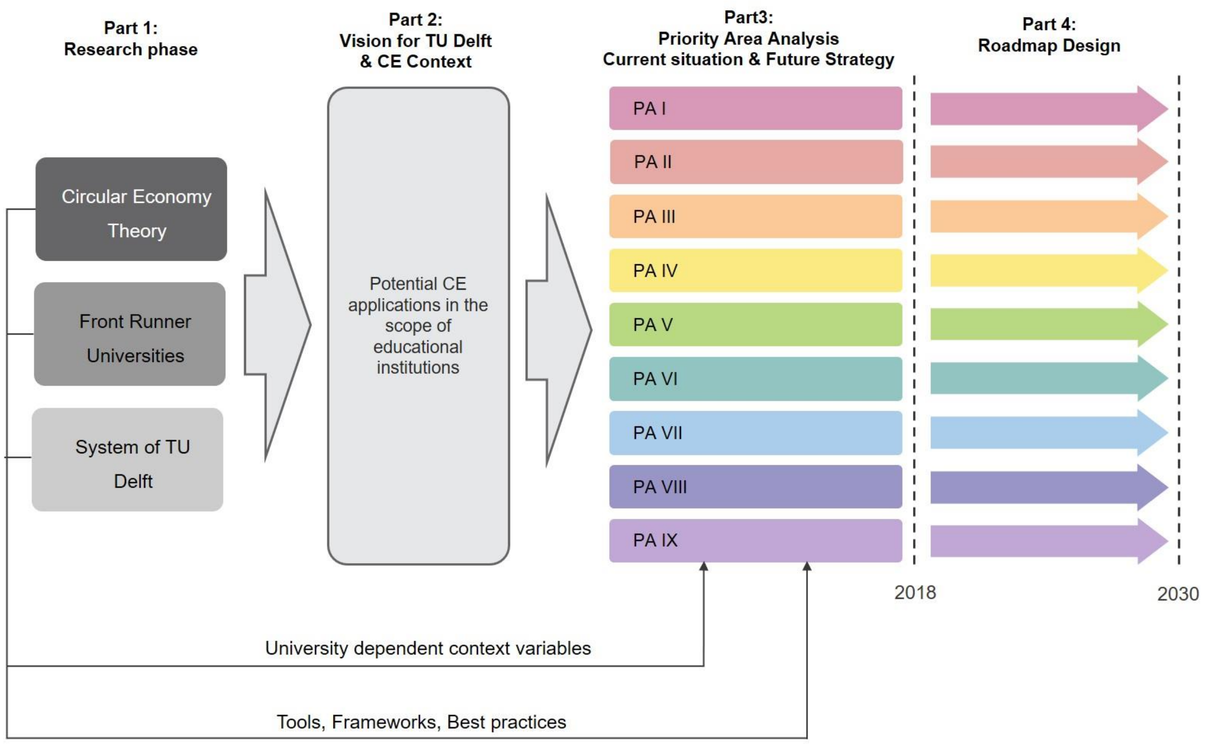

Figure 1: Scheme of the framework applied.

Research Methodology

Depending on the PA, different methods are applied for the phase of acquiring information and for the phase of analyzing the gained insights in Part 3.

Information acquisition

For the information gathering process different methods are applied. First of all a literature review is done regarding sustainable and Circular Economy strategies at universities Literature and further documentation is also found through academic search engines, and through interviewed stakeholders.

In order to ground our research in current realities interviews are conducted with stakeholders from the TU Delft, frontrunner universities and with organizations. The full list of interviews is attached in the appendix (see Appendix A). The stakeholders are interviewed through

"Snowball Sampling" (Biernacki et al., 1981) whereby initially certain essential actors are interviewed who referred us to others we should speak to.

Semi structured interviews are conducted whereby initial questions were drafted but with a fairly open framework which allows for focused, conversational, two-way communication (Jamshed, 2014).

Through the interviews, insights are gained into organizational structures, stakeholder opinions and experiences. This allows to get an understanding of dynamics within the TU Delft and relations between different departments along the life cycle but also between different Priority Areas. Above all, it gives first-hand insights from actors and from frontrunner universities.

Analysis of Priority Areas

When it comes to the analysis of the different PAs in part 3, two main approaches are used (see Figure 2).

For PA I, data is readily available from the department of Logistics and Environment at TU Delft (Renewi, 2018), thus on material outflows from the system of TU Delft. Therefore, a quantitative analysis is conducted and a set of indicators is developed using the index method process developed by Elia et al. (2017). These approaches can show what the current status of End of Use (EoU) material is and what the potentials are within a circular TU Delft. Due to a lack of data on material inputs into the system of the campus, tools such as Material Flow Analysis can, unfortunately, not be applied.

For the other three PAs examined in this report, no quantitative data was available at the time of writing. Hence, the approach is limited to qualitative analyses. This is based on literature research, interviews and best practices from other universities.

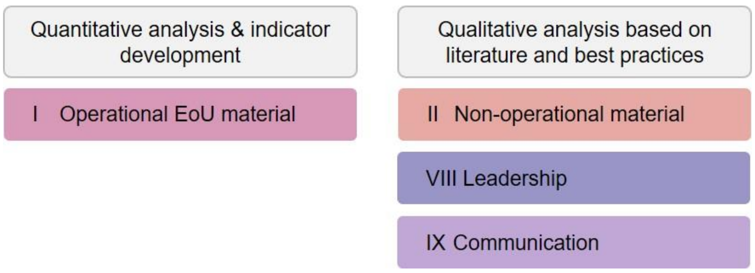

Figure 2: Analysis approaches for the five PAs discussed.

Due to the similarity of PA I, PA II and PA III, we clarify the distinction between the different materials and how they are assigned to the PAs in this report in Figure 3.
PA I comprises day to day waste as it is also created on a household basis. PA II also focuses on materials but contains rather special or big bulk products, such as furniture or electronics,

which are not discarded on a daily basis. Construction and demolition waste in PA III is what applies from the construction, refurbishment or demolition of buildings on campus.
Since TU Delft is mostly a technical campus with laboratories and workshops, additional materials arise from those research activities which are summarized in the category "Others", but not analyzed here due to their rather small share (less than 5% of total EoU material in 2017 (Renewi, 2018)) as well as their very specific, partially hazardous and diverse properties. Thus, intense and time-consuming research with chemical expert knowledge would be required while only tackling a small share of the total TU Delft EoU material stream.

More detailed definition and reasoning for the choice of those categories is given in the respective PA chapters in Part 3.

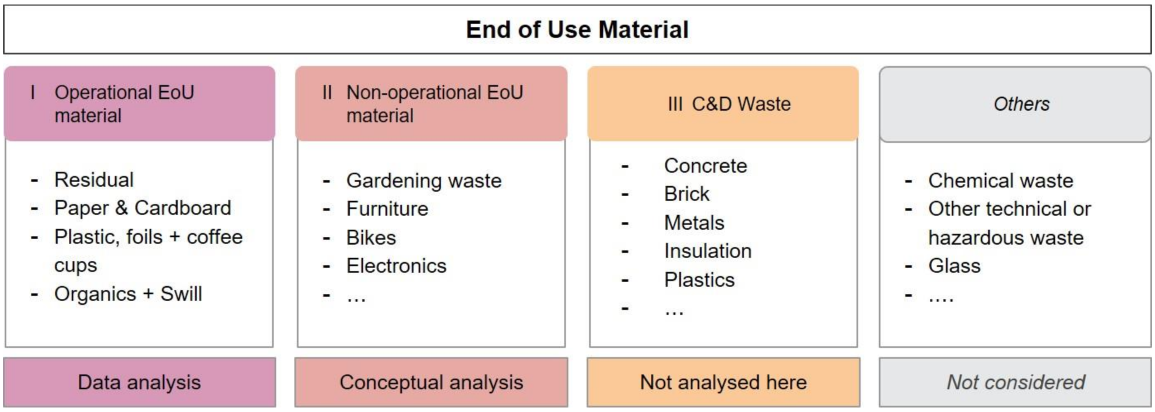

Figure 3: Distinction between the different EoU materials assigned to PAs in this report.

Part 1
Research Phase

1.1 CE Theory

This chapter will introduce the general concept of Circular Economy, and will try to explain what the added value of such a system is. It will also provide a working definition for throughout our report and for future endeavors. The chapter works towards answering the first research question: “What are the principles of CE, and how do they apply to the TU Delft as a system?”

1.1.1 Definition of a Circular Economy

Since its first description, a myriad of definitions of a Circular Economy have popped up in both the academic and mainstream literature. Although most of these definitions more or less appear to revolve around the same ideas, there is a broad spectrum of nuance. Some address social aspects, while others include business aspects or specific environmental issues. Most of this nuance can be explained from the background and intention of the definer. A 2017 paper assessing 114 definitions of Circular Economy aims to find a consensus in the broad diversity of interpretations (Kirchherr et al., 2017).

Although the paper scores definitions to aspects the authors think could be included in a definition, thus leaving out support for potential unknown aspects, it does provide evidence for relative support of the measured aspects. Only 11% of assessed definitions include some articulation of the *why* of a Circular Economy in general, which we thus decided to leave out. In further defense of this, the general relevance of a Circular Economy for sustainable development is addressed in the introduction of this report, and will be further made clear in this chapter.

Next to this, since this report aims to deliver highly applicable advice to the TU Delft, we also aimed to choose a definition that is in line with this goal. Therefore we did decide to include an aspect of *how* this Circular Economy should be implemented. The paper by Kirchherr et al. (2017) does measure the percentage of definitions that include a waste hierarchy (Reduce, Reuse, Recycle, Recover), a strategy posited by the European Union Waste Framework Directive (European Commission, 2008), but the results indicate that definitions in general fail to include the full spectrum of such a hierarchy. One explanation for this could be ongoing debate on the proper wording for such a strategy. For this reason, we include a lower-resolution articulation of the idea of optimal material utilization, and elaborate further on in this chapter how this could look like.

These factors then lead us to use the following definition throughout the report:

A Circular Economy refers to an economic system at micro, meso and macro scale that uses renewable sources for its energy provision and minimizes its virgin material input by closing material resource cycles at their highest possible level of value, through a hierarchy of Prevent, Reuse and Recycle.

In this chapter, we elaborate on what closing material cycles entails in more detail using principles proposed by the Ellen MacArthur Foundation, Circle Economy and De Groene Zaak.

From there, we define the system of the TU Delft on the basis of Industrial Ecology systems theory, and see where these principles apply most.

Micro, meso or macro: The scale of the TU Delft.

Circular Economy can be implemented and studied at several levels of analysis. For example, implementations at micro scale would take place from product component level to the level of medium sized buildings. Interventions at meso scale would encompass large buildings such as skyscrapers up to large industrial parks or city neighborhoods. Everything larger than, such as city, country or international levels would fall under the macro term. Since the campus of TU Delft has the geographical size of a city neighborhood, with the corresponding numbers of students and employees, we consider it to be a meso-scale system. However, we consider subcomponents of the system up to the scale of buildings as micro-scale systems.

Value in a Circular Economy

One of the key aspects of the Circular Economy is keeping products at their highest value, as mentioned in our definition. In Figure 4 this is visualized as the Value Hill as designed by Circle Economy. The Value Hill proposes a categorization based on the lifecycle phases of a product: pre-, in- and post- use (Circle economy, 2016). At the peak of the hill there is a customer whose needs should be fulfilled. The left side shows production or pre-use, where design can have large impact on the lifespan and cycle of the product. The right side shows breaking own of products or post-use, where the aim is to “feed” the product “back” in to the system as high as possible on the hill. Although this visualization of the value hill conveys a product producing company rather than a university, of which the core business is not producing goods but rather education and research, it does give insight into the idea of keeping goods at their highest value.

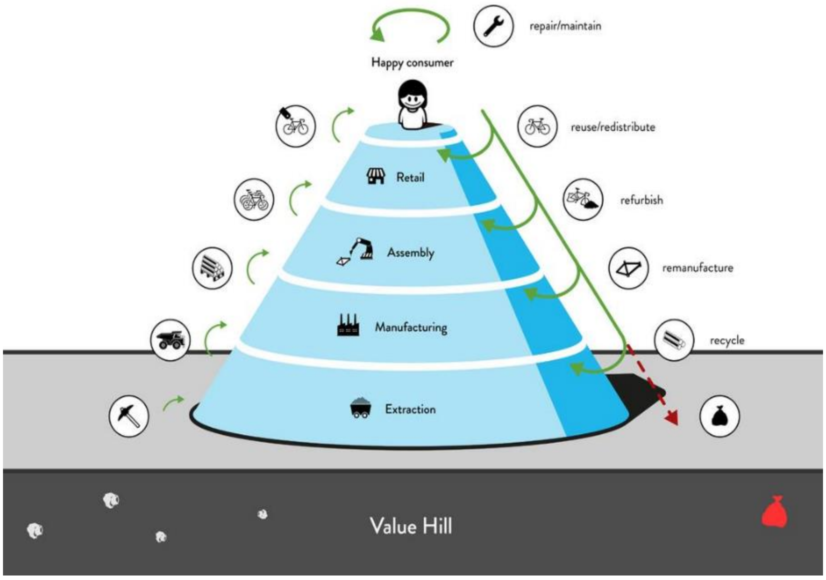

Figure 4: The Value Hill as proposed by Circle Economy (source: Circle Economy, 2016).

The Circularity ladder

In order to achieve keeping products at their highest utility, avoid disposal and ultimately close all cycles, three general strategies should be adopted. These are, in order of favorability, Prevent, Reuse and Recycle.

Prevent - Use less resources to provide the same service, and maintain and repair products in order to prolong their life span.

Reuse - Find new users and uses for products, or take them apart and use the parts that are still of acceptable quality for new products.

Recycle - With recycling only the value of the material is retained. The value that the product had is lost. However, this can provide raw material for new products, thus avoiding the need for extraction of resources from the environment.

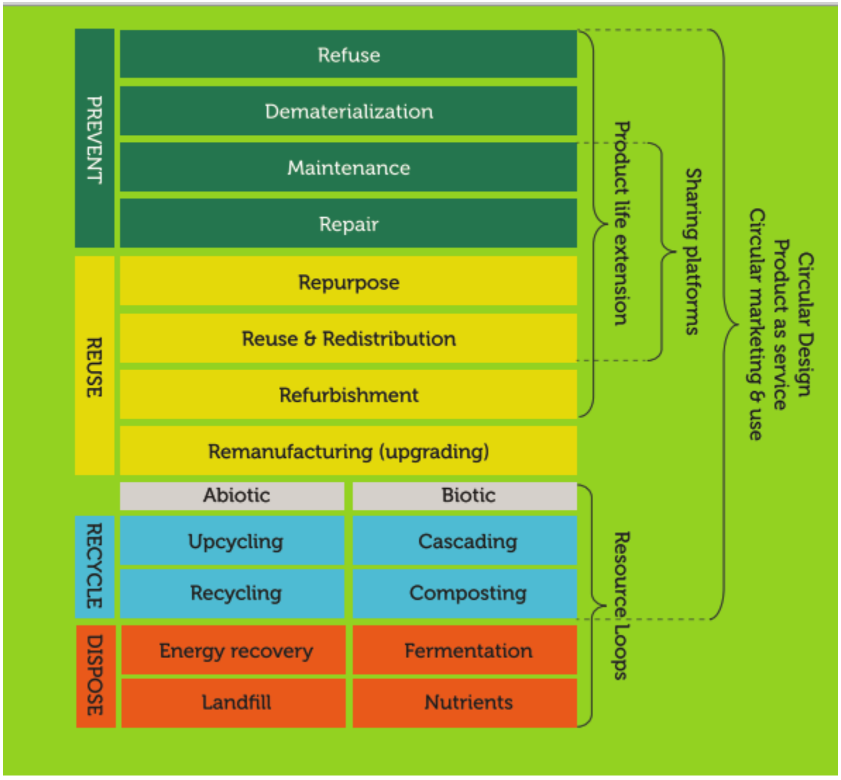

Figure 5: The "Circularity Ladder" as proposed by De Groene Zaak (2015).

Figure 5 further illustrates these strategies in higher resolution and presents economic activities with an increasing "degree of circularity". On the left we see the familiar EU Waste Hierarchy of Prevent, Reuse, Recycle and Dispose. Here, Prevention represents the highest degree of circularity, and Recycling represents the lowest, with Disposal to be avoided. In the middle, each of these stages represent circular activities such as maintenance, repair and refurbishment, and cascading of biomass.

On the right, six circular business models (or strategies) such as Circular Design and Product-as-a-Service are shown that can set these activities in motion.

When looking at the six circular business models we see two important things. First, all business models impact different activities, but some impact a wider range of activities than others. For example, circular design impacts all aspects, whereas a sharing platform does not directly lead to refurbishment or recycling (although it is possible).

Second, some business models are able to achieve higher degrees of circularity than others. For example, using biomass or recyclates as input materials only has a direct impact on recycling – although admittedly they have an indirect impact on prevention of also using virgin material.

1.1.2 Biological and technical cycles

According to the Ellen MacArthur Foundation there are a number of characteristics that are intrinsic to the concept of Circular Economy. Firstly, the distinction is made between biological and technical cycles. The biological cycles cover all cycles which find their basis in primary production by plants through sunlight, with the exception of fossil fuels. This thus includes (among other things) forestry, livestock and crop farming, but also nitrogen and phosphate cycles. Characteristic of these cycles is the short to medium term regeneration speed, which can be supported through processes such as composting and anaerobic digestion. Thus, these resources can be thought of as “renewable”. However, intensive societal demand of them can lead to overexploitation resulting in, for example, soil depletion and biodiversity loss. This in turn can decrease the resilience of the natural ecosystem, decreasing its natural regenerative capacity and future yields. A Circular Economy aims to find the optimum between exploitation of these natural resources and regenerative capacity of the ecosystem. This can for example be done through cascading, in other words, extracting maximum value from a biological product, or feedback processes such as composting or anaerobic digestion (Ellen MacArthur Foundation, 2018c). The added value of a Circular Economy is precisely this fact: ensuring continued economic growth and human development while at the same time managing sustainably managing resources and alleviating environmental pressures.

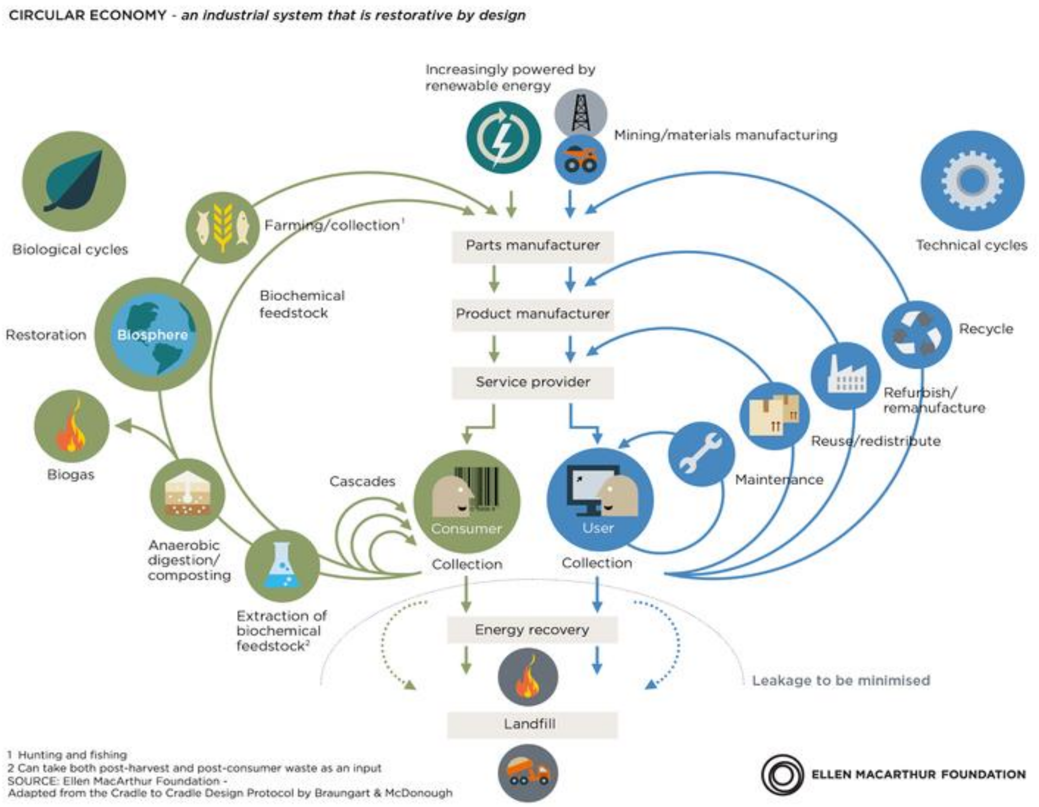

Figure 6: The biological and technical cycles as proposed by the Ellen MacArthur Foundation (Ellen MacArthur Foundation, 2018c).

The technical cycles entail all geological and man-made materials and products, which are characterized by a very small degree of biodegradability and often high levels of eco-toxicity and energy intensity throughout their life cycle. Think of products made with regular plastics, metals and rare earth elements, or other geological resources. These materials generally regenerate in nature through extremely long geographical processes, if they regenerate at all. Therefore, they are often subject to increasing scarcity. A Circular Economy thus aims to “design out” the negative impacts related to the use of these materials by refusing their use, but then tries to keep existing products with these materials in use for as long as possible, and then to reuse, refurbish and recycle them in that order in order to promote the natural regeneration of these materials.

Overarching these two kinds of cycles are a set of general principles that hold for both of them:

"*Preserve and enhance natural capital, by controlling finite stocks and balancing renewable resource flows.*

Optimize resource yields, by circulating products, components, and materials at the highest utility at all times in both technical and biological cycles.

Foster system effectiveness, by revealing and designing out negative externalities (Ellen MacArthur Foundation, 2018)"

1.1.3 Indicators for a Circular Economy

When drafting a long-term plan that aims to achieve circularity at the campus level, indicators are crucial as they are the base to translate outcomes from timely measured actions. In that sense, proposing indicators that are robust enough to grasp the full extent of circularity should be chosen.

Two main assessment methodologies already exist in the "market" for sustainability assessment of campuses: the Dutch based SustainaBul[1] and the international greenmetric[2].

The first one is an initiative from a student association where the main mission is to implement sustainability practices across Dutch universities by making them accountable in a competition environment. Online no information could be found on the assessment other than the information that the assessment is done based on a questionnaire.

The second one takes a holistic approach of all key sustainability areas that can be identified from campus operations: setting & infrastructure, energy & climate change, waste, water, transportation and indicators. Despite the range of reporting items being quite extensive, these are rather simple accounting metrics that look at particular initiatives or per capita ratios of energy and/or water consumption. Greenmetric provides good assessments of elemental sustainability principles which are based on the reduction of different footprints, improvement of green mobility, waste collection and others. Reduction is a step towards sustainability and

[1] http://www.studentenvoormorgen.nl/sustainabul/
[2] http://greenmetric.ui.ac.id/what-is-greenmetric/

resource decoupling but does not give an indication of circularity (even though reduce is the first of the 5 R in the CE).

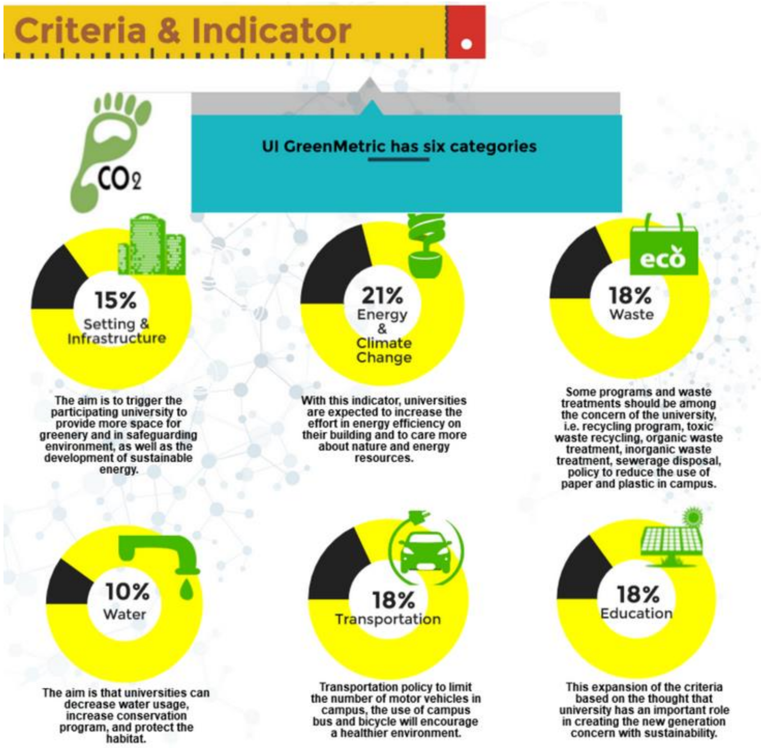

Figure 7: Assessment metrics used by Greenmetrics. From http://greenmetric.ui.ac.id/

Circularity could not be found in any of the metrics compiled by the two leading market benchmarks. This opens up the opportunity for TU Delft to be a pioneer not only at the educational side of the CE but also at the local implementation[3]. The indicators that we propose in the following section take into account circularity as it could be measured in a campus system such as the TU Delft. We do not aim at setting a new benchmark metric like SustainaBul or GreenMetric, the indicators that we have drafted are rather aimed at complementing the current sustainability criteria to assess campuses.

Literature based indicators

In literature there is a myriad of indicators that tries to characterize the functioning of a CE. From monetary to material flows, all indicators seem to approach the CE with one overarching characteristic: how to quantify circularity. Given CE's infant state, it lacks field-proven methodologies/indicators that can be adopted off-the-shelf to any economic actor in our society (Blomsma & Brennan, 2017; Geng 2012). Industrial ecology methods such as Life Cycle

[3] TU Delft is one of the pioneer universities for CE at the Ellen MacArthur foundation. https://www.ellenmacarthurfoundation.org/programmes/education/universities/pioneer-universities/delft-university-of-technology

Assessment (LCA), Material Flow Analysis (MFA) and other accounting/costing principles are all used in trying to quantify circularity. In this section, we will explain our choice of indicators.

Scholars have identified three levels of scale for CE indicators: micro (at the company level and/or product level), meso (industrial cluster, supply chain) and macro (city, province or region) (Pauliuk, 2018). These three levels of scale are the basis for the quantification of the flows that one wishes to assess: mass, energy, monetary, people, etc. For these levels of scale over 300 indicators exist (Pauliuk, 2018) that borrow concepts from energy and material efficiency, life cycle analysis and other scopes of sustainability assessment. These sets of indicators are developed mostly targeting businesses or organizations and in our case are not specific for academic institutions where no economic added value is produced. In our view, the TU Delft fits both the micro and meso levels of scale which makes it challenging to find suitable indicators that could assess performance at both levels. Therefore one should prioritize specific indicators for all levels of scale whether or not these intersect in their scope. Examples are indicators based on material flows within a system.

One of the main objectives of a circular campus is to improve resource productivity and close loops. On this note, we have put our focus in conducting a literature review targeting indicators that characterize material flows in a CE. Resource productivity (GDP/kgin) in our interpretation of a circular campus, means how much material does the TU Delft system require to fulfil its functions while maintaining its scientific output.

Elia et al. (2017) propose that indicators based on material flows should focus on the material input per unit of service (MIPS). The same can be done for water (Water Footprint - WF) and other physical flows. The nuance in the assessment resides on reporting these physical flows with the marginal produced unit of added value of the system. For the case of TU Delft, this is quite challenging due to the lack of knowledge on the input materials - the only quantifiable material flows happen at the level of waste collection. Unit of service in TU Delft, being an educational institution, and following the system definition with the two layers, has been defined as the scientific output produced at the TU Delft. This definition is derived empirically from our system definition where the TU Delft has been divided in two distinct layers.

The Ellen MacArthur Foundation has proposed a similar indicator based on the “fraction of maximum possible effect” principle (Ellen MacArthur Foundation, 2015) which relates to the highest possible yield given known on the inputs of the system, the material circularity indicator (MCI). In this indicator, both the primary feedstock and the EoL stages are characterized based on the recycled content, recycling technology and reusability factors. It is a robust approximation to a circularity indicator but requires full knowledge and disclosure of flows within companies (Pauliuk, 2018).

Micro level indicators like the ones mentioned in the previous paragraph take the physical quantity of material going through the system and assess how much added value was produced from it. Resulting in an incentive to increase the added value per unit of mass or conversely reducing the mass output per unit of added value. For all of these, the principle is in combining mass with added value.

On a meso/macro level, taking monetary units as the indicator value, Di Maio & Rem (2015) have proposed a Circular Economy index (CEI) approach which combines material flows between EoL, recyclers and producers. The logic behind this indicator is the measurement of the recycled EoL materials that have reached the recycling facility over the total material needs to manufacture the same product again. The authors claim that due to market forces, the CEI is more accurate in promoting the supply of secondary materials to producers where recycling rates have failed dramatically to quantify recycling activities (Graedel et al., 2011). For the EC, EoL material that is "sorted", i.e., the efficiency of recycling facilities is not considered.

Another attempt to quantify material circularity has been made by Linder et al. (2017) where the focus is on the circularity at the company level by means of using circulated material in the making of new products. Here, the author shares a similar view as Di Maio & Rem (2015) which is that "our proposed metric requires significant cooperation across the value chain". In other words, companies and private entities must be willing to disclose data for full applicability of such type of indicators.

On a wider macro scale, the EC (2018) has recently published a monitoring framework which includes economy-wide indicators for the implementation and success of a CE. Some principles can also be incorporated at the TU Delft such as the procurement phase in terms of "green procurement" and in developing scientific knowledge to help developing CE.

Figure 8: The CE monitoring framework system. Adapted from EC (2018).

To conclude, many indicators exist that aim at quantifying different levels of scale in material/product circularity. Each of them seems to be tailored with different outcomes in mind. Pauliuk (2018) proposes a robust Circular Economy system definition in his paper that uses an industrial ecology approach to the socio-economic metabolism with processes, flows and stocks. This system depiction is a recurring approach by industrial ecologists to map socio-economic metabolism as a means to model both qualitatively and quantitatively the metabolism of society by means of combining existing accounting frameworks into an overarching system structure (Pauliuk, 2015).

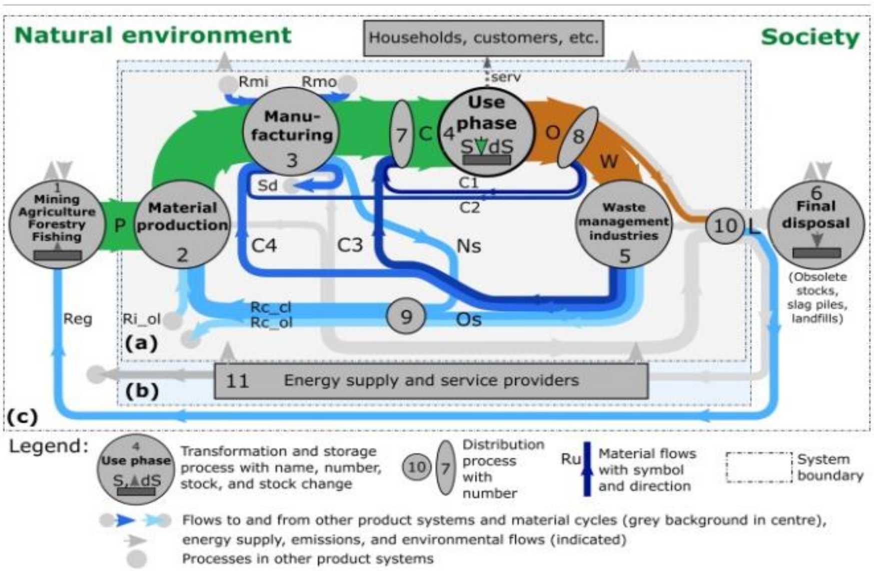

Figure 9: Proposal for a general system definition of processes and material flows associated with Circular Economy strategies in a product life cycle or an organization. From Pauliuk (2018).

