Master Thesis

Circular Economy Potential of Climate Change Adaptation in Cities: The Case of Rotterdam, The Netherlands

Name:

Fatemeh Korminouri

Student number

S1952544

Supervisors

Dr. Gül Özerol (1st Supervisor)

Dr. Yoram Krozer (2nd Supervisor)

Master of Environmental and Energy Management Program

University of Twente

Academic year 2017-2018

Preface and Acknowledgements

This dissertation is the result of my master research for Environmental and Energy Management Program at University of Twente. During my studies for this master program I became interested in the circular economy concept. The motivation for this research is rooted in my curiosity to study how synergies between climate change adaptation in construction sector as the largest consumer of materials and circular economy can be achieved in cities and enhance their ability to efficiently tap their resources. Using Rotterdam as a case study, this research examines the potential of circular economy adoption into climate change adaptation measure.

This graduation project has been supervised by Dr. Gül Özerol. I would like to express my greatest gratitude for her help and feedback. I am eternally grateful for the Skype calls, numerous emails and meetings and discussions when I needed and for providing constructive feedback, corrections and new insights on my document. My thanks also go to Dr. Yoram Krozer, my second supervisor, for his input and guidance during this work. His contribution was of great help.

I would also like to express my gratitude to all interviewees who have contributed to the findings of this research. I could not have done this thesis research without their help. I am grateful that they all welcomed me and shared their knowledge and experiences with me in the interviews.

Last but not least, my heartfelt gratitude to my beloved father, mother and sister for their endless love, support and encouragement when I needed it the most throughout my academic career.

Fatemeh Korminouri
August 2018

Abstract

With increasing populations living in metropolitan areas, it becomes crucial that raw materials and resources are used carefully, reused and recycled. At the same time, urban population and infrastructure are extremely vulnerable to climate change. To tackle climate change and decrease the vulnerability of cities to its impacts, climate change adaptation is considered as a promising solution. The consequences of climate change such as increasing frequency of heavy rainfalls, rising sea levels and rising temperatures will also be felt widely, particularly in coastal and delta cities. Adaptation to climate change in cities implies seeing the climate change challenges as an opportunity rather than a threat and making the city resilient and attractive through keeping it safe, livable and economically strong. The adaptation challenges rise with increasing severity of climate change. Integration of circular solutions at the city level promotes less material consumption, competitiveness in global markets and a cleaner environment. This research has two lines of inquiry. First, it reviews the climate change adaptation literature regarding the linkage between infrastructural adaptation measures in response to climate change. Second, the research focuses on the delta city of Rotterdam, where urban communities and assets are significantly exposed to the impacts of climate change. Specifically, climate change adaptation in Rotterdam is examined with regards to green and grey adaptation measures and the integration of circular economy, where it is feasible in these measures. This conceptual link is not apparent in the existing related literature, so this research aims to fill this gap by constructing a framework to analyse not only the infrastructural responses to climate change, but also the integration of circular economy in the current adaptation practices in response to climate change. The primary and secondary data were derived from desk research and interview with stakeholders. The study concludes with the climate change adaptation measures that have more potential to adopt circularity principles in terms of material and resource use and expanding the functions of measures, as well as the main existing drivers and barriers to this adoption. The research followed with recommendations with respect to drivers and barriers to show the improvement of circular economy approach in green and grey climate change adaptation measures Rotterdam.

List of Tables

Lists of Figures

Table of Contents

Chapter 1: Introduction

1.1 Urbanization and population growth

Global population is predicted to grow by more than one billion people in the next 15 years, and further to 9.7 billion by 2050 and 11.2 billion in 2100 (Koop and Leeuwen, 2017). Rapid urbanization means that currently around 50% of world's population live in cities and this trend is going to reach to 70% by 2050 (Prendeville et al, 2018). Besides, by 2050, the majority of world's population is projected to dwell in cities, near/in delta cities or coastal zones (Piet Dircke et al, 2010). The rapid growth of world population exerts dramatic pressure on urban resources and quality of life.

Rapid population growth and human activities are altering the planet with a huge impact on the environment resulting in anthropogenic climate change. In a rapidly urbanizating world, the threats of climate change challenges are serious and require the adequate protection of cities. To do so, urban managers and planners bring up urban sustainability issues to address climate change challenges in cities (Prendeville, 2018). Across all areas in the world, port cities are most vulnerable to climate change impacts, for instance, flooding in river mouths or rise in sea level at coasts. Besides, the key role of port cities in local and international economies makes these areas of paramount importance (Becker et al, 2011).

Historically, technological changes and industrial revolution have taken place in geographically dynamic locations, where land and water meet. Port cities and port areas are such locations that have always been at the crossroads of change and possess a high industrial development potential. For instance, traders in Amsterdam embarked to explore new trading routes with wooden sailing ships. Port of London developed by the steam mills in the 18th and 19th century (Jansen, 2016). New York and Rotterdam were largest ports in the world in the 20th century. Port cities have always undergone significant changes after revolutions. They developed because the revolutions have often relied on the trade of cargo, raw materials like coal and iron ore, and fishing. Port cities play a vital role for economic growth at local and international levels. At the same time, they are vulnerable to human activities and environmental impacts (Jansen, 2016).

Human activities are altering the planet at an increasing rate with adverse environmental impacts. Global impact of urbanization and human activities are the major threats of climate change in the cities and consequently natural hazards such as floods, droughts and storms (Prendeville et al, 2018). Therefore, the protection of cities is of paramount importance. On the other hand, with increase of world population, the global material consumption has increased eightfold within the past ten decades and is projected to threefold increase by 2050 (Krausmann et al, 2009). The consumption of raw materials (metal, wood, plastic,etc.) follows roughly the same percentage. Cities are concentrations of production, consumption and waste. According to

the ecological studies of cities, sometimes the cities exceed their environmental footprint by a factor 10-150 (Koop and Leeuwen, 2017). This exerts intense pressure on water supply, wastewater treatment and solid waste reuse. Besides, nature and built environment, soil, air and water pollution come under pressure as well (UN, 2013). All these features provide cities with a need to shift to circular economy. To support this mission, research should be conducted on how circular economy approach in Rotterdam could contribute to climate change adaptation in the construction sector.

1.2 Climate change adaptation in cities

Given that the consequences of climate change have been experienced locally, it is understandable that some cities have been taken initiatives to develop adaptation response. The examples are London's climate change adaptation strategy, coastal adaptation planning by New York City Panel on Climate Change, Hamburg's HafenCity climate change project, Germany's Klimzug initiative and Rotterdam's climate proof adaptation program (Carter et al., 2015). Recognizing the threats that changing the climate poses to cities, adaptation is firmly embedded throughout the activities of cities and urban areas. Furthermore, the other projects across the Europe including Prepared (which focuses on water and sanitation under climate change), Sudplan project (which looks at adaptation with long-term urban planning) and Corfu project (which concentrates on flood resilience in urban environment), evidence the richness of ongoing research in urban adaptation (Carter et al., 2015).

1.3 Circular economy model

The linear economy works according to a step plan of "take, make, waste". Resources are extracted and used to produce products. Products after their use, will be discarded and disposed as waste (Figure 1.1). In linear economy, the value is to maximize the amount of products produced and sold. Degradation of natural resources and severe environmental impacts are the main shortcoming of this model. In comparison, circular economy works based on 3R approach "reduce, reuse, recycle". In 1966, Kennet, introduced circular economy model that adopted an approach to long-term economic growth, sustainability and zero waste (Greyson, 2007).

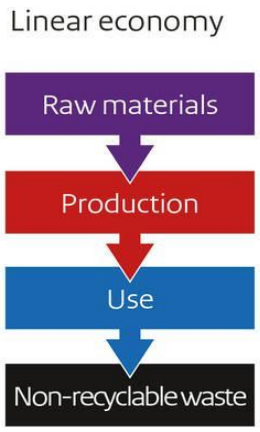

Figure 1. 1 Linear economy, Source: Ellen MacArthur Foundation, 2016.

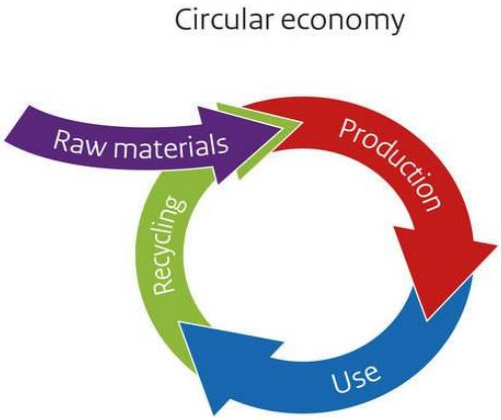

Figure 1.2 Circular economy, Source: Ellen MacArthur Foundation, 2016.

Circular economy model aims to reduce the material extraction by less material consumption, using reused materials for production and recycling after discarding the products. In this model, the value is created by closing the cycles and focusing on value retain. Circular economy is a cradle-to-cradle (C2C) approach (the concept that boost separation of biological from technical materials to recover, reuse or repurpose them) which aims to create a cyclical process (Braungart and McDonough, 2009). A circular economy is regenerative by design aiming at retaining the value of products, parts and materials as much as possible (Van Oppen and Bocken, 2016). It applies interconnected system and market for designing, optimizing material recyclability and eliminating waste (Figure 1.2) (Kraaijenhagen et al., 2016), (Ellen MacArthur Foundation, 2016).

1.4 Problem statement

1.4.1. Empirical problem

With changing climate, climate disasters have been happening more severely and frequently than before (Peng et al., 2018). Floods, heatwaves and droughts are frequent climate disasters across the world. All cities across the world, particularly the delta cities are vulnerable to the impacts of climate change on public health, quality of life, economic progress and physical assets. It is important that cities recognize these risks to be able to adapt to the climate changes and enable their citizens and businesses to achieve the maximum benefit from adaptation. Together, climate-related and infrastructural problems threat the spatial quality of delta cities and urban development. Hence, the transition to climate-adaptive urban development is a significant challenge facing the cities across the world, and one that policy-makers, urban planners and engineers need to tackle (Carter et al., 2015).

Rotterdam, the second largest city in the country, already adopted a climate plan in 2007 as Rotterdam Climate Initiative (Rotterdam Climate Change Adaptation Strategy, 2013). In terms of climate change impacts, Rotterdam is also facing the threat of severe storm events as well as increased peak river discharges. Therefore, Rotterdam aims to protect its citizens against the future impacts of climate change, by making Rotterdam climate proof by 2025. Climate adaptive measures in Rotterdam aim to contribute to creating a safe, attractive, healthy and lively city. The implementation of these measures requires area-specific spatial design as well as multi-functional usage based on adaptive design and construction, which is one of the largest consumers of materials and resources. Dutch construction sector is highly dependent on fossil fuels and materials (iron, aluminum, wood, copper, etc.). Therefore, resource management in this sector is of great importance to retain prosperity. Circular economy is a framework that can help manage scarcity and retain prosperity flourish within essential limits to protect the cities.

1.4.2 Research problem

This research focuses on climate change adaptation responses in Rotterdam with regards to green and grey measures and integration of circular economy into these measures where it is feasible. This link is not apparent in the existing related literature. Therefore, this research aims to fill this gap by identifying the existing climate change adaptation measures (green and grey) and investigating how circular economy can be integrated into these measures.

1.5 Research objective and question

The main objective of the research is to investigate the potential of circular economy model in infrastructural responses to climate change in Rotterdam. In order to achieve this objective, this study examines climate change adaptation and circularity measures applicable to Rotterdam, aiming to answer the following main research question:

> "How can the circular economy model support the implementation of climate change adaptation measures in the construction sector of Rotterdam?".

To be able to answer the main research question, the following sub-questions are formulated:

1. What are the existing climate change adaptation measures in the construction sector in Rotterdam?
2. How is the city of Rotterdam approaching circular economy in the construction sector in terms of policies and regulations to improve climate change adaptation?
3. What are the main drivers and barriers to integration circular economy model into climate change adaptation strategies in Rotterdam for construction sector?

The research is structured based on primary data and existing documents to answer the sub-questions and then the main question. Answering the first question identifies the current climate change adaptation measures, specifically grey and green adaptation measures in Rotterdam. It further analyzes that which sector within climate change adaptation measures (green or grey) has more potential to apply circular econmy principles. The second question aims to identify how the existing incentives, policies, regulation and technology support and enable implementation and improvement of circularity principles in climate change adaptation measures and what the potential further improvements are. The third question identifies the main drivers and barriers in different aspects which motivate or hinder the application of circularity principles in climate change adaptation measures . Answering these questions aids to provide the practical suggestion and recommendation to support and improve the integration of circular economy principles into climate change adaptation measures.

Chapter 2: Literature Review

This chapter reviews the relevant scientific and professional literature by introducing the key concepts and terminologies related to the research topic.

2.1 The key climate change challenges in cities

Climate change is forecasted to intensify the hydrological cycle and give rise to the occurrence and frequency of extreme events such as flood, heatwaves and droughts across the world (Dong et al., 2017). In the sub-sections below, specific attention is paid to major climate change challenges, namely heatwaves and heat stress, floods, and drought, which pose to cities and the need for urban adaptation.

2.1.1 Heatwaves and heat stress

Heatwaves refer to prolonged spells atypical high temperature which last from several days to several weeks. Heatwaves make an impact on hydropower and transport infrastructure beyond the massive impact on the society including an increase in mortality and morbidity (Lass et al., 2011). The rising frequency of heatwaves, particularly in urban areas, is one of the critical consequences of changing climate (Reischl et al., 2018). The expected increase in the heatwaves and number of hot days results in increasing demand for air conditioning. However, overuse of air conditioners generates additional heat outside buildings and emits more greenhouse gases. Hence, the passive measures integrated with adaptation concerns should be considered in first building designs or public spaces. On regional and local scales, land-cover changes intensify the impact of green-house-induced heat or exert more impacts on climatic conditions. Urban heat islands (UHI) resulted from increased heat storage, lowered evaporative cooling and sensible heat flux. UHI caused by lower greenery surfaces and increased impervious surface, exacerbate heatwaves (Patz et al., 2005). Dark surfaces for instance, asphalt roads and rooftops, cause the temperature to increase 30-40 ^{o}C higher than surrounding (Frumkin, 2002).

2.1.2 Floods

Floods are among the most serious climate-related disasters (Hirabayashi, 2013). Flooding is recurrent in many cities particularly in delta and coastal cities and with climate change predictions it is projected to intensify and become more frequent (da Cruz e Sousa and Miranda, 2018). As a consequence, various spatial development visions, plans, programs and strategies by city governments to tackle these risks and challenges (Francesch-Huidobro et al., 2017). Presently, Delta cities are among the most vulnerable areas to the consequences of floods (Hallegatte et al., 2013). Urbanization of deltas and the driving force of making delta landscapes intensify the risk of floods in these areas (Francesch-Huidobro et al., 2017). In Europe, many large cities are located along major rivers where highly exposed to flood risks. Floods cause a range of direct and

indirect impacts in urban areas, from material and economic impacts to health and emergency assistance impacts. For instance, high economic losses including damage to urban infrastructure, erosion or landslides and loss of life and disease (van Riel., 2011). Floods in urban areas can be divided into different types, namely river floods, flash floods, coastal floods, urban drainage and groundwater flooding. Flood adaptation measures in cities involve grey, green and soft measures.