It is beyond our grasp to produce such a system-detailed analysis of the TU Delft. Therefore we will restrict ourselves purely to material flow based indicators at a level of scale and scope that allow us to quantify in a scientific way material circularity in campus. This is further elaborated in section 3.1.4

1.1.4 Campus as a Living Lab

The Living Lab concept and the framework "Campus as a Living Lab" (Verhoef, 2018) are valuable tools that can be used to test the circularity interventions further elaborated in this report.

Given the nature of circularity and its similarities with sustainability in terms of cross-disciplinary approach and stakeholders involved, using the framework provided by Verhoef et al. (2018) will be the first stepping stone towards conducting the practical implementation of the circularity ideas developed throughout this report under the form of a Living Lab in Echo in 2020. The correct design of a Living Lab for circularity will be key for the future circularity plans of the TU Delft due to the learning experience that can be obtained from the Living Lab.

Higher education institutions (HEI) across the world are moving towards setting a leadership role in sustainability inside campus by improving the link between operations and research (Verhoef, 2018). To achieve this, localized experiments under the form of Living Labs can be conducted that aim at "advancing sustainability principles across different levels of impact: the HEI's estate and operations; the educational curriculum; across the university and wider community; and society." (Verhoef, 2018). As a practical approach to this challenge, the concept of Living Lab has emerged as a means to test sustainability related ideas to be implemented within the campus system in a cross-disciplinary way that combines all of the scientific community, staff (operations) and students. Verhoef et al. (2018) have proposed the framework "Campus as a Living Lab" that supports the Living Lab experiment in all its life-cycle stages through 7 data collection categories. Each data collection category is tailored to provide guidance on the monitoring, reflections and lessons learned from the Living Lab and finally by sharing the experiences with the world.

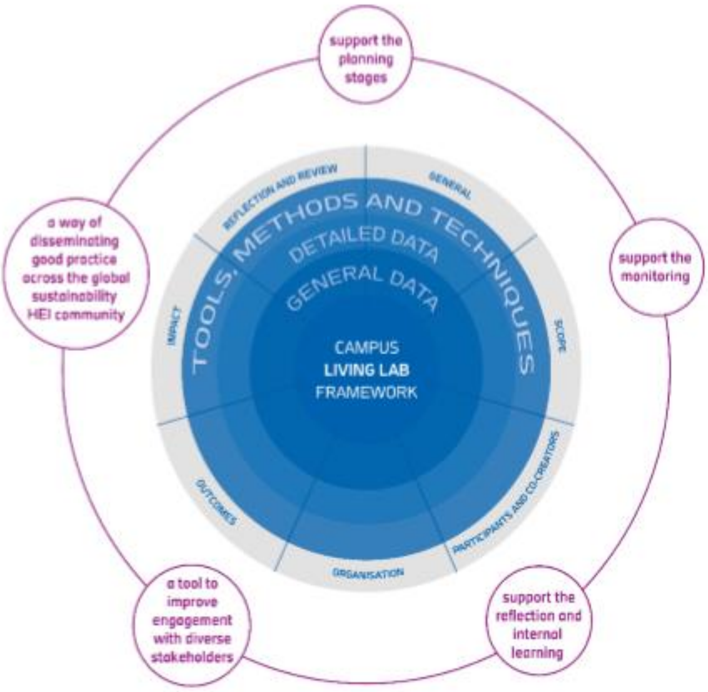

Figure 10: Campus as Living Lab Framework design with its seven categories and five potential values and three levels of detailing and application. From Verhoef et al. (2018).

Many of such Living Lab experiments have already been performed in the TU Delft as shown in the figure below. These include Living Labs on waste & food, mobility & transport, energy, water or smart offices.

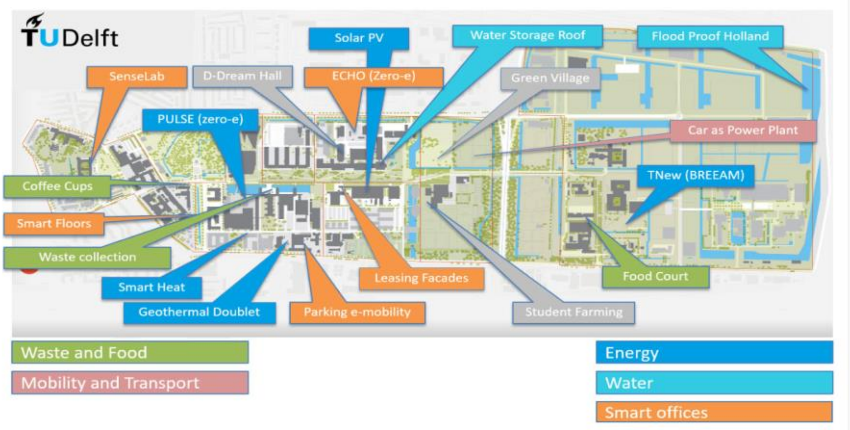

Figure 11: Past and present Living Lab experiments in TU Delft.

More information can be found in the websites of the framework [“Campus as a Living Lab”] or in the Green Office [website] of the TU Delft.

1.2 System TU Delft

The aim of this part is to identify pertinent characteristics of the TU Delft system and qualitatively assess them. To do this we take an IE approach into systems based on a key publication by Lifset & Graedel (2002). An understanding of the system and opportunities and barriers within it is essential to be able to understand the opportunities and barriers in a university setting. From this we can create a vision of the TU Delft system in terms of its inputs, outputs, needed flows and emissions.

1.2.1 System description

Firstly, we describe the campus of the TU Delft applying general system theory borrowed from the field of IE. Since a campus is a very specific case, we will then examine it in detail pointing out its particular characteristics.

General systems theory

Lifset & Graedel's (2015) work describes how to analyze industrial systems through the lenses of Industrial Ecology. They draw an analogy between industrial systems to biological systems, which originates from Ayres (1989) research "Industrial metabolism". This states that the system under study is defined by a boundary and receives inputs in form of material, energy and nutrients from its external environment. Within the system, flows are utilized for the functioning of the system which causes emissions, such as CO2, but also changes their properties. Being processed in the system for various time periods they are released into the external environment again. The crucial point of this system view is the interaction with and its impact on the environment. Therefore, it is essential to analyze the system in respect to its context.

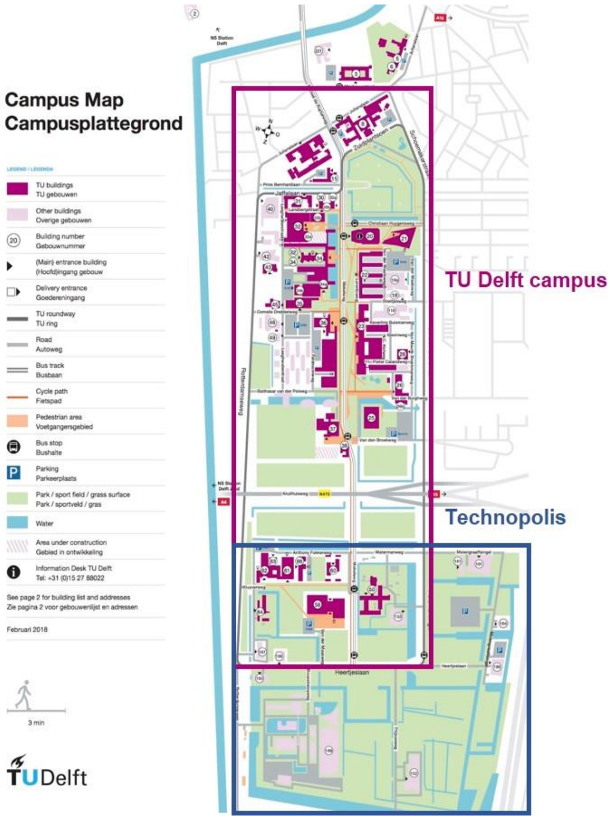

Figure 12: Map of the TU Delft campus with Technopolis. TU Delft Buildings are shown in purple.

Applying this approach to TU Delft, we define the geographical boundary around the TU Delft campus as our system boundary (see Figure 12). As pointed out by Lifset & Graedel (2015) situating the system under study into its surroundings is crucial to assess its impacts but also its context variables.

Figure 13a shows the geographical context of TU Delft. Firstly, the campus is part of the municipality of Delft. Zooming out from here, this belongs to the country of The Netherlands which is part of the European Union and finally the world. Even though this might at the first sight only be seen as a geographical context, it of course also brings factors with it in terms of culture and beliefs, or socio-technical and political aspects. The university dependent context variables will be explained more in detail later.
When locating the TU Delft in the ecosystem, their interactions come apparent in forms of flows. Figure 13b illustrates inputs, outputs and processing of material, energy, nutrients and emissions. In case of the campus material inputs are for instance furniture, building materials, machines, or paper. Energy can originate from renewable or non-renewable sources and can be e.g. sun light, gas, or electricity. Lastly, nutrients are found for example within food, plants or fertilizer. Often nutrients are not in the main focus, but given the relevance of food and green space provision on a campus, we regard it as a vital flow. Different distinction of flows exist,

one could also add water for example. However, this is the most basic categorization of flows in the field of IE, since further categories tend to be a mixture of those three.

As the figure shows, we can distinguish between three flow stages, inputs into and outputs from the system of TU Delft, as well as materials, energy and nutrients cycling within the system boundaries which is also called the consumption phase.
The interaction with the environment and finally their impact are determined by all three flow stages. Therefore, to reduce the campus's ecological footprint, the interplay and interdependencies of flows at all stages need to be taken into account.
How the system of TU Delft is analyzed from the CE view will be explained more in detail in Part II, the CE Scope.

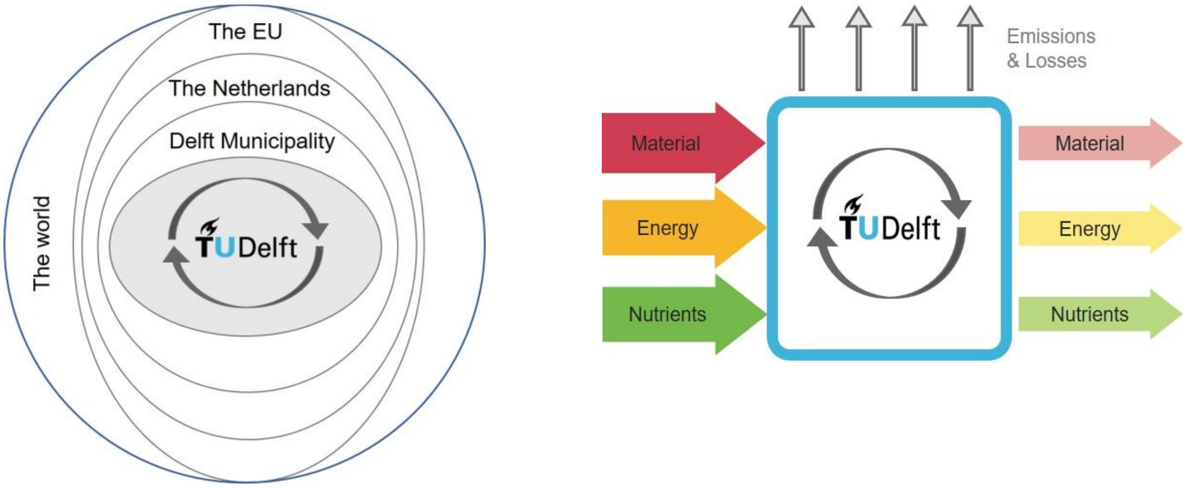

Figure 13: a) The geographical context of TU Delft. b) TU Delft described as a system with a metabolism.

1.2.2 TU Delft as a Socio-Technical System

Besides the perspective of a flow based metabolism system, TU Delft can also be seen from a socio-technical view. Borrás & Edler (2014, p. 11) define socio-technical systems as follows: "Articulated ensembles of social and technical elements, which interact with each other in distinct ways, are distinguishable from their environment, have developed specific forms of collective knowledge production, knowledge utilization and innovation, and which are oriented towards specific purposes in society and economy."

Inspired by the definition above, we have framed the socio-technical system of the TU Delft as a large multi-stakeholder structure where different social networks coexist and align to shape the productive output (added-value) of the TU Delft: graduate students, scientific publications and technology patents. The productive output of the TU Delft needs a supporting layer that consists of different ancillary systems providing services and materials to the upper part of the system as depicted in Figure 14. The inflows to the supporting layer is the required "feedstock" that this layer needs in order to provide services, functions and products to the productive layer. This provision will result in losses such as the down flowing arrows in Figure 14.

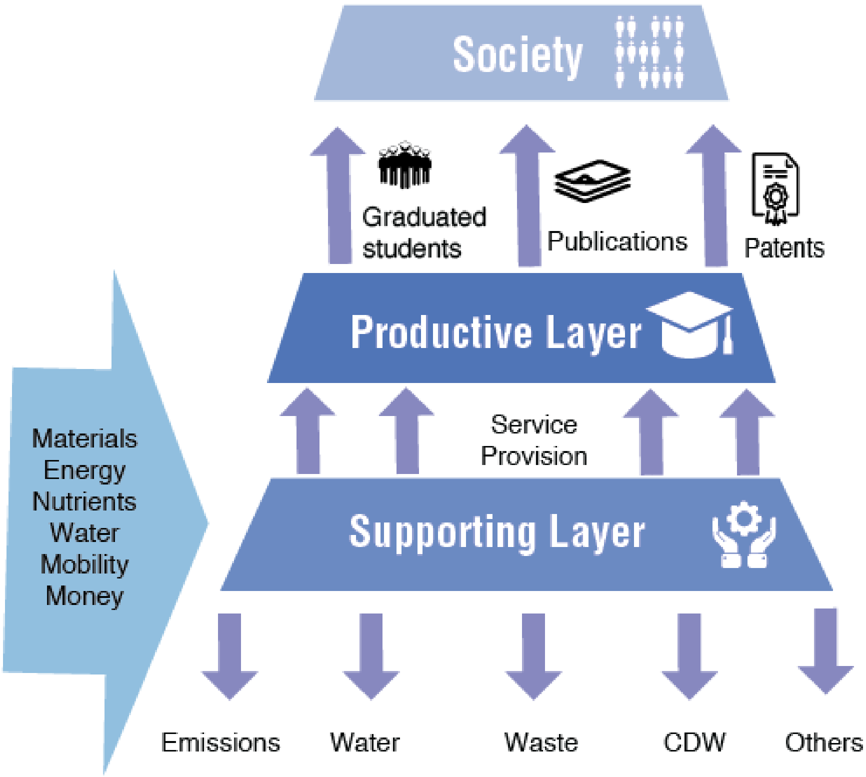

Figure 14: A showing the visual categorization into two important parts of the organizational system.

The nature of this system definition puts added-value output at the level of the productive layer (number of graduate students, scientific publications, patents) while the supporting layer mostly outputting “system losses”.

Nevertheless, there is non-measurable output that can be attributed to both layers such as circular thinking, sustainability practices and general behavior changes in each member of each layer. As an example, if circularity is pioneered in campus under the form of a Living Lab, all the participants are able to learn from the experiment be it students, scientific staff or operational staff. Each of them will have the opportunity of incorporating circular thinking outside of the campus boundaries and make it an intrinsic part of their daily lives.

Supporting layer

In our definition of the TU Delft, the supporting layer consists of the provision of all services and materials that the productive layer requires. These have a large spectrum and can be as diverse as cleaning staff, electricity to power microscopes, bike parking, food outlets, indoor comfort, etc. The diversity of these services and materials are also in turn supported by a huge staff that works together in different departments overseeing different activities/services and material flows. From the management of waste, real-estate, facilities, procurement, etc, all staff in the supporting layer of the TU Delft is employed as if the TU Delft was a company running on a budget and with clear targets. These people in their vast majority do not have a direct impact on the productive layer of the TU Delft (except maybe staff working in labs and the likes). Their function remains to run the TU Delft institution to their best knowledge to achieve the outcomes laid out by the vision & strategy while respecting a budget. This more practical side of the TU Delft is important to understand to be able to draw a line between day-to-day operations and the scientific community of the productive layer.

In terms of the transition to a Circular Economy, the supporting layer has an important role in the transition because it controls most of the key flows that enable the transition such as materials and nutrients. At the same time, with circular thinking and vision, materials and nutrients can stay longer in the system thus extending their service life, which is a key concept of the circular economy. In other words, changes in material and nutrient management at the supporting layer will have marginal impact in the productive layer of the TU Delft given that the quality of the services and materials provided in a circular context remains equivalent to that of the present.

Table 1: Flows within the supporting layer

Inputs	**Outputs**
Staff, materials, energy, water, nutrients, mobility, money, land, etc.	Products and services; Emissions, sewage, water, waste, others.

Productive layer

In a nutshell, this layer is responsible for producing outcomes related to scientific research and graduate students. These are outcomes that can be measured on a yearly basis[4]. To produce such outcomes, plenty of services, functions and materials are need to be provided to this layer in order to ensure that all needs are fulfilled.

To enable a transition to a Circular Economy, the productive layer is as important as the supporting layer. As this is the layer that acts as the demand side in the campus system, material requests, functions or services have to address the needs of the productive layer. As a means to a transition to a circular campus, members of this layer are able to for example request products as services, to request used materials and etc. The effect of this layer should not be neglected in the transition to circularity. Moreover, in the context of a Living Lab the research community can test circularity ideas in-loco and share experiences with the

[4]https://www.tudelft.nl/en/about-tu-delft/facts-and-figures/research/
https://repository.tudelft.nl/islandora/search/?collection=research

operational staff of the campus. Sharing experiences and knowledge helps building strength in the transition to circularity.

Table 2: Flows within the productive layer

Inputs	Outputs
Products and services; Scientific staff, students, outputs	Graduate students, scientific publications, patents

1.3 University dependent context variables

Defining the context in case of a system-wide intervention is useful especially when the intervention intends to replicate best-practices and knowledge from other universities. This is the case when for example other campuses have achieved certain milestones in terms of circularity as it is in the case of UBC's zero waste program. The central question is then: how can the TU Delft implement what works elsewhere? Can it actually be done? Describing the university dependent context variables in play helps in this case to answer these questions.

In the system definition of TU Delft we have already introduced the paradox between the productive layer and supporting layer of the TU Delft. This difference is key to understand the barriers that may hamper the implementation of a CE in campus from a practical perspective. To our knowledge, no campus has implemented a CE strategy to our knowledge and most initiatives hover around zero waste type policies. Despite being closely related, zero waste and CE are two different concepts. We have chosen to define 3 university dependent context variables to put into context what happened elsewhere and what were the driving forces of such changes. Thereby we account for the need to understand the background under which plans are made.

WUR and UBC are mentioned as comparative cases for two reasons. Firstly, WUR has ranked first in the sustainability rankings for campuses across the world and it represents a potential role-model in the context of the Dutch reality (inputs/outputs, behavior, etc.). Secondly, UBC is a campus that has completely overhauled itself when faced with external regulations and thus presents a role model for adapting to change.

1.3.1 University dependent context variable 1: Timing and opportunity

WUR's EcoSmart

The University of Wageningen faced exponential growth of its student population in the period 2005-2017 where its student population tripled to 12,000 students. Bigger student population implied higher amounts of waste generated across campus which tripled in line with the increase in students. This tremendous growth was accompanied with the construction of new buildings in 2007 (Forum) and 2013 (Orion) where the EcoSmart[5] concept was introduced from day 1. Since first-hand implementation is always easier than retrofitting, the two new buildings were the ideal opportunity to start the new separate waste collection not as a pilot but as a new standard process in waste management across campus. If all stakeholders align around

[5] EcoSmart concept is a subsidiary company of Van Gansewinkel.

implementation the new process, success is more likely to take place (Smith, 2005) therefore creating the required legitimacy for the concept to be spread out across other buildings in campus. Since all buildings of the WUR campus are under the EcoSmart concept at this moment in time, this strategy has proven successful (M. Groen, personal email, March 22, 2018). The EcoSmart is not free of charge and it may involve large investments which can amount to several thousands of euros (M. Faber, personal interview, March 16, 2018).

UBC's Zero Waste

In 2010 the UBC was faced with a push from Vancouver's regional authorities to improve the Municipal solid waste (MSW) management system. The targets included (UBC, 2014):

1. Reduce per capita residual waste generation by 2020.
2. Increase diversion rate from landfill to 70% by 2015 and to 80% by 2020.

As part of the vision of the authorities, organic waste within the residual waste stream should be banned by 2015. UBC, being a large producer of organic waste, was legally bound to proactively take a stance in their MSW management.

The legal aspect of the above mentioned targets resulted in the adoption of a long-term view to transform completely the campus by implementing a zero waste plan within 5 years. So far the success has been quite astounding resulting in the accomplishment of the proposed targets of the zero-waste plan although not all targets have been fully reached.
A dual push coming from the legal framework and the vision from the management of the campus have been the driving factors behind UBC's success. A multidisciplinary team was formed and several workshops were held during a whole summer to assess how such a vision could be implemented. The success of the zero waste plan is in part due to this collaborative process (B. Fraser, personal interview, March 23, 2018). The creation of legitimacy from the management was therefore very important.

Contrast with TU Delft

While the TU Delft has experienced constant but much lower growth than WUR in its student population (2-3 % p.a.), the existing infrastructures have more or less adapted in an adequate form to this increase. Notwithstanding, a similar effort like WUR's could have been done in terms of waste management if there had been the willingness from the management structure of the campus.

The TU Delft will have a similar opportunity in 2020 with the inauguration of the Echo building. In Echo[6], a new "EoU material management" concept could be implemented under the umbrella of a Living Lab to showcase a new way of dealing with EoU materials. Timing is relevant because in 2018 already plans have been drafted and storage spaces have been allocated to the facility management. Precisely on the dimension of timing, the PULSE[7] building is a missed opportunity because at the moment of writing this report, all decisions regarding facilities management have been taken and thus steering stakeholders to a new vision would

[6] http://campusdevelopment.tudelft.nl/en/project/echo/
[7] http://campusdevelopment.tudelft.nl/en/project/pulse/

require drastic changes in plans. Therefore, timing is of utmost importance when the opportunity presents itself.

1.3.2 University dependent context variable 2: Strategic vision & governance

Strategic vision relates to the vision laid out by the management of the university which will impact all the people under it. A strategic vision sets the course for a given period on where the university should be and what it should focus on. The importance of the strategic vision in making transitions possible, is that without the hierarchical legitimacy of management, structural changes become harder. Implementing a CE in a campus of 25,000+ people falls perfectly under this.

WUR's vision for 2015-2018

"We want to contribute to the availability of sufficient, safe and healthy food and clean and fresh water for the growing world population, while maintaining and developing a healthy and natural living environment. Our mission is: "to explore the potential of nature to improve the quality of life". (WUR, 2015)

"*It is our mission to facilitate the transition to a Circular Economy founded on bio-based raw materials. The objective is to process natural resources efficiently (...) by closing these loops (Circular Economy), we ensure the long-term availability of biomass. In new, sustainable value chains, biomass can lead to the development of a sustainable chemicals and materials sector."* (WUR, 2015)

Sustainability and CE are deeply rooted in the vision of WUR. These keywords are mentioned several times therefore creating the needed legitimacy for the implementation of sustainable or CE related initiatives as these fall in line with the vision. In the vision, the authors make it clear that CE is not only a more sustainable economy, but also an opportunity for the university to be a frontrunner in the bio-economy. This strategic position gives more leverage to implementing CE principles in both the productive and the supporting layer because this may increase the quality of the scientific output thus improving the attractiveness of the university and its ranking in terms of sustainability.

Moreover, WUR has a website[8] fully dedicated to sustainability with clear information and reports laying down cornerstones for a transition to a more sustainable campus. On top of that,

[8] https://www.wur.nl/en/About-Wageningen/Sustainability.htm

key stakeholders with management positions in WUR occupy management roles in the sustainability group as it can be seen in figure 15:

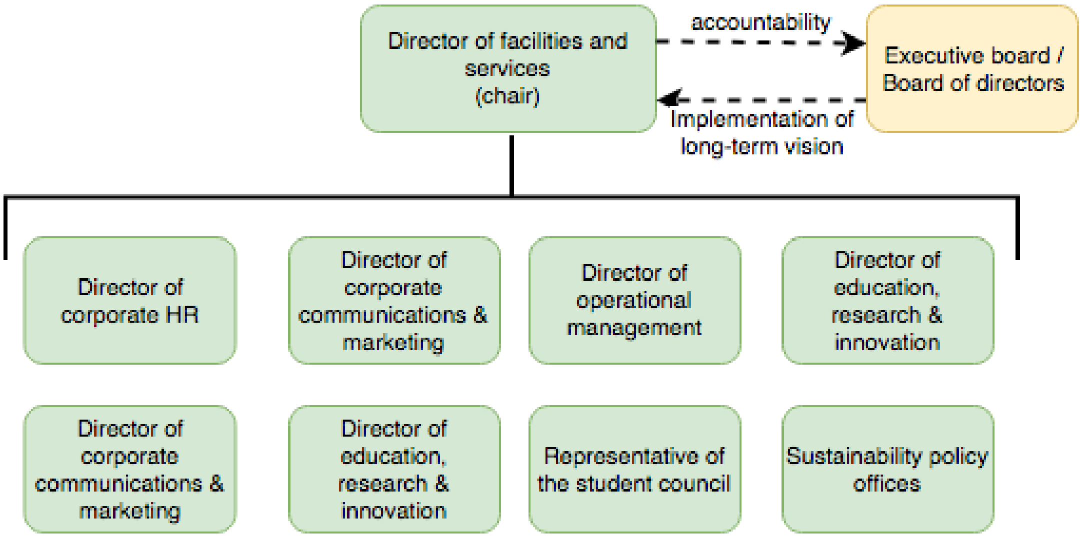

Figure 15: WUR Sustainability Group Organigram

From the above picture, we can understand under which mechanisms legitimacy is created for the rollout of sustainability related actions. Since the vision is laid out by the executive board, the sustainability group makes sure that the vision is implemented and reports back to board on outcomes. This feedback strategy is very successful given that WUR ranks number 1 across the world.

TU Delft's vision for 2018-2024 (TU Delft, 2018)

"(...) 'Impact for a better society' (..) can take many forms and can be found everywhere: from technological breakthroughs and practical applications to intangible cultural value and education; from political, social, economic, and environmental changes (...)"

"In the coming years we intend (...) to further increase our involvement in societal challenges and international developments (...) aligned with the Sustainable Development Goals of the United Nations."

"Develop and execute a plan for a sustainability plan for a CO2 neutral and circular campus in 2030. (...) We gear our facilities and services to our aim to make a sustainable and responsible contribution to the region, the Netherlands and the world."

The vision of the TU Delft (TU Delft, 2018) fits the research profile of the university. It aims at positioning itself as a landmark in terms of the development of new technology to solve pressing problems of our society. Little focus is given on the CE (despite one sentence mentioning the goal to be a circular campus) and sustainability is viewed in a more holistic way where society, economy and environment are represented. This view, which could be interpreted as a more technocratic top-down view, gives little guidance on concrete action and focuses more on a "technology will solve our problems" approach. Perhaps the same decoupling can be observed in the fact that the sustainable vision of the TU Delft always reflects a CO2 neutral footprint achieved through renewable energy implementation.

Moreover, the management structure of the Green Office (see figure 16) is quite different when compared to the sustainability group at WUR.

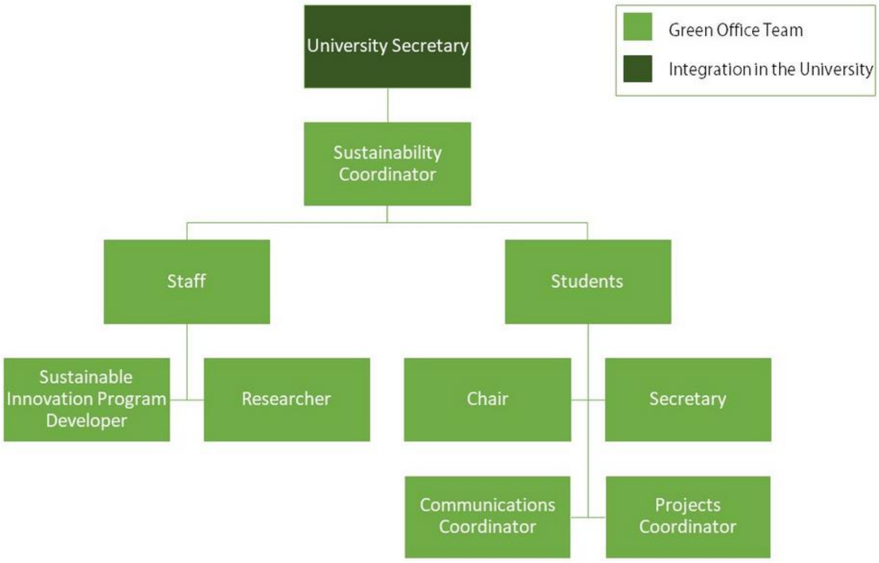

Figure 16: Management structure of the Green Office at TU Delft

The Green Office action plan focuses on energy, as it fits the research of TU Delft and thus it is easier to have the right legitimacy for such projects. As sustainability or even CE could be seen as wicked problems (Pryshlakivsky, 2013), these are harder to tackle and involve a large amount of effort. Another reason could be that measuring first-degree CO2 neutrality is relatively straightforward whereas circularity is not. More on this challenge will be presented in the chapter indicators for a CE.

Despite this, it should be mentioned that the Green Office community is well engaged with the scientific community.

1.3.3 University dependent context variable 3: Logistics of waste

Logistics play an important role when thinking if the current infrastructure is ready to be operated in a different way and if not what is needed for it to change.

WUR's centralized collection infrastructure & in-house organic waste processing

WUR has achieved remarkable collection rates in terms of organic and kitchen waste. Out of all the waste collected, organic waste represents 25% and if reporting only in terms of operational, this number goes to 32%. Two main factors enhance the success of this collection:

firstly, most of the food outlets are concentrated in a couple of locations; secondly, WUR has the EcoSmart concept implemented in food outlets and has use for organic waste.

In the first case, if collection is centralized, economies of scale play a role by enabling higher yields in terms of waste separation while minimizing effort. New buildings like Orion or Forum, can be designed with a concept for waste separation in mind which helps in the implementation. Small bins spread out across the university building will have lower yields in terms of separation because of the scale effect (FTE use per bin).

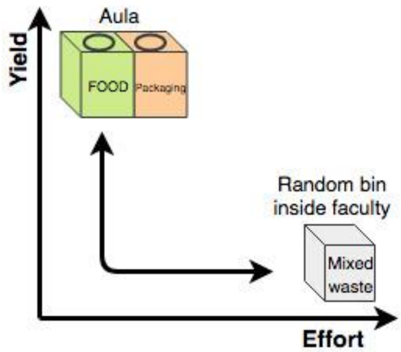

Figure 17: Yield vs Effort

Secondly, the EcoSmart bin concept nudges the community to place waste in the correct bin thus facilitating the collection of separated waste. In this case the community consists students of natural and especially agricultural sciences who are very likely to be sensitive to the organic waste paradigm. Organic waste collection is embedded in WUR's waste policy[9] and environmental plan[10] and the success of its collection and processing is monitored quarterly. Composting or anaerobic digestion are part of the processes related to in-house organic waste processing.

TU Delft's decentralized campus

The campus of TU Delft is quite different from the one of WUR. Food outlets are scattered across campus where centralized collection would be challenging. On the other hand, many faculties like CiTG, I/O, BK, TPM, etc., have their own food outlet with only collection of waste as residual (and in some cases cutlery). Whereas in WUR the EcoSmart bin was implemented from day 1 in some buildings and knowledge was built-up based on experience, in TU Delft this is not the case and the collection system is rather automatized in terms of optimizing space to store waste inside faculties, position of the underground containers for residual waste and the collection routines by FM or Renewi.