2.1.3 Drought

Drought refers to a temporary water shortage mainly caused by climate conditions and soil properties. Most definitions of drought make reference to sever decrease of water availability, resulted from a lack of precipitation, with significant societal, economic and environmental impacts (Hill et al., 2014; Tsakiris et al., 2013). Climate change-induced droughts are problematic since and pose real challenges to all socioeconomic sectors, because of their slow onset in comparison to other climate-related disasters and their variability across time and space (Hill et al., 2014). The degree of a vulnerability to drought in cities depends a range of environmental and social factors (Tigkas and Tsakiris 2014). An increase in water-related stress is projected in areas of high urbanization and population density particularly. Urban adaptation measures to drought include green, grey and soft measures. One of the options of grey infrastructure approaches is re-allocation of water supplies from water-rich areas to water-stressed areas which is often an expensive solution and requires to be tackled at a national level rather than a regional or local level. These kinds of solutions considered as poor adaptation measures due to high cost and energy demand. Local solutions vary from rainwater harvesting to ground water recharge and grey water recycling. These measures are simpler and beneficent since they can contribute to increase in soil moisture level for vegetation, reducing the risk of urban flooding, as well as sustaining evaporative cooling (Shaw et al., 2007). Green infrastructure measures apply vegetated areas to store storm water, delay water run-off and allow water filtration in the soil to keep it available for various usage such as vegetation. Green roof and wide shallow water-ways are the other examples of green adaptation which can contribute to rainwater harvesting.

2.2 Climate change adaptation

Climate change adaptation (CCA) refers to anticipation of adverse impacts of climate change and taking decisive action to avoid or minimize the consequential damages. Adaptation is increasingly considered as an essential complement to greenhouse gas emission measures across the world (Naess et al., 2005). Climate change adaptation can also take advantage of opportunities of climate change rather than threat. It may produce effects on different sectors of economy. In accordance with Intergovernmental panel on climate change adaptation concerns adjustments in human or natural environment/systems in response to observed or projected climatic stimuli or their impacts (EEA, 2012). These adjustments moderate harm or exploit beneficial opportunities rather than threat. This definition emphasizes that adaptation is not solely

anthropocentric and not purely future-oriented. It can be both autonomous and incentivized by policy making. In recent years, the notion of climate resilience has been increasingly attributed with climate change adaptation (Leinchenko, 2011).

2.2.1 Climate change adaptation in cities

Cities are critically important actors in climate change mitigation and adaptation. Tackling climate change is a priority for cities, where has set both short and long-term adaptation and emissions reduction targets (Reckien et al., 2018). Cities can have a prominent role in developing and implementing adaptation programs to response climate change. Because, they deal with the interface between local action and national/international level for climate change adaptation commitments. (Heidrich et al., 2016).

Conceptually, adaptation is conceived of as climate risk management which connects adaptation to the perspective of urban resilience. Risk assessment framework support the approach of adaptation in urban areas through identifying and reducing risks from climate hazards and extreme weathers to lessen the intensity and frequency of risks to urban areas. Rozenzweig et al., 2011, adopted urban climate change vulnerability and risk assessment framework (Figure. 2.1) which offers a useful means of understanding climate risks and developing corresponding adaptation strategies. Figure 2.1 shows the core elements of adaptation agenda that are essential to be understood to appreciate and assess the climate change risk. Firstly, hazards refer to the weather and climate events that cities experience, for instance flood, heat waves and drought. The second element is vulnerability, which is a contested term and no agreement has been concluded over its explicit meaning (Alcamo and Olesen, 2012). Carter et al. (2011) consider vulnerability as of city inhabitants, infrastructure and the natural and built environment as a state. They said vulnerability is attributed with people, areas or things, regardless of whether they experience a hazard that could result in harm. Thirdly, adaptive capacity is the ability of city governors, businesses, inhabitants and related systems and structures to moderate and prepare for potential risks from climate change hazards, recover from climate change impacts and exploit new opportunities through adapting to the changing climate. Lessening vulnerability and adaptive capacity contributes to reduce risk

.

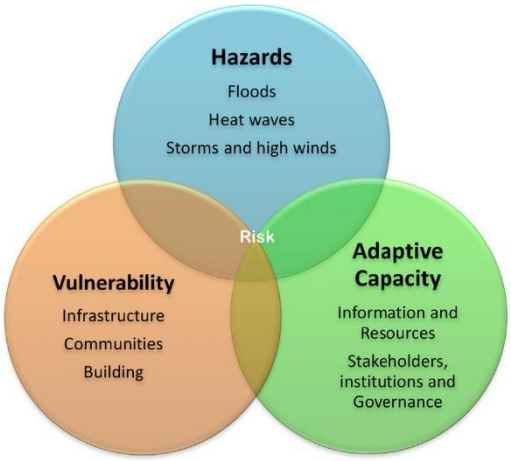

Figure 2. 1. Urban climate change vulnerability and risk assessment framework, Source: Rosenzweig et al. (2011)

It is increasingly accepted that the risks and impacts of climate change must be tackled through both mitigation and adaptation (Hurlimann et al., 2018). To do so, city officials have to strengthen cities' capacity and assess their vulnerability to climate change challenges (Hunt and watkiss, 2011). Then, they can identify corresponding plans and practical guidance on how to respond to climate change challenges. Cities have always experienced climate-related hazards, namely, flooding, drought, heat stress and hurricanes. Climate change challenges range from increase in extreme weather events to temperature rise and public health concerns. Generally, cities are the first respondents to climate impacts. The process which proactively prepares for and adjusts cities to both adverse impacts and potential opportunities of climate change, is defined as climate change adaptation (Carter, 2011). The specific impacts and challenges in each city depends on the actual changes in climate which vary from city to city. For instance, cities in coastal zones face both threats of rising sea level and storm surges. The starting point in building long-term resilience and managing risks is understanding city's sensitivity and exposure to impacts, develop responsive policies and investments to tackle vulnerabilities (Carter, 2011).

2.3 Classification of climate change adaptation measures

Climate change adaptation measures can be classified in different ways. This research applies the classification which is used in European Environment Agency (EEA), since this classification includes both grey and green measures which this study targets (EEA, 2013). In this regard, the classification is presented in the following sub-sections. Table 2.1 lists examples of grey and green adaptation measures for the above-mentioned climate challenges.

Table 2. 1 Examples of green and grey adaptation measures for climate challenges

	Grey measures	Green measures
Flood	● Innovative design of areas and buildings, (such as elevated entrance, temporary water storage, building on poles, floating houses, green roofs). ● Maintenance/upgrade of drainage systems. ● Temporary water storage in basins or fascines ● Dams and flood defenses. ● Separate treatment of rainwater, disconnected from sewage, improved ground drainage. ● Make new infrastructure and buildings flood proof by appropriate material use and design.	● Maintain and increase green infrastructure in cities, (such as wetlands parks and gardens, water bodies green roofs). ● Re-naturalization of rivers and wetlands. ● Maintain green areas inside and outside the cities for flood retention including the use of appropriate agriculture and forest practices
Heatwaves	● Urban designs providing shade. ● Building insulation to keep inside cool ● Blinds for providing shade ● Passive cooling of buildings ● Ventilation of urban space by intelligent urban design	● Increasing the green infrastructure, (such as: green urban areas, green walls and roofs)
Drought	● Water saving systems ● Systems for rainwater harvesting ● Ground water recharge systems ● Greywater recycling systems ● Supply from more remote areas (pipelines) ● Desalination plants	● Storage of rainwater in wetlands and water bodies for later use ● Maintain and manage green areas outside and inside the cities to ensure water storage instead of high run offs ● Use of plants which have adapted to drought conditions (drought resistant plants)

Source: Adapted from EEA, 2012.

2.3.1 Grey infrastructure measures

Grey infrastructure refers to physical interventions and construction measures which apply engineering services to make infrastructure and buildings necessary for the economic and social well-being of society and capable to confront extreme events (EEA, 2012). The grey adaptation approaches focus on the impacts of climate change on buildings and infrastructure, for instance changes in sea level rise, temperature floods, etc. These approaches aim to control over the environmental threat itself or prevent the impacts of climate change and variability (EC, 2009). Notably, adaptation measure which combine green and grey infrastructures are with great potential to deliver flexible and robust solutions over a long period. Besides, grey adaptation measures include specific infrastructural and technological changes which involve capital goods

which consider climate change risks in design and planning (Jones et al., 2012 and Sovacool, 2011). Generally, grey measures are applied to improve energy, housing, transport, water supply and sanitation (Wamsler, 2014). For instance, grey measures that are implemented through legislation or guidelines include floodwalls and dams, improved drainage systems, roofs and streets, flood-prone infrastructure on higher ground, etc. (Walsmer, 2014). Moreover, grey measures are used in conjunction with disaster risk reduction, water management and coastal adaptation (Jones et al, 2012; Agrawala et l., 2011). Grey measures are also applied to tackle the climate threats of heat stress and increased temperature. Drought and water scarcity can also be addressed by grey measures (EEA, 2013).

2.3.2 Green infrastructure measures

Urbanization replaces green and vegetated surfaces, which provide evaporative cooling, shading, rainwater storage, interception and infiltration functions through impervious built surfaces (Gill et al., 2007). In the recent years, the application of green infrastructure is considered as a flexible and effective strategy for adaptation to the disturbances resulted from climate change (Dong et al., 2017). Green infrastructure applies services and functions provided by the ecosystems to achieve cost effective and feasible adaptation solution. Incorporating more green into the cities (green adaptation) make the cities less vulnerable to heat stress, flood risk, extreme rainfall and drought (Herath et al., 2018). It can enhance the capacity of urban environment to adapt to climate change via the functions such as rainwater infiltration and evaporative cooling (Hurlimann et al., 2018). Green urban planning is of great potential for less heat stress, air purification, water storage. In addition, it can produce a cooling effect through the increased temperature, lower radiance and greater shading provided by green and vegetated surfaces beyond its recreational potential (Mabon and Shih, 2018). Green infrastructures refers to vegetated or sustainability-based operations, for instance green walls and roofs, wetlands, parks, forests, bio-retention cells porous pavements and swales which can diminish the amount of storm water entering the urban drainage systems (Tavakol-Davani et al., 2015). Furthermore, green infrastructure approaches can increase ecosystem resilience and halt degradation of ecosystem, biodiversity loss and restore water cycles. It is crucial that green infrastructure established in a careful and efficient way. The selection of greenery and plants needs to consider the availability of local water resources and potential scarcity.

2.3.3 Soft measures

Soft or non-structural measures correspond to application of procedures and policies, land use controls, economic incentives and information dissemination to reduce vulnerability, avoid maladaptation and encourage adaptive behavior. Soft measures can facilitate the implementation of green or grey approaches, for instance through funding, or integrating climate change adaptation into regulations (EEA, 2012). In most literature, soft adaptation measures

refer to those which do not involve constructions such as dams or dikes, but mostly involve awareness raising, sharing information and dissemination activities on climate change adaptation issues. This designation refers to strategy developments, instruments for policy, as well as new governance, institutional and social learning arrangements that support developments on adaptive capacity (Olsson et al., 2006). Since, this research targets adoption of circular economy into climate change adaptation in the construction sector, the soft measures are not discussed in the following sections.

2.4 Construction sector and climate change adaptation

Although climate change adaptation in urban areas is relatively a new topic, in recent years significant progress have been made in policy, practice and research on climate change adaptation in urban areas (Carter et al., 2015). To reduce the risks of greater variations of temperature, extreme weather events, drought, sea level rise, flooding and coastal defenses, adaptation to climate change is necessary. A sustainable and resilient built environment can cope with the climate change impacts. For instance, cities can harvest rainwater, improve energy efficiency and preserve quality of living for their habitants. Governance strategies have focused on policy making on national and municipal level. However, the actors have to take into account the significance of physical adaptation activities to the construction sector. Construction is the sector in which physical adaptation measures can be applied for infrastructures and buildings. It is also critical how we deliver the construction of these infrastructures in a circular economy model to extend the lifecycle of raw resources and improve energy efficiency (Carter et al., 2015).

The construction sector includes the agents engaged in constructing, maintaining, improving, renovating, demolishing of physical infrastructures such as system of storm surge barriers, canals and lakes, dikes and sewers. However, maintaining and strengthening the basis is not enough to make the cities climate proof. Adaptation involves making use of the entire urban environment and alleviate the system and increase its resilience. Besides the current system, small-scale measures are going to be adopted in the city in both public and private property. The examples are the small-scale measures are green roofs and water squares.

The main impacts of construction are the extraction of raw materials and the excessive use of energy. Material extraction of the virgin resources causes significant environmental impacts through loss of ecosystem and inhabitants. Construction industry is the largest consumer of resources. The extraction of materials from natural resources has various environmental and economic consequences which extend beyond boundaries and affect further generations. Extraction and depletion of natural resource stocks leads to environmental pressure associating with extraction, processing, transport, consumption and disposal of materials. These environmental pressures are namely, habitat disruption, pollution and waste. Besides, the adverse impacts on environmental quality (climate, air, water, soil and landscape). Therefore,

selection of appropriate material to adopt to a sustainable approach is of great importance (OECD, 2013).

2.5 Circular economy model

Climate change and impending resource scarcity has challenged the world and demand a shift from linear to circular pattern of consumption. Where businesses were unable to tackle the concerns related to sustainability and environmental issues, the concept of circular economy were applied. In 2012, the Ellen MacArthur Foundation (EMF) introduced an alternative to the linear model of consumption, so called take-make-dispose (Ness, 2008; Ghisellini et al., 205). The realization of circular economy concept is of great importance. In recent years circular economy is receiving raising attention throughout the world as a solution to overcome the existing production and consumption model based on increasing resource throughput (Ghisellini et al., 2015). Circular economy develops an environmentally sound and appropriate use of resources targeting the implementation of a green economy by a new business model (Stahel, 2014). Linear economy is facing competition from a model of resource deployment, which is circular by design and significantly contributed to the opportunity for durable goods. On the contrary, circular model creates significantly more value of products and virgin materials through recovering and regenerating them at the end of each service life (EMF, 2016). Circular economy provides a cyclical system with an alternative flow model (Korhonen, 2018). More specifically, circular economy aims to create a system which offers long life, optimal reuse, refurbishment, remanufacturing and recycling of products and materials (Kraaijenhagen, Van Oppen & Bocke, 2016; Braungart et al., 2007).

Circular economy is based on closing loops and extending a product use cycle, as represented in figure 2.2 with the so-called “butterfly diagram”. This model aligns a compelling business rationale with the need to decouple wealth creation from the consumption of finite resources. It invites increased use of renewable energy, and to preserve natural capital, optimize resource yield, relieve pressure on ecosystem, and promote system effectiveness by eliminating toxic substances. In circular economy, it is assumed that waste is the start of the next phase of life and reuse is a part of the design phase (Verberne, 2016).