On the other hand, TU Delft relies on the partner (Renewi) for waste management to properly dispose all waste produced on campus. The latter produces a yearly report that informs TU Delft's FM of what were the processing methods used for all waste streams based on the

[9] https://www.wur.nl/upload_mm/d/6/0/4bfd080d-8c83-4df6-990e-d6e917993953_20140325_Afvalbeleid_Wageningen_UR_versie1_engels_intranet.pdf
[10] https://www.wur.nl/upload_mm/9/f/f/12b0ab3e-bef3-4edf-bf5b-90f0e871e95f_EN%2020151005_vertEN_MJP2015_2017_v1.1_competent%20authority.pdf

yearly averages. According to Arie van Ziel (A. van Ziel, personal interview, March 30, 2018), big waste players are not capable of processing all the organic waste that they receive either because of lack of knowledge or because it is not economically feasible. Waste-to-energy is then the most common end process for all the organics. TU Delft is in a situation where it relies on its waste partner to treat according to the state-of-the art its waste streams but has no leverage into what preferred treatment should be given (at the moment Renewi claims 95% of recycling but no guidance is given on how much % of it is WtE). It is widely known that burning organic waste is one of the main bottlenecks in the transition to a CE and hence TU Delft should rethink how it addresses its organic waste stream.

Having said that, it does not mean that implementing a new logistics for waste collection at the TU Delft would be impossible, it would just be more challenging when compared to WUR.

Part 2
Circular Economy Context & Vision for the TU Delft

2.1 CE Scope

Now that the TU Delft as a system has been defined, we can assess how the principles of CE are relevant to this system, where they apply and eventually how they can be improved. This chapter works towards establishing a set of Priority Areas based on CE theory, the system TU Delft is embedded in, stakeholder interviews, the identified flows and services of the system and the internal sociocultural systems we identified.

It is important to point out, that these Priority Areas are not created with the claim to completely categorize CE for TU Delft. They should rather be seen as the aspects which need to be addressed most urgently according to our findings in Part 1. This means they shall give guidance how to most effectively tackle the campus' transition to circularity but do not represent the whole concept of a circular campus. These Priority Areas require specialized expertise and attention and can be tackled by several working groups. As mentioned before, this report will focus on the Priority Area of Operational Material, but where our expertise allows we will also make recommendations on other Priority Areas.

2.1.1 CE within the EU context

As established in chapter 1.2, the TU Delft is embedded in the systems of the municipality of Delft, The Netherlands and the EU. It makes sense to align, where possible and relevant, in their priority areas, to ensure the streamlining of the transition to a CE. These priority areas will thus be described here, in descending order of magnitude of the systems.

The European Commission established a monitoring framework in January 2018 aiming to keep track of the EU's progress towards CE (European Commission, 2018). In this framework a set of priority areas was defined along with the policy structures responsible for their progression. These areas are:

- EU self-sufficiency for raw materials
- Green public procurement
- Waste generation
- Food waste
- Overall recycling rates
- Recycling rates for specific waste streams
- Contribution of recycled materials to raw materials demand
- Trade in recyclable raw materials
- Private investments, jobs and gross value added (through CE)
- Patents (related to CE)

Here we can already clearly see how TU Delft can contribute to an EU-wide transition to CE and why aligning the goals is so important, since patents are one of the main output flows of the TU Delft productive layer. From this point of view, the EU can also be beneficial to the TU

Delft transition, since it falls directly under the regulations of possible improvements of green procurement.

2.1.2 CE within the NL context

The Dutch government drew up a contract called the National Agreement on the Circular Economy in September 2016, in which it appointed five priority areas (Rijksoverheid, 2016):

- Biomass and food
- Plastics
- Manufacturing
- Construction
- Consumer goods

TU Delft has co-signed this agreement and promises support in the priority areas Manufacturing, Construction and Consumer Goods, specifically with the intention to provide knowledge on circular design and manufacturing.

2.1.3 CE within Delft Context

With regards to the municipality of Delft, while plenty of action is being undertaken with regards to sustainability in general, no overarching policy with regards to CE has currently been implemented. However, one step up in the geographical scale the region of Rotterdam - The Hague, which Delft falls under, has made plans for what they call the “Next Economy”. This program includes a section for CE, but mainly focuses on the Rotterdam port and built environment (Roadmap Next Economy, 2018).

2.2 Derivation of Priority Areas

Having analyzed CE principles, the larger CE context and having conducted stakeholder interviews, we define several Priority Areas. They can be seen as a recommended categorization for starting and managing the transition process towards a circular campus. We thus will now answer sub question 3: "*Into which Priority Areas can future work for a circular campus be structured in order to facilitate a CE transition?"*

Figure 18 shows the defined Priority Areas within the previously defined framework.

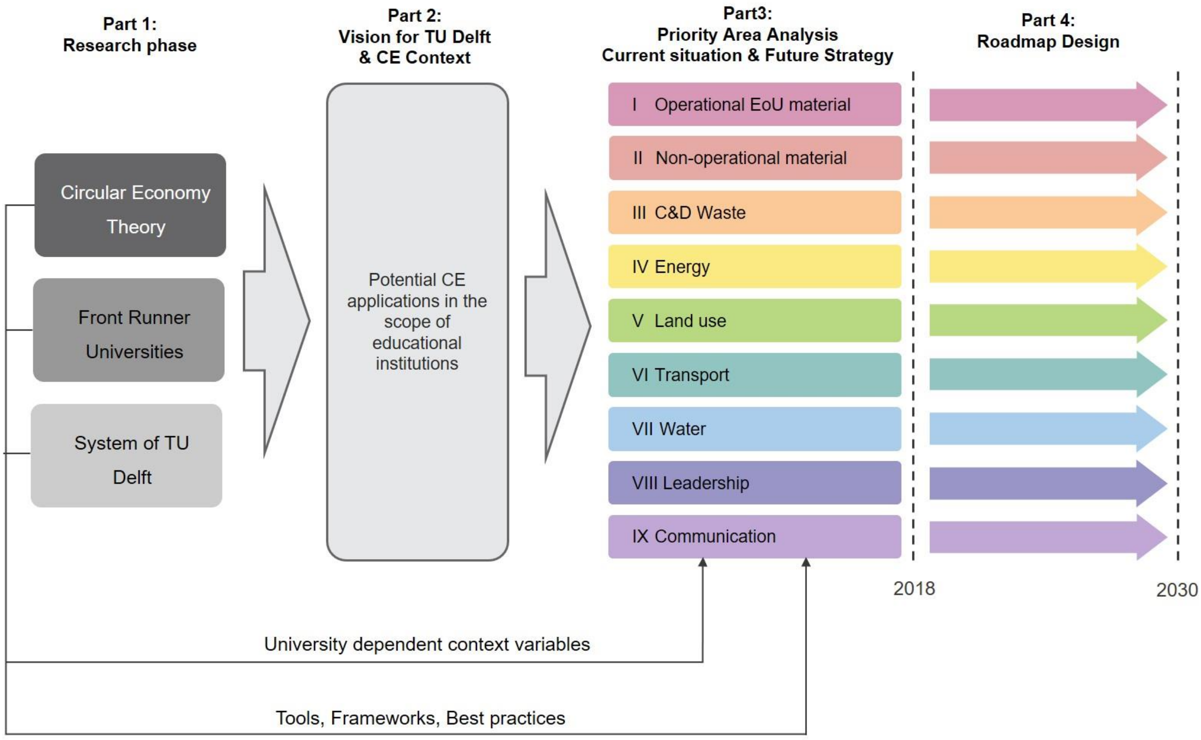

Figure 18: Defined Priority Areas for the framework.

2.3.1 Operational EoU Material/Non-Operational Material/Construction & Demolition Material

Beginning with the material throughput of the system, as this is the main focus of our efforts, we can separate this into several categories. Classically in a CE, the distinction is often made between the biological and technical cycles, as described in the first chapter. However, for the sake of utility of this report and inspired by the UBC Vancouver Zero Waste Action Plan, we decided to make the initial distinction based on the timescales in which materials reside in the system and their functionality, since these appear to be closely related to the manner in which they are disposed of and thus at which level interventions can be made. The material streams that, broadly speaking, result from daily operations we categorize to be **Operational End-of-Use (EoU) Material**. Materials with a somewhat larger lifespan that in general are designed for multiple uses we categorize as **Non-Operational EoU Material**. Lastly, the materials embedded in buildings are categorized as **Construction & Demolition EoU Material**. These three Priority Areas will be defined in more detail later on in this report.

2.3.2 Energy

Material throughput, though, does not fully encapsulate the whole principle of CE. A true Circular Economy in line with our definition also fully utilizes renewable energy, as our current fossil-fuel based energy systems are almost by definition non-renewable and might jeopardize regenerative capacity of other resources (Challinor et al., 2014). We therefore argue that **Energy** should form another Priority Area. However, TU Delft already has been active and knowledgeable in this field for quite some time. Some examples are the new Pulse building, which will be 100% energy neutral when in use, and the Green Village area, where new sustainable building techniques with regards to energy are tested. Clear milestones have also already been set for the future (Campus Development TU Delft, 2018b). Therefore, this Priority Area will not be discussed much further in this report.

2.3.5 Land Use

From our interviews with stakeholders the allocation of campus grounds emerged as a recurring bottleneck for the implementation of infrastructure that can aid the transition to CE (Verhoeven & de Vos, 2018; Faber, 2018). For example, closing a deal with Renewi on recycling of styrofoam appeared to be blocked by limitations on storage space (Faber, 2018). While there is certainly room for Living Lab-type experiments, such as the Green Village, the allocation of grounds for these purposes is not ubiquitous. However, if TU Delft aspires to be a frontrunner with regards to circularity on campus, we believe maximizing utility campus grounds for these purposes is critical.

On another note, since one of the grand aims of CE is balancing regeneration of natural resources with yields, it follows that an optimal functioning of natural ecosystems is essential to achieve this. However, European ecosystems have come under increasing pressure, historically mainly due to agricultural intensification, habitat fragmentation and active reforestation and increasingly through climate change and pollution (Millenium Ecosystem Assessment, 2005; Musters & Van Bodegom, 2018). While single-mechanism causal drivers are hard to pinpoint, the collection of these stressors has arguably resulted in a marked decline in insect biomass over the last decades (Hallman et al. 2017; Hallman et al., 2018). This has the potential to severely disrupt the food chain, and cause so-called “trophic cascades”, in which effects in one layer of the food chain impact all others. These effects can hamper ecosystem services (e.g. agricultural production and the biological cycles) in unpredictable ways, as can be seen from the classic example of the changed flow of rivers in Yellowstone after the reintroduction of wolves (Ripple & Beschta, 2012).

Since TU Delft is located on a significant share of land (161 hectares), it has the potential to alleviate some of the pressures currently driving decline of biodiversity and population sizes by providing a safe haven for insects, plants and birds to settle and procreate. For this reason then, combined with our previous argument, we argue that **Land Use** should be a Priority Area.

2.3.6 Transport

As implied before in the derivation of the Energy PA, climate change has the potential to significantly diminish our yields of resources. Since global transport accounts for 26% of CO2 emissions worldwide, we propose **Transport** as another Priority Area (Chapman, 2007). TU Delft already recognizes to some extent the need for a sustainable transportation infrastructure, and we will not discuss this PA much further in this report.

2.3.7 Water

Next to this, we argue that **Water** should be a Priority Area. Climate change is predicted to have significant impacts on global water availability, calling for anticipation on future scenarios (Schewe et al., 2014). Besides, sewage is a major pathway of nutrient loss, complicating the ideal scenario of closed biological cycles.

2.3.8 Leadership

Taking into account, as we saw in the CE context of EU and the Netherlands, how the ultimate goals of technical universities and that of the systems which the TU Delft is embedded in align, we argue that **Leadership** is one of the Priority Areas. Not only for becoming circular ourselves, but also to create the momentum for transitioning to CE at least EU-wide. TU Delft has the unique position to both generate and spread knowledge and technology, thereby dissipating it into policy and everyday life. We thus have both the opportunity and responsibility to lead the way to a circular future. To a large extent this is already recognized by the TU Delft, as can be seen from the fact that TU Delft has been a Pioneer University for the Ellen MacArthur Foundation since 2014. Current activities in this field include the provision of a Massive Open Online Course on an introduction to Circular Economy and several large scale research projects for, among others, Horizon 2020 and Circular City Amsterdam (Ellen MacArthur Foundation, 2018b). Furthermore, the TU Delft has already recognized its capability for aiding in the Manufacturing, Construction and Consumer Goods priority areas of the National Agreement of The Netherlands through its knowledge and has co-signed this agreement.

Leadership thus both has an internal and an external component. On the one hand, Education and Research make up the internal mechanisms driving Leadership, but these elements are of little value if they are not put into practice. Therefore Valorization forms the external component of Leadership. Valorization essentially means how Education and Research is shaped into valuable action.

2.3.9 Communication

Lastly, we established that **Communication** is an essential Priority Area for the transition to a circular campus. Having participated in the recent decision process for the disposables in the canteens, the added value of connecting stakeholders throughout the value chain has become abundantly clear to us. It creates an atmosphere where life cycle thinking can emerge which, combined with proper research, can lead to decisions that initially did not seem obvious but eventually make the most sense with regards to circularity. Streamlining and upscaling the process of stakeholder communication thus can be of great value. However, since those decisions might not have been obvious initially to those that were not present in the decision process, it is critical that the reasoning is communicated efficiently.

2.3.10 Summary and relation between Priority Areas

Summarizing, we defined 9 Priority Areas (see Figure 18). A closer look at the various PAs, shows that they address different aspects and act on different levels.

Figure 19 illustrates, that seven PAs rather relate to physical aspects, while the last two PAs regards organizational aspects. Within the physical category, one can distinguish between mostly material based and mostly energy based ones, as it is suggested by Lifset & Graedel (2015). The name others is used to show, that a combination of different features apply. For instance, water can be seen as a matter carrying material, energy and nutrients. Similarly, transport and land use are mainly dependent what an analysis focuses on.
So, even though a division has been made, overlaps occur, and this categorization does not claim to be ultimate or discrete, but more a suggestion to base future work on. Especially for the organizational PAs, it needs to be pointed out, though being depicted here as another category, principles from Leadership and Communication do not act in isolation but should be applied campus wide and therefore are relevant for each individual PA.

The resolution of this categorization is not the same for materials, energy, others and organizational PAs. Due to the focus of this project the material category is divided into three PAs here, while this is not the case for Energy and Others. Useful additional categorization could be e.g. renewable and non-renewable energy. Thus, for future projects, it might be helpful to increase the resolution of this categorization in order to get a more detailed overview or to better divide future research.

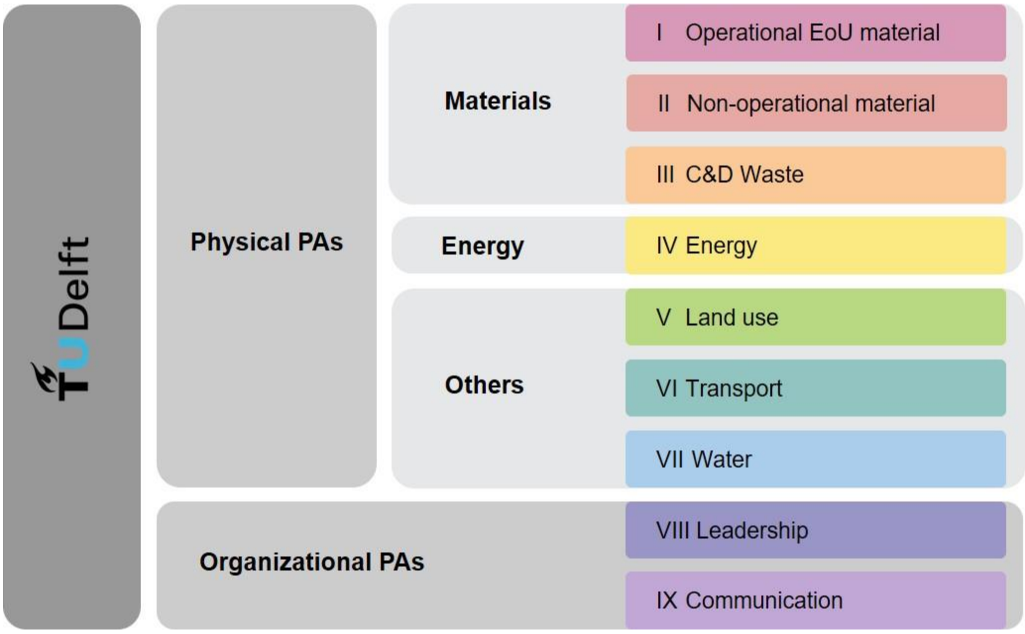

Figure 19: Categorization for the proposed PA's for TU Delft

2.3 Vision of a circular campus

Our future vision has been inspired by the European Commission's vision for a circular economy in Europe (EC, 2015). Although a high-level of aggregation is usually presented in such policy documents similar to the 2050 Nederland action plan (Rijksoverheid, 2016), we have skimmed through the most relevant points that are applied to the context of a campus in terms of its socio-technical system. Narrowing down to the most relevant points has allowed us to develop a realistic vision of where we think TU Delft should be in 2030 to achieve its "(...) Circular campus in 2030" vision (TU Delft, 2018b).

We have also been inspired by the participatory backcasting framework and its usefulness in deriving future visions while at the same time creating a normative transition pathway (Quist, 2013). Due to time constraints, we have not fully developed the applicability of the participatory backcasting framework as developed by Quist (2013) but we recognize its potential in driving the change process needed to implement our vision. Therefore our use of the framework for the vision remains topical in the sense that we used only features of the framework that we deemed relevant and easy to apply for our vision. Saying that, we have developed a *"what should happen"* type of backcasting scenario (Quist, 2013) which entails the pursuit of a normative vision to reach the desirable future. As defined in Quist (2013), such normative transition scenarios imply "*The involvement of a broad range of stakeholders(…), not only when defining the problem but also when searching for solutions and developing shared visions(...) Incorporating not only the environmental component of sustainability, but also (...)*

its economic and social components. (...) generating a desirable future, and then looking backwards from that future to the present in order to strategize and to plan how it could be achieved (...).

To drive the transition to the desirable future situation, milestones should be used as reference points to guide stakeholders in the transition process.

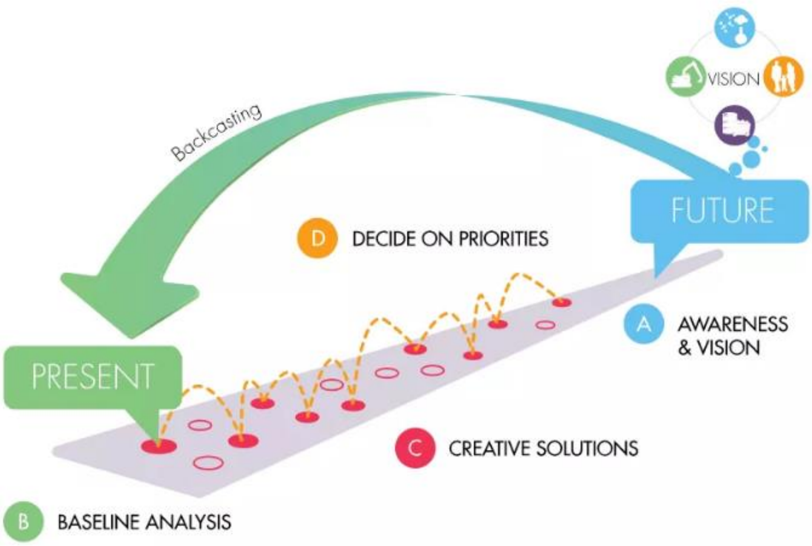

Figure 20: The natural step approach. From thenaturalstep.org

2.3.1 The vision

TU Delft becomes the first circular campus in the world by 2030 through a new approach to sustainability in campus that goes beyond carbon neutrality. Circular thinking is applied in every operational department in the university and the transition to a circular campus is given legitimacy by the board of directors through the elaboration of parallel strategic vision for circularity. As collaboration is an essential element for a circular campus, the TU Delft externally takes the lead with other universities in implementing CE and internally is continually working on strengthening their own network of stakeholders to enable collaboration throughout life cycles and learning experiments such as Living Labs. Startups and spinoffs are invited to help develop a circular ecosystem where the campus is used as a testing bed for creative solutions aiming at circularity. Procurement favors products as services in detriment of ownership giving room for innovative business models to find their market. Students are engaged into circularity and explore beyond the contents of the materials learned in the classroom through competitions and other bottom-up initiatives aiming at fostering innovation through ingenuity without the pressure of success. Researchers use Living Labs as a means to test circularity principles through innovations. Operational staff in the TU Delft recognizes the importance of circularity and participate in closing the gap between research and operations. Circular economy champions within operational staff drive the transition to circular material management by developing a new circular approach to change the existing process-based departmental decision-making process. Land is viewed not only as landscape but as an ecosystem that is able to provide services for the wellbeing of the campus population. Food waste is reduced to a minimum and the nutrients that are found within are recycled to offset the need for fertilizer. Separation at the source is prioritized and the holder of the waste tender contract is involved in developing creative ways on campus to process end-of-use materials by using TU Delft's technology.

This is our vision for a circular campus.

Part 3
Priority Area analysis & Strategy for the TU Delft

Part 3

This chapter analyses the selected Priority Areas of:

• PA I	Operational Material	(Chapter 3.1)
• PA II	Non-Operational Material	(Chapter 3.2)
• PA VIII	Leadership	(Chapter 3.4)
• PA IX	Communication	(Chapter 3.5)

The focus lies especially on the first two. PA III - VII are not part of this report, but should be investigated by other project groups.
For the analysis CE concepts are applied, such as life cycle thinking or the circularity ladder, to the current system of TU Delft taking into account university dependent context variables. This allows to answer the following research questions:

RQ 4: What is the current situation of selected Priority Areas, what are best practices of other universities for them, and which measures are required to realize the implementation of those within TU Delft's roadmap to circularity?

RQ 5: How can the circularity performance of investigated material based Priority Areas, Priority Area I and II, be measured in order to include them in a monitoring system?

Therefore, firstly it is investigated what the current situation is per PA. Then, this is compared with best practices found at other universities. Consequently, recommendations are drawn how to improve practices of each PA for TU Delft. Finally, we translate those recommendations into a set of suggested milestones. This has the purpose of breaking down the recommendations into smaller steps to encourage stakeholders to take action.
After part 3, a roadmap design is presented which summarizes those milestones to provide a full picture of the approach. These milestones primarily serve as a proposal how interventions towards a circular campus could look like.

The possibility of defining a set of indicators for a future monitoring system is discussed for PAI and PA II.

3.1 PA I - Operational EoU Material

This section will develop PA I firstly by introducing it in more detail in the context of TU Delft, elaborating more on why the focus on operational waste is a step towards the implementation of circularity, the analysis of the current situation, best practices from other universities and closing with the recommendations for the roadmap in terms of achievable reduction targets. To elaborate the detailed data analysis of this section, data obtained from Renewi (Renewi, 2018) is used.

3.1.1 Definition of Priority Area and Relevance within CE

The definition of operational waste was borrowed from the zero waste action plan developed by UBC (2014). In this plan, operational waste includes waste generated during the normal operation of the campus buildings which includes: food scraps, paper and cardboard, containers, e-waste, garbage and others. Naturally, UBC and TU Delft are subject to different realities in terms of waste management and waste profiles. While UBC's aim with the zero waste plan was to divert waste from landfill, in TU Delft the aim is to increase separation at the source.

We found appropriate to define operational EoU material at the TU Delft to include the following streams: residual waste, paper and cardboard, organic (food outlets), swill, plastics and coffee cups. This is in line with what for example other universities are doing outside of the Netherlands (like in UBC) and in the scope of the zero waste framework. Moreover, TU Delft has data for the above mentioned streams from the collection partner despite very aggregated thus it makes it favorable for setting long-term targets based on the improvement of the separation at the source and reduction of material input.

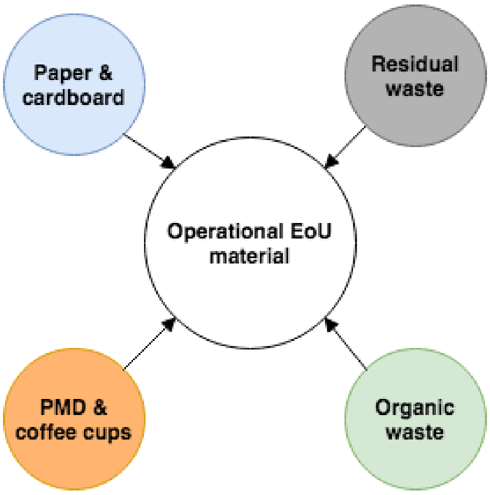

Figure 21: Overview of all components of operational EoU material

One of the main aims of the focus on operational EoU material is the potential to reduce the amount of residual waste. According to data by Renewi to date 95%[11] of the residual waste is being "recovered" either as energy or as secondary materials. What would be interesting is to know exactly how much % of the materials sent to Renewi is incinerated in waste-to-energy (WtE) and how much % is recycled as secondary material. Renewi presents yearly results to TU Delft under the form of a waste pyramid (M. Faber, personal interview, 2018) where WtE is seen as the fourth R in the waste pyramid developed by Lansink in 1979[12]. Renewi uses Lansink's waste pyramid as a way to show that WtE is still better than nothing which is indeed right for the case of landfilling. But for circularity, Van Ewijk & Stegemann (2016) argue that such use of Lansink's waste pyramid might divert the focus of reduce or re-use in the context of a Circular Economy.

Knowing what's inside residual waste is a step towards improving the EoU profile of this stream and the overall operational EoU material stream. This can be achieved by avoiding WtE unless no other solutions can be used, by removing all nutrients from the organic fractions or by having quality materials that can be recycled more times.

3.1.2. Current situation

In the description of the current situation, present costs related to handling operation EoU materials taking place at the TU Delft will not be added. Although they are known to us, we preferred shift the focus away from the economic perspective and redirect it towards the

[11] https://www.tudelft.nl/sustainability/campus/
[12] http://www.recycling.com/downloads/waste-hierarchy-lansinks-ladder/

conceptual analysis of the material flows. More information on associated costs can be obtained from the FM department of the TU Delft.

The current situation at the TU Delft in terms of material streams is shown below in a collection of graphs.

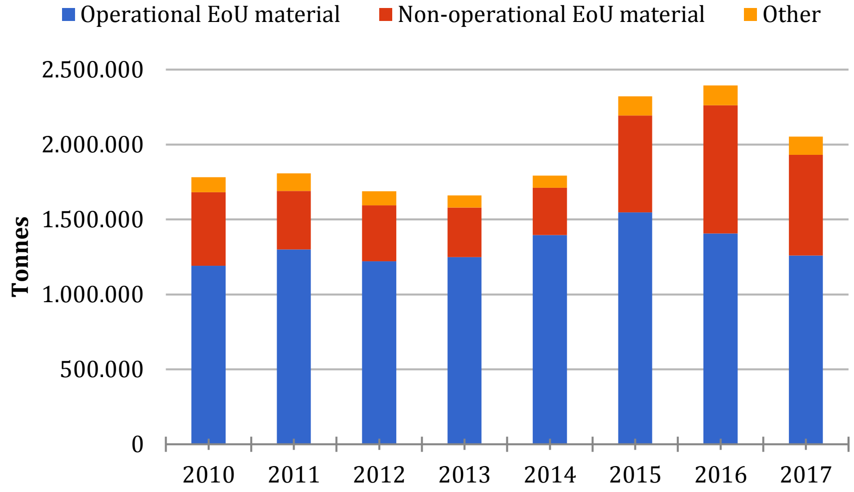

Figure 22: Yearly evolution of the different material streams in TU Delft

In Figure 22 the yearly evolution of different material streams in the TU Delft is shown for the years 2010-2017. It is clear that the largest material flow is operational waste.

Figure 23: Yearly evolution of the amount of generated operational EoU material in TU Delft

Being the largest material flow in TU Delft means also that the potential for recovery of valuable EoU material is also evident. In Figure 24 below, waste data shows that to date the only components of operational EoU material are residual and paper & cardboard.

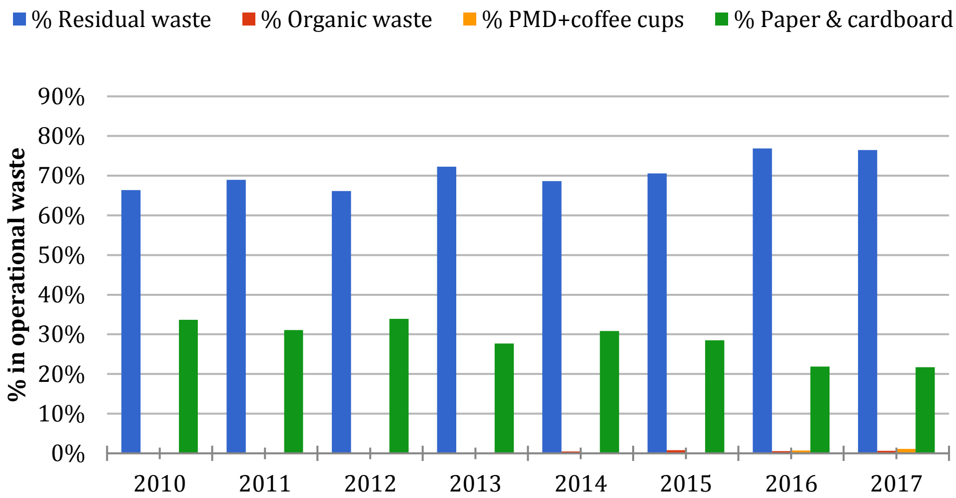

Figure 24: Yearly evolution of the share of different streams in operational waste in TU Delft

Operational EoU material - Residual and organic waste

In 2017, Jan Henk Welink conducted a Living Lab experiment in the 3mE-building to assess the potential for increased waste separation in TU Delft and to optimize waste collection

(Welink, 2017). The experiment was setup by means of adding additional collection of organic waste and PMD next to the traditional paper and residual waste.

Table 3: Results from the 2017 Living Lab experiment in 3mE conducted by Jan Henk Welink.

Operational EoU material	Share [%] in 3mE Living Lab
Residual waste	23.9
Paper & cardboard	52.8
Organic waste	9.6
PMD & coffee cups	13.7
Total	100

This experiment highlighted the potential that resides in further separating at the source what ends up in the residual waste stream.

The theoretical separation shares that would be achievable at the TU Delft, have been achieved at WUR for the reasons already described in section 1.3. The success of the increased separation at the source at WUR is shown in the following figures.

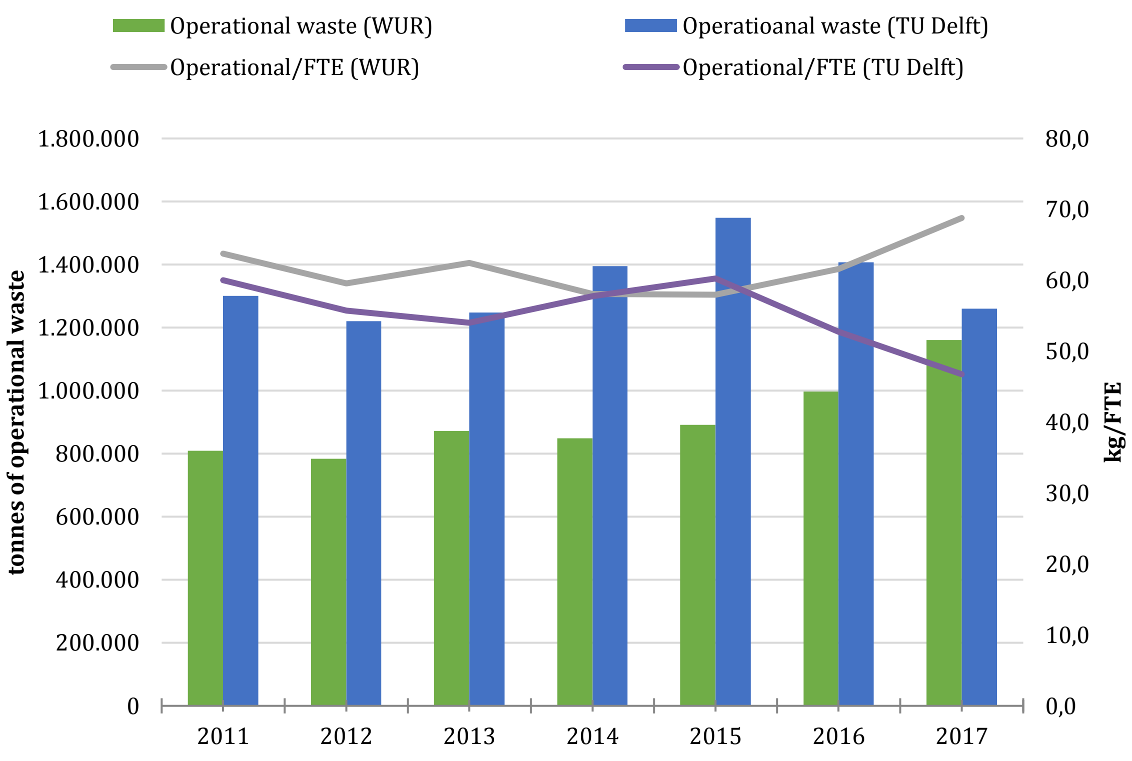

Figure 25: Evolution of operational waste in TU Delft & WUR 2011-2017

In Figure 25 it is visible that there was not a decrease in the amount of waste being generated at WUR, on the contrary with both per FTE and absolute values of operational waste generation increasing. In the case of TU Delft, the value per FTE and absolute operational waste generation are decreasing.