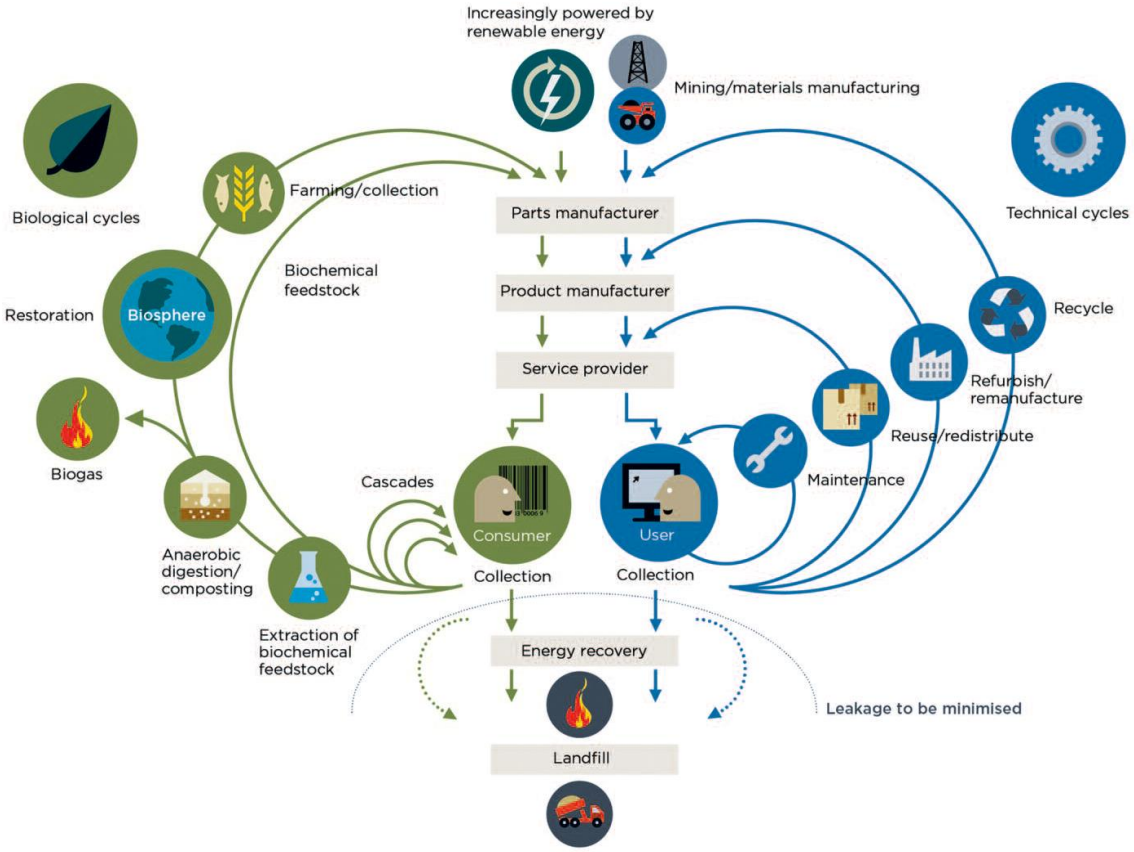

Figure 2. 2. Circular Economy - The butterfly diagram, Source: EMF,2016

2.5.1 Circular economy principles

Circular economy encompasses a multitude of different concepts to mitigate pollution from production, extend the lifetime of products and consequently decouple economic growth form environmental harm (Ghisellini et al., 2016). Some of those concepts include “efficiency” to optimize materials, energy and production output and at the same time, minimize inputs and pollutant discharge to the environment; “recovery” of any waste in the value chain before it goes to landfill; valorization of waste, re-economized for social benefit. Recently, EU documents paid particular attention to encourage recycling and recovery strategies along a product’s lifecycle (EEA, 2016) in which circular economy follows the 3R principles: 1) reduction (material input reduction), 2) reuse (repair and refurbishment process), and 3) recycling (output resource utilization) (Haas et al., 2015; Wu et al., 2014; Yuan et al., 2008; Wang et al., 2014). Similarly, the EMF states that preserving and fostering natural capital, maximizing resource yield, and improving system effectiveness are the three principles of circular economy. According to EMF (2013), circular economy is based on few fundamental principles, namely design out waste, rely on energy from renewable resources, build resilience through diversity, think in systems and waste is food. In addition, some authors such as Wiel et al.

(2012) support the circular economy with “Cradle to Cradle” (C2C) concept (an approach for designing products, systems and processes which considers the entire life cycle of the product, recyclability, optimizing material health, use of renewable energy as well as water efficiency and quality). Both groups of principles (3R and C2C) provide the framework of circular economy and can coexist, however, these principles understood at two different functions and levels. To be more specific, according to Yuan et al. (2008), the 3R principles can be applied throughout the whole cycles of production, consumption as well as return of resources. While, the C2C principle function as guidelines and catalyzers to design products and services which could be reintroduced in the system in the long term as technical or biological resources (Braungart et al., 2007).

2.5.2 Circular economy in the construction sector

The literature on circular economy in the construction sector discusses the importance of construction sector in transition to circularity (Laubscher, 2014; Cacho et al., 2017; Adams, 2017). Construction is of critical importance to the healthy functioning of economy. The construction sector is one of the largest users of virgin materials and energy. The application of circular economy concept in the construction sector has been mainly limited to construction waste minimization and recycling to minimize negative impacts on the environment (Adams et al., 2017).

As figure 2.3 shows, material flows fulfil a key role in the concept of circular economy. In circular economy, materials are efficiently used in a closed loop. The closed loop circular design enables materials to retain high residual value, since there are less primary material extraction and waste treatment cost. Construction sector has priority over the other sectors for the circular economy (EU, 2012), due to large amount of resources and energy use and high potential for reuse and recycling these materials.

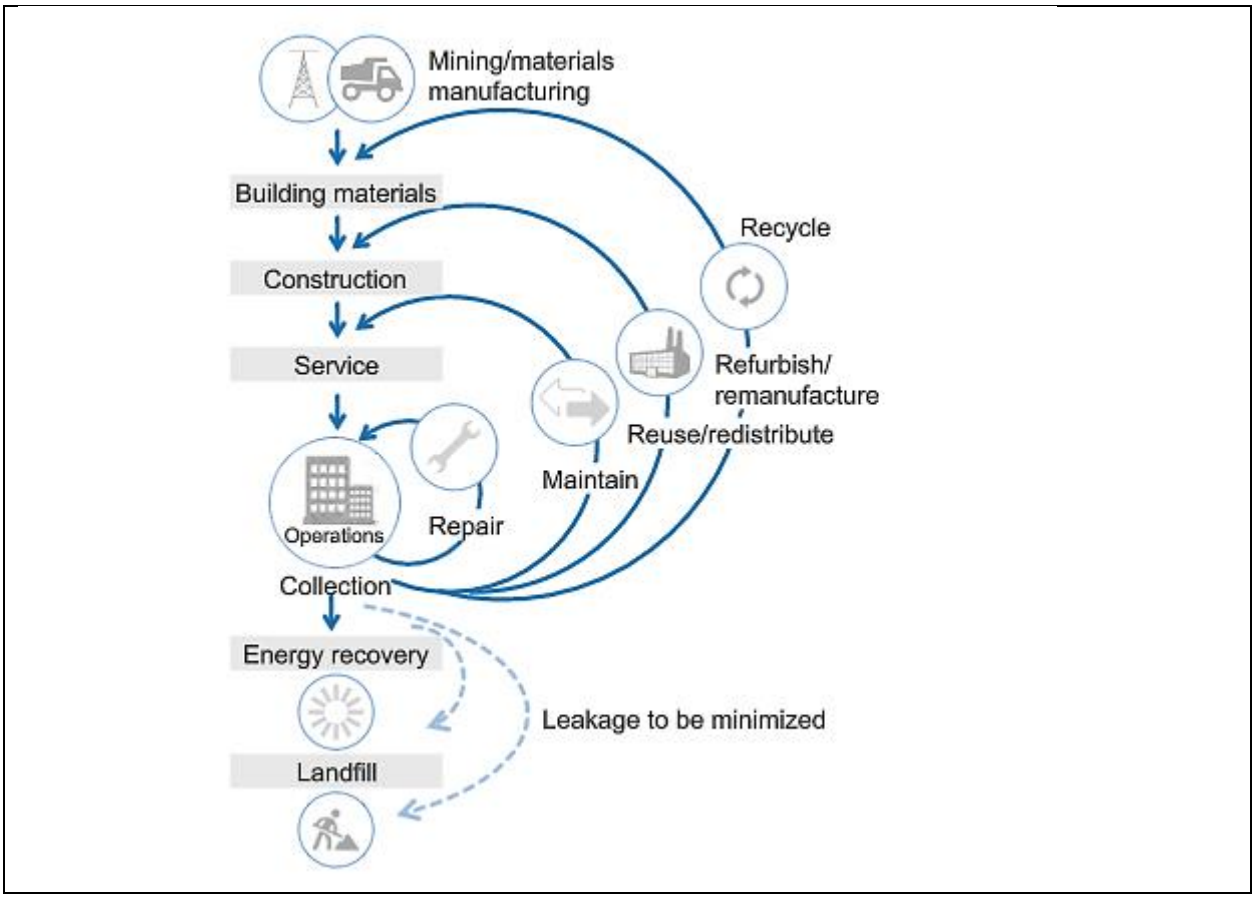

Figure 2. 3. Circular economy principles in the construction value chain

Source: EMF, The Boston Consulting group (2016)

By definition, circular economy refers to an industrial system which is regenerative or restorative by design and intention (EMF, 2016). It replaces the concept of "end-of-life" with restoration and shifts towards renewable energy use and eradicates the use of toxic chemicals impairing reuse. In addition, it aims at eradicating waste through surpassing design of materials, products, business models and systems. Circular economy eliminates construction sector waste through preserving the added value in building materials as long as possible as well as recirculating them to close their loops and manufacturing new products (Smol et al., 2015).

2.6 Circular economy at the city level

Cities are the major contributors to resource consumption and environmental problems (World Bank, 2017). Cities disproportionally consume over 70% of world's total energy and are responsible for 70% greenhouse gas emissions across the planet (Boyd and Pablo, 2016). They are and will continue to be an essential part in solving resource restrictions and environmental problem through circular economy development (Wang et al., 2018). Cities are important

components in the construction of circular economy and after years of development, assessment of urban circular economy has become an important task (Wang et al., 2018). The circular economy should be implemented from the micro to macro level. First, it should be implemented at enterprises level, then industrial parks and then moving to cities and regions (Zhijun and Nailing, 2007). At the city or regional level, pollution prevention is of paramount importance characterized by material and energy circulation, and the prime objectives of sustainable social economic and environmental development, including maximum resource and energy use as well as reduction of waste discharge (Zhijun and Nailing, 2007). Circular economy at city and provincial level can be categorized into four systems: 1) the industrial system, 2) the infrastructure, 3) the cultural setting, 4) and social consumption (Zhijun and Nailing, 2007). These four systems together form a larger complex system. The industrial systems affect social consumption and social consumption affects human habitation environment. The infrastructure system serves as the basis for the rest and is indispensable. It includes the buildings and infrastructures for water-recycling system, clean energy system and clean mass transit systems. A sound urban infrastructure supports circular economy. An urban infrastructure orienting towards circular economy is based on circulation of materials, information sharing within the system, efficient use of energy, eco-industry and eco-agriculture, integration of clean production and formulation of a holistic strategy (Zhijun and Nailing, 2007). Besides, a commitment to green planning, architecture and landscaping is also needed in urban areas. An eco-friendly human habitation environment contributes to restore the ecosystem and increase the quality of life in cities.

To identify the motivational factor for implementation of circular economy in cities, the drivers and barriers should be examined. Circular economy model presents both opportunities and challenges. The drivers and barriers for the development of circular economy in cities are described in the following sections based on their financial, institutional (policy and regulations), infrastructural, technological and societal aspects. Based on the previous literature review, the classification of drivers and barriers of circular economy used in this study to provide the overall picture of circular economy in cities.

2.6.1 Circular economy drivers in cities

Financial:

The risks of resource scarcity and continual depletion of resources are already posed to cities and will continuously show their impacts in the near future (EMF, 2013). This results in limited availability of primary materials and resources for production and further financial consequences for businesses. Besides, geopolitical problems related to resource depletion, reflected in trade barriers and further in materials' prices (Kok et al., 2013). The circular economy framework has obtained significant attention in business agenda over recent years. Circular economy provides opportunities for businesses to turn around these risks and driving the development of the

concept. The other driving trend for circular economy is financial crisis that impels businesses to change the ways to save their costs (EMF, 2014).

Institutional:

This driver is closely related to above-mentioned drivers since it acts from the macro level of action. Governments in different countries have started to make laws to provide positive incentives when adopting circular business models (EMF, 2014). These laws can significantly eliminate political barriers of circular economy and support environmental practices, promote cleaner production and consumption, secure resources health and safety by promoting the end of life management (Hazen et al., 2017). For instance, EU member states increased the costs of landfills for demolition waste and discarding construction, that effectively increased the rate of recycling and reuse of timber, steel, concrete (EC Dg Env., 2011).

Societal and value-related:

Increasing urbanization and population result in increasing consumption and demand on basic resources (Pringle et al., 2016). This trend demands to shift the traditional linear system to a circular system. It is necessary to implement circular economy in supply chain to protect the future growth of population. The circular economy will improve the efficiency of materials and energy use in supply chain and increase the value of products by their quality and lifetime (Su et al., 2013; Ilić and Nikolić, 2016).

Technology:

Technologies oriented to a circular economy approach are of great importance, since, they contribute to reduction or stabilization of materials demand as well as satisfaction of human needs. Some empirical cases reveal that the improvement of technologies and waste management can mitigate unsustainable use of primary resources (Haung et al., 2014). Innovative technologies can be developed at different levels such as institutions, local businesses and the region as a whole to close the industrial loops (Deuts and Gibbs, 2008). Industrial technology is currently available and support closure of material loops. The advances in technology enable tracking of materials, improve forward and reverse logistics and reinforce collaboration and knowledge sharing (EMF, 2014).

2.6.2 Circular economy barriers in cities

***Financial*:**

Transition from linear to circular economy needs massive investment costs in supply chain (Kok et al., 2013). One of the important issue in the financial sector is the fact that the environmental costs are not reflected in the price of products. This results in a discrepancy between financial

flows and material flows (Kok et al., 2013), difficulties in establishing the correct price of resources and products and insufficient incentive for industry to take into account the impacts of the resources in the products' prices. Issues about the costs of setting up a circular business model are a final financial barrier. These costs include both materials and labor costs (higher costs are attributed with management and planning around a service logistic network) (Kok et al., 2013). Since, virgin materials are generally cheaper than recycled ones, consumers often focus on price rather than on entire lifecycle of the products. Moreover, production costs including purchasing cost of environmentally friendly materials and packaging are getting higher in circular economy (Shahbazi et al., 2016).

Institutional:

Although governments show interest in circular economy, existing regulations and rules make an unlevelled playing field for implementation of circular economy. In general, regulatory barriers encompass unclear vision (goals, objectives, targets, indicators) in regards of circular economy in supply chain. Besides, financial incentives still support the traditional linear economy and circularity is not effectively integrated in policies (Kok et al., 2013). For example, in Netherlands, waste and recycling policies are ineffective to improve high-quality recycling (de Man and Friege., 2016). Another example is China, where the existing laws on circularity have been insufficiently implemented because there is no especial tool to assess the effectiveness of the proposed laws. Besides, the current environmental laws, e.g. on waste management, do not fit the concepts of circular economy, so they cannot support circularity.

Social and value-related:

Practices in Japan and Germany demonstrate that public participation is essential for development of the circular economy programs (Govindan and Hasanagic, 2018). Different studies have stated that the institutional and human capabilities to inspire public participation in circularity and environmental management programs and academic organizations are limited (Govindan and Hasanagic, 2018). Public awareness of the importance of circular economy is quite limited and customers in general have the insufficient perceptions towards refurbished products and their quality and safety. This lack of knowledge and willingness on buying refurbished products makes it more difficult to implement circularity in supply chain (Govindan and Hasanagic, 2018).

Technology:

As of today, the growing complexity of products poses a massive challenge to effective and efficient recycling and reuse of products (Velis and Vrancken, 2015). Additionally, it is difficult for enterprises to manage the quality of products through their life cycle as well as maintaining quality of products made from recycled materials (Govindan and Hasanagic, 2018). Although

technology is advancing, but technologies related to recycling often result in downcycling of materials (Kok et al., 2013). Furthermore, closed material loops require zero loss of materials, valuable technical materials in particular. This demands an ideal collection systems that are able to collect every tiny bit of technical material. However, it is practically impossible to make (Menthink, 2014). The bio and techno-cycle concept of circular economy poses another challenge of separating materials (bio-gradable products from waste streams) in order to safely return in biosphere (Ghisellini et al., 2016). Another technological barrier is that many technical materials can be only reused or recycled a limited number of times. Moreover, in terms of energy-related technologies, the main barrier is the existing rootedness of linear technologies and less. Another barrier regarding energy technologies is that in order to drive the endless loops of materials, endless energy is required. For instance, recycling requires a lot of energy. The use of renewable energies requires a lot of materials that practically are not available (Kleijn, 2012).