WUR nevertheless as mentioned earlier, implemented the EcoSmart concept across several buildings in campus which has led to a significant increase in the collection rate of organic waste from the residual stream. This is clearly depicted in Figure 26 where it is visible that the collection rate improved from 0 to 32% of all organic waste collected.

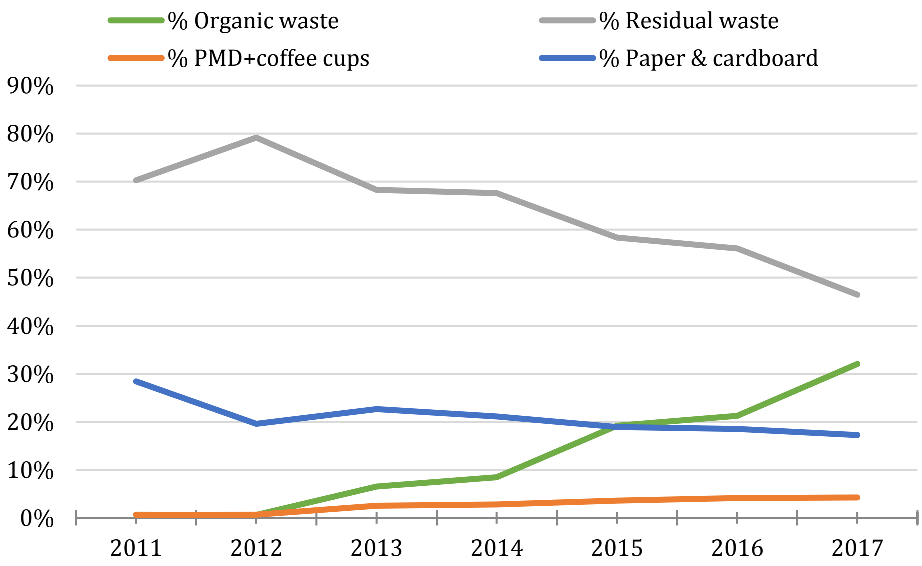

Figure 26: Evolution of operational waste separation in WUR 2011-2017

This organic fraction in WUR does not account for GFT and reflects only organic & kitchen waste collected at food outlets and similar places. From these pictures it is clear that TU Delft could undergo a period of trial under the form of a Living Lab with a given faculty building to test whether or not such ratios like in WUR could also be achieved. The collection of 19.6% of organics from the sample at 3mE is also not representative because that building has no big food outlet like IO, CiTG, etc. Therefore higher shares could be achieved.

From Table 3 we know that much more could be done to improve the current situation. In the picture below, the contrast is clear on the opportunity for further development. One crucial aspect if the fact that WUR has a well-defined goal for organic collection (in-house composting) but for the TU Delft, a target “market” is still yet to be found. Partnering with the municipality or TU Delft’s Botanical Garden are types of partnerships that could be successfully explored.

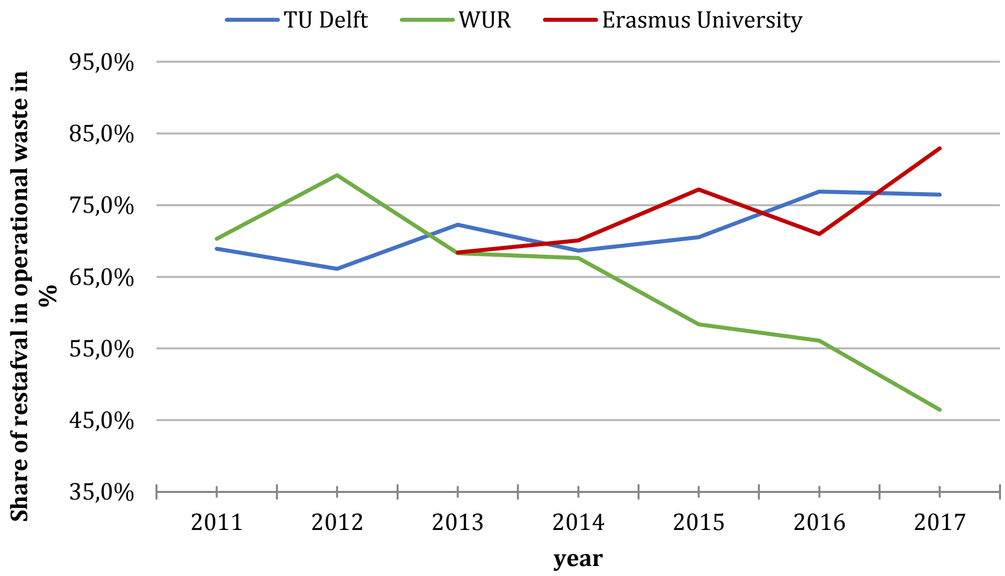

Figure 27: Share of residual waste in the operational material stream

But the benefit of further separating the residual waste stream does not stop at the additional shares of usable materials. It also presents a big economic opportunity for the TU Delft to reduce its costs in processing residual waste which are quite considerable. On the other hand, compost is a twofold profitable venture because it reduces the need of artificial fertilizer and it reduces the mass of residual waste by 32%wt (if a similar separation rate could be achieved in TU Delft looking at WUR) which significantly reduces the cost of residual waste handling. We talked to a Dutch expert of compost (Van Ziel, personal interview, 2018) and the following numbers were given to us as a reference for the economics of compost:

- Fungi compost 60€/kg
- Worm compost 120€/m3
- 1m2 grass needs 250g of compost per year
- 1 worm hotel: €4000
- 1 underground compost container: €15.000 (includes digging the hole, approximately half of that when using an existing hole)

In the section “Recommendations for roadmap and milestones” we will introduce more concrete data on how the impact of for example converting Aula with an improved collection or implementing from day 1 something similar in Echo would impact on the EoU material streams.

Operational EoU material - PMD & coffee cups, paper & cardboard

PMD is composed by packaging material ranging from all sorts of polymers. In this stream, contamination is a sensitive point because it can remove all value to the stream. In the processing facility, or even at the level of the FM, workers decide upon visual inspection if the stream is pure enough to be sold in the market. If this is not the case, it merges with the residual waste stream thus offsetting all the benefits from secondary material supply (M. Faber, personal interview, February 21, 2018).

We learned from an interview with Renewi (M. van Eersel, personal interview, May 3rd, 2018) that a critical bottleneck is in place when it comes to business-to-business PMD collection. An initiative in the Netherlands exists that brings together big plastic producers together and municipalities, the “Afvalfonds verpakkingen”[13], literally translated to the fund for packaging waste. In a nutshell, the fund collects contributions from producers (0.64€/kg) that put plastic products in the market (like bottled water producers for example) based on mass put in the market (Afvalfonds Verpakkingen, 2018). The pot of money, which amounts to several thousands of euros, is then distributed to municipalities to fund the reverse logistics needed to collect and process PMD waste. In this way, PMD collection costs are covered by the fund and municipalities do not need to heavily tax citizens to cover associated costs. It is a smart way for producers to have security of supply for secondary material to remake packaging polymers (Afvalfonds Verpakkingen, 2018).

The bottleneck for efficient PMD collection is thus when in business-to-business, in our case TU Delft-to-Renewi where for Renewi the PMD stream is not a very advantageous stream from an economic point of view. Again skipping the costing part of how much TU Delft pays Renewi to process PMD, the problem resides in the price that Renewi has to pass upstream to TU Delft to be able to have a profitable downstream application for all the collected PMD. It is straightforward that PMD collected in business-to-business cannot “compete” with PMD collected by municipalities (Van Eersel, 2018). Thus when thinking about recycling of EoU material, not only the technology plays a role but also the governance side is starkly important (creating a market, etc).

Coffee cups are a different story. Although only representing around 1.3 %wt of the total residual waste, a lot of effort has been put into this stream. It is a quite “visual” stream because everyone is using coffee cups all the time from the coffee machines, thus it has high impact. Furthermore, in the course of 2018, the majority of all collected coffee cups with be reprocessed into toilet paper. This is a direct collaboration between TU Delft, Renewi and the recycler of paper. The old coffee cup will become toilet paper but not a new coffee cup thus we classify it as downcycling which means that demand for new paper to make coffee cups is not decreasing. This approach is vaguely in line with CE theory.

Paper is a profitable stream for the TU Delft and for the recycler thus many efforts have been already undertaken to improve both the collection and reduction of this stream. Although from the results of the Living Lab in 3mE, paper & cardboard represent 53% of the total mass of material collected in that experiment, we can also argue that on average, 22% in campus is in line with what other universities have obtained. Despite the case of Erasmus as it is depicted in Figure 28Figure 28 where a footprint as low as 2 kg/FTE is reported. Not being able to check

[13] https://afvalfondsverpakkingen.nl/

the accuracy of the data, we rely on the values of WUR to conclude that the paper/FTE footprint reduction from 18 kg to around 11 kg is already quite remarkable.

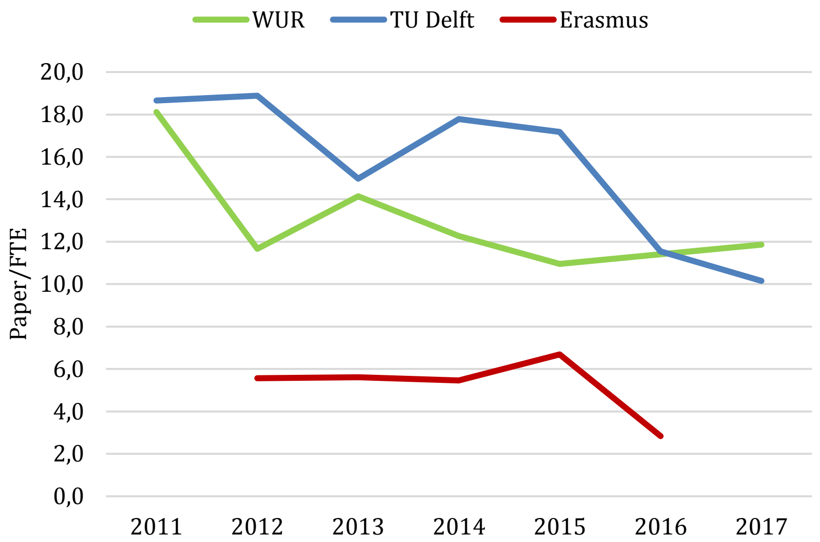

Figure 28: Overview of the paper/FTE ratios across 3 different universities

Further remarks

Operational EoU material relates mostly to material flows that are not directly dependent from the operational side of the TU Delft but instead from the supplying partners. In other words, organic and packaging material is introduced by Sodexo or vending machines, coffee cups by MAAS, students bringing their own short-lifespan materials from home, etc. Given this, a clear distinction can be made between operational and non-operational in terms of who is responsible for the introduction of it in the system. Operational EoU material is then a multi-stakeholder problem because of all the different contributors to its existence. The TU Delft has two different ways of improving this stream: act at the source or improve the EoU phase.

Act at the source means promote reduction of packaging, incentivize the community to eat at local food outlets (for example by subsidizing food prices) or imposing stricter requirements for external suppliers.

Improve the EoU phase can be applied in two axes. On the one hand improve separation at the source to augment quality of separated streams hence increase value and reduce cost burden related to handling residual waste. On the other hand, once out of the system, purer streams can have another path other than WtE like being reintroduced as secondary materials.

These improvements can be done in scope of the 2020 waste tender contract or further in the future in the 2025 waste tender.

Table 4: Potential shares in operational EoU material for the TU Delft based on WUR

Stream in operational EoU material	Share [%]
Residual	43
Organic	31
Paper & cardboard	22
PMD & coffee cups	4

This leads us to conclude that much more can be done with residual waste and the challenge resides in part in behavior change at the user level but also a long-term view on clearly defined targets for separation. If a monetary driver would be in place, i.e., TU Delft commits to reduce its residual waste burden by means of higher separation at the source, then more engagement could be seen from all stakeholders. More on the future in the "recommendations for roadmap" section.

3.1.3 Best practices from other Universities

This subchapter will analyze best practices of other universities to serve as inspiration or guideline for new infrastructure or policy.

Dutch Universities

Currently listing 1st in the UI Greenmetric World University Rankings, Wageningen University & Research Centre appears to be a frontrunner university with regards to waste separation. Their system of day-to-day waste collection was partly established in cooperation with EcoSmart, a subsidiary company of Van Gansewinkel. In the Orion and Forum buildings, 16 different waste streams are separated. Since its implementation in 2009, general waste from the Forum building has been reduced by 25% (Wageningen University & Research Centre, 2018).

Cascading and Composting

Another noticeable intervention in on-site composting of "green waste" and application of this compost on their own lands. Wageningen University does this, and Utrecht University also started this practice with its garden waste and even claims to compost into high quality Bokashi compost. This Bokashi is then, after handing it out to employees, applied on its own lands (Utrecht University, 2018). On the topic of biomass, Radboud University Nijmegen's academic hospital also has an inspiring solution to the problem of used coffee grounds. The grounds are given to the 'Versfabriek' in Nijmegen, that uses it to grow oyster mushrooms. These mushrooms are then sold back to the catering. The leftover coffee grounds are further used to make biogas, which powers the municipal buses (Van Gestel, 2016).

Policy mechanisms

Some universities, such as Leiden and Nijmegen, give discounts at the coffee bars when students bring their own reusable cup. It could be argued that the impact of such a policy is marginal compared to the scale of the complete waste stream of a university, but it may turn out to be an excellent way of raising awareness and steering the norm towards the reuse of disposables in general. The VU Amsterdam currently also is involved in an interesting development. They claim to have implemented a ban on the sale of PET bottles for water, and are working on banning the sale of PET bottles for all beverages (Vrije Universiteit, 2018). It would be interesting to keep track of the effectiveness of such a policy and its influence on the composition and size of the residual waste stream.

Waste collection infrastructure

A striking example of a technical solution for a more efficient operational waste collection is the solar-powered waste compressor found at the Zerniketerrein of Rijksuniversiteit Groningen, shown below. This compressor decreases the number of collections throughout the week that need to be done, reducing both emissions from transport and costs. Twente University aims to go one step further with these kinds of solar-powered waste compressors. With their so-called *Clean Cubes*, they aim to optimize waste collection using Internet-of-Things, saving both fuel and costs. According to the developers, this has the potential to reduce operational costs up to 85% (ESE World Ltd, 2015).

The universities of Twente, Utrecht, Leiden and Rotterdam now appear to have some form of separate waste collection system beyond what is driven by external regulation, especially in the canteen areas. These can be seen below. While it could be argued that the effectiveness of such interventions is fully dependent on how the waste is processed by the externally contracted party, we believe that nevertheless it shows a future vision and serves as a signal to waste processors and students. Furthermore, it can provide information on the quality and quantity of residual waste fractions. Interesting to note is the overlap in colour coding among universities used on the bins: blue for paper, green for organic, orange for PMD and grey for residual waste. These appear to have developed somewhat naturally over the years and now seem to have become the norm.

However, while these kinds of interventions might be a good signal or pilot study, communicating them as such and not as actual solutions is of utmost importance. For example, Leiden University received some backlash in the weekly students paper "*Mare*", where a highly critical column was published complaining about both the complexity of the system as well as its perceived futility (Kloosterman, 2018). This could result in a breach of trust with students and staff, and reduce the efficiency of the separate collection.

Figure 29: Waste bins in Twente

Figure 30: Waste bins in EUR

Figure 31: Waste bins at Leiden University

Figure 32: Waste bins at the Victor J. Koningsberger building at Utrecht University

Figure 33: Waste compressors of Twente University

Figure 34: Rijksuniversiteit Groninge

International Universities

The foreign universities discussed here either place somewhere in the top 10 of the UI Greenmetric ranking or emerged as interesting to assess from stakeholder interviews.

University of Nottingham, besides composting both food waste from outlets as well as garden waste and applying this on their own lands, provides an extensive “A-Z guide to waste” on their website which describes proper disposal methods for a large variety of waste. UC Davis also implemented these practices, and also provide a very extensive “Zero-waste manual” (UC Davis, 2018). University of Bradford has also adopted this A-Z method.

UBC Vancouver Zero Waste policy

The Canadian University of British Columbia Vancouver campus has initiated a Zero-Waste Action Plan from 2014 onwards, with the aim of going from a 61% operational, semi-operational and C&D waste diversion from landfill and incineration, to 70% in 2016 and 80% in 2020. While the 2016 milestone was not achieved, the plan did manage to reduce per capita waste generation by 14%, from 80 to 69 kg/(FTE year).

The plan puts strong emphasis on the utility of pilot projects and the priority of waste reduction. For example, UBC has been composting from 2004 onwards, and currently has a facility capable of processing about 5 tons of organic waste a day. This started as a pilot project behind a food outlet, in order to maximize the ease of implementation. Furthermore, the recycling infrastructure that is currently installed throughout the campus also started as a pilot project, in order to measure its effectiveness and feasibility (UBC, 2014).

3.1.4 Derivation of useful indicators

Using the “Critical steps for assessment of a Circular Economy strategy” proposed by Elia et al. (2017) we will derive what are important indicator to monitor circularity in TU Delft based on the system definition of the campus and on the vision that was laid out for the campus. In Elia et al. (2017) a systematic approach to choosing circularity indicators based on the types of processes to monitor and requirements has been developed and is depicted in Figure 35.

In red, we have highlighted the most important features of a monitoring system for circularity in campus and also based on the scope of this report (deep-dive into the material flows of the TU Delft)

Following the flowchart in Figure 35, we start by identifying the “material input” as the flow to monitor and highlight the activities where the monitoring will be implemented. The next step in the flowchart guides us to the accounting method which is taken as direct and the focus of the analysis. Single requirement is taken because of the focus in material flows and “reducing the input and use of natural resources”. For most of the novel indicators the we have derived, the material input per unit service (MIPS) type of indicator appears to us to be the most relevant and applicable in the short-term when the aim of the indicator is to measure the material footprint of a service (in the case of TU Delft system - to provide scientific output).

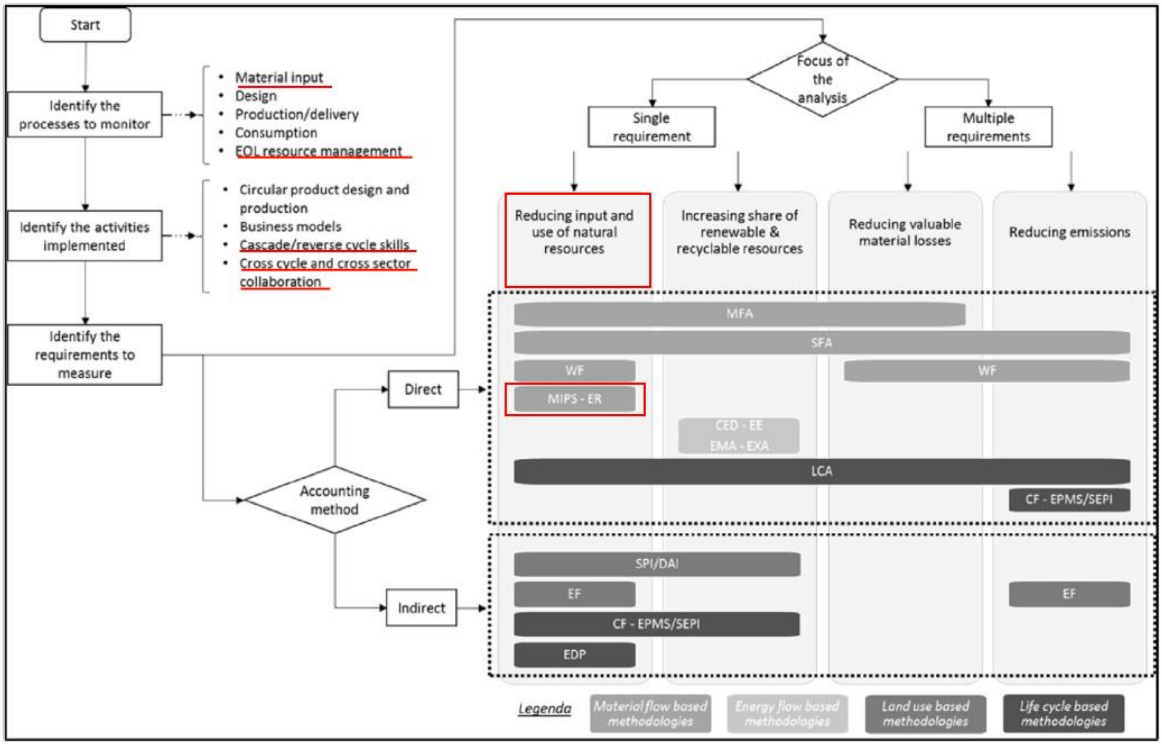

Figure 35: Critical steps in the assessment of a CE strategy. Adapted from Elia et al. (2017)

Table 5 below gathers all indicators derived from our research into circularity in the campus context. To our knowledge, this is the first time that indicators for circularity in campus have been compiled and described.

Table 5: An overview of the chosen material based indicators.

Indicator #	Name	Formula	Metric type	Scale	Description
1	Material output per unit of science (MOUS)	$\frac{Material\ output}{Scientific\ output}$	Circularity	Micro (Campus)	Measures the footprint of scientific output. In an ideal system, the scientific output should use as least material as possible. Adapted from the MIPS in Elia et al (2017).
2	Material output per graduate student (MOGS)	$\frac{Material\ output}{number\ of\ graduate\ studer}$	Circularity	Micro (Campus)	Measures the footprint of student output. Does not account for the time delay or in other words the absolute material needed per degree, as there is no data to support it. Adapted from the MIPS in Elia et al (2017).
3	Product-level circularity metric	c=economic value of recycled parts/economic value of all parts	Recycling / circularity	Meso (Campus/Industrial)	Could help to capture value of closed loop cooperation between suppliers and the TU Delft. Inspired by Linder et al. (2017).

4	Net recycled content (NRC)	NRC = EoL RR x RC	Recycling / circularity	Meso (Campus/Industrial)	Ratio of the actual recycling content times the amount of material leaving campus that is recycled. Quantifies the ratio between recycled material output from the system and the related offset in primary supply. Fosters the cooperation between EoL and suppliers.
5	Material Circularity Indicator (MCI)	See Ellen Macarthur Foundation (2015)	Recycling / circularity	Meso (Campus/Industrial)	Discriminates both virgin input and EoL paths into RC, reuse factor and recycling technology. Gives a robust approximation to a holistic circularity indicator.
6	Operational EoU material footprint	$\frac{Operational\ waste\ collected}{FTE}$	Circularity	Micro (Campus)	Measures the footprint of of operational waste per FTE.
7	Organic EoU material footprint	$\frac{Organic\ waste\ collected}{FTE}$	Circularity	Micro (Campus)	Measures the footprint of of organic waste per FTE.
8	Residual EoU material footprint	$\frac{Residual\ waste\ collected}{FTE}$	Circularity	Micro (Campus)	Measures the footprint of of residual waste per FTE.
9	PMD fraction footprint	$\frac{PMD\ waste\ collected}{FTE}$	Circularity	Micro (Campus)	Measures the footprint of of PMD per FTE.
10	Paper footprint	$\frac{paper\ collected}{FTE}$	Circularity	Micro (Campus)	Measures the footprint of of paper per FTE.

3.1.5 Recommendations and milestones for a circular campus

In section we will introduce achievable targets under the format of milestones in a roadmap. The targets that we will put forward are backed by our data analysis meaning that they are feasible from a mass/collection point of view. We will use the indicators introduced in chapter 3.1. We will leave aside the logistics of collection since this is the responsibility of the operational side of the FM. If the TU Delft sets internal targets on collection at the source, then it is the role of the operations within FM to participate in discussions and give valuable input into how it could be achieved. The participatory nature of the process will yield positive results if all stakeholders are involved and know what they are doing at each moment in time and for what they are working for (De Bruijn & Heuvelhof, 2002; Verhoef, 2017)

We have designed 3 realistic scenarios which vary in the magnitude of the effects of improved collection at the source by using Aula and Echo as Living Labs for a new EoU material strategy. These scenarios are based in our interviews with the relevant stakeholders to PA I: FM, Sodexo, Renewi, Buurtcompost, WUR and GreenOffice. In **Error! Reference source not found.** a summary of the assumptions for each scenario is presented.

Table 6: Summary of the 3 scenarios for operational EoU material

Scenario	Description
1	**Business as usual (BAU)** scenario reflects what the future situation at the TU Delft could be if no circularity measures are adopted at the level of operational EoU material. It implies the footprint of EoU materials based on the projected growth in terms of FTE. Separation at the source, Living Labs or organic collection are not contemplated.
2	**Best practices (BP)** scenario reflects the incorporation of best practices from other institutions at the TU Delft. Examples are inspired from WUR but also from UBC. The Echo building and Aula are used as a Living Lab for separation at the source from 2020 onwards. Progressively the outcomes of these Living Lab experiences are retrofitted into existing buildings. Parallel to this, the amount of operational EoU material per FTE does not decrease but only the reduction of residual waste is modelled.
3	**Frontrunner (FR)** scenario means that the TU Delft excels and goes beyond the implementation of what has been done elsewhere. It sets trends in terms of reduction of operational EoU material. Both at the input and at the output with strict standards for operational material entering the system and implementing requirements on the discard phase with the associated recycler. This initiatives lead to progressive decreases over time of material footprints per FTE.

The scenarios are a mixture of both qualitative and quantitative assessments. Due to the limited availability of time and the nature of the project, we have limited ourselves to milestones that could be justifiable with data and feasible. **Error! Reference source not found.** provides an overview of the milestones which are applied in a mixed way scenarios BP and FR given that scenario BAU does not contemplate any changes in the system.

Table 7: Summary of most important milestones in scenario 3

Milestone	Description	When	Effect
1	Echo as a Living Lab where separation at the source is introduced. The effects are based on the “Fellowship” building which has a similar EoU material generation as the Echo will have in 2020. The reduction ratios are based on Table 8	2020	Composition of operational EoU material stream (2017/new): Residual: 76.5 % / 43 % Paper & cardboard: 22 % / 22 % Organic: 0.67 % / 31 % PMD & coffee cups: 1 % / 4% Yield in terms of kg/FTE: Residual: -1.04 Paper & cardboard: 0.2 Organic: 0.74 PMD & coffee cups: 0.1
2	Aula as a Living Lab where separation at the source is introduced. Given the high influx of people during lunch time, the concentration of bins and the 3 underground containers outside, Aula could be a perfect example of a Living Lab.	2020	Composition of operational EoU material (2017/new): Residual: 76.5 / 43 % Paper & cardboard: 22 / 22 % Organic: 0.67 / 31 % PMD & coffee cups: 1 / 4% Yield in terms of kg/FTE: Residual: -1.97 Paper & cardboard: -0.64 Organic: 1.05 PMD & coffee cups: 0.22
3	Based on proven success of Echo and aula Living Labs, the TU Delft could roll out to other buildings in campus the new separation at the source strategy.	2025	Similar to what is mentioned above

4	Reduction of paper input into the TU Delft.	2025	An additional reduction of EoU paper of 5% from 2025 onwards
5	Improved net recycling ratio (NRC) through clauses in waste tender whereby the contractor is forced to find creative ways to improve the EoL RR and supply enough secondary raw materials (SRM) to the secondary market. We addition of SRM and extraction of PRM in global terms	2020/2025	Progression of 5 % per year in RC and increase in EoL RR in 2025. This will yield approximately 5 tonne of recycled material as feed to the TU Delft system in 2020 and between 15 to 30 tonne in 2025.
6	Overall reduction of material input into the TU Delft by means of finding creative solutions with those responsible for the material footprint of the institution (catering, vending machines, procurement, etc). Examples are: reduce availability of coffee cups or impose a deposit, remove PET bottles from vending machines, reduce packaging in food outlets, give reusable water bottles to students, etc.	2020	Reduction of 2.5% per year on the residual EoU material which results in a continuous reduction of approximately 1 kg/FTE until 2030

If the optimist scenario (FR) is used and the six milestones described above are employed, the following targets could be achieved:

Table 8: Changes in operational EoU material in 2018 and 2030 in scenario 3

Stream	**2018 [kg/FTE]**	**2018 total [t]**	**2030 [kg/FTE]**	**2030 total [t]**	**Absolute change [t]**
Residual	35.8	976.3	10.2	335.6	-640.7
Organic	0.3	8.2	14.5	479.7	471.5
Paper	10.7	291.8	7.9	259.7	-32.1
PMD & coffee cups	1	27.3	2.8	93.5	66.2
Total (operational)	46.8	1,275.2	35.4	1,168.4	-106.8

As depicted in Table 8, the change is quite dramatic even more if involved costs per tonne of collected material would be included (as mentioned before, this will not be the case).

It is also noteworthy to analyze how this change could be monitored through indicators. For that, indicators 1, 2, 4, 6, 7, 8 and 9 yield as follows:

Material Output per Unit of Science (MOUS):

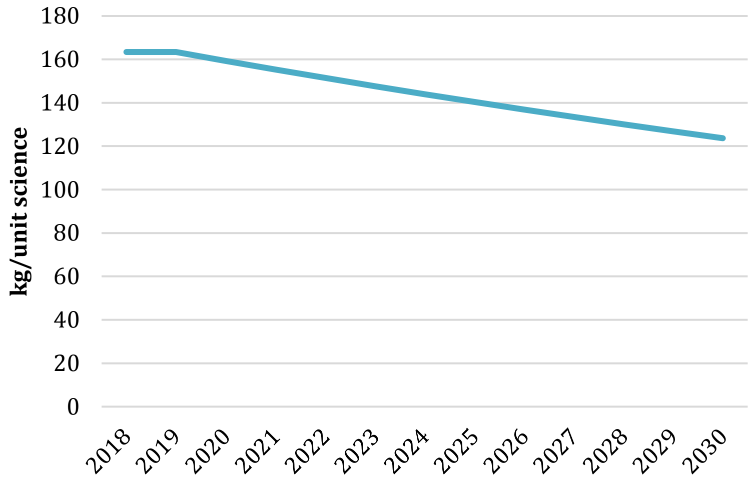

Figure 36: Material Output per Unit of Science (MOUS)

Material Output per Graduate Student (MOGS):

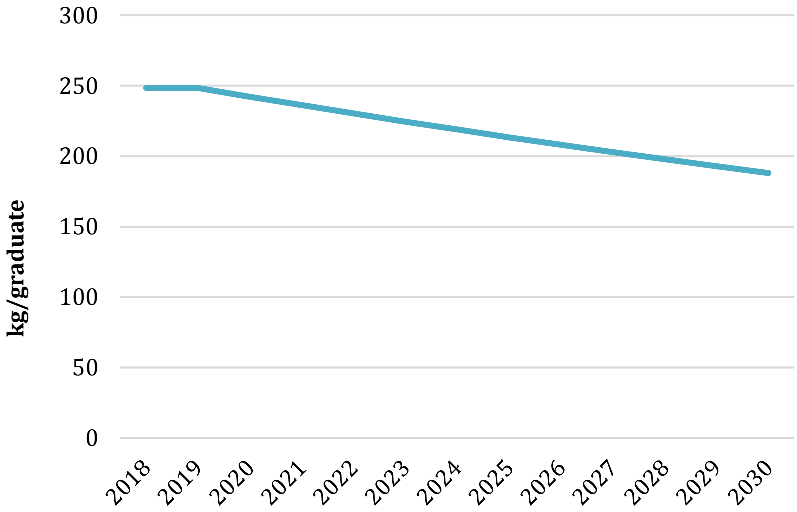

Figure 37: Material Output per Graduate Student (MOGS):

Net Recycled Content (NRC):

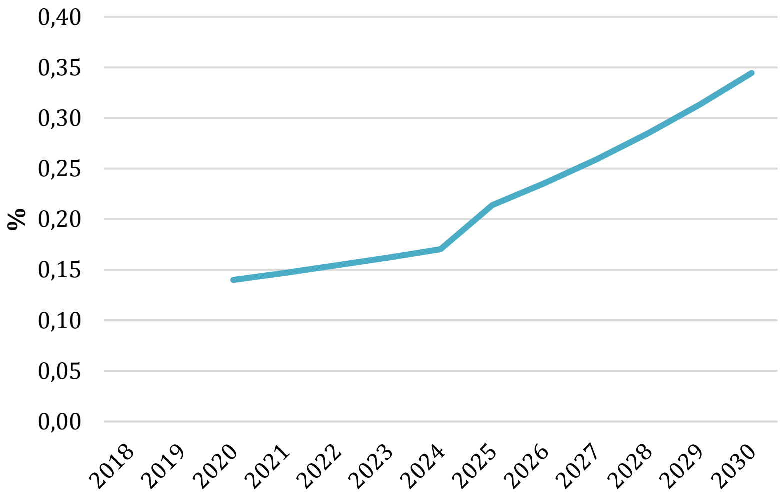

Figure 38: Net Recycled Content (NRC)

Footprint indicators:

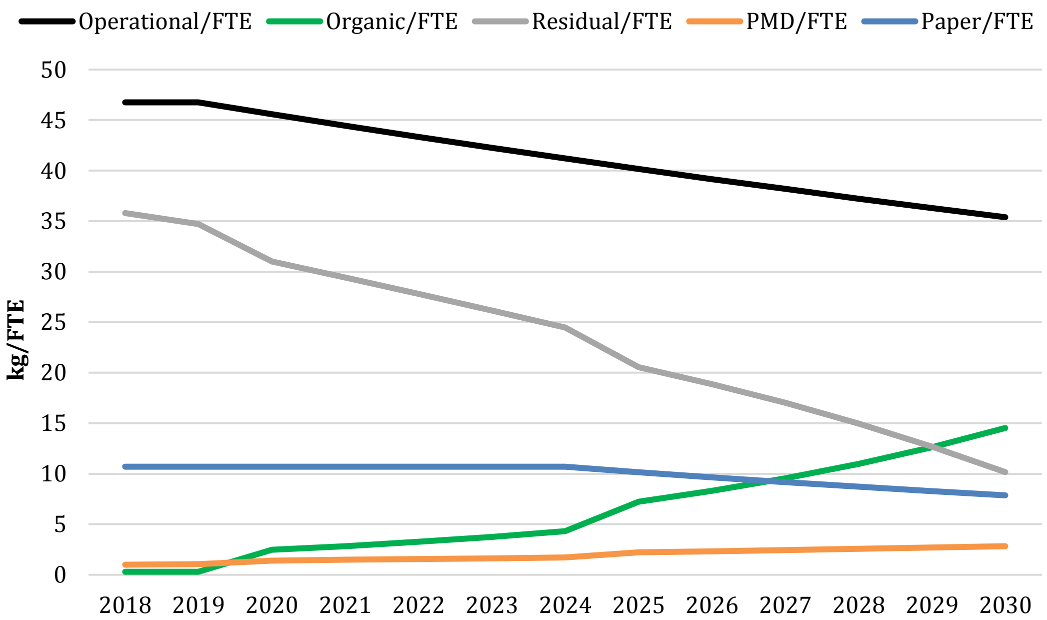

Figure 39: Changes over time in footprint indicators

As depicted above, the proposed indicators can be used to monitor the progress in circularity over time. These indicators go beyond the requirements of SustainaBul or GreenMetric because they introduce notions of circularity. To create legitimacy for the indicators, the recycling partner should be imposed to perform according to the NRC target and at a campus level, MOUS, MOGS, and others should be part of the annual sustainability report and incorporated in the targets of the waste tender contract.

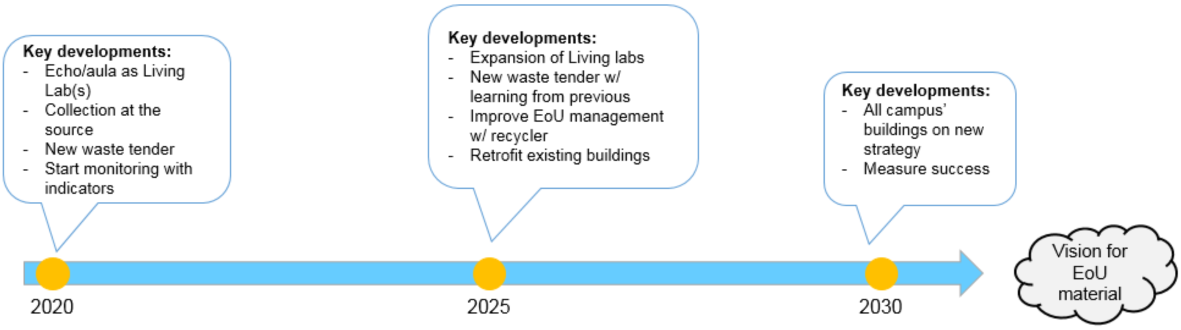

Figure 40: The key developments in the management of operational EoU material

3.2 PA II - Non-operational material

Having discussed PA I, this chapter elaborates on PA II: its definition and role, the current situation at the TU Delft, and recommendations for future improvements necessary for a transition to a circular campus.

3.2.1 Definition of Priority Area and Relevance within CE

As depicted in Figure 3 in the methodology chapter, PA II non-operational materials are not caused by individual students/staff themselves but rather by the fact that the campus must be in an appropriate condition to deliver its function as a campus. Thus, this is rather campus-owned material originating from objects within buildings such as furniture or electronics, or from the outdoor area of the campus, such as gardening waste or abandoned bikes. Hence, opposed to operational EoU material of PA I, non-operational EoU material of PA II does not apply on a daily basis but mostly due to special occasions, such as breakage, failure, technical updates, redesigns or landscaping.

Using the lifecycle perspective from Chapter 1.1, non-operational material on a campus passes through the following stages (see Figure 41):

1. Commissioning:

An employee sees the need to purchase something for the university and therefore contacts the procurement department which is in charge of conducting the purchase according to regulation. In case of non-operational material, FM is often the commissioner.

2. Procurement:

Since TU Delft is a public institution it has to oblige to European regulations when it comes to purchases of a certain value. This department ensures that purchases are following the law as will be explained more in detail in a later section.

3. Usage:

Once objects are purchased they are put into usage. Here, they can be used by students and staff.

4. Facility Management & EoU collection:

When something breaks down, for example when a chair is broken or when computers need to be replaced they get collected and brought to the waste management on campus.

5. Waste management on campus:

The waste management has additional storage space for non-operational waste and sorts it in such a way that it can be picked up by the waste contractor. Depending on the type of material TU Delft needs to pay for this disposal or receives a payment from the waste contractor due to the value of the material handed over. The waste management is in charge of the coordination between different buildings on campus and the waste contractor and has the task to ensure a clean campus, where “waste” is not visible to people.

6. Waste contractor:

The waste contractor collects non-operational EoU material from the waste management as agreed upon in a contract. Depending on the contract, the different materials follow specific routes. From this point onwards, the waste contractor has the responsibility over the material. The treatment happens as specified in the contract and according to the price agreed upon.

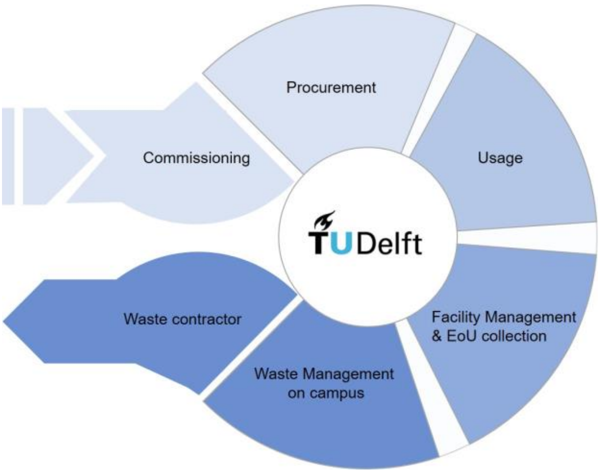

Figure 41: General life cycle of non-operational material on a campus.

It is important to mention, that this life cycle stands in the context with rules and regulations given by the campus management but also by the Dutch and European law. Thus, it is embedded within a bigger system of the campus, The Netherlands and the EU as also illustrated in Chapter 1.2. This leads to decisive influencing factors and also brings university-dependent context variables. Furthermore, the production stage before commission is not depicted here, since it usually does not happen on campus, but it still needs to be considered in decision-making.

Compared to PA I, non-operational material comprises bigger-sized objects which translates into higher mass per object and usually also into higher economic and material value per object. In the context of CE thinking and value preservation, this means that it is of high importance to apply principles such as reuse, repair or refurbish. Those actions mostly require organizational effort or additional human labor. However, by investing into human labor which conducts for example repairs, small actions can achieve high yields in form of material, value and embodied energy which is prevented from ending up in an incineration plant. Furniture for example currently counts as residual waste for the waste treatment even though repair and reuse can be very efficient and easily implemented to prolong the lifespan (M. Faber, personal email, May 17th, 2018). Looking at this example it becomes apparent to examine the current system handling non-operational EoU material and how CE principles can be realized in this area.

3.2.2 Current situation

This section will reveal the current system and conditions of non-operational material at TU Delft in the order as presented in Figure 41: General life cycle of non-operational material on a campus.. Since the current waste contractor is the company Renewi, this name will be used to refer to the actor of the waste contractor.

Commissioning and procurement process at the TU Delft

Since the commissioning and procurement process goes hand in hand, it will be described here in one section.

The procurement process at the TU Delft is bound by external regulations which apply to all (semi-)public institutions in the European Union. This section will illustrate what these regulations look like, how they shape the composition of private parties supplying goods and services to the TU Delft and how this can influence the transition to a circular campus. Since PA II relates to non-operational EoU material, procurement is very relevant for this priority area because non-operational material is mostly purchased via procurement processes.

Procurement may involve a single time purchase of a simple good up to the negotiation of a multi thousand euro contract for the supply of more complex products/services. The procurement process was discussed in an interview (K. Flapper, personal interview, April 24, 2018) and is summarized in Figure 42. The simplified depiction in Figure 42 starts with the requestor (staff member of TU Delft or facility manager from FM) requesting budget to the so called budget holder of the faculty or group to initiate a purchase process. Depending on the value of this purchase, the process will follow different routes. An important point in this process is that for purchases below 209k€, the requestor has some power to drive the purchasing power towards suppliers meeting certain sustainability standards and/or circularity principles given that the budget holder agrees. For larger purchases that are subject to European rules, or for purchases where a list of approved suppliers already exists, the requester has much fewer capabilities to request a product/service meeting certain sustainability standards and/or circularity principles.

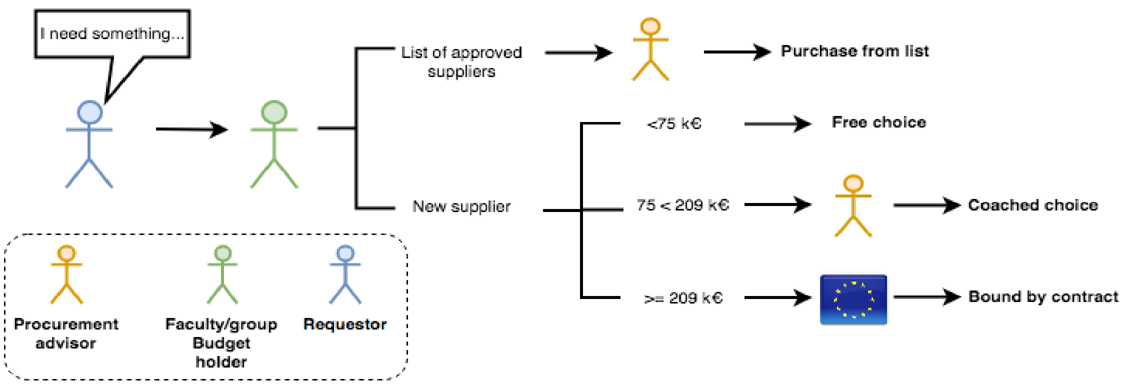

Figure 42: The process of procurement at TU Delft.

An important aspect of the procurement process resides on the fact that the procurement department of the TU Delft, either while giving purchasing advice (75<209 k€), or when carrying out a new tender process where European rules must be observed, holds a very important position in deciding to what sustainability standards and/or circularity principles suppliers must comply with.

The European tender process

As stated before, the European tender process is a requisite for purchases that over a period of 4 - 6 years will be higher than 209k€. For these cases, the TU Delft is obliged to hold a tender process that is defined by European rules (K. Flapper, personal interview, April 24, 2018). The intention of these regulations is to avoid the formation of market cartels and to ensure a level playing field for companies throughout the EU. Figure 43 depicts the process.

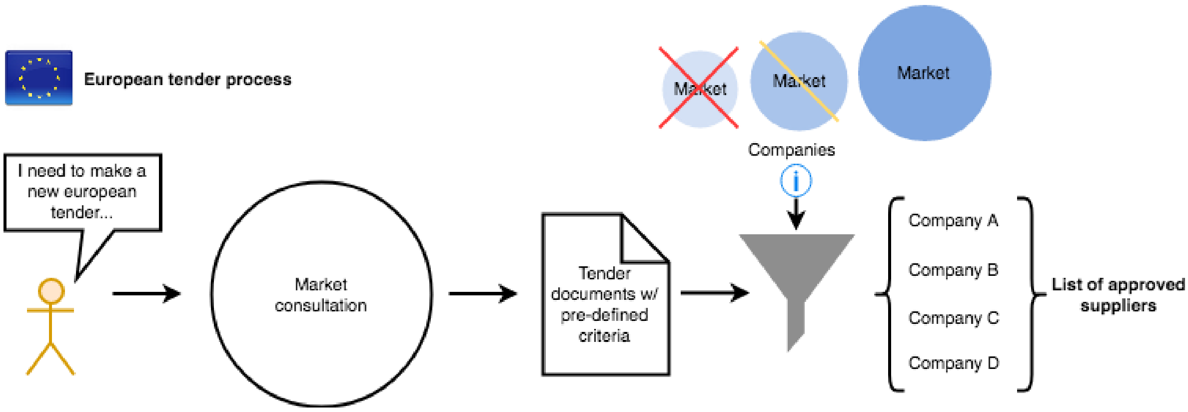

Figure 43: Impacts of the European tendering process.

In this process, certain criteria have to be matched by companies that apply for the tender process. If a company has high sustainability or circular ambitions but fails to comply with the criteria in the tender given its lack of market maturity or inability to answer the tender, this company, depicted in Figure 43 as the small market circle, will be selected out.

Very often, spin-offs or start-ups from alumni of the TU Delft have developed technology or ideas that could help not only the TU Delft but other companies in reducing their environmental footprint or to become more circular. But before these ideas reach a mature state of development where the market is already very well developed, new enterprises have to grow slowly in more dedicated markets before reaching the state where they have the assets to enter a European tender. In Figure 44 a depiction of our understanding of how the TU Delft can supply the market with ideas is depicted. It is natural that innovation coming out of the TU Delft will first enter smaller niche markets before maturing enough to reach a bigger market.

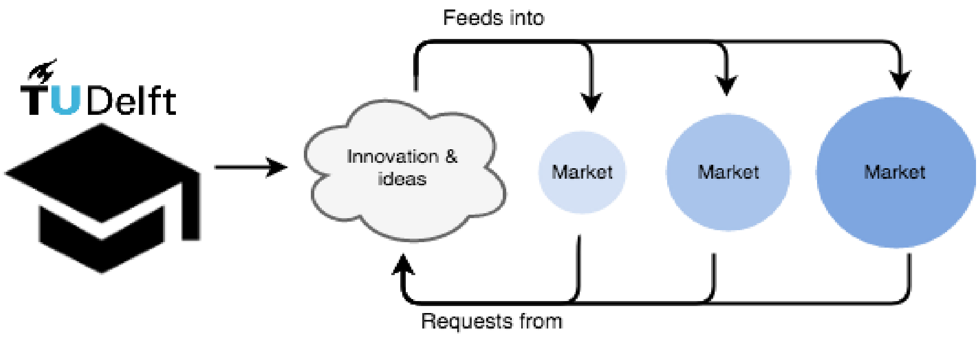

Figure 44: The relation between innovations at TU Delft and the market.

Facility management, usage and EoU collection

After the procurement, products are put into use. As revealed during the interview with Koen Flapper from the procurement department, his responsibility ends here (K. Flapper, personal interview, April 24, 2018). Once objects are in use, they are more or less subject to the user alone. In case of an unusual defect for example of a new device purchased for a laboratory, the user will report the complaint back to the procurement department such that the problem can be solved with the producer. However, in the general case of non-operational products, no communication takes place between the usage phase and the procurement about the performance of products in terms of quality, durability or reparability. This means that the procurement does not receive feedback about the purchase decision made and consequently can't learn from the user experience to improve future decision e.g. for certain type of chairs. This also implies that no documentation exists about the user satisfaction. Figure 45 demonstrates the current EoU system and desirable structures to optimize the organization with the purpose of aiming at a circular campus.

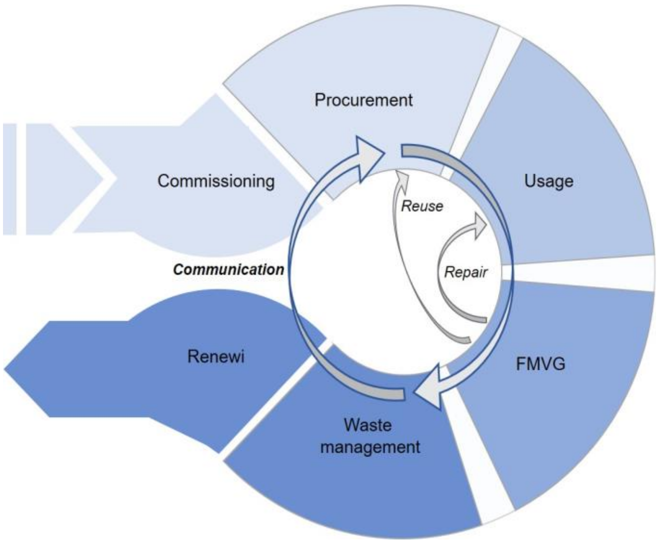

Figure 45: Desirable structures for the material life cycle management to improve the system

Insights into facility management (FM) at TU Delft

A second actor related to the commissioning and usage phase is FM, which is responsible for purchasing equipment needed in buildings and for ensuring a good status of this equipment. Facility managers are employed per faculty and can be in authority of several faculties. Being a large institution, the campus is organized in different departments, meaning employees are assigned to specific tasks which also applies for the planning, purchase and maintenance of non-operational materials. As found out through interviews this fact leads to three problems:

Firstly, in big institutions employees tend to do feel responsible for only their own task but rather little what would be out of their field of responsibility. This depends of course on the type of persons and job but it can be seen as one phenomenon.

Secondly, given the size and regulations within the institution, there is generally less room for drastic changes or improvements for example due to the limitations of the European tendering processes. So even if a facility manager has the aim to progress in practices to increase sustainability, many ideas are hindered by the given bureaucratic structures or by already existing contracts with companies, as stated during an interview with Erik de Vos, the facility manager for EWI (the faculty of Elektrotechniek, Wiskunde en Informatica) and Sports & Culture. During the interview it became apparent, that Erik is a very open-minded and environmentally aware person who is ambitious to achieve change at TU Delft. So, he pointed out that there are already innovative systems in place but only on a small scale. A good example are carpets from Desso a company which strives for closed loop production for their products. These cradle to cradle certified products are currently tried out at the TU Delft, but not on a large scale (E. de Vos, personal interview, May 31, 2018).

The third problem is, that the inherent complexity of taking the right decisions. As explained by Erik de Vos during the interview, guidance and rules are missing from the campus management. Despite his strong will to implement new solutions and to improve in terms of

sustainability, he often does not know where to start or how to assess different possibilities. The problem of sustainable consumption and of CE is so complex and includes a wide variety of aspects, such that an overall strategy is needed to provide guidance how to tackle the problem. Both Sven Verhoeven, the project manager for Echo, and Erik de Vos are fully aware of the fact, that CE does not only mean an improved waste collections system but also entails factors at the supply and consumption side. Additionally, they pointed out that finding the right products and technologies are only the first step and the second step is to ensure a correct usage and consumer behavior.
Thus, the conversation with the facility manager, Erik de Vos, and the Echo project manager, Sven Verhoeven, reveals that despite their CE awareness and strong ambitions they experience a situation of being rather left alone with the challenges and desire a guidance from the campus management in terms of rules but also in terms of receiving organizational support to include new ideas in the current campus structures (E. de Vos & S. Verhoeven, personal interview, May 31, 2018).

CE practices for non-operational materials

Next to the insights into to the challenges of employees who would like to contribute to a more circular campus, it is important to look back to the principles of CE and to which extent they are addressed at TU Delft for non-operational material. Here the circularity ladder or the value hill give guidance (see Figure 5 and **Error! Reference source not found.**).

First CE principle: Prevention
As shown in chapter 1.1, it is crucial for a CE to prevent an unnecessarily high use of primary resources. Therefore, strategies such as refuse, dematerialize, maintenance and repair should be applied (De Groene Zaak, 2015).

Investigating what is currently done in terms of the strategy of prevention, primarily research projects can be found. For example is TU Delft involved in the European research project REPAiR (http://h2020repair.eu/) which aims at improving resource management in cities. Other research focuses on product design optimized for a circular product design, such as David Peck, Marcel den Hollander or Conny Bakker (Bakker et al., 2014). Studies about repair cafes has also been conducted (Delta, 2015).

However, when it comes to putting the prevention principle into practice on campus, still much more can be done. So far, only three initiatives stand out: the previously mentioned repaircafe delft which is available on campus once a month (Repaircafe Delft, 2018), free of charge bike repair stations scattered over the campus (TU Delft, 2018a) and a bike leasing company, swapfiets (https://swapfiets.nl), which offers free of charge repairs to their customers.

Yet, these examples are rather independent bottom-up developments, but were not initiated by the campus management applying a top-down approach. Thus, initiatives from the campus management itself which originate in the institutional structure are lacking. The system of TU Delft operations in the current status does almost not account for a CE strategy of dematerialization, maintenance or repair. Our interviews did not reveal the existence of some department which is responsible for repairs or proper maintenance to directly and efficiently serve the purpose of product life extension of non-operational materials. Nor is the procurement department engaged in efforts of dematerialization as far as we found out.

Looking at the system definition of TU Delft in chapter 1.2.2, this means that only the productive layer reacts to the issue of the first CE principle, while the supportive layer of the campus itself has not internalized measures towards prevention. This discrepancy illustrates a gap between research and operations.

Second CE principle: Reuse
Next to repair, reuse e.g. through repurpose or redistribution is another very important aspect of CE to prolong life spans and avoid primary resource inputs as well as the creation of disposed material.

Regarding existing solutions in practice, the kringloop shop in Delft serves as a good example, since it resells used products, furniture or clothes for low prices. Since students are generally financially limited, sharing platforms are frequently used. The digitalization in the last years offered great opportunities for bottom-up sharing platforms which especially developed in facebook organized in groups such as: “student sale in Delft”, “for free and for sale in Delft”, “Bike sale in Delft” etc. Here, basically all kind of personally owned products get redistributed in particular within the student community. The numbers of members reach several thousand which demonstrates the high demand for such sharing platforms within the community of students.

Similar to the case of the first CE principle, no redistribution network or platform is known as part of the institution of TU Delft itself despite the previously mentioned need. None of the activities, repurpose, reuse & redistribution, refurbishment, remanufacturing which fall under the second CE principle, seem to incorporated into the official organizational structure at the university.

Waste management on campus

If something is declared as non-operational EoU material, it gets collected and stored at the Logistics and Environment (Logistiek en Milieu) location (Building 60) on campus until Renewi picks it up. This department is managed by Michiel Faber, who we conducted several interviews with. Logistics and Environment takes the role of the middle man between the waste contractor and the different EoU materials sources in campus buildings. It manages the cooperation between the faculties and Renewi and ensures a smooth collection between the sources and the waste contractor.

Third CE principle: Recycle
In the case of recycling non-operational EoU material no direct analysis could be conducted within the scope of this project, since the focus is primarily on operational EoU material. Furthermore, so far no comprehensive data is available on these material streams. Therefore, no conclusions can be drawn in this respect. To our knowledge, the most common

destinatination for these materials is either incineration or high temperature incineration (chemically treated materials such as C-type wood and etc).

What is known is that electronic waste (abiotic material) for example gets collected separately by Renewi as well as gardening waste (biotic material). To which extent these materials are efficiently recycled is not to our knowledge. As communicated by Arie van Ziel from Buurtcompost, big players in the recycling industry cannot master the art of compost making because of short residence times and high contamination in streams (A. van Ziel, personal interview, March 30, 2018). The biochemical processes involved in producing quality compost require a dedicated facility either with warm or cold compost stations and only through this approach one can obtain economic profitability from making compost. For a recycler this tends not to be the case although compost can be a very profitable stream if of high quality (c.f. current situation in PA I). On the other hand, if there is 10 % of biological material in the compost, this can be called compost. But both for abiotic and biotic, most likely rather downcycling than upcycling takes place and some portions might be used for waste to energy. Yet, these are only assumptions and more research is needed in this respect.

It can be stated, that no recycling takes place within the system boundary of TU Delft. Thus, all EoU non-operational material leaves the campus once it arrives at Logistics and Environment. For the subsequent treatment, Renewi is responsible.

Insights from Michiel Faber

During the interviews with Michiel Faber, similar issues could be revealed as in the conversations with Erik de Vos and Sven Verhoeven. Generally, there is no guidance or regulation on how to improve the EoU material system. The job of Michiel Faber is not to progress towards more resource efficient systems but to ensure a clean campus. Moreover, within the material life cycle system there are no structures foreseen to allow for collaboration between the end of the life cycle and previous stages such as the procurement and usage phase. However, being at the end of the life cycle and functioning as a collection point for all EoU non-operational material, Michiel Faber has an overview what the system of TU Delft actually produces as an outflow.

Yet, the organizational structure does not make use of his experiences, for foreseen feedback loops do not exist between the department of waste collection on campus, commissioners, and employees or students during the usage phase. Consequently, knowledge from different life cycle stages is not combined or exchanged to facilitate an optimization of resource utilization.

As Michiel told us, two problems reoccur when he tries to implement changes:

Firstly, more advanced separation of streams to improve the following treatment e.g. towards reuse or recycling require increased intermediate storage capacity at individual buildings either through bigger sized container rooms, or underground containers. In both cases conflicts arise, since usually during the building planning phase, storage of waste is not prioritized and dedicating space to containers is seen as a loss of space for other purposes such as study areas. Regarding underground containers, disagreement arises with a department of TU Delft which is responsible for the look and atmosphere on campus. Storing EoU products somewhere outside of buildings collides with their vision of a clean campus and is therefore mostly rejected (M. Faber, personal interview, February 21st, 2018).

The second problem mentioned by Michiel Faber, is the regulation regarding ownership. Many collected items, such as abandoned bikes or wooden pallets, are in a status still suitable for reuse. However, since the ownership is not clearly defined, Michiel's department is not allowed to redistribute them but has the duty to ensure a safe disposal via Renewi. This means that a big amount of products in still very good condition, is sent towards waste disposal. In case of furniture, we know that it counts as residual waste (M. Faber, personal email, May 17th, 2018), thus most likely it will go to Waste to Energy recovers, which is great material loss (M. Faber, personal interview, February 21st, 2018).

Overall, we conclude that once non-operational material arrives at the waste management on campus, the further treatment is bound by regulations which focus on cleaning the campus and safe disposals. Thus, at this stage of the life-cycle there is little room for implementing different practices towards a circular campus and therefore, interventions should rather be realized at an earlier stage.

Waste Contractor, Renewi

As described, Renewi is the current waste contractor for TU Delft meaning that it collects all waste streams from the campus. No deep analysis has been done regarding the specific processes of Renewi for non-operational EoU material since that is out of the scope of this project. However, in the current situation the practices of Renewi fall under the fourth principle of CE: dispose.

Fourth CE principle: Dispose

The cooperation between the waste management on campus and Renewi's treatment with the received materials is defined via the contract between the TU Delft and Renewi. As explained by Marthien van Eersel, a project manager for business development at Renewi, Renewi offers a wide range of possible treatments, also advanced high-quality treatments. These are however more costly to book (M. van Eersel, personal interview, May 3rd, 2018). Thus, TU Delft can optimize the fourth CE principle, by investing more money in the contract with Renewi which in return can offer advanced treatments resulting in higher material efficiencies for the campus.

Based on this fact, we can assume that at least some of the non-operational EoU material is treated via WtE, however, this needs further investigation.

As in case of the procurement, the cooperation with the waste contractor is also hindered by the European tender regulations. If Renewi invested in research into better treatment technologies and processes for TU Delft, the resulting innovations would have to be published in the next European tendering process for a waste contractor. For Renewi this means that they would lose their intellectual property on the researched innovation and consequently the resulting business. Thus, this option is not favourable for them as a business (M. van Eersel, personal interview, May 3rd, 2018).

Conclusion of this analysis and problem identification

From the analysis on the current situation of non-operational material at the TU Delft, we can conclude with a set of identified problems. Limited by the scope of this report, this PA is only analysed qualitatively and some areas still need further research. Therefore, the problems identified mostly concern aspects which could be investigated and which were revealed during interviews with stakeholders. The identified problems can be summarized in four main categories. Needed structures for a transition towards a circular campus are illustrated in Figure I5.

1. Lack of communication and organization due to departmental structure

Looking at the whole life cycle and the departments involved at the different stages the analysis showed that currently departments mostly work in isolation and do not communicate with the other ones. The current organizations in departments is structured in such a way that almost no cooperation takes place between the departments responsible at different life stages for the non-operational materials. This shows characteristics of a process-based organizational structure, where departments are structured along the different stages of one process (Devaney, 2018), the material life cycle in our case. Therefore, the system does not encourage a striving for resource optimization in the four dimensions of prevent, reuse, recycle and dispose. An exchange of knowledge, experiences or ideas is not foreseen since jobs are dedicated rather for tasks at one stage than for the whole life cycle view, which is also a typical disadvantage of process-based organizational structures (Devaney, 2018). This means that no feedback loops are currently arranged, for example between the waste management and the procurement or between the user and the procurement.

2. Lack of dedicated departments for CE principles

So far, no departments are in place which are responsible for necessary practices such as repair or reuse to increase the cycling of resources within the campus. The system is defined in such a way, that EoU considered products or materials get transferred to the waste management on campus as fast as possible and with as little attention as possible. So the resource life cycle on campus is mostly linear and treatment processes largely happen off campus. To implement feedback loops for materials, specific departments need to be set up. This also applies for the improvement of communication and coordination.

3. Obstacles in form of regulations

In many cases regulation occurred as a problem when people try to improve something on campus. Examples are the restrictions towards more sustainable but innovative products through the European tendering process or through already existing contracts. This concerns both procurement but also the waste contractor. Also in respect of the waste management on campus reuse and redistribution processes are inhibited due to regulation, meaning safe disposal is obligatory also for still functional products. Another related issue is the conflict between an improved resource management system and the expectations of a good and clean looking campus.