Chapter 3: Research Design

Research design refers to strategy implemented to address the research problem. In this chapter, the research framework, and the methodology for data selection, collection and analysis are described. This research identifies which climate change adaptations go through the city and to what extent can circular economy model can be integrated into climate change adaptation strategies to improve the performance. The focus is on construction sector in terms of grey and green climate adaptation measures. This baseline measurement forms the basis for the future to work on concrete measures that make the transition to a waste-free and circular Rotterdam possible.

3.1 Research framework

According to Vershuren and Doorewaard (2010), research framework is schematic presentation of the research objective. It contains seven-step-by-step activities as following:

Step 1: Characterizing the objective of the research project

This is the primary step in developing a research. The objective of the present research is to identify and investigate how circular economy can contribute to climate change adaptation and be part of the solution to the climate challenges.

Step 2: Determining the research object

Vershuren and Doorewaard (2010) define research object as the phenomenon. The research object in this research is Rotterdam, the foremost port in the Europe and the second largest city in the Netherlands.

Step 3: Establishing the nature of the research perspective

The research perspective refers to “spotlight” or “lenses” used to study the research object closely (Vershuren and Doorewaard, 2010). This study observes Rotterdam in in the perspective of the circular approach to climate change adaptation in construction sector. To give recommendation, the research used in-depth interviews and qualitative analysis to assess implementation of climate change adaptation measures in construction sector in Rotterdam, highlighting the potentials, successes, difficulties and conflicts of integration of circular economy into the measures.

Step 4: Determining the source of the research perspective

This research uses relevant scientific literatures (scientific journals, articles and municipality reports) to develop a conceptual model. Besides, the existing practices with regards to climate change adaptation and circular economy are reviewed.

Step 5: Making a schematic presentation of the research framework

The research framework is presented in Figure 3.1 as below:

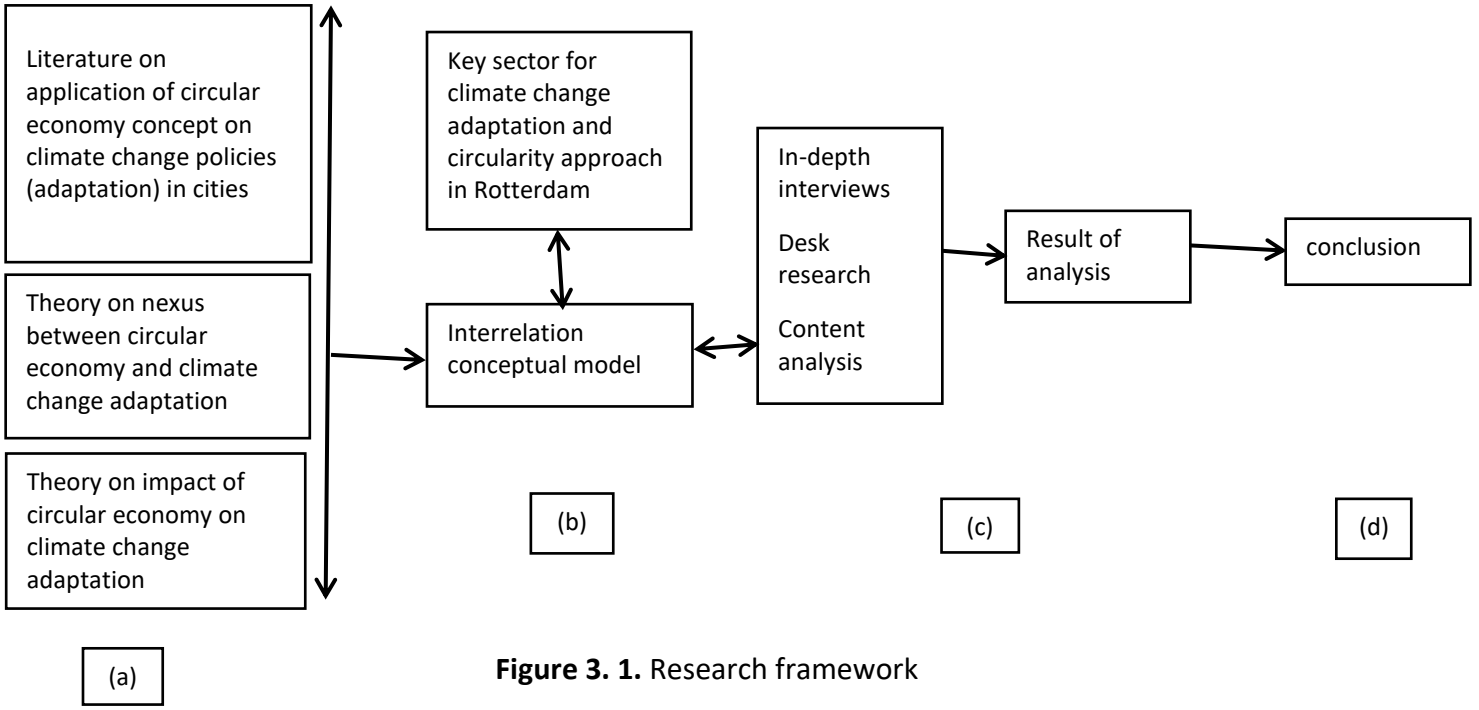

Figure 3. 1. Research framework

Step 6: Formulating the research framework in the form of arguments which are elaborated

a) This section formulates the research framework according to the relevant scientific literature, the theories would be applied to develop new definition from the existing definition and its scopes, applies the results into objectives and propose recommendation based on the results.

b) In this section, the research perspective is applied on the research object.

c) The results of analysis are confronted as the basis for recommendation.

d) The research draws a conclusion to answer the main research question.

Step 7: Checking whether the model requires any change/adjustment

There is no indication that any adjustments or change is required at this point of research design.

3.2 Concept definition

To provide better clarity of general terms used in this research, the key concepts are defined as following:

Climate change adaptation (CCA): Refers to the response to climate change and global warming, whereby seeks to reduce vulnerability of the city to climate change impacts. It also offers opportunities from changing climate rather than threats.

Circular economy: A circular economy is a restorative and regenerative system by design and aims to keep materials, products and components at their highest value and utility.

Grey adaptation measures: The use of engineering services including construction measures and physical interventions (such as buildings, technical and transport infrastructure, dikes and other technical protection constructions using engineering services) in cities to be more capable of withstanding extreme events.

Green adaptation measures: The use of multiple services of nature such as vegetated areas parks, gardens, wetlands, natural areas, green roofs and walls, trees etc. contributing to the increase of ecosystems resilience.

3.3 Research strategy

This research uses the single case study method and interview approach as its strategy. It means the research focused on one case deeply and aimed to obtain a profound insight into the research objective (Vershuren and Doorewaard, 2010. Throughout an in-depth study on Rotterdam, conducting interviews with the relevant actors and stakeholders, and studying all sorts of relevant documents, a profound insight and data was obtained (Vershuren and Doorewaard, 2010). An exploratory case study was deemed suitable for the research method as the research aims pertaining to this study, as well as the research objectives, could be met using this method.

3.3.1 Research unit

The unit of this research is the construction sector of the city of Rotterdam. The following criteria was applied to justify the case selection:

- Being the perfect showcase for climate change adaptation in the Netherlands
- Being an inspiring example for delta cities worldwide
- Serious commitment to developing CE

3.3.2 Research boundary

Research boundary determines the limitation and constraints of the study and its consistency to achieve to the research objective within the scheduled time. In this research, the following two boundaries are used ng:

- The research focuses on construction practices that play an important role in climate change adaptation.
- The research reviews the documents which were published within the past 10 years (from 2008 to present).

3.4 Research materials and data collection methods

Research material refers to all types of material for defining and operationalizing the key concepts of the research objective and the set of research question (Verschuren and Doorewaard, 2010). To address the research question, data and information required were collected via:

Document review: documents related to climate change adaptation strategies and circular economy in Rotterdam, including the municipality and consultancy (companies such as Metabolic etc.) reports and roadmaps, as well as academic and scientific articles by renewed researchers and experts.

In-depth interviews: Next to the literature review, a total of 12 in-depth interviews were conducted with position holders from both climate change adaptation sector and circular economy sector. The interview is applied to gather accurate data and complete pictures on the current practices of climate change adaptation in construction sector and stakeholders involving in circularity and climate change adaptation measures. In choosing some informants, the research used convenience sampling which chooses the informants willing to participate in the research within the time available. Besides, snowball sampling technique was applied to identify the other informants. Table 3.1 presents a brief description of the interviewees, their affiliations, their functions and type of interview conducted. The content analysis is applied to analyze literature and interviews held with experts and representatives from municipality, academia etc.

It should be mentioned that overall, most of the interviewees consented to take part in the research and approved for their transcriptions to be used in the findings of this study. However, one of the participants from Municipality of Rotterdam decided to withdraw from the study after the interview took place. Therefore, according to the ethics consideration and norms, the transcription of this interview is not included in the findings of this study.

To guide the interview preparation, Table 3.2 describes the type of data required and method of accessing this information in accordance with the above-mentioned research strategy.

Table 3. 1. Lists of the interviewees, their affiliations and functions

No.	Name	Affiliation	Function	Type of interview
1	Marco Hoogvliet	Deltares	Project Manager and Senior advisor. Research program manager resilient cities	47 minutes Skype interview
2	Nanco Dolman	Royal HaskoningDHV	Leading Professional in Urban Flood & Water Resilience	30 minutes Skype interview
3	Luca Sittoni	EcoShape/Deltares	Programme manager	30 minutes Skype interview
4	Interviewee 1	Rebel	Prefers to remain anonymous	35 minutes Skype interview
5	Charlie Spork	Drift , Dutch Research Institute for Transitions	Researcher and Advisor	40 minutes Skype interview
6	Ardi Dortmans	TNO	Director of Circular Economy and Environment	30 minutes Skype interview
7	Albert Jan Kerssen	BTL Advies B.V.	Project leader and manager for building green and climate adaptive cities	22 minutes telephone interview
8	Christophe Brière	Deltalinqs	Senior Advisor Coastal Adaptation to Climate Change expert	25 minutes Skype interview
9	Bouke Bakker	Municipality of Rotterdam	Consultant & Entrepreneur in Circular Economy	Interview on paper (written directly on interview sheet)
10	Johannes de Groot	Arcadis	Specialist Geotechnical Engineering and Flood Protection	Interview on paper (written directly on interview sheet)
11	Jacqueline Cramer	University of Utrecht	Professor in Sustainable Innovation at Utrecht University. Member of the Amsterdam Economic Board in charge of Circular Economy.	17 minutes telephone interview

3.4.1 Ethics statement

This research has been carried out with full compliance of research ethics considerations and norms. The research in hand involves participation of respondents through Skype/telephone interviews. The online Ethics Assessment form of the University of Twente was filled in. Besides, I took on great responsibility to explain in appropriate details, the objective and scope of the research to the interviewees. An informed consent form was used as well for each interview. Besides, I provided a one-page “project information sheet” including the purpose of study and the required contact information. Additionally, after analysing the data, feedback on the interviews was offered to respondents through a report to enable them for further improving or modifying.

Table 3. 2. Data, information and sources required

Research question	Data/Information required to answer the question	Sources of data	Accessing data
What are the existing climate change adaptation measures in Rotterdam in the construction sector?	• Identify the measures for climate adaptation in the city in terms of construction in Rotterdam. • Identify which sector within CCA measures (green or grey infrastructure) has more potential to apply circular economy principles.	● Primary data (representatives from municipality, businesses, consultants and experts) ● Municipality reports ● Secondary data (published articles and journals, accessible literature and documents)	Search method and content analysis
How is the city of Rotterdam approaching circular economy in the construction sector in terms of policies, regulations and technology to improve climate change adaptation?	• Identify the current climate adaptation across the construction sector with a consumption-based approach. • Identify where value is lost in material flows in construction sector in the city. • Identify the short-term and long-term incentives to support Rotterdam in transition towards circularity in infrastructural CCA measures. • Identify how the existing policies, regulations and technology support and enable the implementation of CE in CCA measures. • Identify the role of technology in facilitating towards circularity in CCA measures.	● Primary data (representatives from municipality, businesses, consultants and experts) ● Secondary data (published articles and journals, accessible literature and documents)	Interview Search method and data analysis

What are the main challenges for integrating circular economy model into climate change adaptation strategies in Rotterdam for construction sector?	• Identify the actors and stakeholders who involved in the climate adaptation and their awareness and willingness level. • Actor's mindsets and awareness to integrate circularity into climate adaptation • Identify the factors that hinder the application of circularity principles in the infrastructural climate change adaptation measures.	● Primary data (representatives from municipality, businesses, consultants and experts) ● Secondary data (published articles and journals, accessible literature and documents)	Interview (face-to-face/skype) Content analysis

3.5 Data analysis

Data analysis is the process of data evaluation using analytical and logical framework/reason as presented in the following subsections.

3.5.1 Method of data analysis

This research applied qualitative methods to analyse data based on an exploratory case study and interviews conducted to make a comprehensive perspective of the data analysis. The qualitative content analysis is chosen, since this research aims to understand the contents and roughly classify them (Verschuren and Doorewaard, 2010). The information is extracted from the literature review and interviews including accessible scientific articles and municipality reports to elucidate the concept of circular economy and climate change adaptation regarding the linkage between physical/infrastructural adaptation measures in response to changing the climate. The obtained information will be analysed through qualitative process. Table 3.3 describes the type of data required and method of analysis.

Table 3. 3. Data and Method of Analysis

Data/Information Required to Answer the Research Questions	Method of Analysis
Adaptation measures and solutions for climate adaptation in Rotterdam in terms of construction	Qualitative: Analyzing the current climate change adaptation across the construction sector
How Rotterdam is adopting circular economy concepts in their adaptation measures	Qualitative: Analyzing the approach of the city in adopting circular economy concept in adaptation measures
Actors and stakeholders who involved in the climate adaptation Actor's circular approach Actor's challenges to carry out their activities Actor's mindsets and awareness to integrate circularity into climate adaptation	Qualitative: Analyzing the roles of actors in promoting circular economy concepts and the incentives/barriers for integration of circular economy in the adaptive measures

3.5.2 Validation of data analysis

In this research, the validation of data analysis was done through respondent validation. Respondent validation method will be done through soliciting feedback on the data and information collected from the interviews and making conclusions from the key informants. This helped to avoid misinterpretations of meaning and events. In this research, each interview was taped to do not miss any comments of interviewees. Then, after each interview, they transcribed thoroughly and the transcription was sent to each of the interviewees to review, validate the accuracy of the information, necessary updates and approval to ensure the transcripts are in line with what they had mentioned. And where there was any doubts in terms of a single term which seemed to be unclear in the recordings, the interviewees were asked to confirm the terms that they had used previously in the interviews. This was done to strengthen the validity of the data used in this research.

Chapter 4: Results

This chapter presents the research results from the analysis of the data collected through primary and secondary sources of information, through semi-structured interviews and document reviews, respectively. The findings are presented in three main sections aligned with the research sub-questions. Section 4.1 presents the existing green and grey climate change adaptation measures in Rotterdam. Section 4.2 presents how the city of Rotterdam is approaching the circular economy principles in terms of policies and regulations into the green and grey climate change adaptation measures. Section 4.3 elaborates the main drivers and barriers of integrating circular economy into climate change adaptation measures that are implemented in Rotterdam. In some cases, quotes are used to present examples or illustrations and support specific interviewee's statement.

4.1 The existing climate change adaptation measures in Rotterdam

Rotterdam is very active in terms of climate adaptation measures. The city wants to be attractive and economically healthy for its residents, companies and other partners (Rotterdam Climate Change Adaptation Strategy, 2013). Urban planning programs in Rotterdam include numerous measures to enhance the safety of the city against flooding and other uncertain effects of climate change. Table 4.1 shows the overview on green and grey adaptive measures in Rotterdam with respect to the key climate change challenges presented in Chapter 2.