4. Lack of guidance and decision support
Due to the complexity of the issue, many employees reported during interviews that they experience a lack of guidance or rules when it comes to taking a decision towards the most environmentally beneficial option. Thus, a set of guidelines is needed to instruct employees during their decision phases. This partially goes hand in hand with problem 2, since a dedicated department is necessary to research and define such guidelines, but also to offer advice. This primarily applies for the procurement phase and the first CE principle of prevention.

3.2.3 Best practices other Universities

Some universities currently take measures to reduce or reuse their non-operational waste, albeit in mostly semi-structured or informal ways. For example, Twente University has made some informal agreements on the reuse of office furniture in 2014, and Wageningen University also claims to choose for reusing old furniture in their procurement of furniture for new buildings (WUR, 2018; Twente University, 2018). Erasmus University donated End-of-Use furniture to Romania in 2011 (EUR, 2018).

The University of Bradford also has a yearly unwanted items collection scheme, called the Green Move Out, of which the collection is given to new students coming for the next year (University of Bradford, 2018).

With regards to international best practices on dealing with non-operational waste such as furniture and e-waste one recurring factor emerged, namely the “Warp It” platform. This service provides an online platform for universities to offer their unwanted but still useable inventory to students and other parties, while at the same time tracking (among other things) avoided CO2 emissions and tons of material waste. Prominent universities currently using the platform include University of Nottingham, University of Oxford and University of British Columbia (Fraser, 2018). The University of Oxford is claimed to have avoided over 220 tons of solid waste (Warp It, 2018).

3.2.4 Recommendations and milestones for a circular campus

The previous sections analyzed the current system at TU Delft for non-operational material, identified associated problems and looked into current practices at other universities. Based on these results, this section draws recommendations for future improvement.

Recommendation 1: Implementation of a Material Life Cycle Management

Most of the identified problems result from a lack of communication and long-term systems thinking. Since those problems are quite complex it is recommended to implement a Material Life Cycle Management (MLCM). This department is dedicated to obtain a systemic overview regarding non-operational materials in combination with keeping track of the realization of the four CE principles, prevent, reuse, recycle and dispose. Thus, it aims at reducing virgin material input and output of the campus as well as at extending product life times.

Its main tasks are:

1. Facilitation of communication & collaboration between departments
2. Provision of top-down guidelines
3. Management of CE dedicated departments
4. Coordination of bottom-up projects on campus
5. Circularity monitoring with the help of indicators
6. Allocation of financial assets

The idea of the MLCM resembles a "circular organizational structure" (see Figure IOO), which is still based on hierarchy, however has the aim of enabling communication and information exchange between departments. Thus, departments are seen as part of a whole instead of working in isolation (Devaney, 2018). This circular organizational structure could not be found to be mentioned in the context of Circular Economy or of campuses becoming circular. However, the recently published British Standard "BS 8001:2017 - Framework for implementing the principles of the Circular Economy in organizations" (BSI, 2017) recommends similar principles for organizations as the here suggested MLCM. Amongst others, it proposes *systems thinking* "to understand how individual decisions [...] interact within the wider systems" (BSI, 2017, p.28) and *stewardship,* "an organization is responsible for the management of all facets of its decisions [...]" (BSI, 2017, p.29). Thus, it also expresses the need to incorporate circularity principles into organizations, but does not provide a stepwise framework for the actual realization.

Furthermore, Birgit Hopff, who researches how to apply principles of circularity in campus area development concerning the spatial sector, identified similar problems during her work. She agrees with the necessity of the proposed MLCM department: *"Bringing information together from the whole life-cycle, but also to integrate the knowledge in an active way of communication between all departments: that is what we need"* (B. Hopff, personal email, June 6, 2018).

This leads to the conclusion, that the MLCM can be seen as a novel idea to manage material life cycles for large public institutions. It enables to transition from a process based structure which cannot cope with the cross departmental challenges of incorporating material circularity principles towards a more circular organizational structure (see Appendix A1 for additional information). However, further research is needed here focusing on the administrative and organizational background of such a department.

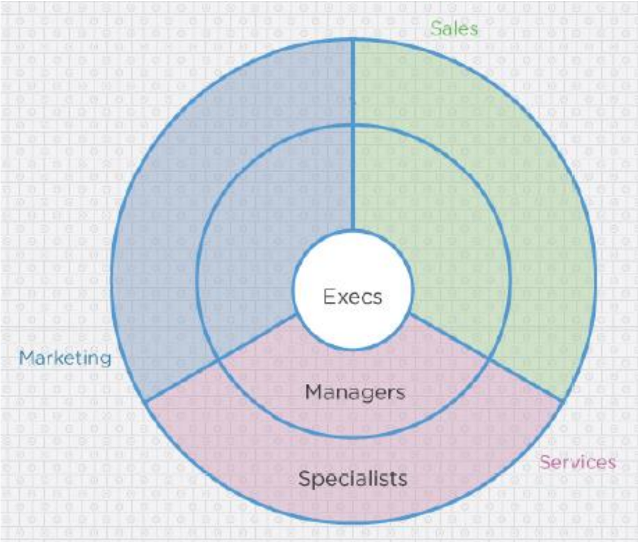

Figure 46: Circular organizational structure for businesses with the executives in the centre (source: Devaney, 2018).

The following explains how the MLCM addresses all four problems identified in the previous chapter. It is important to point out that a combination of bottom-up and top-down measures should be combined here as well as measures regarding the productive and the supportive layer.

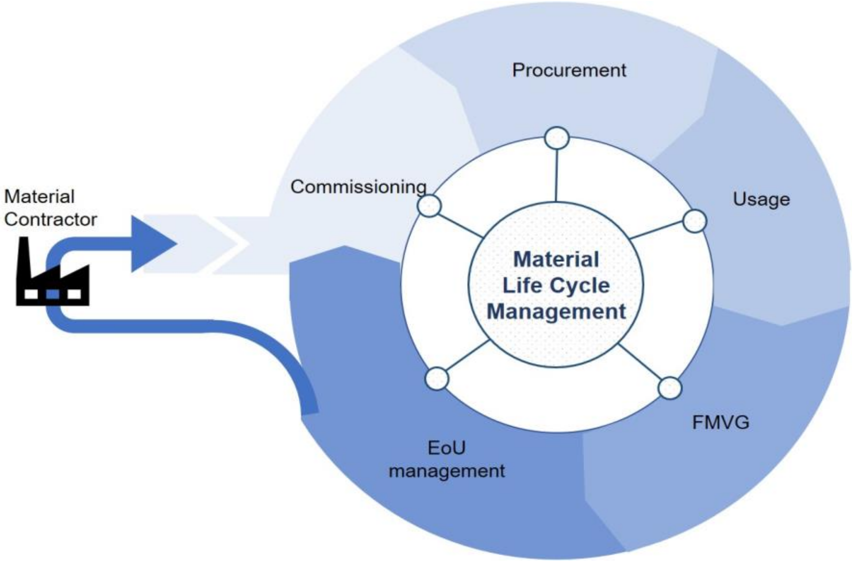

Figure 47: Material Life Cycle Management connecting all departments along the non-operational materials life cycle chain.

Facilitation of communication & collaboration

Firstly, a communication between the different departments along the life cycle chain has to be implemented in order to realize an optimization of resource utilization taking into account all stages.

This includes that the MLCM should create for examples channels for feedback between different departments to overcome the problem of isolated decision-making.

Additionally, the MLCM should organize regular meetings with representatives of all departments where ideas, knowledge and experience can be exchanged. This shall enable an efficient and productive collaboration. Moreover, it helps to create awareness of problems occurring in different departments which are caused at previous stages and therefore, improve future decisions.

Provision of top-down guidelines

As mentioned especially by Erik de Vos, Sven Verhoeven as well as by our commissioner Dennis Meerburg, guidelines where to start with improvements and how to include them in the current system of TU Delft are missing (De Vos & Verhoeven, personal interview, May 31st, 2018; D. Meerburg, personal interview, March 8, 2018). This leads to a lot of personal time and effort being spent on research by individual employees for example in building planning and FM. Usually the campus management has the task to provide certain guidelines, however, since CE is not extensively implemented yet in TU Delft's vision, the MLCM should undertake this task. Thereby, an MLCM employee should develop a set of rules and guidelines, which are applicable for each department and represent instructions how to implement the four CE

principles. This shall not only support ambitious employees but also alert those who so far are not reflecting their actions.
In particular commissioners and procurement agents are the ones who can have high influences through prevention and reuse measures in the case of non-operational products. Therefore, the process of defining guidelines should start there.

Management of CE dedicated departments

In order to achieve system change, it is most important, that the supportive layer gets adopted to the requirements of a circular campus to combat the gap between the research and operations at the TU Delft. For largely, the supportive layer is the one which dictates the environmental performance of the campus.
Therefore, the MLCM should establish dedicated departments to adjust according to the principles of a CE. The following presents some solutions closest at hand, however, more research needs to be done here, since many possibilities exist.

Prevention: Repair
The most obvious measure for prevention is to create a maintenance and repair department which is for example responsible for several faculties. Here, craftsmen should be employed with the specific task of repairing e.g. furniture or electronic devices in order to extend the life span of non-operational products as long as possible.

Reuse: Sharing Platform
Universities offer very unique opportunities when it comes to reuse. There is a very high rate of students moving in and moving out, which translates to a high need of quickly purchasing products like furniture, and of quickly getting rid of them again. At the same time, they have only limited financial possibilities, but also demand only little regarding their commodities. These low expectations combined with a high level of creativity offer best conditions for realizing reuse systems, such as sharing platforms.

The university should contribute to a high level of reused goods, also from its own supportive structure. Therefore, the MLCM should establish a reuse sharing platform which both enables sharing between different departments but also with students and lastly with organizations outside of the campus boundary.
This sharing platform should originate from the official campus organization to gain enough legitimacy. Its serves as an institution between the usage phase and the waste management on campus to avoid, that products reach the campus waste management from where they cannot return to the system due to regulation. This kind of organization is also recommended by Michiel Faber who is bound by regulation to transfer everything to Renewi regardless of the status of a product (Faber, personal interview, 2018).

Currently, the best known example for such a product sharing platform is “Warp It” as seen from the best practices of other universities. It enables a bridging between different departments where often no communication takes place. Thus, for example procurement persons on campus get connected with a person which is responsible for the EoU of products.

Consequently it allows for an efficient way of linking a person who plans to purchase a specific product with a person which has exactly this product leftover.

Warp it provides the following tips and advantages:

- The system can be directly connected it with the procurement, meaning that when new items are planned to be bought, a reminder is sent in case a similar item is available for reuse.
- The implementation should start on a small scale and then be extended stepwise on a spatial and a product level.
- A reward system (such as chocolate bars) is successful in encouraging employees to get to know the system.
- It really helps if one person is reachable as the “reuse person” on campus, who can be contacted.
- The system can be linked with many other organisations, such as kringloops or charity organizations outside of the campus which also supports their work.
- In case of electronic devices, the problem of confidential and personal data can easily be solved by removing hard drives.

Warp It shows great success not only in Great Britain and is therefore a promising solution also for TU Delft. Being a campus university with very short distances between buildings and student housing further supports its functionality. First contact has already been established with Daniel O'Connor from Warp it, who can be reached for further questions.

Recycle and Disposal

The principles of recycle and disposal on campus for example via cascading of gardening waste needs further research. It offers many possibilities for future student projects or for creative innovations. The MLCM should provide suggestions and ideas to stimulate progress in this respect.

Coordination of bottom-up projects on campus

Next to the implementation of CE principles in the supportive layer, the MLCM should also enable bottom-up initiatives such as student projects or Living Labs. As already mentioned, there is a great possibility especially due to the newness of the field.
Space and possibilities should be provided to try out new ideas which, if successful, could be adopted into practices within the supportive layer. This can also help to bridge the gap between the two layers. Additionally, it brings advantages in terms of learning processes for students and researchers as it will be explained in PA VIII. It furthermore closely links with PA XI, communication. Being a technical university the university has a lot of potential in form of students’ creativity and knowledge. Therefore, the MLCM should try to utilize this good and steer it to the challenges of a circular campus.

With regard to problem III, obstacles in form of regulation, the MLCM should try to create some working space, to avoid this problem.

In the coming months, the plans and design of the new building Echo will be finalized. During this process student participation is desired from Erik de Vos and Sven Verhoeven. Living Labs can for example be implemented there. This approach is researched e.g. by Leendert Verhoef (Verhoef et al., 2018). This offers a good possibility to combine the research for a transition to a CE with practical examples on campus and the required knowledge in Living

Labs. The MLCM should aim at preparing and promoting such possibilities to students. More insights into future outlooks regarding these kind of projects will be given later.

Circularity monitoring with the help of indicators

To assess the performance of the non-operational material system of TU Delft, the MLCM should implement a monitoring system which works via indicators. This can also be applied in guidelines for instance for procurement.

The focus for indicators should lie on the four principles of a CE, since the whole life cycle needs to be covered in order to avoid problem shifting. However, the topic of indicators requires deep research to ensure, that correct guidance is given.

The work by Lonca et al. (2018) demonstrates that even though the Material Circularity Indicator by the Ellen Macarthur Foundation is considered to be the most suitable one (Elia et al., 2017), following its advice in decision-making processes, can lead to undesirable side effects on human health and ecosystems. These undesirable, but not measured side effects by the MCI, e.g. in the case of product life extension can be proven via an LCA (Elia et al., 2017).

This shows that the validity of indicators needs to be thoroughly investigated in order to ensure a correct guidance leading to actual impact improvements.

Therefore, setting up a functional indicator system needs to be researched in detail and is out of the scope of this project. This task could e.g. serve as a thesis topic for students at TU Delft.

The following list provides ideas of possible indicators without any claim to completeness.

For Prevention:

- MCI, Material Circularity Indicator (Ellen MacArthur Foundation, 2015)
- Product-level circularity metric defined by Linder et al. (2017)
- Recycled content
- Repairability
- Content of critical materials

For Reuse:

- Durability

For Recycle:

- Recyclability
- Compostability

For Disposal:

- Biodegradability
- Toxicity

With the implementation of Warp it, one indicator would be a good start, a disposal diversion rate (unit: kg/year):
The mass of non-operational material reused instead of disposed per unit of time e.g. per year or per FTE.
This measures how much material is not discarded but reused.

Allocation of financial assets

Since the activities described above require some investments at the beginning, the MLCM should take care for the financial support. Many measures regarding CE need high up-front investments, however, they will lead to savings in the long-term. This is for example reported by Warp It. It is important that the MLCM presents not only the environmental benefits but also the financial benefits of a CE. Thereby, future projects should receive enough financial support to allow for a realization.

Recommendation 2: Procurement considerations in the context of a Living Lab

A strong negative point is that the innovation being developed at the TU Delft cannot be immediately tested on a large-scale size such as the campus because of all constraints inherent to the size of the public institution. Despite being a high-tech campus, the operational side of the institution remains a public company handling public money. But as shown before in Figure 48, certain paths of procurement may help to circumvent to a certain extent this barrier.

In the case of small purchases, which do not have to obey the European tender procedure, the requester of the purchase (in this case someone running a Living Lab experiment or with a different mindset) can request products or services from small-scale innovative business as depicted in Figure 48 (the two smaller market circles), therefore giving the opportunity to smaller initiatives to be part of the TU Delft and to showcase/test new ideas. In this way, European tender procedures can be bypassed and the inclusion of new technology/ideas can thereby be accelerated.

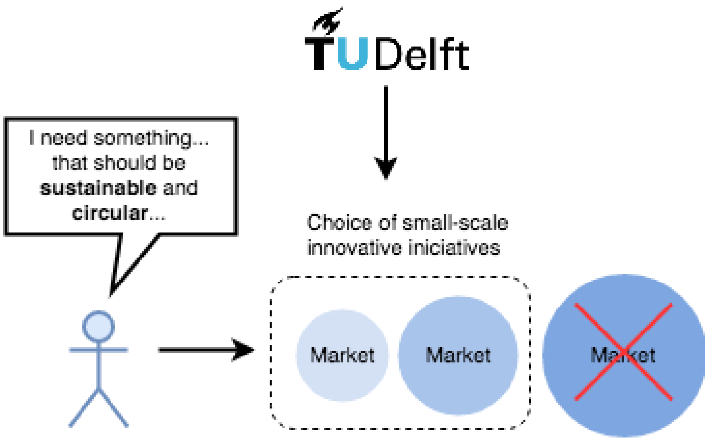

Figure 48: TU Delft and small scale innovations

The campus as a Living Lab thus can contribute firstly as a pilot for campus-wide rollout of innovate solutions given that their effectiveness is proven.

When it comes to spreading out new ideas across campus, which given the sheer size of the campus will most likely involve large spending, the scope will automatically be that of a European tender. Unless that by reverting to PSS (Product Service Systems), the cost of services would be lower than the cost of the ownership and thus offsetting the need of a

European tender. Therefore, contracting services instead of products may help the TU Delft to go one step further towards improving the circularity on campus.

According to Tukker (2004), PSS such as pay per unit use, product pooling or functional result[14] may offer the largest potential for environmental gains. A similar view is shared in Kjaer (2018) where PSS may help to achieve absolute resource decoupling in the context of a CE.

PSS types of product offers are the ones that more often are used in the context of Living Labs because of either their infant state (niche type initiatives) or just because a PSS type of business relationship will help to make users accountable for each service used, to question the need of each use, to nudge users towards lowering the use of the service therefore suiting the philosophy of a Living Lab. Other benefits from PSS are that by involving the manufacturer in the full life-cycle of the product, the manufacturer has direct incentives to improve the design of the product and to rethink the way business is done and what type of materials he uses in

[14] Where the supplier tries to match to the maximum the desire of the customer in terms of function

the manufacturing. Concepts such as Extended Producer Responsibility (EPR)[15] can be very valuable in the overall procurement process.

Milestones

Based on our analysis, we derive milestones for PA II, non-operational material. These are a suggestion how to proceed in the future in order to bring about a circular campus. **Error! Reference source not found.** shows them categorized into short -, medium- and long-term milestones. These need to be updated over time, depending on developments taking place on campus.

Table 9: Suggested milestones for PAII, non-operational material

Time span	Milestone	Remarks
Short term 2018 - 2020	Implement Warp it for furniture & 1 faculty with one responsible person.	A small scale start of the platform is recommended by Warp It. It should also be connected with student housing and organizations off campus e.g. thrift shop.
	Apply the disposal diversion rate for the Warp It activities and share the results publicly.	Disposal diversion rate = mass of non-operational material reused instead of disposed per unit of time (unit: kg/year)
	Actively promote Echo as Living Lab for research and student projects.	This needs active promotion, since students are not in direct contact with FM, since it is part of the supportive layer.
	Provide thesis topics on developing CE monitoring system on campus for non-operational material and on conducting LCAs for campus relevant products.	
	Find CE champion from different faculties and departments to form a first circular campus consortium with frequent meetings.	CE champions are people from different departments and faculties who are motivated for a circular campus and firstly serve as representatives. They form the start of the MLCM.
	Expand Warp It to more faculties and to more products (stepwise).	As recommended by Warp It.
	FM implements small scale contracts for PSS.	These small scale PSS contracts should not require a European tender process, to avoid its regulations.
	CE champions research guidelines for procurement and for FM.	Researchers should also be part of CE champions to support bridging the gap of the productive and supportive layer.

[15] EPR consists of making the producer accountable for the full life-cycle of the product from manufacturing to end of its use life.

Medium term 2020-2025	Employ repair specialists for FM and dedicate space for their workshops.	Enough space should be provided to also enable storage for parts or certain products.
	Include electronics & other materials or products to Warp it.	Follows the expansion plan as recommended by Warp it.
	Translate living lab results from Echo to other buildings.	This follows the strategy of Wageningen and their Ecosmart transition.
	Expand PSS contracts to more buildings/products	
	Campus management sets up a department for the MLCM and employs Material Life Cycle Manager.	This forms a transition from the consortium of CE champions to the MLCM department. Next to representatives from departments/ working groups along the life cycle, fully employed experts serve as managers of the department.
	MLCM applies the researched circularity monitoring system as widely as possible and publish results in an annual report.	To apply the indicators, the necessary data collection should be implemented as well. The MLCM is responsible for a successful monitoring system.
	MLCM establishes guidelines for procurement and includes results from relevant studies.	The guidelines should be revised and updated to always provide state-of-the-art knowledge.
Long term 2025-2030	The MLCM has representatives in relevant decision-making processes which involve materials.	To ensure a coherent systemic approach, it is crucial to apply material life cycle thinking at the whole system of TU Delft.
	MLCM establishes a network with researchers, suppliers and other universities to increase the impact and optimize the TU Delft system.	This takes into consideration that TU Delft is a subsystem embedded into other systems. Therefore, linkages are crucial
	MLCM makes bigger scale contracts with PSS companies.	This aims at rooting PSS more into TU Delft.

3.3 PA VIII - Leadership

Having elaborated on the previous PA's, leadership in this chapter will be further analyzed here. However it needs to be noted that leadership should be further developed, since we made the conscious decision to keep our recommendations as general as possible, due to the limits of our expertise and time constraints.

3.3.1 Definition of Priority Area

Universities can play a critical and increasingly important role in moving towards a more sustainable society. They can contribute to this through multiple ways. These are education and research, but also through the estate where they are situated and through their wider community involvement, which included businesses, government, and community stakeholders. By integrating these four areas they can also contribute (Verhoef, 2018). Where the estate is discussed in previous chapters, education and research will be further discussed in this chapter.

The importance of Leadership as a PA is that unlike a company that produced goods, a university 'produces' skilled and educated graduates and research. After their time at the TU Delft they go into the workforce and will have a large impact on society through the work they do. This means that giving students a rounded education - regarding the education, possible further research and valorisation regarding Circular Economy (and sustainability) is one of the largest aspects that the TU Delft can increase its positive impact on society with.

3.3.2 Current situation

The current situation of the PA of Leadership will be analyzed in terms of research, education and valorisation at the TU Delft.

Research

Within the TU Delft there are multiple research groups that are researching Circular Economy. For example within Industrial Design there is a Circular Product Design research group and there are ongoing research projects at IDE on the subject of CE (circulardelft, 2018), there is a range of circular EU Horizon 2020 projects including Project CIRCUIT; ResCom partner (Resource Conservative Manufacturing), ProSUM; Prospecting Secondary raw materials in the Urban mine and Mining wastes and REPAiR.

The amount of research that is being done on on Circular Economy has grown recently grown and over 250 master theses have been written on the subject in the study year 2017-2018. Nearly 150 research papers including doctoral theses, journal articles, conference papers, reports and books in 2017-2018 from less than 40 in 2007-2008. The amount of research on the subject is steadily rising (TU Delft repository, 2018). This means that there is a substantial amount of knowledge already on the subject within the TU Delft. However this knowledge can be shared more within the TU Delft campus and university.

Education

There is a lot that can be learned about sustainability and the Circular Economy within the TU Delft. Initially, in a TU Delft degree, there is a lot of lecture based learning. Within education learning is done through lectures, Project work in groups, and there are many opportunities for further personal development through committees and trainings. The focus that we feel needs to be strengthened with Circular TU Delft 2030, is learning from applying the knowledge.

As Circular Economy has relatively recent started to gain momentum and create a system change, it can be very valuable to see the TU Delft as a Circular Economy Living Lab and to gain insights from applying this theory in the university campus. There is a lot of theory that has been written about how Circular Economy can have a positive impact on society and companies. Bringing this into practice, however, is a new hurdle that companies are facing as large scale implementation requires a radical change in the way businesses operate (Lieder, M. et al., 2016). By introducing students to these lessons during their time at the TU Delft they will be better equipped to tackle these issues in business further on in their career.

Although students of most faculties can follow Circular Economy related courses (Studiegids, 2018) and there are 15 courses that are stated to be directly linked to Circular Economy and more than 80 that look at sustainability. An Online course ‘Circular Economy: An Introduction’ can be followed by both students from the TU Delft and for free by students worldwide, and already had over 1000 participants in 2017 (circulate news, 2017)

The Kolb’s experiential learning style theory

To understand the importance for different ways of learning and the benefits that Living Labs at the TU Campus can have Kolb's experiential learning style is used.
By using Kolb’s experiential learning styles it becomes clear that there are important reasons for bringing research on Circular Economy and practice closer together, viewing the TU Delft as a Living Lab for all other aspects of a Circular Economy.
In this chapter the experiential learning styles will be elaborated and its implications for the rolling out of Circular TU Delft 2030 are given.
David Kolb published his learning styles model in 1984 from which he developed his learning style inventory. Figure 49describes the process of learning (Smulders, 2004). Learning as an explicit process has been linked to educational institutions such as schools, monasteries and universities for a long time. This learning within these types of educational institutions can be seen as individually gaining knowledge or acquiring skill. Kolb’s model integrates cognitive and

behavioral changes and consists of four stages. This can be used to explain the relevance of Living Labs within the TU Delft.

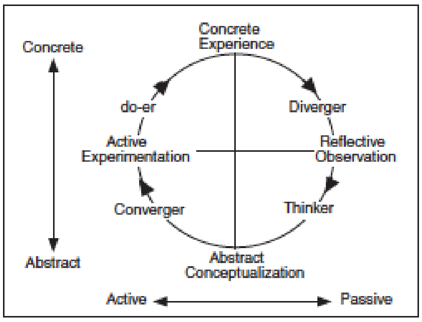

Figure 49: David Kolbs model for experiential learning (source: Kolb, 1984).

The model differentiates between concrete and abstract, and active and passive learning. Within this cycle there are 4 stages of learning:

1. Concrete Experience - when a new experience or situation is encountered, or of existing experience are reinterpreted, such as seeing implemented Circular Economy solutions on campus.
2. Reflective Observation of the new experience - any inconsistencies between experience and understanding are important, currently the implementation of circular solutions within campus are seen in limited amounts by student studying there, while there is a steady amount of research and education focused on it, students and staff can learn from reflection on difficulties of implementation in living labs of theoretical knowledge.
3. Abstract Conceptualization - when reflection gives rise to a new idea, or a modification of an existing abstract concept. Difficulties in implementations of Living Labs can make those involved gain insights in implementation of solutions.
4. Active Experimentation - when the learner applies knowledge gained to the world around them. Learning through active experimentation can be done by giving students opportunities to implement their own ideas within the TU campus or take part in Living Lab experiments and solutions.

The incentive for development of new concepts is created by new experiences and therefore Living Labs on campus can increase learning on campus and bring implementation and theory about Circular Economy closer together. As Figure 50 shows, the more often this cycle is repeated the more understanding one gets for a subject (such as Circular Economy) and the more they will become knowledgeable in a certain field (Smulders, 2018).

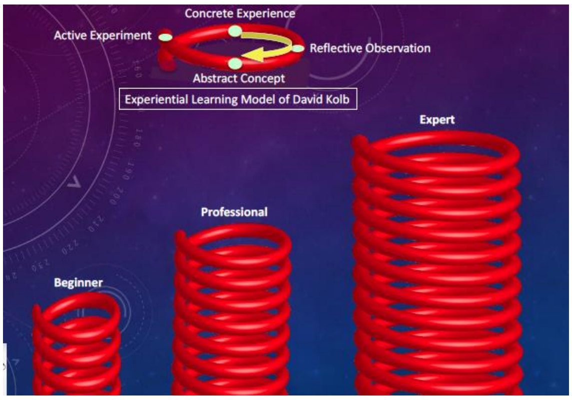

Figure 50: The experiential Learning Model of David Kolb (source: Smulders, 2018)

Students should be getting familiar with Circular Economy solutions on campus to better be able to implement them in their future career and life and for research on the subject to increase understanding and possible impact.

Valorisation

The last aspect that falls under leadership is valorisation. This is also called 'valorisation of knowledge' or 'technology transfer' and can be defined as: "The process of value-creation out of knowledge, by making this knowledge suitable and available for economic or societal utilization and to translate this into high-potential products, services, processes and industrial activity." (Netherlands Proteomics Centre, 2018). Valorisation "concerns the creation of social and economic value based on scientific knowledge and skills" (TU Delft 2018c).

Together with specialists from around the world scientists from the university work on creating solutions that can have positive impacts on society. This knowledge valorisation has developed over the years and is seen as the TU Delfts third core task (Campus Development, 2018c). Education and research becomes more valuable when it can be implemented and is useful for society. Impact can be created by disseminating the knowledge that is gained through research and education at the university by valorisation and applying knowledge in society.

As knowledge valorisation is a key task within the TU Delft students can gain insight and experience in bringing knowledge into practice. Sustainability issues are often complex and solutions will not come from "ready-made solutions" but rather need professionals that have the capabilities to be able to improvise, adapt, innovate and be creative (Atkisson, 1999). Skills such as interdisciplinary thinking, problem solving, team working and holistic thinking are important to have (Thomas, I, 2009).

Learning from the TU Delft campus as a Living Lab can be beneficial. Holistic thinking accompanies looking at the TU Delft as a system and finding ways of optimizing it.

Reconnecting to real life situations becomes easier if the real life situation is the university campus at which you are studying and spending a significant amount of time.

3.3.4 Recommendations and milestones for a circular campus

Based on the analysis of the current situation, we now derive general recommendations for future measures and suggest milestones which can guide the way towards a successful implementation of those recommendations.

Recommendations

The necessity for educating students to become the leaders of the future and using their strengths in moving to a circular campus implies the need for actions that can be taken to involve them in the process. This can be done by both involving more groups of students, master theses or workshops in creating solutions for the TU Delft. This can also be done by organizing widespread Circular Economy challenges for which all staff and students can sign up with ideas for circular solutions. This can involve students in the development of the campus. Within a challenge like this the choice can be made between allowing only students of the TU Delft or global or Dutch applications. Another choice that can be made is to specifically look for solutions that are immediately applicable to make the TU Delft campus circular or to also encourage solutions that would be applicable elsewhere.

Another way of involving students and valorizing is by providing prizes for theses that have a Circular Economy linked subject. This could incentivize students to link their projects and research to Circular Economy opportunities on the TU Delft campus.

Milestones

Table 10 illustrates recommended milestones for further improvement of the Leadership at TU Delft.

Table 10: Suggested milestones for PA IX, Leadership.

Time span	Milestone	Remarks
Short term 2018 - 2020	Create Circular Economy challenges that make students think Repabout their own campus.	This can make students more involved and interested in the CE developments of their campus.
	Involve student groups from courses in the development and implementation of Circular Economy solutions.	To both further develop knowledge and interest in the subject.
Medium term 2020-2025	Allow room for Circular Economy and sustainability initiatives from within the student society of Delft.	Reward initiatives and have a central platform for ideas from students.
	Prize for CE themed thesis created.	This can provide incentive for students to actively look into CE research.
	Involve students in the development and insights of Living Labs.	Active dissemination of gained insights.
Long term 2025-2030	Strive towards a university that nurtures the CE and sustainability leaders of the future.	To support graduates in pursuing CE and sustainability goals

3.4 PA IX - Communication

This chapter will explain in more detail why communication is important for successful implementation of a Circular Economy strategy. It will look at how the TU Delft currently performs and at opportunities to improve and how other universities handle this Priority Area.

This chapter also takes into account communication regarding sustainability. Communication plays a crucial role in any sustainability strategy (Genç, R, 2017). The choice for the ambition of being a 'circular' university in 2030 was made out of sustainability reasoning and therefore this chapter looks at Circular Economy from a sustainability communication starting point.

3.4.1 Importance of PA

A proper way of communication needs to be shaped by a defined strategy, it represents the message that needs to be shared and strengthens the vision that has been stated and its goals.

Firstly, when measures with regards to Circular Economy or sustainability in general are not communicated, it may lead students and staff to believe that little effort is being put in this area. This could be considered a partial waste of effort, since it could be argued that some of the added value of implementing Circular Economy at a university is the creation of support among its students.
Besides, lack of communication is a unused chance to involve students and staff to contribute to the developments. It may have the potential to provide a large motivation if people can build on to existing accomplishments and possibly also set up their own projects. Depending on the group that is targeted and the goal, the communication channel and content has to be carefully chosen (Keys to the future, 2015).