Table 4.1. Overview on green and grey adaptation measures to the key climate adaptation measure in Rotterdam

Green Measures		**Grey Measures**	
	The Objective		**The Objective**
Higher number of thick and older trees	● To provide cooling and make the neighborhoods less vulnerable to heat-stress	Benthemplein water square	● To prevent urban floods ● To retain water during heavy rainfall
Maintain and increase of parks and vegetation	● To absorb water ● To diminish the amount the amount of storm water entering the urban drainage systems	Underground water buffer	● To retain rainwater in the city for longer in the soil, in order to prevent flooding and to have extra water available during drought
Shift from a mainly built and paved neighborhood to a more mixed area with (more) green public spaces for children, recreation opportunities and shaded streets	● To store rainwater ● To provide cooling and make the neighborhoods less vulnerable to heat-stress	Blue roof	● To reduce flooding ● Retain rainwater ● Provide delayed drainage
		Slim roof	● To adapt the city adaptively in the future and to become more resistant to flooding ● Water storage capacity (7 x more than an ordinary green roof)
		Green roofs	● To store rainwater ● To provide greening and cooling ● Make the neighborhoods less vulnerable to heat-stress

4.1.1. Green measures

According to Bouke Bakker, the consultant and entrepreneur in circular economy at the Municipality of Rotterdam, green measures can contribute in the design of products, since they can function as resource for new products. In the current situation, it can be said that green measures have more potential to apply circular economy since, many concepts, techniques and technologies are available. However, if similar level of knowledge becomes available for grey infrastructure this would change the situation (Bouke Bakker, August 12, 2018, Personal interview). Besides, according to the new policy in Rotterdam there will be more green roofs and parks in the city with the support from municipality as well as citizens (June 22, 2018, personal

communication). These measures also reiterated by Luca Sittoni, the program manager at Deltares and EcoShape. He pointed out to the importance of these green measures in the city, since, vegetation is an essential component to a city which absorbs water (Luca Sittoni, July 17, 2018, Personal interview). According to Prof. Cramer, from University of Utrecht, one of short-term climate change adaptation measures is increase of the pavements by garden or at least materials through which the water can dissipate instead of having flooding. She stressed on this point that there are lots of stones and pavements in the Netherlands and water cannot go anywhere except flooding the homes. Therefore, the first priority is to ensure that we can have all kinds of leeway for water to percolate. She further asserted that the next step is to keep the captured water in the system to reuse it for growing vegetables, farming, etc. In a word, it is very important to manage the water and keep it in cycle (June 25, 2018, personal interview).

4.1.2 Grey measures

Rotterdam has a unique roofscpae consisting of 14.5 km^2 of flat roofs. The municipality of Rotterdam aims to encourage citizens to use their rooftops more actively. The roof landscapes provide space for a multifunctional use and offer a lot of space to the city to deal with different challenges in the city, namely water storage, greening and cooling the city as well as generating sustainable energy (De Urbanisten, 2015). As it is shown in table 4.1, there are different types of sustainable roofs in which discuss further in section 5.1. Water squares as one of the important adaptation measures help the city keep its feet dray and when showers become more intensive. Bouke Bakker stated that Urban Roofs are international well-known practices in Rotterdam to response climate change. He further represented that the grey measures are highly demanding resources that are not currently so circular.

The respondent from Rebel mentioned the water squares in Rotterdam, as one of the climate change adaption measures that can adapt to heavy rainfalls in the city. Water squares combine the water storage with the improvement of the quality of urban public space. (June 22, 2018, Personal interview). The multi-functional water square was also mentioned by Luca Sittoni. The main water square in Rotterdam (Benthemplein) is dry in the normal conditions, while in the rainy periods it can hold the water for the few hours. Even that area fluxes, but, it still protects the other areas from flooding. That is one of the important measures to adopt the city to water and rainfalls. Christophe Brière from Deltares pointed out to the dikes and recently so-called nature-based solution in Rotterdam as the significant climate change adaptation measures (Christophe Brière, August 6, 2018, P interview).

Johannes de Groot, from Arcadis, asserted that they study and design embankments with a predicted water level which can occur in the next 50 or 100 years. He further mentioned that

they are trying to use soil, sand or clay from the surrounding areas instead of buying it elsewhere. The transportation of resources and materials from the supplier to the construction site is a significant factor and needs to be reduced as low as possible to ensure reducing carbon dioxide emission. Since, in applying the circularity principles, the amount of emitted carbon dioxide has to be taken into account (Johannes de Groot, June 24, 2018, Personal interview).

Marco Hoogvliet interpreted that the grey adaptation measures have more potential to apply circular economy principles in comparison with the green ones. Since, adopting the grey measures involves different kinds of materials and for that reason the circular economy can be applied more to those grey measures (Marco Hoogvliet, June 22, 2018, Personal communication). On the contrary, Albert Jan Kerssen asserted that the green infrastructure has more nature by itself and is more circular already. He stated that: "In green we can talk about the circular life. The green has always circularity in itself". He further expressed that plants start growing, dye and then they have the circle, and in that way, the potential of circularity is already there. Whereas, the grey infrastructures are consisting of more materials and resources. Therefore, there is maybe more potential in changing to circular economy (Albert Jan Kerssen, July 17, 2018, Personal interview). In like manner, Nanco Dolman from Royal Haskoning DHV asserted that the green adaptation measures have more potential to apply circular economy principles. Because circularity is really related to resources and materials and closing the loops. He explained that the green measures are mainly about energy, waste, food, water and materials in general. He mentioned some examples of green solutions in Rotterdam, namely rainwater harvesting in roofs, rooftop urban farming and green roofing which have the circular potential (Nanco Dolman, June 25, 2018, Personal interview).

4.2 Policies and regulations for the integration of circular economy into CCA measures

Circularity in the construction sector can be stimulated by regulations and obligated requirements of authorities in the permitting procedure (IWA, 2016). According to the interviewee from Rebel, regulations block various innovations. For instance, the materials from demolition are already assigned as waste. However, they could be reuse again and be valuable resources. The current policy in the Netherlands focus on mitigatin of waste and not at maximizing the value of materials. Therefore, in the future, waste to resource policy needs to be made for stimulating measurements aiming at adoption of circular economy. She expressed further about the C2C certified product standard which guides designers and manufactures for using the recycled/reused materials for construction and infrastructural measures (June 22, 2018, Personal interview).

Marco Hoogvliet stated that currently the construction regulations towards adopting circular economy in the Netherlands are up to the contractors themselves first and then to the government. Although the Ministry of Infrastructure and the Environment & Ministry of Economic Affairs has been trying to enhance sustainability, in the end various constrictions are created in a conservative way by the private companies. Because, for them it is difficult to use renewable/circular materials and compete with sustainable materials due to the higher price of these materials. Equally important, existing regulations and laws for corporate governance need reassessment with regard to their potential to decease the influence of stakeholders with a short-term agenda (Kok et al., 2013). He stressed further that Deltares is trying to make it possible for the government to offer criteria for renewable material usage for infrastructural measures. He stated that the regulations on infrastructural climate adaptation measures are nationwide and are defined by the Ministry of Infrastructure and the Environment & Ministry of Economic Affairs and experts. For instance, one of these regulations is the strength and the kind of concrete that should be used for the infrastructural measures such as dikes and hikes. There are also other norms and standards for using new materials for each type of infrastructure that have to comply to the existing norms. Also, the contractors have to know what kinds of materials are circular. Therefore, there is need for legislation which they can use to ask for more circular way of construction or more circular construction materials. He expressed further that the national government should specify or define new policies which stimulate more and more innovations. Because circular economy is a subject in which innovation is essentially important and is key (Marco Hoogvliet, June 22, 2018, Personal interview). By the same token, Kok et al., 2013 interpreted that innovation policy needs adjustment to improve circular research, innovation and development. In the Netherlands, research and development is supported by top sector policy. However, this policy seems to be ineffective, because it does not structurally tackle the need for a circular/sustainable economy (Kok et al., 2013). Adjacent to this, Prof Cramer asserted that, the circular procurement policies can be a very good instrument in developing new infrastructural climate change adaptation measures. She mentioned that the water sector and municipalities are the most influential stakeholders in terms of facilitating circularity implementation in the infrastructural and construction adaptation measures. She further expressed that these are the ones who can ensure the procurement policies and strategies meet the climate adaptation strategies. Furthermore, municipalities are very important to spear from the start. The construction sector need a push which can be either procurement or regulation (Jacqueline Cramer, June 25, 2018, Personal interview).

4.3 Drivers and Barriers to integration of circular economy into infrastructural climate change adaptation measures

To identify the motivational factors to integrate circular economy in climate change adaptation measures, the drivers and barrier are examined. The drivers and barriers have been classified into financial, innovation and technology, societal and value-related. It has to be mentioned that institutional driver and barrier has been discussed in this research in terms of policy and regulation approaching circular economy in CCA measures, as a separate section (4.2 and 5.2) to answer the second sub-question.

4.3.1 Drivers

Drivers: Financial

Circular economy can reduce the need for raw materials and resources by developing new business models and closing loops (Kok et al., 2013), for instance, by keeping the water in the cycle and circulate it as long as possible (Cramer, June 25, 2018, Personal interview). An example of this is the Urban water buffers and water squares in Rotterdam aim to retain rainwater in the city. In addition, Marco Hoogvliet mentioned that with developing new research it can be explained that using circular concepts will not be more expensive and can also prove that using circular concepts can boost the economy of cities by providing jobs within factories that produce circular materials. On balance, various short-term and long-term approaches can be implemented to accelerate the progress of the transition towards circular economy, such as incentives, subsidies and loans. These approaches will be further elaborated and explained in chapter 5.

Drivers: Innovation and Technology

The attention to innovation contributes to all continued features in all phases of transition towards circularity (Kok et al., 2013). In order to encourage circular research, development and innovation, the innovation policy needs adjustment. Nanco Dolman from Royal Haskoning DHV, stated that currently the new developments in Rotterdam are combining functions. For instance, the dikes not only defend high water levels but can also have additional programs or functions which the circular aspects or transition can come in and create circular systems by closing the loops. One example is the multi-functional dike at the northern water front of Meuse river in Rotterdam. This multi-functional dike is actually a sort of elevated park that includes the parking garage and a lot of shopping malls as well. Therefore, more thinking about the circular aspects is like that we are going to recycle or upcycle resources as well. And that is best illustrated more by the blue and green measures than by the grey ones (Nanco Dolman, June 25, 2018, Personal

interveiw). In terms of innovation, unlike decades ago that the focus was mainly on expansion of cities, now the primary focus is on reconstruction of cities which is the connection and opportunity where the circular economy comes in. In this case, Rotterdam has ambition to implement infrastructural climate change adaptation measures for its inhabitants to be safe from flooding. With this in mind, the old port areas are now being changed or in transition for living, working spaces, leisure, recreational and warehouses, etc. That is really circular and are kept in the way to get the new use (Nanco Dolman, June 25, 2018, personal communication).

Albert Jan Kerssen interpreted that from the technology point of view, there is need to focus on reuse and then recycle and then new materials to facilitate towards circular practices in infrastructural and construction adaptation projects (June 17, 2018, Personal interview). In the light of this, Marco Hoogvliet stressed the importance of using sand, sediment and clay in the Netherlands to be able to maintain the flood and coastal defense. He asserted that Deltares thinks to develop a new circular system in which they can reuse sand, sediment and clay in a sustainable way. With respect to this, it is necessary that new researchers invest in a range of circularity models which inherently capture more value rather than only developing a specific technology front runner. By the same token, Marco Hoogvliet stated that: "*I am putting a lot of hope in the new students maybe like you, that are trying to be more integral and for whom it is usual or not difficult to think out of the box*".

Johannes de Groot mentioned that to optimize transition towards circular economy, pilot projects embarked by public and/or private sectors is a promising solution. He asserted that the pilot projects are very new territories for organizations, since we need to learn by doing. Additionally, Charlie Spork, an advisor at Dutch Research Institute for Transitions, stated that a resilience nature-based solution research can be very valuable. He expressed further: "*We try to set up small-scale experiments in the city with front runners, people who are already exploring these new ideas and we try to connect front-runners together and try to come up with even more radical new ideas. So, for the circular economy, we are really at the beginning of the transition. Yes, there is a lot of attention on recycling but also a lot of down cycling*". He emphasized that most of the research should focus on learning this context and then trying to scale those experiments and ideas up to a broader level (Charlie Spork, August 2, 2018, personal communication).

A respondent from Rebel expressed that there is still ample potential to apply circular economy principles in the construction and infrastructure sector. She stressed on a new way of thinking, for instance, the integration of disassembled green roofs that can be completely disassembled after the life-time and can get circular. Since the green roofs are a very important climate

adaptation measure in Rotterdam. She represents an example that Rebel made a contract with the Ministry of Infrastructure and the Environment of Economic Affairs assigned to do circular economy and sustainable infrastructural mobility. To do so, they involved different parties namely expertise from circular economy and the companies that mainly aim to focus on climate adaptation measures. Then they worked on the proposal and exchange knowledge based on the request from their clients.

Drivers: Societal and value-related

To ensure circularity, the collaboration among the stakeholders is essential. Identifying stakeholders in the construction sector for CCA is of great importance, since they can alter the system with their influence on other stakeholders in their network. The relevant stakeholders in the Netherlands are from a vast variety of economic and societal roles, namely local government, municipalities, residents of the cities, clients, research institutes, etc. Ardi Dortmans from TNO asserted that the main stakeholders in the Netherlands are government, industry and scientific community and in the regional initiatives, the collaboration among them works nicely (July 23, 2018, Personal interview). The role of collaboration among the stakeholders was reiterated by Charlie Spork who asserted that there is need to connect the small-scale initiatives to the bigger players. Because what small-scale initiatives do not have is capacity to scale up, but the big companies do. Therefore, it could be a valuable connection there. (Charlie Spork, August 2, 2018, personal communication). Marco Hoogvliet asserted that when the government wants to apply circular concepts within the infrastructural and construction sector, the politics or politicians have to be convinced that it will work. He stated that there is numerous literature now available on the technical side, and there is a need for translating all technologies to more social and economic report for politicians, decision-makers and inhabitants of cities. This is necessary because stakeholders have to be convinced that there are lots of social and economic aspects and opportunities in this transformation (June 22, 2018, personal communication).

Involved stakeholder groups	Type of organizations
Government	Local governments (municipalities), National government (Ministry for the Infrastructure and Environment, Ministry of Economic Affairs and Climate, Water Board), European Union, principals
Investors	Investment funds, private equity, crowd funding
Users/residents	Construction companies, residents
Suppliers	Direct suppliers, infrastructural material merchandisers
Designers	Architects, urban planners, consultants
Contractors	Residential building contractors, civil building contractors
Research and knowledge institutes	General knowledge institutes (Drift, Deltares, EcoShape, University of Utrecht, Erasmus University Rotterdam) Dutch Research Institute for Transitions
Influencing agents	Rebel, Metabolic, HHSK (Hoogheemraadschap van Schieland and Krimpenerwaard)

Table 4.2. Composition of and Stakeholders

4.3.2. Barriers

Barriers: Financial

The financial support creates one of the most significant barriers to transition from a linear to a circular business model CCA measures. Marco Hoogvliet pointed out to the finance as one of the main barriers for integration of circular economy at the moment for climate change adaptation measures. He stated that municipalities are not the wealthiest part of the government. Besides, there are many problems that are much more urgent than circular economy or climate change adaptation even at the present time. For instance, security, crime, social problems, poverty and health within the city (June 22, 2018, Personal interview). In the light of this, Albert Jan Kerssen said that in some projects there is financial support provided by the Dutch government. But, it is actually never enough to cover risk of innovation (July 17, 2018, Personal interview). He further stressed on the importance of subsidizing as a promising way of optimizing the transition towards circular procurement. The lack of financial challenge was reiterated by Charlie Spork who stated that the upfront costs and initial investment are high and project developers or investors will get the back later (Charlie Spork, August 2, 2018, Personal interview). According to the respondent from Rebel, the long-term policies is needed to subsidize the use of circular materials. She stated that the dominant concern of using the reused/recycled materials for infrastructural measures is the price. She stressed that the virgin materials are now cheap, and the suppliers mostly concerns

about the price. She gave an example of the energy transition which is already ahead due to devoting massive subsidy for sustainable energy. However, there is still lacking the generous subsidies for real circular models or innovations in infrastructure and construction sector (June 22, 2018, Personal interview). Albert Jan Kerssen also pointed out to the higher cost of circular materials compared to the less sustainable ones. He further mentioned that the contractors and project developers need to be convinced to invest in more expensive materials, otherwise, there is no choice than going back to less sustainable materials (Albert Jan Kerssen, July 17, 2018, Personal interview). According to Luca Sittoni, the financial problem is more evident when you are in a mix public-private environment. Because, private parties only want to pay for what they care. Maybe the public parties want to pay for more sustainable and circular long-term idea, but they have less power of making just decision (June 17, 2018, Personal interview).

Barriers: Innovation and technology

Bouke Bakker asserted that recycling techniques to achieve higher levels of mono materials are important resources required for transition towards circularity for infrastructural climate adaptation measures. He further mentioned that technological solutions are often not advanced yet to reclaim mono streams of material from waste (August 13, 2018, Personal interview). Besides, Marco Hoogvliet from Deltares interpreted that it can be seen that circular materials are being used in climate change adaptation measures in practice, but most of the time, those materials are still in the pilot case, or presenting as an experiment. Therefore, the main concern of using reused/recycle materials is that, there is no proven technology for using these materials, maybe it has proven to work in a testing facility but not so much in practice. On the other hand, the contactors are very conservative investors and only want to pay for something that has proven to work (June 22, 2018, Personal interview). To reiterate this, Albert Jan Kerssen said the use of reused and recycled materials could be challenging, since their life span is not proven yet (Albert Jan Kerssen, July 17, 2018, Personal interview). This was confirmed by another interviewee, Luca Sittoni from EcoShape. The availability of using recycled/reused materials for grey and green adaptation measures in the Netherlands is a concern, since, this concept is still developing and relatively new. In an example, he explained that EcoShape is now working on a project which take mud and sediments from the river and bring it to the land and make it to soil to build the dikes. It is an additional advantage to build in a way with sustainable circular economy concept. By the same token, transition to circular economy partly depends on urban areas to become more self-sufficient for their resources (Metabolic, 2017).

Nanco Dolman asserted that for construction of infrastructural climate adaptation measures, especially flood defences, they have to meet the safety levels to protect the city assets and people. To do so, they have to ensure the use of right materials and resources which meets the

standards in safeguarding areas behind the flood defences (June 26, 2018, Personal interview). Ardi Dortmans asserted that there are a lot of very good initiatives in the Netherlands now at the level or part of cities and certain regions. But in order to get things really moving, you need to scale up a few initiatives up to the level of the Netherlands. However, there is not much driving force to create the big initiatives (July 23, 2018, personal communication). In the light of this, he asserted that technology plays an important role in improving circular infrastructure and construction, however it is not enough (July 23, 2018, personal communication).

Barriers: Societal and value-related

One of the interviewees asserted that the principal concern for applying circular economy in the climate change adaptation measures is definitely cultural and social barrier. Because, circular economy is not only using materials differently, but also it is about the whole new way of thinking. Therefore, the people's mindset is the biggest challenge to accept the transition towards circular economy. So, there is a significant need to work on awareness (Charlie Spork, August 2, 2018, Personal interview). This was also reiterated by Jacqueline Cramer that residents' awareness is important and can promote the movement towards transition. She stressed on this point that first people have to understand and admit the problem before they can act accordingly (June 26, 2018, personal communication). In like manner, Albert Jan Kerssen stated that the main presenting barrier to applying circular principles to the grey and green adaptation measures is getting the stakeholders willing to invest in this type of projects. He asserted that willingness starts with the need to introduce the circular principles to the stakeholders s to focus on grey and green adaptation measures (July 17, 2018, Personal interview). Besides, citizens are essential to ensure circularity as they are the ones to adopt the circular activities. He further stressed that as a commercial company, they always try to work as sustainable as possible, using sustainable and circular materials. But, if their clients have no goal for sustainability and circularity and the only focus would be on financial aspects, then the sustainability and circularity will have less attention. In the same way, Ardi Dortmans pointed out to the importance of people's mindset and acceptance for circularity adoption. He mentioned that although the proper technology and business model exists, but if the people do not want the transition, it will not happen. (July 23, 2018, personal communication).

To work on a construction project for climate change adaptation and integrate circular economy, multiple stakeholders need to participate whom always need to align within a project. In this case, there is a need to find the clear advantage for all the stakeholders, then it is simply difficult to manage all stakeholders at once (Luca Sittoni, July 17, 2018, Personal interview). He further pointed out to the time scale as another barrier for stakeholders, giving the following example: "*The benefit of one stakeholder today, maybe will be the benefit of another stakeholder in ten*

years. For instance, if the we plant vegetation, we may have the better water quality in ten years, but the other stakeholders may not be there in ten years and then it is difficult to show what happened and the importance of that". In the light of this, Johannes de Groot stated that the infrastructural adaptation measures are designed to work for at least 50 or 100 years. Part of circular economy is making agreements with suppliers and other stakeholders, which is very difficult due to this very long life-cycle (June 24, 2018, Personal interview).

Chapter 5: Discussion

This chapter discusses the results presented in the previous chapter. The analysis of the interview findings and the existing documents provides answers to the research questions. This chapter is structured in line with the research sub-questions as presented in Chapter 1. Section 5.1 answers the first research question discussing what the existing climate change adaptation measures are in the construction sector in Rotterdam. Section 5.2 discusses the policies and regulations governing the construction sector to improve climate change adaptation and section 5.3 presents the main drivers and barriers to integration of circular economy into climate change adaptation measures. The analysis in this chapter is aligned with the main areas presented in Chapter 4.

5.1 The existing green and grey climate change adaptation measures in Rotterdam

The application of the circular economy principles in construction, which is in its infancy, has been largely limited to waste minimization and recycling. There has been little research on how circular economy might enable resources and materials to retain high residual values (Adams et al., 2017). The grey and green adaptation measures with multifunctional usage, namely water squares, multifunctional roofscape, multifunctional dike can adopt the concepts of circular economy in terms of retaining the value of materials and resources. In the light of this, Nanco Dolman pointed out that thinking about the circular aspects is like that we are going to recycle or upcycle resources.

The construction sector within built environment expands into five phases including design, manufacture and supply (building materials), construction processes, maintenance and end of life (Cacho et al., 2017; Adams, 2017). For each phase different aspects of circular economy have been specified. However, these aspects are mostly applied within a particular sector or project and lack wide-scale adoption (Adams, 2017). The following sections discuss integration of circular economy into green and grey climate change adaptation measures where applicable within these stages. In this research, climate change adaptation measures refer to a new construction, renovation and maintenance of existing green and grey measures in Rotterdam, namely dikes, water squares, green roofs, etc. However, these measures need to be optimized to reduce energy consumption and decrease wastage to fully enable resource efficiency and recovery. The circular economy provides opportunity for a more prominent role for these measures in protecting and enhancing resources (IWA, 2016).

Resource efficiency is connected to the materials, water and energy flows in the city. Circular economy can offer various approaches to increase the resource efficiency of these flows; for instance, closing cycles by use waste or other material flows in the city. With this in mind, the concrete chain is an example of a material chain in which circular economy plays a part (IWA,

2016). The grey adaptation measures demand different kinds of materials, namely concrete and brick, therefore, the circular approach can be effectively applied to these measures for reusable concrete in the climate change adaptation measures (Marco Hoogvliet, June 22, 2018, personal communication). The following sections discuss how the existing climate change adaptation measures in Rotterdam can support to retain high residual value and create the circular system.

5.1.1 Disassembled green roofs

An extensive green roof system would cost two or five times more, compared to the conventional bare roofs. Adopting a green roof to a modular system, which allows disassembly of components after the life-time, is a promising option to adopt circularity in this important climate adaptation measure. Most of the components and materials can be reused after the life-time, demolishing or even can be relocated. The high potential of green roofs for applying circularity was rightfully mentioned by the respondent from Rebel. The material selection with no heavy environmental impact which support circular economy is one of the main challenges of building green roofs (Hui, S. C. M., 2006). In like manner, Marco Hoogvliet, stated that when we talk about circular economy we have to make sure to close that cycle and think about how you can close that cycle from the start. Therefore, when you make your first design, you have to think about how you can disassemble that design. It has only been a couple of years that we start thinking about how to design construction in a way in which we can disassemble them in a good way and reuse the materials. "*Therefore, that is my definition, the pure definition of circular economy".* He further mentioned that: "*At Deltares we are specializing water and in soil and in sediment and those are not such construction materials, but we do think a lot about how we can think in circular systems."* (Marco Hoogvliet, June 22, 2018, Personal interview).

5.1.2 Urban water buffer

Water sector is the central part of the circular economy and the most important resource across all supply chains. This was also reiterated by Prof. Cramer, stating that "what we need is of course keep the water in the cycle." Although the importance of natural environment in providing water services is well understood, but it is still undervalued. The great potential of the natural environment can be unlocked in providing storage, buffers, recreational, etc. and arise opportunities for transition to circular economy. The urban water buffer as a nature-based solution for climate change adaptation mainly deals with downpours and droughts can collect the rainwater or stormwater and store it for the further use. It can absorb the water from streets, squares and roofs. This decreases the risk of flooding in the streets. Furthermore, this process creates a completely circular system, where the rainwater is used sustainably and kept in cycle. The importance of keeping water in the cycle was also mentioned by one of the interviewees.

5.1.3. Blue roof

Another adaptation measure in Rotterdam which is currently developing by 'BlueRoof' company and can incite the shift towards circularity is the Blue Roof. This measure develops the application of residual materials as a valuable substrate for developing upcycled/circular green roofs. The residual materials are from a collection of solid sewage system waste. In this way, sustainable green roofs will be accessible for the citizens of Rotterdam. BlueRoof aims to demonstrate that these residual materials not only lead to better results, but also do not have to cost more than the regular green roofs. However, the main challenge to develop this innovation is creating more awareness for both the residual flow and the usefulness of green roofs.

5.2 Policy and Regulations approaching integration of circular economy into CCA measures

The infrastructural adaptation approach and measures must communicate with the policy and regulations to be most effective and to have the best chance of becoming more sustainable. In the Netherlands, the Ministry of Infrastructure and the Environment (IenM), together with the Ministries of Economic Affairs and Interior and Kingdom Relations (BZK), is responsible for the 'Groene Groei' (Green Development) policy, the key sustainability objective of the current government (RWS, 2015). Circular economy is an integral part of this green development policy (RWS, 2015). The Ministry of IenM requested Rijkswaterstaat (RWS) and the National Institute for Public Health and the Environment (RIVM) to conduct a preliminary survey of policy options for a circular economy in the construction sector, based on stakeholders' consultation (RWS, 2015). Through the Environment and planning act, the Dutch government wants to combine and simplify for spatial projects (Peeters, 2010). They aim to make it easier to start up projects. The current policy's focus is directed towards the mitigation of damaging effects for example from waste and emissions and not at maximizing the value of materials (Ministry of Infrastructure and the Environment & Ministry of Economic Affairs, 2016). However, the material flows fulfil the key role in the body of thought concerning circular economy. In addition, it is also about a new way of thinking about economic principles including 'value' and about business models that give shape to the desired value creation. The existing construction laws already provide a legislative framework within which the government and the other parties can undertake adaptation measures.

The Government-wide program for a Circular Economy aims to develop projects with pioneering cities for the adaptation of local area planning, such as disconnecting rainwater collection in new construction and installing green roofs. In collaboration with the business community, the sectors, and the Netherlands Standardization Institute (NEN) they are adapting the process in

place for setting standards and issuing certificates. The Netherlands is making a contribution to the efforts launched by the European Commission to establish European standards for a circular economy (Ministry of Infrastructure and the Environment & Ministry of Economic Affairs, 2016).

Well-designed constructions laws contribute to the transition towards more sustainable construction. Besides, the regulations should offer incentives for circular designs and materials to enhance the demand for circularity in the construction sector and the prevention of material use. Additionally, the policy instruments such as taxes could be applied to discourage people to proceed with a linear-traditional approach (Ministry of Infrastructure and the Environment & Ministry of Economic Affairs, 2016). Accordingly, circular procurement guidelines and frameworks (e.g. checklists, Cradle to Cradle Certified Product Standard) should be issued to offer criteria for the design phase and material use for the infrastructural measures.

To achieve the goals towards the use of eco-design principles, increasing the life span of products and optimal reuse of residual material flows, the Netherlands encourages the making of Green Deals as an instrument to ensure bottom up initiatives from stakeholders. During the recent years, the Green Deals have started in various areas of construction including bio-based buildings, circular buildings, sustainable concrete, sustainable approach to ground work, road and hydraulic. But, less attention has been paid to Green Deals in the area of spatial planning for climate change adaptation measures. However, spatial planning has been identified as a critical mechanism which can facilitate climate change adaptation. Coupled with, the Netherlands Environmental Assessment Agency (PBL) indicates that spatial planning solutions can also contribute to the transition to circular economy (Ministry of Infrastructure and the Environment & Ministry of Economic Affairs, 2016). In other words, regional spatial planning policy offers greater scope for supporting circular activities. Hence, the Government-wide program for a circular economy aims to develop projects with pioneering cities for the adaptation of local area planning, such as disconnecting rainwater collection in new construction and installing green roofs (Ministry of Infrastructure and the Environment & Ministry of Economic Affairs, 2016). The climate adaptive measures with spatial design and multi-functional usage can make use of one another's materials and residual stream. Consequently, at the local level, loops are then closed, and the measures will be circular since they can be used for multiple solutions.

The circular procurement policies can be a very good spearing instrument and certain legal requirements in developing new infrastructural adaptation measures. You can do a lot to place regulations in order to ensure that at least basic requirements are met (Jacqueline Cramer, June 26, 2018, Personal interview).

5.3 Drivers and barriers to integration circular economy into infrastructural climate change adaptation measures

The following sections present various drivers and barriers for adopting circular economy in the CCA measures inquired from the interviews and existing document.

5.3.1 Drivers

Drivers: Financial Aspects

With the financial crisis began in 2008 and hovering over Rotterdam, a greater attention must be paid to economic efficiency in projects (Knowledge for Climate, 2012). The financial crisis urges the investors and project developers to make possible measures to stabilize and save costs. To do so, prevention of waste by applying circularity principles is a promising candidate. Adoption of circular economy in construction sector could enhance the long-term revenue generation through remanufacturing activities and effective recycling. Grants and subsidies are important funding source for start-ups. During the interview with Bouke Bakker from Municipality of Rotterdam, it was stated that there are various subsidized programs to help companies and start-ups with their concepts and ideas. For longer-term projects the firms can apply for Innovatiekrediet (innovation credit). With the Innovation Credit, the government is filling the gap in the capital market, whereby innovative projects cannot be financed entirely from their own resources or by the market. Besides, cooperative funding facilities can provide financial aid in the supply chain where different parties rely on one central actor. Municipality may be the central party to distribute funding.

Drivers: Technology and innovation

The circular economy necessitates the development of new technologies and materials (Kok et al., 2013). In other words, the development of new technology is often the principal asset of early-stage circular approach. However, the cost of technology assessments might be prohibitive for project developers, investors or lenders, given the degree of specialization required and the lack of scale (Oliver Wyman, 2017).