To further support these points, we observed a noteworthy development at Leiden University where backlash occurred in the university paper Mare against the current waste collection bins. The new system of separated waste collection was implemented before the waste processing company treated the waste separately. This was not actively communicated to students and staff however, causing students to perceive the intervention as "greenwashing", thereby breaching trust (Kloosterman, 2018). This seems to be a problem that corporations in general tend to encounter, as appears from De Vries et al (2013).

The difference between Internal and External communication also has to be made. According to UNEP (2015) staff motivation and understanding of the relevance of sustainability progress to their own department can be ensured through internal communication campaigns. With external communication it should be considered if separate organizations would be better placed to share a message on your behalf.

3.4.2 Current situation

Current communication measures and channels will be analyzed in this section.

Circular Economy vs. Sustainability at TU Delft

The current website of the TU Delft, while addressing sustainability in a broad scope of activities (Achievements, Campus, Community, Research, Education, Events), has a strong focus on renewable energy, and so does the website of Campus Development (Campus Development TU Delft, 2018a; TU Delft, 2018d). Circular Economy as a concept does not seem to have been incorporated as of yet.

Apart from a small section in the Annual Report (TU Delft, 2016a), there is no separate yearly sustainability report of the TU Delft. There is however the application for the Green Metric and a small part in the TU Delft general strategy. With a sound sustainability reporting database, a CE strategy could be backed with existing reporting. For this reason this chapter should be read with the communication of sustainability efforts in mind as well as Circular Economy.

An added benefit of improving communication materials that are available and created, is that it can benefit the claims that are made to enter in awards such as SustainaBul and the Green Metric. Therefore an added benefit of improving the communication strategy is to with it improve the chances at raising the score in sustainability / Circular Economy awards.

Internal versus External Communication

To be able to analyze the possibilities with communicating sustainability efforts the current situation and possibilities for communication are needed. Table 11 illustrates available communication channels within the TU Delft which are categorized in internal and external channels. The goals of these two types of communication differ.

Table 11: Different communication platforms for TU Delft

Internal	• Emails • Brightspace • Staff portal • Presentations • Reports • Lunch lectures • courses
Internal & External	• University Website • Promotional materials (flyers., posters) • Signs (Boards, canteen food descriptions) • Net Presenters • Press releases • Videos • Social Media (Facebook, Instagram, Twitter)

Internal communication is needed to achieve a successful implementation of measures towards more sustainable practices which are dependent on people's behavior. Issues with respect to sustainability are usually characterized by a high level of complexity and uncertainty. Therefore communication plays a key role in delivering information across agents. Communication becomes essential for creating a common understanding “about societal values on sustainability and determining some concrete goals which require being followed” (Genç, 2017 p. 514) at a point when sustainability goals appear ambivalent in terms of containing conflicts of interest and of values.

Central CE/sustainability communication strategy

It is important to understand which stakeholders are responsible for communication of sustainability and Circular Economy efforts. Communication about sustainability is currently largely done by the Green Office. This is done in the form of the website, Facebook, LinkedIn and a newsletter (TU Delft, 2018e).

This leaves a number of opportunities that are not thoroughly explored within the TU Delft. By increasing the focus on a central communication plan and creating a Circular Economy (or sustainability) communication strategy not every faculty has to decide on how they want to communicate separation of waste for example, one house style can be made to communicate multiple relevant pieces of information meaning that many departments can combine efforts to create a circular TU Delft, and the TU Delft can guide contractors (like Renewi & Sodexo) about how they want to communicate regarding CE. (Faber, 2018b)

For example there are no central guidelines for the waste collection communication on waste bins. The fact that a central communication guideline is needed becomes clear from all the different types of operational waste communication on the TU Delft campus (Appendix A3). “Success is always easier to achieve when policy makers and communications work together” (UNEP, 2005 p11). This means that to achieve desired outcomes, internal and external communications need to be added to the implementation of new infrastructure and policies.

To increase waste recycling rates governance, waste management and communication need to be coordinated (See Figure 51).

Figure 51: an example of combining governance, waste management and communication as proposed for Leiden University (source: Keys to sustainability, 2015)

3.4.3 Best practices other Universities

Here some initial examples of sustainability communication of other universities are given. More examples can be found in Appendix A3.

Use of Instagram

The Green Office of Delft does not have an Instagram account, this medium provides a quick way of sharing events that the Green Office organizes directly and quickly. Dutch universities that use this medium to communicate Green Office information are University Utrecht, RUG, HU, Leiden University, UvA and TUe.

Use of Infographics to explain goals and inform community

Figure 52 shows an example of communication regarding campus waste. It is downloadable from the website but infographics such as this one can also be printed on banners and placed on the campus.

It is a good example of communication of goals, insights into the data and what the university community can do to support the goals. It states that the user should:

1. Reduce waste
2. Use as few paper towels as possible
3. Use a sustainable water bottle
4. Reduce the amount of packaging waste
5. Throw waste into the correct waste bins (Utrecht University, 2018). It also contains links to websites so if interested the viewer can find out more.

The effects of such infographics can also be tested in Living Lab settings by putting a banner. For example the waste separation data can be analyzed before and after the information is provided.

Figure 52: An example of a banner that is used by the University of Utrecht to inform campus population (source: Utrecht University, 2018).

Central communication of publications on sustainability on campus

The Green Office of Maastricht University has a central point where all publications about the sustainability of the university are collected. This makes it easier for anyone interested to find out more and makes it possible to follow up on research that is done. **Error! Reference source not found.**show the website of the Green Office Maastricht. (Maastricht University Green Office, 2018a). By having a central point where documentation can be found, it becomes easier for future research to be done.
Although there are many more examples of communication of sustainability and circular economy issues these best practices are provided as inspiration for opportunities in which information can be shared with the university community.

3.4.4 Recommendations and milestones for a circular campus

Here, the material discussed above will be condensed into recommendations for improving the current communication system. In it a separation of operational waste will be used as an example in some cases.

Recommendations

Internal Communication Channels

It is essential that changes in the Campus system regarding Circular TU Delft 2030 and an implementation of a new waste system are communicated with the staff and students of the TU Delft to be able to have positive effects on the behavior of students. It should be seen as a way to both avoid negative backlash and to seek positive feedback and implement systems effectively and efficiently. Additionally it is an important measure that can be taken to increase the impact of Circular TU Delft 2030 in terms of knowledge development that extends solely the scope of the TU Campus, but also makes a positive impact when students/staff go home, by separate collection at home and in the future and by making them aware of circular opportunities in future workplaces.

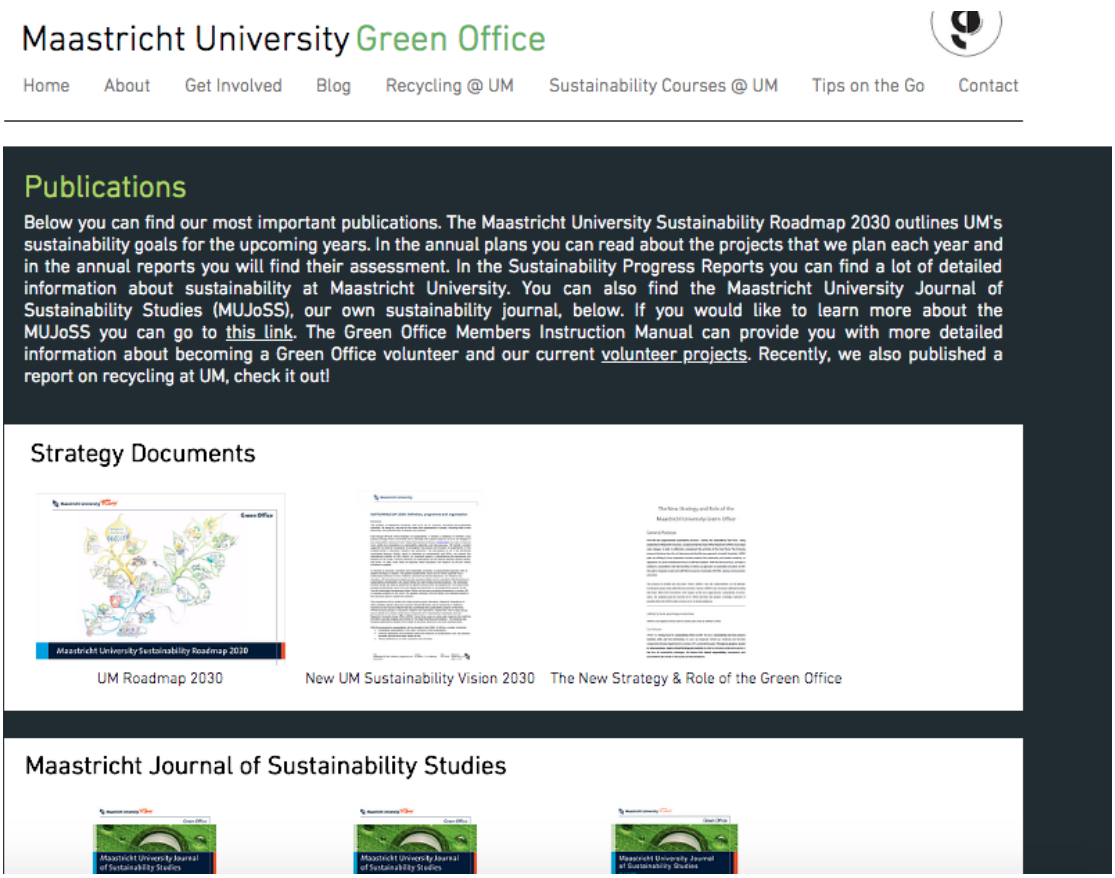

Figure 53: The availability of sustainability publications of the Green Office Maastricht (Source: Maastricht University Green Office, 2018a).

Although more work needs to be done to decide on a definitive communication plan, both for sustainability and Circular Economy 2030 purposes, this list provides a start for a final plan. Conducting a survey to better analyze the information needed by students and staff can provide important insights into what channels should be used to communicate (Keys to the future, 2015). However due to the scope and time of this project this was not possible.

1. Signs in the TU Delft
Goal: To inform on people about changes that will be made
Where information will be shared: On net-presenters at important faculties on the TU and on Posters throughout the TU. It can contain a link to the videos that are made explaining in more detail the system. By developing a certain house style it becomes possible to brand all notices together and raise awareness about the vision of circular TU Delft and information can be quickly shared. For sustainability communication Wicinski & Griffith (2013) identify that only using words is not enough and "a picture is worth a thousand words". An example of this are

the Leiden university banners regarding sustainable food choices at cafeteria (Appendix A.4.4.2)
Time: Can be done often and creating a house style can lower the barrier, making it possible for more stakeholders to be able to share information.

2. Videos explaining new systems
Goal: To inform the university community that are interested or have questions about certain aspects of the goal of the TU Delft (comparable to the video made for coffee cups). To explain, to students/ staff, why choices have been made and even how they can help. It can support in educating students through changes on the TU. These videos can be shared on the website of the TU Delft, through the social media pages of the Green Office among others. A good example of this is the video that was made about the coffee cup separation (TU Delft, 2016c)
Time: Videos can be used to precede a new system that will be implemented to all involved members of staff and sometimes students that will be involved in the project, or to elaborate on a Living Lab project that is in development.

3. Articles in Breen or TU Delta
Goal: To explain the new systems to University community and share knowledge about Circular Economy and sustainability. An example of this is an article explaining what happens to your coffee cup after you throw it away (TU Delta, 2018) and an article on the TU Delft website explaining the new coffee cup system (TU News, 2016)
Time: When it matches with the topic that Breen or TU Delta wants look at. Breen is published 5 times a year (Breen, 2018), TU Delta also publishes a magazine but is a journalistic platform with “news, background and opinion articles about science, education and campus life” (TU Delta, 2018). Timing of these articles should be discussed with the editors.

4. Presentations for students or staff
Goal: Presentations should be done for involved members of staff to communicate goals and change of roles with a new system. This will increase the chance that people change their habits in alliance with the new system.
Time: Whenever new systems are put in place. Regarding operational waste this could be a medium used to communicate plans with all staff members involved in collection of waste.

5. Use of Social Media
Goal: There are many different ways of using social media for sustainability communication (Wicinski & Griffith, 2013) and it can be useful to share sustainability and Circular Economy information in a quick and easy way and to have an accessible medium of communication for the University community. Both for those who would be interested in sharing information and those who are interested in what is happening at the TU Delft regarding sustainability, Circular Economy and what the Green Office does.
Time: As this is meant as an accessible means of communication this should be used often and can communicate smaller events and pieces of information.

House style for Circular TU Delft

By creating a house style for Circular Economy at the TU Delft, it becomes easier to recognize efforts within the TU Delft as part of a larger ambition; making the TU Delft circular. By developing a house style it new projects can be branded more efficiently and seen as adding to a large system change. Figure 54provides inspiration on the idea of a house style. However this house style would have to be personalized to fit in with the TU Delft, to make it possible to reuse and share, in film and images, and to prevent copyright issues. For this reason, and because of the scope of this project it is only possible to give an idea of the style of communication that can be used for the long term goal of this project.

Figure 54: An example of the styles in which communication should be done with the students of the TU Delft. (Adapted from: Zen Design Firm, 2018; Clean Europe Network, 2018; European Parliament, 2016; Plasticseurope, 2018; Dreamstime, 2018)

Regarding communication of information about circular economy on campus there are more questions that can be tackled. This chapter serves as a start for this research and implementation of communication strategies can be iterative and improved while being used. Other aspects that would be interesting in the follow up are how all stakeholders involved in a material cycle be convinced to look at the problem in the same way could also be looked at to put in the effort to make sure a certain material can be recycled as efficiently as possible for example. Another question is what kind of communication channels work best to achieve different desired outcomes and look at net Presenters, word-of-mouth communication, websites or social media such as Facebook, Twitter, Instagram. Lastly, how effective messages should be formulated and what the role should be of communication could be useful questions to answer.

Milestones

Based on our analysis, we derive milestones for PA IX, communication. These are a suggestion how to proceed in the future in order to incorporate communication for a sustainable and circular campus. Table 12 shows them categorized into short -, medium- and long-term milestones. They can be further developed in the future when a full sustainability communication plan is developed

Table 12: Suggested milestones for PA IX, Communication

Time span	Milestone	Remarks
Short term 2018 - 2020	Develop a communication plan for the sustainability	The current plan can be further elaborated to include responsible parties for different aspects of the plan.
	Centrally analyze different communication channels and how their use can be optimized for CE	Knowing what different channels there are and what their impact and related target can help in creating a central communication of sustainability and circular economy plan.
	Green Office to link Instagram to Facebook account to increase awareness within student population.	Using the example of how other universities communicate small chunks of information.
	TU Delft sustainability website focus on more than energy.	There is an opportunity to communicate more on other aspects of sustainability than large focus on energy currently.
Medium term 2020-2025	Communicate prevention of food waste, reasoning for disposables and sustainable food choices (vegetarian / vegan options)	This can be done in collaboration with the new catering company.
	Develop house style of circular TU Delft. Standard video format, logo and branding	Makes it possible to communicate fast & effectively.

	Implement separate waste stream communications across campus, timed to fit the implementation of collection infrastructure	More research should be done on how this is most effective.
	Goals and vision of the TU Delft are actively communicated	Information regarding Circular Economy and sustainability is actively and clearly communicated and TU Delft community can easily find it.
Long term 2025-2030	The vision and plan are communicated clearly and in the same way throughout all channels regarding sustainability and Circular Economy	There is a strong awareness amongst the university community about Circular Economy and sustainability

Part 4
Recommendations for the Future

Part 4: Living Lab & Roadmap Design

This chapter summarizes the results found in Part 3. Firstly, we explore more in detail the concept of Living Lab in the context of campus. Secondly we summarize the milestones of each PA analyzed to provide a full picture of a possible transition towards a circular campus.

4.1 Living Lab Design

To achieve what has been proposed in the previous sections of the report, the TU Delft should take advantage of key developments like the construction of the Echo building as a cornerstone for a new approach in incorporating circularity in campus. All stakeholders that we have interviewed throughout the learning process are eager to participate and to take action in something that would lead to a more sustainable campus but are lacking the tools to do so. We believe that Living Labs hold the key in the transition to a circular campus because they will allow to test organizational innovations such as the new material life cycle management (MLCM) and the effectiveness of a building-wide separation at the source for operational EoU material. New tools and approaches like IoT can be tested in a small-scale prior to campus-wide rollout which translate into smaller costs. Operational and scientific staff can test ideas and learn from the outcomes. The benefits of using Living Labs in the transition to sustainable campuses is outlined in more detailed in the “Campus as a Living Lab” framework by Verhoef et al. (2018). Advantage should also be taken by the TU Delft in the sense that Dr. Verhoef is a member of the scientific staff of the TU Delft and has extensive knowledge and involvement in projects worldwide related to sustainability in campus.

A wider scale of applicability of the internal learning outcomes of the Living Lab in Echo is the implementation across campus of the knowledge gained through the experiment. As pointed out by our commissioner Dennis Meerburg during an interview, the added-value of a circular campus is also financial: companies willing to lease land in the Technopolis area will be on the lookout for circularity innovations in campus and will apply them in their buildings (D. Meerburg, personal interview, March 8, 2018). Therefore leveraging the knowledge of the Living Labs beyond the boundaries of the TU Delft and maybe into the operations of those companies. The magnitude of the impact is yet to be determined and monitored in the future.

As pointed out earlier in PA II (section 3.4.2) about the MLCM: *“The idea of the MLCM resembles a “circular organizational structure” (...) which is still based on hierarchy, however has the aim of enabling communication and information exchange between departments.”* Disrupting the current process based management structure will require to some extent an overhaul of some departments or the creation of a new department only responsible for the material aspects of the campus under a circularity umbrella. Prior to dismantling or creating new departments, the MLCM concept can be tested in the Living Lab by setting up a test team involving all pillars depicted in figure (MLCM FIGURE). The success of this setup will be greater if the responsibility of the outcomes is left out to the stakeholders without the intervention of campus management. In other words, staff will have to talk to each other and brainstorm in a creative way how the best outcomes could be reached in terms of improving the material life cycle in campus. For this, they should be aware of the vision and of the desired outcomes of the implications of such a circular management "structure".

Not only internal stakeholders can participate in the Living Lab but also the holder of the waste management contract can be called to be a participant of the Living Lab. This can enable circular innovations in EoU material management that may not be of knowledge of the internal stakeholders of the TU Delft. By involving such partners, the learning experience of the Living Lab can be enhanced as their input can be valuable by providing insights into the external ecosystem of material recycling in the Netherlands.

4.1.1 The design

As a way to pass on our learning outcomes while elaborating the report, and in an experimental way given that our knowledge of a Living Lab remains theoretical and bound to the academic context, we have made an exercise which is the following:

1. We have been hired to design the Living Lab in Echo.
2. We were chosen because through our research we gained valuable insight that would go beyond what we could have written in the report given time and academic constraints.
3. We are aware of the outcomes that such a Living Lab would have to bring in terms of internal learning for the institution.

What do we think are important points that should not be left out in the design of such a Living Lab experiment? Our inspiration comes from the "Campus as a Living Lab" framework and from the talks we had with our interviewees. Our ideas are organized in a "loosened way", i.e., they are key ideas that we find relevant for the success of the Living Lab.

Logistics of collection and processing:

- Start with a **traditional layout** of bins scattered across the building.
- **Use IoT** to assess whether hotspots of collection are properly addressed or not, i.e. if there is too much accumulation somewhere then another bin or collect more frequently. Conversely, think about yield VS effort when designing the collection system.
- Apply **feedback from cleaners and users** to improve layout and number of bins as they are the ones that experience hands-on the experiment.
- Allow for **initial bulk space** to store EoU material streams but over time optimize storage space with learned outcomes in order to know how much per FTE each building requires in storage space.
- Design and test **separate collection bins**, starting with **disposables** (because of new contract) and **organic** (because of composting potential).
- **Scale up composting** after learning outcomes of the Green Office's Sport & Cultuur pilot, use these results to check feasibility of replacing 1 underground container with an **underground composting container.**
- Make sure that there is a **recipient for the organic stream** (e.g. TU Delft Botanical Garden or Buurtcompost). Failure to do this will jeopardize organic collection.

Communication:

- **Make a survey** to be able to analyze the current knowledge about different waste streams and to better understand what the focus of communication will be.

- Design a **communication campaign** informing students & staff on different waste streams.
- Keep in mind **upscaling to the rest of the TU Campus** when designing the campaign so it can be implemented throughout the campus if successful.
- Make sure that **the message is understood** and users are “nudged” accordingly to the desired learning outcomes.
- Use **communication platforms** (coffee machines, screens, etc) to inform users.
- Communicate **weekly outcomes** and target numbers in a fun way to engage users into participating.
- Potentially make **competitions** between lecture rooms to create engagement into reaching targets.
- Use **best practices examples** in the design of bins (see section 3.1.3).

Organizational aspects:

- **Test material life cycle management (MLCM)** approach (see 3.2.4 for more details).
- Steering committee **to monitor Living Lab** and to learn outcomes to apply elsewhere in campus.
- **Report** and collect data using “Campus as a Living Lab” framework (Verhoef, 2018).
- Monthly meetings to decide how to **adapt the Living Lab**. In a process over time, allow for a learning phase where the initial conditions may change.
- **Assign local champions**, high in the managerial hierarchy with decision power to make quick changes or steer policy without consulting steering committee. These champions can be from FM or from the catering, etc.
- Involve all stakeholders in the building (catering, facilities and management) to create a **vision towards making Echo a truly sustainable and circular building**.
- Give the opportunity to the holder of the **waste management contract** to participate in the design of the Living Lab and ask from them concrete ways on how EoU materials could be re-used in the system after a recycling process.

4.2 Roadmap & recommendations

For each priority area that was analyzed in detail, milestones and future recommendations were developed to ensure that the first steps in the attempt to make the campus circular by 2030 are taken. Even though 9 priority areas are identified above, due to the scope of our assignment, we focused in great detail in the material based priority areas I & II and shed some initial light on priority areas VIII and IX. Notwithstanding the explorative character of what is written in PAs VIII & IX, we believe that those general recommendations are good starting points for further work. The same applies for PAs I & II where in the case of PA II a novel circular management strategy is identified as key element to the transition to circular material management. In this report we had to limit ourselves to what was feasible in the amount of time and scope of the assignment.

In PA I a detailed analysis on operational EoU material is done with time dependent milestones that will favor a dovetailed transition to circularity in campus. These milestones are backed by data and should not be hard to interpret as they pertain to implicit events in terms of mass of material and collection at the source. For the other PAs, the same time dependent milestone approach was not possible to elaborate. These are then presented under the form of milestones in short-, medium- or long-term. This approach allowed us to still bring forward the idea of milestone over time which is important to achieve the future vision but without the analytical background work.

Table 13: Milestones for PA I: Operational EoU Material

Milestone	Description	When	Effect
1	Echo as a Living Lab where separation at the source is introduced. The effects are based on the “Fellowship” building which has a similar EoU material generation as the Echo will have in 2020. The reduction ratios are based on Table 8	2020	Composition of operational EoU material stream (2017/new): Residual: 76.5 %/ 43 % Paper & cardboard: 22 %/ 22 % Organic: 0.67 %/ 31 % PMD & coffee cups: 1 %/ 4% Yield in terms of kg/FTE: Residual: -1.04 Paper & cardboard: 0.2 Organic: 0.74 PMD & coffee cups: 0.1
2	Aula as a Living Lab where separation at the source is introduced. Given the high influx of people during lunch time, the concentration of bins and the 3 underground containers outside, Aula could be a perfect example of a Living Lab.	2020	Composition of operational EoU material (2017/new): Residual: 76.5 %/ 43 % Paper & cardboard: 22 %/ 22 % Organic: 0.67 %/ 31 % PMD & coffee cups: 1 %/ 4% Yield in terms of kg/FTE: Residual: -1.97 Paper & cardboard: -0.64 Organic: 1.05 PMD & coffee cups: 0.22
3	Based on proven success of Echo and aula Living Labs, the TU Delft could roll out to other buildings in campus the new separation at the source strategy.	2025	Similar to what is mentioned above
4	Reduction of paper input into the TU Delft.	2025	An additional reduction of EoU paper of 5% from 2025 onwards

5	Improved net recycling ratio (NRC) through clauses in waste tender whereby the contractor is forced to find creative ways to improve the EoL RR and supply enough secondary raw materials (SRM) to the secondary market. We addition of SRM and extraction of PRM in global terms	2020/2025	Progression of 5 % per year in RC and increase in EoL RR in 2025. This will yield approximately 5 tonne of recycled material as feed to the TU Delft system in 2020 and between 15 to 30 tonne in 2025.
6	Overall reduction of material input into the TU Delft by means of finding creative solutions with those responsible for the material footprint of the institution (catering, vending machines, procurement, etc). Examples are: reduce availability of coffee cups or impose a deposit, remove PET bottles from vending machines, reduce packaging in food outlets, give reusable water bottles to students, etc.	2020	Reduction of 2.5% per year on the residual EoU material which results in a continuous reduction of approximately 1 kg/FTE until 2030

Table 14: Recommended Milestones for PAII: Non Operational Material

Time span	Milestone
Short term 2018 - 2020	Implement Warp it for furniture & 1 faculty with one responsible person.
	Apply the disposal diversion rate for the Warp It activities and share the results publicly.
	Actively promote Echo as Living Lab for research and student projects.
	Provide thesis topics on developing CE monitoring system on campus for non-operational material and on conducting LCAs for campus relevant products.
	Find CE champion from different faculties and departments to form a first circular campus consortium with frequent meetings.
	Expand Warp It to more faculties and to more products (stepwise).
	FM implements small scale contracts for PSS.
	CE champions research guidelines for procurement and for FM.
Medium term 2020-2025	Employ repair specialists for FM and dedicate space for their workshops.
	Include electronics & other materials or products to Warp it.
	Translate living lab results from Echo to other buildings.
	Expand PSS contracts to more buildings/products
	Campus management sets up a department for the MLCM and employs Material Life Cycle Manager.
	MLCM applies the researched circularity monitoring system as widely as possible and publish results in an annual report.
	MLCM establishes guidelines for procurement and includes results from relevant studies.
Long term 2025-2030	The MLCM has representatives in relevant decision-making processes which involve materials.

	MLCM establishes a network with researchers, suppliers and other universities to increase the impact and optimize the TU Delft system.
	MLCM makes bigger scale contracts with PSS companies.

Table 15: Recommended Milestones for PA VIII Leadership

Time span	Milestone
Short term 2018 - 2020	Create Circular Economy challenges that make students think about their own campus.
	Involve student groups from courses in the development and implementation of Circular Economy solutions.
Medium term 2020-2025	Allow room for Circular Economy and sustainability initiatives from within the student society of Delft.
	Prize for CE themed thesis created.
	Involve students in the development and insights of Living Labs.
Long term 2025-2030	Strive towards a university that nurtures the CE and sustainability leaders of the future.

Table 16: Recommended Milestones for PA IX: Communication

Time span	Milestone
Short term 2018 - 2020	Develop a communication plan for the sustainability
	Centrally analyze different communication channels and how their use can be optimized for CE
	Green Office to link Instagram to Facebook account to increase awareness within student population.
	TU Delft sustainability website focus on more than energy.
Medium term 2020-2025	Communicate prevention of food waste, reasoning for disposables and sustainable food choices (vegetarian / vegan options)

	Develop house style of circular TU Delft. Standard video format, logo and branding
	Implement separate waste stream communications across campus, timed to fit the implementation of collection infrastructure
	Goals and vision of the TU Delft are actively communicated
Long term 2025-2030	The vision and plan are communicated clearly and in the same way throughout all channels regarding sustainability and Circular Economy

Discussion

Discussion

The following will consider the work done in this report from a critical point of view.

A substantial part of this report was to investigate the application of CE within a university campus. Some universities have already tried to implement measures which contribute to a circular campus, such as general sustainability plans at Leiden University, Zero Waste at UBC or Warp It at the University of Edinburgh. However, these strategies address the issue of circularity only partially and are not embedded within a systemic plan towards circularity. The specific aim of the TU Delft to transition towards a circular campus in the Dutch context is thus a new development. Therefore, we needed to develop a framework for our work and to identify Priority Areas for circularity at an educational institution. This required substantial amount of time which could have been spent on the actual analyses of PAs. Therefore, the Leadership and Communication PA could not be investigated as much in detail as initially planned.

Since before writing this report there was no general framework existing yet that is applicable to the context of a university campus, we defined a new framework based on the pre-existing framework of backcasting. The novelty of our framework is that it splits up the larger problem at hand and has been tailored to be adapted instantly by future (student) groups either at the TU Delft or at other universities. In general, our framework has proven itself to work successfully at answering the research questions posited. In future projects, though, it could be further improved. The general theory of CE does not need to be fully reiterated at the start of every project, for example. Besides, even though our method of using semi-structured interviews and “snowballing” proved especially useful for quickly maneuvering through the organizational network of the TU Delft, making use of surveys could potentially increase time efficiency and strengthen results through a larger sample size.
Lastly, it is important to note that our methodology is intended as a start to an iterative process, in which its resulting actions are constantly reassessed and steered. Our posited indicators are intended to serve as a guideline for this process.

Since the Priority Areas we established are based on desk research and interviews, we do not claim that they fully reflect the entire functioning of the TU Delft. There should be critical reflection throughout the transitioning process on whether these are the best divisions of the workload. Besides, they should not be seen in isolation. For example, Operational Material and Non-Operational Material have significant overlap at times in terms of management. Leadership and Communication also function to support other PA’s. Rather, the PA’s are intended to converge the right stakeholders and create the momentum for action at this moment.

When it comes to the quantitative analysis used in PA I, Operational EoU material, limitations need to be pointed out.
Firstly, the residual waste forms a substantial share of the total amount of EoU material produced by the campus. However, it is not to our knowledge which materials it actually comprises. Therefore, ratios from other frontrunner universities are applied to TU Delft’s data.

This can give some indication about potential streams for TU Delft and the content of the residual waste, but cannot be taken as ultimate ratios. The EoU material produced by a campus is influenced by many factors, such as procurement guidelines, the kind of research conducted e.g. in laboratories, the catering strategy, consumer behavior etc. The university dependent context variables form an attempt of taking such factors into account, however, they should not be seen as complete. Some factors which could not be revealed in this report might have more influence than expected.
Secondly, the data collection strategy can also have influence on the interpretation of data. Depending on the aggregation of different waste streams, misinterpretation of the data can happen if contents are not clearly defined or unknown. Some universities for example distinguish between organic materials and swill and landscaping material while others might aggregate those.
For instance is furniture included in the residual stream of TU Delft. Thus, we compare residual streams of different universities, even though they probably have different contents. Given the data provided, this issue is to our knowledge however could not be resolved.
Lastly, the material inputs into the system of TU Delft are so far not reported, therefore no data is currently available. This limited the quantitative analysis and no MFA could be conducted. For future studies it would be very useful to have more data available such that more scientific quantitative analyses can be conducted.

As a side note, the PA’s of Leadership and Communication are developed less than Operational and Non-Operational Material. This is a conscious decision based on the limits of our expertise and time constraints. Nevertheless, during our efforts we encountered some information on these topics that we believe to be of added value to the report, which we therefore decided to add. However, there is the need to investigate them more in detail.

The Roadmap is intended to complement the convergence of stakeholders and serve as an overarching platform in which ideas can be placed and discussed. We have already filled in part of this Roadmap to provide starting points in the form of ideas we encountered. The Roadmap should be seen as a suggestion on how further planning could be organized while still keeping the system as a whole in mind. However, since we did not thoroughly assess the financial aspect of the whole system, we do not necessarily claim that these are the most cost-effective ways to reach the targets. That being said, allocating budget towards new infrastructure will be essential for a proper transition to CE.

The indicators recommended in this report are not claimed to fully capture the degree of circularity of the campus. Rather, they are intended to start up and refine the process of reporting in general since, at least in the yearly reports, sustainability reporting is still both strongly focused on energy and in lower resolution with regards to material throughput. When this process is successfully scaled up, more sophisticated circularity indicators should be applied, like the literature-based indicators described in Part 1, to paint a clearer picture of the circularity of the campus. To apply those, however, more data needs to be gathered during the operations of the campus e.g. about the materials of products procured.