Multifunctional solution

The creativity at construction sector aims at finding new solutions for subsurface water and energy storage in the public domain of the city. Besides, subsurface storage of rainwater or infiltration of it through pavements presents opportunities for reuse of water from a more efficient design of the sewer system (IWA, 2016). Currently, new initiatives for combined use of

climate change adaptation measures and water recycling are in development in Rotterdam, such as water buffer and multi-functional dike.

Bio-based materials in construction sector

The use of bio-based materials for the construction sector having advantages of material efficiency, lower dependency of fossil resources, small carbon footprint, is largely growing and plays a significant role in construction innovation. The bio-based materials are relatively easier to be reused or recycled compared to chemical-based materials making their usage important to reach sustainability goals (ENC, 2016). However, due to the rigid construction sector and lack of regulation on material usage for it, the implementation of bio-based materials is relatively low. It has to be mentioned that the project developers and contactors are boosting the demand for more sustainable construction (ENC, 2016).

From waste to resource

Embracing the concept of "from waste to resource" can contribute to transition towards circularity. In this regard, fine sediments is an essential material for sustainable development. Using the surplus fine sediment is of great value as a natural resource and building material for land reclamation and dike construction to provide new residential areas for the growing urban population and protect them from flooding. Across the world, different coastal areas, rivers and shores face the challenges of excess sediment or sediment shortages. Excess sediment dredged from coastal areas and rivers can be used to build or strengthen dikes or reclaim land. Therefore, surplus fine sediments can be used sustainably and locally to meet the needs of society and generate different benefits, namely flood risk management, land reclamation and nature development. In this way, the sediments can be transformed from waste into a valuable resource and incite transition towards circular economy. With respect to this, as stated in one the interviews, EcoShape together with other partners is developing knowledge about the sustainable use of fine sediment by working on pilot projects. In the meanwhile, they are investigating how to generate benefits for society, for instance, the restoration of ecosystems by capturing sediment and transforming sediment into a building material (EcoShape, 2017).

Drivers: Societal and value-added

Increasing the demand for the climate change adaptation measures urge drives the integration of circular economy in the supply chain. Besides, integration of circular economy can contribute to job creation (specifically semi-skilled and entry-level jobs) (Govindan & Hasanagic, 2018). This was also reiterated by Marco Hoogvliet stating that applying circular economy in the city can boost the economy of the city by providing jobs within the factories that produce circular materials.

5.3.2 Barriers

Barriers: Financial

The threat of the cost benefit for each party adopting circularity principles and the perception that the initial investor may not benefit is the largest challenge for adopting circularity in built environment projects. Cost and the expected profit are considered as the dominant feature in any decision-making process by many stakeholders and clients. Moreover, the challenges of low value of materials at the end of life are also important for designers and manufacturers which can make take-back schemes and processing uneconomical (Adams, 2017). The research inquired from most of the interviews that there is a lack of subsidies for real circular models or innovations in infrastructure and construction sector. Sustainable products are often more expensive than non-sustainable alternatives. This is mostly because damage to the health public and environment is still insufficiently reflected in the raw materials' price and accordingly in the price of products. Equally important is the budget deficit of some authorities such as municipalities which are not the wealthiest part of government and have more urgent priorities that should be sorted out before circular economy (Marco Hoogvliet, June 22, 2018, personal communication). Common challenges to raising finance include the use of new technology or unproven business models, dependence on third parties in the value chain and above-average time to recover investments. In particular, the development of new technology needed in the resource recovery business models and circular supplies presents a high risk of failure, which discourages investors (Oliver Wyman, 2017).

Barriers: Technology and innovation

Technology is a significant help in supporting circular economy and although it is advancing, the adoption of circular economy faces some challenges with respect to technology. Recycling technologies often lead to downcycling of materials (Kok et al., 2013). In terms of technology, the recycling industry will have to make substantial technological improvements to be able to deliver the required quality (RWS, 2015). The common challenge for use of new technology is that the development of new technology needed in the resource recovery and circular supplies entails a high risk of failure that discourage project developers and investors. As mentioned by Bouke Bakker from Municipality of Rotterdam, the technological solutions are not advanced yet to reclaim mono streams of material from waste. He further asserted that to change a certain chain from linear to circular, there is a need for collaboration between stakeholders and new technology. Therefore, the municipality is collaborating with the market to understand how the chain works and to steer on collaboration between stakeholders and to implementation of required technologies or researches. He also pointed out to the need for digital systems for

registration and value determination as well as recycling techniques to achieve higher levels of mono materials. Besides, the research inquired from the interviewees that there is a need for innovative projects with the aim of developing a circular system in which the materials such as sand, clay and sediments can be reused for infrastructural adaptation. In this regard there is need to think out of box and apply the technology to develop new infrastructural adaptation measures combining different functions. In the light of this, one of the informants stated that we need to learn by learning, therefor, the pilot projects are promising solutions to optimize transition towards circularity. However, innovation in this field is linked to business models and supply change management. Currently, most business models focus on short-term profits and do not recompense the suppliers who deliver sustainable solutions on the long run. Therefore, apart from technical solutions, there is a need to adopt new business models which enhance change by finding ways to incentive long-term value creation (BIS, 2013). The interviews identified that these technological developments are currently being made in which different parties such as Dutch universities, research institutes, private sectors are involved. However, as mentioned by one of the respondents, the main concern about reused materials and concrete is that they are still in pilot cases or experiment phase. Therefore, the proven technology must acknowledge the efficiency and safety of the materials and this requires more long-term projects. Besides, according to Marco Hoogvliet, the organizational part and creating a business case in which different parties could be able to make a little bit of money is more of challenge than technical aspects. To reiterate this, Jacqueline Cramer said that the main challenge is to find a new system and to find way ways to finance the system.

Barriers: societal and value-related

An important precondition for circular economy is that all steps in the cycle fits to its sequent step in the chain and this requires collaboration to achieve. As mentioned earlier, collaboration among stakeholders in both climate change adaptation and circular economy is an essential. Based on one of the interviews, the main stakeholders (government, industry and scientific community) in the Netherlands, are collaborating on regional initiatives (Ardi Dortmans, July 23, 2018, personal communication). Although this might be true in general, making agreements with suppliers and other stakeholders faces some challenges due to the long life-cycle of infrastructural measures which is at least 50-100 years. It is mainly due to short-term risks and short-term profits.

The societal and cultural barriers for adoption of circular economy are the unwillingness of powerful players (front-runners) to cooperate and lack of public knowledge and awareness. One of the important conditions for applying circular economy principles is citizen's participation for the rolling out of any successful initiatives. As mentioned earlier, a serious lack of awareness

leads to poor levels of participation. In this research, the majority of interviews has confirmed that awareness and knowledge have a significant influence on circular economy behavior. Although there is a growing knowledge and awareness on importance of circular economy compared to the past, the public awareness of importance of circular economy is still inadequate. Under this circumstance, even if the proper technology and legislation support the transition towards circularity, but the people's mindset does not allow to adopt the circular economy, circularity will not happen.

Additionally, the time scale was inquired from the interviews as another challenge of integration of circular economy within the adaptation projects. The construction adaptation projects are usually long-term projects and since, the integration of circular economy demand multiple stakeholders and they need to ensure if the projects will benefit them or not. In this case, Charlie Spork stated that transition towards circularity might takes about 20 to 50 years, so it takes multiple generation. However, the upfront costs are high, and the stakeholders involved in a startup, might be not guaranteed to get their initial investments back at the desired time. Consequently, this lead to less willingness to invest in long-term projects of climate change adaptations applying circularity concepts.

Chapter 6: Conclusions and Recommendations

The purpose of this research was to investigate the integration of circular economy into green and grey climate change adaptation measures in Rotterdam. Section 6.1 presents the concluding results which addresses the research questions. Section 6.2 entails recommendations based on the findings of the current situation of practices and the challenges for integration of circularity principles into CCA measures.

6.1 Conclusions

In order to answer the first sub-question, the research identified the main green and grey CCA measures in Rotterdam and sought to identify their potential to apply circularity principles. This is in accordance with the restorative and regenerative nature of circular economy which aims to ensure that the value of resources is being used to their optimal level and also retained within the system for as long as possible. The grey infrastructure in highly demanding resources and the material and resource optimization is a significant factor to eliminate waste and optimize resource and material reuse across projects and supply chain. Moreover, with respect to the design phase, the multi-functional design can contribute to creating a circular system and retain the value of resources.

The second sub-question examined how Rotterdam is approaching circular economy in green and grey adaptation measures in terms of policy and regulation. It came out clear that in terms of regulation, a greater focus on resource efficiency can pave the way for adoption of circular economy. However, in the long term, construction regulations need to evolve to better enable the adoption of circularity principles. For instance, in the regulation of specific resources as materials rather than waste, there is a need for critical review of current waste policies. Henceforth, the waste will be a source of valuable resource. Besides, with recycling policy, the construction sector can further improve the waste hierarchy aligned with the circularity principles, by aiming at high quality of circular/recycled materials and preventing the incineration of valuable resources.

The third sub-question identified the existing drivers and barriers to integration of circularity principles into green and grey CCA measures. Various drivers and barriers were identified and classified into three main aspects: financial, innovation and technology and societal and value-related. The drivers and barriers were investigated to find out how they stimulate or hinder the adoption of circular economy into CCA measures.

Lastly, the main research question aimed to address how circular economy can be adopted to climate change adaptation measures in Rotterdam and better support. Based on the answers to the sub-questions, it is concluded that circular economy can be adopted in the grey climate change adaptation measures since, these measures have more potential to adopt circularity principles in terms of material and resource use and expanding the functions of measures. On balance, both climate change adaptation and circular economy are two major programs in the city of Rotterdam. However, presently in the Netherlands and specifically in Rotterdam, the focus of circular economy is not on climate change adaptation measures. There is not much of a connection between these two approaches, which is something the municipality is going to work on in the near future.

6.2 Recommendations

This study is able to identify key challenges and gaps in the regulation, financial, societal and value-related aspects for adoption of circular economy into climate change adaptation measures. Having presented the results on the sub-questions, some recommendations can be made for the integration of circular economy into climate change adaptation measures.

6.2.1 Recommendations for policy and regulations

Taking into account that stakeholders operate in a world of rules and incentives set by the government, policies and regulations should be evaluated upon their alignment with the principles of circular economy. In the renewed “Circular Economy Package” of the European Commission, new measures are taken regarding circular design, instead of solely focusing on waste (Euractiv, 2015). In the Netherlands, there are still some obstacles in legislation, such as the legal ascription of some resources as waste. The procurement guidelines and checklists, which define criteria for the design phase, material usage and environmental performance of the infrastructure, contribute to improving the adoption of circular economy into climate change adaptation measures. Besides, developing an efficient authorization procedure for new circular materials proposed by companies is important at the early stage of circularity adoption. Furthermore, a comprehensive information should be provided covering material content, the amount of reused, recycle and recyclable materials and the amount of undesirable materials used in the buildings. Also, a voluntary standard system (self-regulatory) at regional level can be introduced for the development of circularity standards, which it further can form the basis for mandatory standard system. In this way, enterprises and stakeholders would be able to actively participate in a higher transparency through standards and improve competitiveness in new markets.

6.2.2 Recommendations for societal and value-related

Another challenge that came out in the research is the social obstacle. The lack of awareness and knowledge leads to unwillingness of powerful players to cooperate. Therefore, there is a clear need to articulate the benefits and opportunities of circular economy among different parties. The creation of a virtual platform for Rotterdam is a promising solution to promote adoption of circular economy into CCA measures. Different stakeholders can take part in the platform in the annual conference by interacting on the website to share their knowledge about circular materials and designs. Furthermore, the platform can provide a database of technical guidelines on reusing and recycling material usage, a monitoring framework on progress towards the circular economy in the city. In the same way, the development of regional agenda in Rotterdam can be a promising starting point for collaboration in Rotterdam, incentivizing knowledge exchange, involvement of various stakeholders from both circular economy and climate change adaptation sections. Additionally, various measures can be taken for awareness-raising, such as running awareness campaigns, production of brochures, and increased use of social media. Notably, the Climate Change Academy in Rotterdam can be asked to add relevant courses in the academy's curricula. Lastly, the principles of a circular economy, specifically for construction sector should become an integral part of programmes in associated academies such as Climate Change Academy in Rotterdam. This is essential to raise awareness and knowledge and sence of urgency concerning the transition towards circular economy.

6.2.3 Recommendations for financial aspects

One of the largest barriers to adoption of circularity principles in climate change adaptation measures is lack of financial aid. The costs of transition towards circularity costs occur in any phases within the construction processes, namely research, development, planning, management, physical and digital infrastructure (World Economic Forum, 2018). In this regard, it is suggested that the government considers short-term and long -term approaches such as subsidies, loans and green deals to bring down the upfront costs and remove financial barriers to start up projects, use of circular and sustainable materials. Alongside the financial aid, the government can then shift the central focus onto the value of raw materials rather than countering the damaging effects of waste emissions. To achieve this, the government should establish concrete circular standards, criteria, explicit policies and regulations for circular material usage. Therefore, it is recommended that authorities, research institutes and financial institutions align their plans and works together to compensate the possible budget deficit of each other. Thereupon, the adequate financial support can cover risk related to innovative projects. Furthermore, to better support the circular economy, the extraction of resources from nature and renewable resources should be untaxed and non-renewable materials should become

taxed. In this way the stakeholders will be discouraged to proceed with a linear-traditional approach.

6.2.4 Recommendations for innovation and technology

In terms of technology, the long-term pilots and projects which prove the safety, strength and life-span of circular/recycle materials should be embarked. However, the financial support should be also provided for project developers and investors. Besides, the more advanced technology is needed to reclaim mono streams of material from waste. In addition, the CCA measures should be developed or renovate to adopt multifunction usage aim to retain high residual values by closing the loops.

REFERENCES

Adams, K., Osmani, M., Thorpe, A., Thornback, J. (2017). Circular economy in construction: current awareness, challenges and enablers. Proceedings of the Institution of Civil Engineers: *Waste and Resource Management*, 170 (1),15-24.

Agrawala, S., Carraro, M., Kingsmill, N., Lanzi, E., Mullan, M. & Prudent-Richard, G. (2011). Private Sector Engagement in Adaptation to Climate Change: Approaches to Managing Climate Risks (OECD Environment Working Papers). Organization for Economic Co-operation and Development, Paris.

Bakker, B. (2018, August 12). Personal interview.

Becker, A., Inoue, S., Fischer, M., & Schwegler, B. (2011). Climate change impacts on international seaports: knowledge, perceptions and planning efforts among port administrators. *Climatic Change*, 110(1-2), 5–29. doi:10.1007/s10584-011-0043-7.

Boyd, C. & Pablo, M. (2016). Sharing cities and sustainable consumption and production: towards an integrated framework. *Journal of Clean Production*. 134, 87e97.

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.

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), 1337-1348.

Brière, C. (2018, August 6). Personal interview.

Carter, J. G., Cavan, G., Connelly, A., Guy S., Handley, J & Kazmierczak, A. (2015). Climate change and the city: Building capacity for urban adaptation. *Progress in Planning*, 95, 1-66.

Carter, J.G. (2011). Climate change adaptation in European cities. *Current Opinion in Environmental Sustainability*, 3(3), 193-198.

Cramer, J. (2018, June 25). Personal interview.

da Cruz e Sousa, R. & Miranda, O.L. (2018). Incorporating wetlands in hydrologic and hydraulic models for flood zone delineation: An application to Durán, Ecuador. *International Journal of Disaster Risk Reduction*. 28, 375-383.

de Groot, J. (2018, June 24). Personal interview.

de Man, R. & Friege, H. (2016). Circular Economy: European Policy on Shaky Ground, *Waste Management & Research,* 34 (2), 93-95.