During our work stakeholders have been willing to collaborate and also interested in the topic of CE on campus. They have been very open in interviews which allowed us to reveal important aspects of TU Delft's structure. This proves that there is high potential for future work to be even more successful and to achieve an impact towards a transition to a CE.

However, a general trend seemed to be the statement that stakeholders do not know where to turn with questions or ideas regarding CE or sustainability in general. We encountered the explicit desire for a clear vision for example in our interview with Sven Verhoeven and Erik de Vos on the planned Echo building. There is a need for an institution to connect stakeholders better and to facilitate collaboration amongst different departments. Campus Real Estate has recognized this issue and has established a monthly sustainability meeting for this purpose during the writing of this report (E. De Vos & S. Verhoeven, personal interview, May 31st, 2018).

Moreover, we think that a group of students could support these efforts of Campus Real Estate and the action points we defined. This could be either in the form of a new group or as an expansion of the Green Office. Besides, it is important to define who in the management structure is responsible for different PA's of the transition. For this purpose, our project is designed and documented in such a way that it can easily be continued. To make our work accessible, we created a specific email and Skype account through which communication with stakeholders has been done. Moreover, all notes and files are stored in a transferable online google drive folder. To support the maintenance of the network that has been established throughout the course of several months, a contact list is set up reporting relevant stakeholders with their function and their contact details.

This approach has the aim to not only conduct a report, but to actually create the basis of coming projects and a new network with the intent of achieving the required momentum and changes within the system of TU Delft.

Conclusion

Conclusions

The TU Delft has stated its intent of becoming a circular campus by 2030 in the Strategic Framework 2018-2020. This report aimed to address this ambition and answer the question "*How can TU Delft as an educational institution implement the principles of CE in order to reach its circularity target by 2030?"* To answer this question, we posited sub-research questions, and answered them through interviews and desk research.

The first sub question was "*What are the principles of CE, and how do they apply to TU Delft as a system?"* We saw that the main principles of CE consist of managing material resources through a Refuse-Reduce-Reuse-Recycle hierarchy of priority in both their procurement as End-of-Use treatment. This is done to ensure the regenerative capacity of these resources and alleviate environmental pressures. The TU Delft as a system was then defined as consisting of a supportive and productive layer, where the supportive layer provides services to the productive layer so it can produce research, patents and education. Since the supportive layer is responsible for the procurement and disposal of resources, this layer is where the principles of CE apply most.

Through investigating the next sub question, "*What is the CE context and what does a vision for TU Delft look like?"* we established that both the European Union and the government of The Netherlands have developed quite extensive policy for transitioning to CE and that the goals of these institutions and those of TU Delft are very well aligned. We also articulated a vision based on the principles of CE and the TU Delft's intention to be a leading university.

Having formulated this vision and having spoken to several key stakeholders we constructed a division of the complex problem of CE into nine Priority Areas, with the intent of facilitating the transition. We defined these as Operational EoU Material, Non-Operational Material, Construction & Demolition Material, Energy, Water, Land Use, Transport, Leadership and Communication. This answers the third sub question, "*Into which Priority Areas can future work for a circular campus be structured in order to facilitate a CE transition?"*

Since the initial project proposal emphasized the topic of waste, the first Priority Area was analyzed in depth both qualitatively and quantitatively. The quantitative assessment of the current situation showed that the current operational End-of-Use material generation per FTE is lower than of the frontrunner Wageningen University and Research center. However, since WUR makes use of the EcoSmart services its fraction of residual waste is much smaller, decreasing from 70% to 45% in 5 years. This is largely due to a 32% increase in organic waste from food and swill collection, which is partly composted on site. As this fraction is currently not collected separately in TU Delft, and a pilot at 3mE has shown an average potential for 16,9% organic collection even without food outlet, it is thus clear that separate organic waste collection and composting has the potential to significantly reduce the fraction of waste that is incinerated.

With regards to PMD we saw that there is a bottleneck for private waste processors such as Renewi in the form of the public Afvalfonds Verpakkingen, driving the need for these parties to charge high PMD collection prices. We also saw how paper is already collected quite intensively since this flow is easily recyclable in a profitable way for both disposer and processor. We proposed Living Lab strategies for testing and upscaling separate waste collection infrastructure and composting installations on campus.

Non-Operational Material was analyzed qualitatively. The life cycle of this material was described and from this we identify several bottlenecks that hinder the implementation of circularity principles.
Firstly, the departmental structure of management prevents life cycle thinking, for which we proposed the Material Life Cycle Management structure. Besides connecting stakeholders throughout the TU Delft internal life cycle and keeping track of indicators for this PA, this structure would also have the function of providing guidance and decision support for FM, procurement and CRE staff.
Secondly, it became clear that the European tendering regulations prevent implementation of innovation developed at the TU Delft and thus keep the gap between the supportive and productive layer open. It also prevents the purchasing from small innovative start-ups from elsewhere. Our recommendation was therefore to purchase in smaller amounts below the budgetary threshold of 75,000 euros. From the best practices of other universities it emerged that a large number of universities make use of the Warp-It system to facilitate the reuse of products and materials which we thus recommend implementing. Lastly, we observed the absence of a repair team, which could greatly increase the lifespan of furniture. Establishing a repair team helps to expand the lifetime of material in the system and therefore decrease material output and the need for input into the system of TU Delft.

Furthermore, our research shows that Leadership is a relevant Priority Area for the TU Delft, which is one of the eight Pioneer Universities of the Ellen MacArthur Foundation (Ellen MacArthur Foundation, 2018b), and its goals are very well aligned with the larger systems (The Netherlands and EU) its embedded in. We defined this Leadership as consisting of Research, Education and Valorization, and concluded that while Research on CE is already rapidly growing within the TU Delft, Education could benefit from taking Kolb's experiential learning style into account by including students into the implementation of Living Lab experiments. Valorization, being the external component of Leadership, further supports the importance of gaining practical experience. From this reasoning, we established the recommendations to provide room for CE initiatives among students, for example in the form of challenges or by involving them in the implementation of measures.

Our last discussed Priority Area was Communication. This Priority Area emerged as important from both our interviews as well as from literature. From our analysis of the current situation we observed that the online communication on CE or sustainability in general in the TU Delft campus needs to be improved. We also observed that Green Offices from other universities make use of Instagram, and recommended this to the TU Delft Green Office. Our further recommendations included using the net presenters and posters for basic information on new

CE measures, and making videos for more in-depth descriptions. A Circular TU Delft house style would also help to increase visibility of CE-related measures.

Having discussed these Priority Areas, we had then answered “What is the current situation of selected Priority Areas, what are best practices of other universities for them, and which measures are required to realize the implementation of those within TU Delft’s roadmap to circularity?” The question that then remains is: “How can the circularity performance of investigated material based Priority Areas, Priority Area I and II, be measured in order to include it in a monitoring system?” For this, we used the framework by Elia et al. (2017) in order to come up with a set of indicators for the Operational Material PA, specific for a campus context. We refrained from establishing a decisive set of indicators for Non-Operational Material, although some recommendations were included.

Overall, we conclude, that further research is needed in the here not discussed PAs and especially also for the PAs of Leadership and Communication which are analyzed in less detail. To bring about a transition towards a circular campus, more effort and changes in the TU Delft system are required. Thus, we recommend to actively promote further student projects or theses on this topic to support the implementation of circular practices on campus.

References

Afvalfonds Verpakkingen (2018a). Afval Beheersstructuur. Retrieved from https://afvalfondsverpakkingen.nl/organisatie/afvalbeheerstructuur

Afvalfonds Verpakkingen (2018b). Tarieven. Retrieved from https://afvalfondsverpakkingen.nl/verpakkingen/alle-tarieven

Atkisson, A. (1999). Believing Cassandra: An optimist looks at a pessimist's world. White River Junction, VT: Chelsea Green Publishing

Ayres, R. U. (1989). Industrial metabolism. In Technology and Environment (pp. 23–49). National Academy Press. https://doi.org/10.1287/mnsc.19.10.1110

Bakker, C., den Hollander, M., Van Hinte, E., & Zijlstra, Y. (2014). Products that last: Product design for circular business models. TU Delft Library.

Berkhout, F. (2003). Negotiating environmental change: new perspectives from social science. Edward Elgar Publishing.

Biernacki, P., & Waldorf, D. (1981). Snowball sampling: Problems and techniques of chain referral sampling. Sociological methods & research, 10(2), 141-163.

Biesmeijer, J. C., Roberts, S. P., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., ... & Settele, J. (2006). Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. Science, 313(5785), 351-354.

Blomsma, F., & Brennan, G. (2017). The Emergence of Circular Economy: A New Framing Around Prolonging Resource Productivity. Journal of Industrial Ecology, 21(3), 603–614. https://doi.org/10.1111/jiec.12603

Blu Blu Studios, (2018) Retrieved 27 March from : https://www.blublustudios.com/services/animated-commercials

Borrás, S., & Edler, J. (Eds.). (2015). Governance of socio-technical systems: explaining change. Retrieved from https://ebookcentral-proquest-com.tudelft.idm.oclc.org

Braungart, M., McDonough, W., & Bollinger, A. (2007). Cradle-to-cradle design: creating healthy emissions–a strategy for eco-effective product and system design. Journal of cleaner production, 15(13-14), 1337-1348.

Breen(2018). Het magazine van/voor studenten. Retrieved 2 June 2018 from : www.breenmagazine.nl

BSI (2017). BS 8001:2017. Framework for Implementing the Principles of the Circular Economy in Organizations – Guide. The British Standards Institution, London.

Campus Development TU Delft. (2018a). Sustainability. Retrieved from http://campusdevelopment.tudelft.nl/en/theme/sustainability/

Campus Development TU Delft. (2018b). Sustainably Accessible. Retrieved from http://campusdevelopment.tudelft.nl/en/theme/sustainable-accessibility/

Campus Development TU Delft (2018c). Valorisation. Retrieved from http://campusdevelopment.tudelft.nl/en/theme/valorisation/on 8 June 2018

Challinor, A. J., Watson, J., Lobell, D. B., Howden, S. M., Smith, D. R., & Chhetri, N. (2014). A meta-analysis of crop yield under climate change and adaptation. Nature Climate Change, 4(4), 287.

Chapman, L. (2007). Transport and climate change: a review. Journal of transport geography, 15(5), 354-367.

Childers, D. L., Corman, J., Edwards, M., & Elser, J. J. (2011). Sustainability challenges of phosphorus and food: solutions from closing the human phosphorus cycle. Bioscience, 61(2), 117-124.

Circle economy, (September 22, 2016) Master circular business with the value hill. Retrieved from https://www.circle-economy.com/master-circular-business-with-the-value-hill/#.Wq 59 ZPw baY

Circular Economy Delft (2018) Retrieved from http://circulardelft.wixsite.com/tudelft/research on 4 june 2018

Circulate News (2017) TU Delft offer free introduction Circular Economy retireved from (http://circulatenews.org/2017/02/tu-delft-offer-free-introduction-circular-economy/) .

Clean europe network (2018) Litter is in the middle of the eu Circular Economy. Retrieved 2 June 2018 from https://www.cleaneuropenetwork.eu/de/blog/litter-is-in-the-middle-of-the-eu-circular-economy/aaz/

De Bruijn, H., & Heuvelhof, E. T. (2002). Policy analysis and decision making in a network: how to improve the quality of analysis and the impact on decision making. Impact Assessment and Project Appraisal, 20(4), 232-242.

De Groene Zaak. (2015). Governments going circular. Retrieved May 2018 from http://www.govsgocircular.com/media/1354/governments-going-circular-dgz-feb2015.pdf

Delta. (2015). TU Delft studies repair cafés. Retrieved May 31, 2018 from: https://www.delta.tudelft.nl/article/tu-delft-studies-repair-cafes

Delta (2018). What happens to your coffee cup? Retrieved, 7 June, 2018 from: https://www.delta.tudelft.nl/article/what-happens-your-coffee-cup

Derraik, J. G. (2002). The pollution of the marine environment by plastic debris: a review. Marine pollution bulletin, 44(9), 842-852.

Devaney, E. (2018). Illustrated guide to organizational structures. Hub Spot. Retrieved from https://cdn2.hubspot.net/hub/53/file-2131160376-pdf/illustrated-guide-to-org-structures.pdf?t=1486764493083

De Vos, E., & Verhoeven, S. (2018, May 31st). Personal interview.

Di Maio, F., & Rem, P. C. (2015). A Robust Indicator for Promoting Circular Economy through Recycling. Journal of Environmental Protection, 6 (October), 1095–1104. https://doi.org/10.1680/warm.2008.161.1.3

Dreamstime, (2018) Circular Economy illustration. Retrieved 2 June 2018 from https://www.dreamstime.com/stock-illustration-circular-economy-vector-illustration-showing-product-material-flow-product-life-cycle-natural-resources-taken-to-image66817606:

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., ... & Kriemann, B. (2014). IPCC, 2014: summary for policymakers. Climate change.

Elia, V., Gnoni, M. G., & Tornese, F. (2017). Measuring Circular Economy strategies through index methods: A critical analysis. Journal of Cleaner Production, 142, 2741–2751. https://doi.org/10.1016/J.JCLEPRO.2016.10.196

Ellen MacArthur Foundation, & McKinsey & Company. (2014). Towards the Circular Economy : Accelerating the scale-up across global supply chains. World Economic Forum, (January), 1–64. https://doi.org/10.1162/108819806775545321

Ellen MacArthur Foundation. (2015). Circularity Indicators - An Approach to Measuring Circularity (Methodology). https://doi.org/10.1016/j.giq.2006.04.004

Ellen MacArthur Foundation (2018a). Delft University of Technology. Retrieved on 24 May, 2018, https://www.ellenmacarthurfoundation.org/programmes/education/universities/pioneer-universities/delft-university-of-technology

Ellen MacArthur Foundation (2018b). Pioneer Universities. Retrieved on 05 June, 2018, from ttps://www.ellenmacarthurfoundation.org/programmes/education/universities/pioneer-universities

Ellen MacArthur Foundation (2018c). Circular Economy System Diagram. Retrieved on 9 May 2018 from https://www.ellenmacarthurfoundation.org/circular-economy/interactive-diagram

Erasmus University Rotterdam (2018). Afvalmanagement. Retrieved from https://www.eur.nl/over-de-eur/profiel/strategie/erasmus-duurzaam/bedrijfsvoering/afvalmanagementhttps://www.eur.nl/over-de-eur/profiel/strategie/erasmus-duurzaam/bedrijfsvoering/afvalmanagement

ESE World Ltd (2015). Solar Powered Compacting Bins. Retrieved on 16 April 2018 from http://eseworld.uk.com/wp-content/uploads/2015/07/ESE-World-Ltd-Clean-Cube-Email.pdf

Europarl (2016) Circulareconomy infographics. Retrieved 2 June 2018 from http://www.europarl.europa.eu/thinktank/infographics/circulareconomy/public/index.html

European commission (EC), (2015). Closing the loop - an EU action plan for the Circular Economy. Brussels, Belgium. Retrieved from https://eur-ex.europa.eu/resource.html?uri=cellar:8a8ef5e8-99a0-11e5-b3b7-01aa75ed71a1.0012.02/DOC_1&format=PDF

European commision (EC) (2018). Monitoring framework for a Circular Economy. Strasbourg, France. Retrieved from http://ec.europa.eu/environment/circular-economy/pdf/monitoring-framework.pdf

Faber, M. (2018, February 21st). Personal interview.

Faber, M. (2018, March 16th). Personal interview.

Faber, M. (2018, May 17th). Personal email.

Fraser, B. (2018, March 23rd). Personal interview.

Jamshed, S. (2014). Qualitative research method-interviewing and observation. Journal of basic and clinical pharmacy, 5(4), 87.

Geissdoerfer, M., Savaget, P., Bocken, N. M., & Hultink, E. J. (2017). The Circular Economy–A new sustainability paradigm?. Journal of Cleaner Production, 143, 757-768.

Genç, R. (2017). The Importance of Communication in Sustainability & Sustainable Strategies. Procedia Manufacturing, 8(October 2016), 511–516. https://doi.org/10.1016/j.promfg.2017.02.065

Geng, Y., J. Fu, J. Sarkis, and B. Xue. (2012). Towards a national Circular Economy indicator system in China: An evaluation and critical analysis. Journal of Cleaner Production 23(1): 216–224.

Graedel, T. E., Allwood, J., Birat, J. P., Buchert, M., Hagelüken, C., Reck, B. K., … Sonnemann, G. (2011). What do we know about metal recycling rates? Journal of Industrial Ecology, 15(3), 355–366. https://doi.org/10.1111/j.1530-9290.2011.00342.x

Greyson, J. (2007). An economic instrument for zero waste, economic growth and sustainability. Journal of Cleaner Production, 15(13-14), 1382-1390.

Green Office, (2018) Interview with Tom Millross

Greenmetric (2017) Overall Rankings 2017, Retrieved from http://greenmetric.ui.ac.id/overall-ranking-2017/ on 23 May 2018

Groen, M.. (March 22, 2018). Personal email.

Hallmann, C. A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., ... & Goulson, D. (2017). More than 75 percent decline over 27 years in total flying insect biomass in protected areas. PloS one, 12(10), e0185809.

Hallmann, C. A., Zeegers, T., van Klink, T., Vermeulen R., van Wielink, P., Spijkers, H. & Jongejans, E. (2018). Analysis of insect monitoring data from De Kaaistoep and Drenthe. Retrieved from http://res.cloudinary.com/natuurmonumenten/raw/upload/v1526284069/2018-05/Rapport%20insectensterfte%20-%20wetenschap-ENG.pdf

Homrich, A. S., Galvão, G., Abadia, L. G., & Carvalho, M. M. (2017). The Circular Economy Umbrella: Trends and Gaps on Integrating Pathways. Journal of Cleaner Production.

Hopff, B. (June 6, 2018). Personal email.

Keys to the Future (2015). Report IPG February 6, 2015. For Leiden University

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the Circular Economy: An analysis of 114 definitions. Resources, Conservation and Recycling, 127, 221-232.

Kjaer, L. L., Pigosso, D. C. A., Niero, M., Bech, N. M., & McAloone, T. C. (2018). Product/Service-Systems for a Circular Economy: The Route to Decoupling Economic Growth from Resource Consumption? Journal of Industrial Ecology. https://doi.org/10.1111/jiec.12747

Kloosterman, A. (2018) Geen Commentaar: Alles op een grote hoop. Leids Universitair Weekblad Mare, 25(41), 2

Leiden University, (2016) Environmental Policy plan 2016-2020 retrieved 11 June, 2018 from :https://www.universiteitleiden.nl/binaries/content/assets/algemeen/duurzaamheid/environmental-policy-plan-2016.pdf

Leiden University, (2018) dossierrs impressies. Retrieved 12 March 2018 from: https://www.universiteitleiden.nl/dossiers/impressies/duurzaamheid

Lieder, M., & Rashid, A. (2016). Towards Circular Economy implementation: a comprehensive review in context of manufacturing industry. Journal of Cleaner Production, 115, 36-51.

Lifset, R., & Graedel, T. E. (2015). Industrial Ecology. In International Encyclopedia of the Social & Behavioral Sciences: Second Edition (pp. 843–853). https://doi.org/10.1016/B978-0-08-097086-8.91023-7
Linder, M., Sarasini, S., & van Loon, P. (2017). A Metric for Quantifying Product-Level Circularity. Journal of Industrial Ecology, 21(3), 545–558. https://doi.org/10.1111/jiec.12552

Lonca, G., Muggéo, R., Imbeault-Tétreault, H., Bernard, S., & Margni, M. (2018). Does material circularity rhyme with environmental efficiency? Case studies on used tires. Journal of Cleaner Production, 183, 424-435.

Losada, M., & Heaphy, E. (2004). The role of positivity and connectivity in the performance of business teams: A nonlinear dynamics model. American Behavioral Scientist, 47(6), 740-765.

Maastricht University Green Office (2013). Maastricht University Sustainability Roadmap Retrieved from https://www.greenofficemaastricht.nl/publications

Maastricht University Green Office (2018a). Publications. Retrieved from https://www.greenofficemaastricht.nl/publications on 4 June 2018

Maastricht University Green Office (2018b). Recycling. Retrieved 26 March 2018 from https://www.greenofficemaastricht.nl/recycling

Marks, K., & Howden, D. (2008). The world's rubbish dump: a garbage tip that stretches from Hawaii to Japan. The Independent, 25, 2008.

Meerburg, D. (2018, March 8). Personal Interview.

Musters, C. J. M., & van Bodegom, P. M. (2018). Analysis of species attributes to determine dominant environmental drivers, illustrated by species decline in the Netherlands since the 1950s. Biological Conservation, 219, 68-77.

Nerlich, B., Koteyko, N., & Brown, B. (2010). Theory and language of climate change communication. Wiley Interdisciplinary Reviews: Climate Change, 1(1), 97-110

Netherlands Proteomics centre, (2018) retrieved from http://www.netherlandsproteomicscentre.nl/npc/valorisation/what-is-valorisation.html

Ny, H., MacDonald, J. P., Broman, G., Yamamoto, R., & Robért, K. H. (2006). Sustainability constraints as system boundaries: an approach to making life-cycle management strategic. Journal of Industrial Ecology, 10(1-2), 61-77.

Pauliuk, S., Majeau-Bettez, G., & Müller, D. B. (2015). A general system structure and accounting framework for socioeconomic metabolism. Journal of Industrial Ecology, 19(5), 728-741.

Pauliuk, S. (2018). Critical appraisal of the Circular Economy standard BS 8001:2017 and a dashboard of quantitative system indicators for its implementation in organizations. Resources, Conservation and Recycling, 129, 81–92. https://doi.org/10.1016/j.resconrec.2017.10.019

Plastics Europe (2018). The facts. Retrieved 2 June 2018 from https://www.plasticseurope.org/en/resources/publications/plastics-facts-2017?ccm_paging_p=2&ccm_order_by=ak_publication_date&ccm_order_by_direction=desc

Pryshlakivsky J., Searcy C. (2013). Sustainable Development as a Wicked Problem. In: Kovacic S., Sousa-Poza A. (eds) Managing and Engineering in Complex Situations. Topics in Safety, Risk, Reliability and Quality, vol 21. Springer, Dordrecht

Quist J. (2013) Backcasting and Scenarios for Sustainable Technology Development. In: Kauffman J., Lee KM. (eds) Handbook of Sustainable Engineering. Springer, Dordrecht

Renewi (2018). Rapportage TU Delft (2014 to 2018) [Excel workbook]. Available from TU Delft FM.

Repaircafe Delft (2018). Retreived May 31, 2018 from: http://repaircafedelft.nl/

Rijksoverheid (2016). National Agreement on the Circular Economy: Letter of intent to develop transition agendas for the Circular Economy together. Retrieved from https://www.circulaireeconomienederland.nl/grondstoffenakkoord/default.aspx

Ripple, W.J.; Beschta, R.L. (2012). "Trophic cascades in Yellowstone: The first 15 years after wolf reintroduction". Biological Conservation. 145: 205–213. doi:10.1016/j.biocon.2011.11.005.

Roadmap Next Economy (2018) Circular Economy: Naar Nul Afval. Retrieved from https://roadmapnexteconomy.com/transitiepad/circular-economy/

Schewe, J., Heinke, J., Gerten, D., Haddeland, I., Arnell, N. W., Clark, D. B., ... & Gosling, S. N. (2014). Multimodel assessment of water scarcity under climate change. Proceedings of the National Academy of Sciences, 111(9), 3245-3250.

Smith, A., Stirling, A., & Berkhout, F. (2005). The governance of sustainable socio-technical transitions. Research policy, 34(10), 1491-1510

Smulders, F. (2018). Build your own startup, 15 May [Powerpoint slides] Retrieved from https://brightspace.tudelft.nl/d2l/le/content/66667/Home

Solomon, S., Plattner, G. K., Knutti, R., & Friedlingstein, P. (2009). Irreversible climate change due to carbon dioxide emissions. Proceedings of the national academy of sciences, 106(6), 1704-1709.

Stiff, J. B., & Mongeau, P. A. (2016). Persuasive communication. Guilford Publications.

Su, B., Heshmati, A., Geng, Y., & Yu, X. (2013). A review of the Circular Economy in China: moving from rhetoric to implementation. Journal of Cleaner Production, 42, 215-227.

Sustainabul (2017). Uitslag 2017. Retrieved from https://www.universiteitleiden.nl/binaries/content/assets/algemeen/duurzaamheid/sustainabul-uitslag-2017.pdf

Tableau TU Delft (2018). Student population. Retrieved May 24th, 2018, from https://www.tudelft.nl/en/about-tu-delft/facts-and-figures/education/student-population/

Thomas, I. (2009). Critical thinking, transformative learning, sustainable education, and problem-based learning in universities. Journal of Transformative Education, 7(3), 245–264. https://doi.org/10.1177/1541344610385753

TU Delft, (2016a). Annual report 2016

TU Delft (2016b). Open menu Student Population. Retreived April 26, 2018, from https://www.tudelft.nl/en/about-tu-delft/facts-and-figures/education/student-population/

TU Delft (2016c) video - Recycling of coffee cups. Retrieved June 12,2018, from https://docs.google.com/document/d/112c6jisHn9dXC7tAUkQCqPgBY8bujRbvT9YOXWU1d4M/edit#

TU Delft (2018a). General cycling information. Retrieved June 1st, 2018, from https://www.tudelft.nl/over-tu-delft/werken-bij-tu-delft/nederland-tu-delft/support-for-international-employees/transport-information/cycling-information/general-cycling-information/

TU Delft (2018b). Impact for a better society: TU Delft Strategic Framework 2018-2024

TU Delft (2018c). Facts &Figures Retrieved 11 June 2018, from: https://d1rkab7tlqy5f1.cloudfront.net/TUDelft/Over_TU_Delft/Feiten_Cijfers/jaarverslagen/opmaak%20facts%20%26%20figures%202017%20def.pdf

TU Delft (2018d). Sustainability Retrieved on 13 June 2018 from: https://www.tudelft.nl/sustainability/

TU Delft (2018e). Sustainability: About us. Retrieved on 13 June 2018 from: https://www.tudelft.nl/sustainability/contact-us/

TU Delta (2018) About. Retrieved 10 June 2018 from www.delta.tudelft.nl

TU News (2016) Recycle your coffee cup and play your part. Retrieved 7 June 2018 from https://tunews.weblog.tudelft.nl/2016/04/05/recycle-your-coffee-cup-play-your-part-in-sustainability/

Tukker, A. (2004). Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. Business Strategy and the Environment, 13(4), 246–260. https://doi.org/10.1002/bse.414

Twente University. (2018). Initiatieven: Hergebruik Kantoormeubilair. Retrieved from https://www.utwente.nl/nl/cfm/ontdek/duurzaamheid/initiatieven/!/2014/11/47811/hergebruik-kantoormeubilair

UBC Campus and community planning. (2014). UBC Vancouver Campus Zero Waste Action Plan, 35. Retrieved from http://sustain.ubc.ca/sites/sustain.ubc.ca/files/uploads/CampusSustainability/CS_PDFs/RecyclingWaste/Zero_Waste_Action_Plan 2014 10 03 final.pdf

UC Davis (2018). Retrieved from http://sustainability.ucdavis.edu/local_resources/docs/zero_waste/manual.pdf

UNEP & Futerra (2005) Communicating sustainability: how to produce effective public campaigns

Union, I. (2014). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Brussels. Retrieved from http://eur-lex.europa.eu/resource.html?uri=cellar:8a8ef5e8-99a0-11e5-b3b7-01aa75ed71a1.0012.02/DOC_1&format=PDF

United Nations, Department of Economic and Social Affairs, Population Division (2017). World Population Prospects: The 2017 Revision, Key Findings and Advance Tables. ESA/P/WP/248.

University of Bradford. (2018). Green Move out. Retrieved from https://www.brad.ac.uk/estates/environment/be-greener/advice-waste/green-move-out/

University of Nottingham. (2018). Jubilee Grounds Guide. Retrieved from https://www.nottingham.ac.uk/sustainability/documents/jubileegroundsguide.pdf

Utrecht University. (2018). Afval Retrieved from https://www.uu.nl/organisatie/duurzame-uu/bedrijfsvoering/afval

Van Eersel, M. (2018, May 3rd). Personal interview

Van Ewijk, S., & Stegemann, J. A. (2016). Limitations of the waste hierarchy for achieving absolute reductions in material throughput. Journal of Cleaner Production, 132, 122-128.

Van Gestel, M. (2016). 5 dingen die je nog niet wist over afval op de campus. Vox. Retrieved from https://www.voxweb.nl/nieuws/vijf-dingen-die-je-nog-niet-wist-over-het-afval-van-de-universiteit

Vergragt, P. J., & Quist, J. (2011). Backcasting for sustainability: Introduction to the special issue. Technological Forecasting & Social Change, 5(78), 747-755.

Verhoef L., Graamans L., Gioutsos D., van Wijk A., Geraedts J., Hellinga C. (2017) ShowHow: A Flexible, Structured Approach to Commit University Stakeholders to Sustainable Development. In: Leal Filho W., Azeiteiro U., Alves F., Molthan-Hill P. (eds) Handbook of Theory and Practice of Sustainable Development in Higher Education. World Sustainability Series. Springer, Cham

Verhoef, L.A., Bossert, M., Newman, J., Ferraz, F., Robinson, Z.P., Agarwala, Y., Wolff III, P., Jiranek, P., Hellinga, C. (2018). Towards a learning system for University Campuses as Living Labs for sustainability. In: Universities as Living Labs for Sustainable Development: Supporting the Implementation of the Sustainable Development Goals - Volume 2. Springer, ed. Leal, W. et al., 2018 (inpress)

Vries, G., Terwel, B. W., Ellemers, N., & Daamen, D. D. (2015). Sustainability or profitability? How communicated motives for environmental policy affect public perceptions of corporate grreenwashing. Corporate Social Responsibility and Environmental Management, 22(3), 142-154.

Vrije Universiteit (2018). DUURZAME CAMPUS: (AFVAL)WATER EN AFVAL(STOFFEN) Retrieved from https://www.vu.nl/nl/over-de-vu/profiel-en-missie/profileringsthemas/s4s/afval-water-en-afval-stoffen/index.aspx

Wageningen University & Research Centre. (2018). Afval. Retrieved from https://www.wur.nl/nl/Over-Wageningen/Duurzaamheid/Themas/Bedrijfsvoering/Show/Afval.htm

Wageningen University & Research Centre. (2018) Bouwen. Retrieved from https://www.wur.nl/nl/Over-Wageningen/Duurzaamheid/Themas/Bedrijfsvoering/Show/Bouwen.htm

Wageningen University & Research Centre. (2015). Strategic plan 2015-2018. Retrieved from https://www.wur.nl/upload_mm/5/e/b/929b8071-3b1a-416c-bb43-0630b726e75c_8412101823_CC_strategisch%20plan_UK_LR.pdf

Warp It. (2018) Leagues. Retrieved from https://www.warp-it.co.uk/leagues

Welink, Jan-Henk. (2017). Pilot Optimalisatie Afvalinzameling - Uitkomsten. TU Delft.

Wellmer, F. W., & Becker-Platen, J. (2002). Sustainable development and the exploitation of mineral and energy resources: a review. International Journal of Earth Sciences, 91(5), 723-745.

Wicinski, M & Griffith, J. (2013). 5 Ways to communicate sustainability beyond words. Greenbizz. Retreived 12 June, 2018 From https://www.greenbiz.com/blog/2013/05/01/5-ways-communicate-sustainability-beyond-words

World Bank (2017). Retrieved from
https://data.worldbank.org/indicator/SI.POV.DDAY?end=2013&locations=1W&start=1981&view=chart

World Wildlife Fund (2014). Living Planet Report

World Economic Forum In collaboration with PwC. (2018) (Circular Economy in Cities: Evolving the model for a sustainable urban future. Retrieved from
http://www3.weforum.org/docs/White_paper_Circular_Economy_in_Cities_report_2018.pdf

Zendesignfirm (2018) The art of branding, Retrieved 2 June 2018 from
https://zendesignfirm.com/2016/04/art-of-brand-storytelling-part-2-how-to-construct-a-story/