De Urbanisten. (2015), *Rotterdam roofscapes.*

Deutz, P. & Gibbs, D. (2008). "Industrial ecology and regional development: eco-industrial development as cluster policy." *Regional Studies*, 42(10), 1313-1328.

Dircke, P., Aerts, J., Ikert. M., & Molenaar, A. (2013). *Connecting Delta Cities part 3*. [Amsterdam: VU University Press].

Dolman, N. (2018, June 22). Personal interview.

Dong, X., Guo, H., & Zeng, X. (2017). Enhancing future resilience in urban drainage system: Green versus grey infrastructure. *Water Research*, 124, 280-289.

Dong, X., Guo, H., Zeng, S. (2017). Enhancing future resilience in urban drainage system: Green versus grey infrastructure. *Water Research*, 124, 280-289.

Dortmans, A. (2018, July 23). Personal interview.

EC Dg Env. (2011). Service contract on management of construction and demolition waste, SR1. Final Report Task 2 (Vol. 33). Paris. Retrieved from http://ec.europa.eu/environment/waste/pdf/2011_CDW_Report.pdf

EC, (European Commission), (2009). Promoting sustainable urban development in Europe: achievements and opportunities, European Commission, Brussels.

EC, (European Commission). (2009), Adapting to climate change: Towards a European framework for action COM. 147/4, 1 April 2009.

ECN (2016), Climate resilience and circularity in construction assignment.

EcoShape 2017, Living Lab for MUD, Retrieved from https://www.ecoshape.org/en/projects/living-lab-mud/

EEA, 2013. Adaptation in Europe: Addressing risks and opportunities from climate change in the context of socio-economic developments (No. 3/2013). Publications Office of the European Union, Luembourg.

Ellen MacArthur Foundation. (2013). *Towards the Circular Economy - Opportunities for the Consumer Goods Sector* (Vol. 2). Cowes, United Kingdom.

Ellen MacArthur Foundation. (2014). Towards the Circular Economy - Accelerating the scale-up across global supply chains (Vol. 3). World Economic Forum Reports. Geneva, Switzerland.

Ellen MacArthur Foundation. (2016). Circular Economy-interactive diagram. Retrieved from http://www.ellenmacarthurfoundation.org/circular-economy/interactive-diagram

Euractiv (2015). Circular economy package. Retrieved from https://www.euractiv.com/topics/circular-economy-package/

European Environment Agency (EEA), 2012, Urban adaptation to climate change.

European Environmental Agency (EEA). (2016). Circular Economy in Europe developing the Knowledge Base (No. 2).

European Union. (2012). *Cities in Europe the New OECD-EC Definition*. Brussels: EU.

Francesch-Huidobroa, M., Dabrowski, M., Tai, Y., Chan, F., Stead., D. (2017). Governance challenges of flood-prone delta cities: Integrating flood risk management and climate change in spatial planning. *Progress in Planning*, 114, 1-27.

Frumkin, H. (2002). Urban sprawl and public health. *Public Health Rep*. 117, 201–217.

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). "A Review on Circular Economy: The Expected Transition to a Balanced Interplay of Environmental and Economic Systems." *Journal of Cleaner Production*, 114, 11–32.

Gill, S.E., Handley, J.F., Ennos, A.R., Pauleit, S. (2007). Adapting cities for climate change: The role of the green infrastructure, *Built Environment*, 33 (1), 115-133.

Govindan, K. & Hasanagic, M. (2018). A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective. *International Journal of Production Research*, 56(1-2), 278-311.

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

Haas, W., Krausmann, F., Wiedenhofer, D. & Heinz, M. (2015). How Circular is the Global Economy?: An Assessment of Material Flows, Waste Production, and Recycling in the European Union and the World in 2005. *Journal of Industrial Ecology*, 19, 765-777.

Hallegatte, S., Green, C., Nicholls, R.J. & Corfee-Morlot, J. (2013). Future flood losses in major coastal cities. *Nature Climate Change*, 3 (9), 802-806.

Hazen, B.T., Mollenkopf, D.A. & Wang, Y. (2017). "Remanufacturing for the Circular Economy: An Examination of Consumer Switching Behavior." *Business Strategy and the Environment*, 26 (4), 451-464.

Heidrich, O., Reckien, D., Olazabal, M., Foley, A., Salvia, M., De Gregorio Hurtado, S., Orru, H., Flacke, J., Geneletti, D., Pietrapertosa, F. Hamann, J.J.P. Tiwary, A., Feliu, E., Dawson, R.J. (2016). National climate policies across Europe and their impacts on cities strategies, *Journal of Environment and Management*. 168, 36-45.

Herath, H.M.P.I.K., Halwatura, R.U., Jayasinghe, G.Y. (2018). Evaluation of green infrastructure effects on tropical Sri Lankan urban context as an urban heat island adaptation strategy, *Urban Forestry and Urban Greening*, 29, 212-222.

Hilla, H., Hadaritsa, M., Riegerb, R., Strickertc, G., Daviesd, M.G.R. & Strobbe. K.M. (2014). The Invitational Drought Tournament: What is it and why is it a useful tool for drought preparedness and adaptation? *Weather and Climate Extremes*. 3, 107-116.

Hirabayashi, Y., mAhendran, R., Koirala, S., Yamazaki, D., Watanabe, S., Kim, H., Kanae, Sh. (2013). Global flood risk under climate change. *Nature Climate Change*, 3, 816-821.

Hoogvliet, M. (2018, June 22). Personal interview.

Huang, C.L., Vause, J., Ma, H.W., Li, Y., Yu, C.P. (2014). Substance flow analysis for nickel in mainland China in 2009. *Journal of Cleaner Production*, 84, 450-458.

Hui, S.C.M. (2006). Benefits and potential applications of green roof systems in Hong Kong, In Proceedings of the 2nd Megacities International Conference 2006, 1-2 December 2006, Guangzhou, China, 351-360.

Hunt, A. and Watkiss, P. (2011). Climate change impacts and adaptation in cities: a review of the literature. *Climatic Change*, 104 (1), 13-49.

Hurlimann, A.C., Browne, G.R., Warren-Myers, G. & Francis, V. (2018). Barriers to climate change adaptation in the Australian construction industry – Impetus for regulatory reform. *Building and Environment*, 137, 235-245.

Ilić, M., & Nikolić. M. (2016). "Drivers for Development of Circular Economy-A Case Study of Serbia." HaZuabitat International, 56, 191–200.

Interview 1, (2018, June 22). Personal interview.

(International Water Association) IWA (2016), *Water utility pathway in a circular economy*.

J. Alcamo & J.E. Olesen (eds.), 2012. *Life in Europe Under Climate Change*. Wiley-Blackwell, West Sussex & Oxford.

Jasen, M. (2016), The Fourth Industrial Revolution and the future of ports, Erasmus university, Rotterdam.

Jones, H.P., Hole, D.G., Zavaleta, E.S. (2012). Harnessing nature to help people adapt to climate change. *Nat. Clim. Change*, 2, 504-509. doi:10.1038/nclimate1463

Kerssen., A.J. (2018, July 17). Personal interview.

Knowledge for Climate (2012), *Exploring Opportunities for green adaptation measures*.

Kok, L., Wurpel, G., & Ten Wolde, A. (2013). Unleashing the Power of the Circular Economy. Amsterdam, the Netherlands: IMSA for Circle Economy. Towards the Circular Economy - Opportunities for the Consumer Goods Sector (Vol. 2). Cowes, United Kingdom.

Koop, S. H. A., & van Leeuwen, C. J. (2016). The challenges of water, waste and climate change in cities. Environment, *Development and Sustainability*, 19(2), 385–418.

Korhonen, J., Nuur, C., Feldmann, A., Eshetu Birkie, S. (2018). Circular economy as an essentially contested concept, *Journal of cleaner production*, 175, 544-552.

Kraaijenhagen, C., Van Oppen, C., & Bocken, N. (2016). *Circular Business: Collaborate and Circulate* (1st ed.). (Bernasco. C & Goodchild-Van Hilten. L, Eds.).

Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K. H., Haberl, H. & Fischer-Kowalski, M. (2009). Growth in global materials use, GDP and population during the 20th century', *Ecological Economics*, 68(10), 2696–2705.

Lass, W., Haas, A., Hinkel, J., & Jaeger, C. (2011). Avoiding the Avoidable: Towards a European Heat Waves Risk Governance. *Int. J. Disaster Risk Sci*. 2 (1), 1–14. doi:10.1007/s13753-011-0001-z

Laubscher, M., Marinelli, T., (2014). Integration of circular economy in business, Vienna, doi: 10.13140/2.1.4864.4164. Philips International B.V., High Tech Campus 5, 5656 AE Eindhoven, The Netherlands.

Leichenko, R. (2011). Climate Change and Urban Resilience. Current Opinion in Environmental Sustainability. 3, 164-168. http://dx.doi.org/10.1016/j.cosust.2010.12.014

Leinchenko, R. (2011) Climate change and urban resilience, *Current Opinion in Environmental Sustainability*, 3, 164-168.

Mabon, L. & Shih, W.Y. (2018). What might 'just green enough' urban development mean in the context of climate change adaptation? The case of urban greenspace planning in Taipei Metropolis, Taiwan. World Development, 107, 224-238.

Mentink, B. (2014). Circular Business Model Innovation: a process framework and a tool for business model innovation in a circular economy. Design Engineering Department, TU, Delft.

Metabolic, (2017). Circular Amsterdam: Spatial implications.

Ministry of Infrastructure and the Environment & Ministry of Economic Affairs (2016). *A Circular Economy in the Netherlands by 2050*.

Naess, L.O., Bang, G., Eriksen, S. & Vevatne, J. (2005) Institutional adaptation to climate change: Flood responses at the municipal level in Norway. *Global Environmental Change*. 15(2), 125-138.

Ness, D. (2008). Sustainable urban infrastructure in China: towards a factor 10 improvement in resource productivity through integrated infrastructure system. *Int. J. Sustain. Dev. World Ecol*. 15, 288-301.

Núñez-Cacho, P., Górecki, J., Molina, V. & Corpas-Iglesias, F.A. (2018). New measures of circular economy thinking in construction companies*, Journal of EU Research in Business*, 2018, 909360, doi: 10.5171/2018.909360

OECD (2015), Material Resources, Productivity and the Environment, OECD Green Growth Studies, OECD Publishing, Paris, from https://doi.org/10.1787/9789264190504-en.

Olsson, P., Gunderson, L.H., Carpenter, S.R., Ryan, P., Lebel, L., Folke, C., Holling, C.S. (2006). Shooting the rapids: navigating transitions to adaptive governance of social-ecological systems, *Ecol. Soc.* 11, 1–18.

Patz, J. A., Campbell-Lendrum, D., Holloway, T., Foley, J. A. (2005). Impact of regional climate change on human health. *Nature*, 438, 310-317.

Peeters, M. & Van Asselt, H. (2010). Klimaatwetgeving in Nederland: Stand van zaken anno, STEM-project, 2010, available at <www.evaluatiemilieu wetgeving.nl.

Peng, Y., Long. S., Ma, J., Song, J., & Liu, Z. (2018). Temporal-spatial variability in correlations of drought and flood during recent 500 years in Inner Mongolia, China. *Science of The Total Environment*, 633, 484-491.

Prendeville, S., Cherim, E. and Bocken, N. (2018). Circular Cities: Mapping Six Cities in Transition, *Environmental Innovation and Societal Transitions*, 26, 171-194.

Pringle, T., Barwood, M. & Rahimifard, S. (2016). "The Challenges in Achieving a Circular Economy within Leather Recycling." *Procedia CIRP*, 48, 544–549.

Reckien, D., et al. (2018) How are cities planning to respond to climate change? Assessment of local climate plans from 885 cities in the EU-28. *Journal of Cleaner Production*. 191, 207-219.

Reischl, C., Rauter, R., & Posch, A. (2018). Urban vulnerability and adaptation to heatwaves: A case study of Graz (Austria). Climate Policy, 18(1), 63-75. doi:10.1080/14693062.2016.1227953

Rijkswaterstaat (RWS), (2015, December 18), Circular economy in the Dutch construction sector, a perspective for the market and government.

Rosenzweig, C., Solecki, W.D., Hammer, S.A., Mehrohtra, S. (2011). *Climate change and cities first assessment report of the urban climate change research network*, Cambridge University Press, Cambridge.

Rotterdam Climate Initiative (2013). *Rotterdam Climate change adaptation Strategy*.

Shahbazi, S., Wiktorsson, M., Kurdve, M., Jönsson, C. & M. Bjelkemyr. (2016). Material Efficiency in Manufacturing: Swedish Evidence on Potential, Barriers and Strategies, *Journal of Cleaner Production*, 127, 438-450.

Shaw, R., Colley, M. & Connell, R. (2007). *Climate change adaptation by design: a guide for sustainable communities*. TCPA, London.

Sittoni., L. (2018, July 17). Personal interview.

Smol, M., Kulczycka, J. Henclik, A., Gorazda, K., Wzorek, Z. (2015). The possible use of sewage sludge ash (SSA) in the construction industry as a way towards a circular economy, *Journal of cleaner production*, 95, 45-54.

Sovacool, B.K. (2011). Hard and soft paths for climate change adaptation. *Clim. Policy*, 11, 1177-1183. doi:10.1080/14693062.2011.579315

Spork., C. (2018, August 2). Personal interview.

Stahel, W.R. (2014). Reuse Is the Key to the Circular Economy. Available: http://ec. reuse-is-the-key-to-the-circular-economy_en.htm (accessed 16.05.15.).

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.

Tavakol-Davani, H., Burian, S.J., Devkota, J. & Apul, D. (2015). Performance and cost-based comparison of green and gray infrastructure to control combined sewer overflows *J. Sustain. Water Built Environ*., 2 (2), 04015009.

Tigkas, D. & Tsakiris, G. (2015). Early Estimation of Drought Impacts on Rainfed Wheat Yield in Mediterranean Climate. *Environmental Processes*. 2(1), 97-114.

Tsakiris, G., Nalbantis, I., Vangelis, H., Verbeiren, B., Huysmans, M., Tychon, B., Jacquemin, I., Canters, F., Vanderhaegen, S., Engelen, G., Poelmans, L., De Becker, P. & Batelaan, O. (2013). A system-based paradigm of drought analysis for operational management. *Water Resource Management*. 27, 5281–5297.

UN. (2013). Sustainable cities, Facts and figures. Retrieved October 15, 2015, from http://www.un.org/en/sustainablefuture/cities.asp

van Riel, W. (2011). Exploratory study of pluvial flood impacts in Dutch urban areas, Deltares, Delft.

Velis, C. A., and K. C. Vrancken. (2015). Which Material Ownership and Responsibility in a Circular Economy?, *Waste Management and Research*, 33 (9), 773-774.

Verberne, J.J.H. (2016). Building circularity indicators: an approach for measuring circularity of a building.

Verschuren, P., & Doorewaard, H. (2010). *Designing a Research Project. The Hague*: Eleven International Publishing.

Wamsler, C., Brink, E. (2014). *Planning for Climatic Extremes and Variability*: A Review of Swedish Municipalities' Adaptation Responses. *Sustainability*, 6, 1359–1385. doi:10.3390/su6031359

Wang, N., Lee, J.C.K., Zhang, J., Chen, H. & Li H. (2018). Evaluation of Urban circular economy development: An empirical research of 40 cities in China. *Journal of Cleaner Production*, 180, 876-887.

Wang, P., Che, F., Fan, S. & Gu, C. (2014). Ownership governance, institutional pressures and circular economy accounting information disclosure: An institutional theory and corporate governance theory perspective. *Chinese Management Studies*, 8(3), 487-501.

Wiel, A.V.D., Bossink, B. & Masurel, E. (2012). Reverse logistics for waste reduction in cradle-to-cradle-oriented firms: Waste management strategies in the Dutch metal industry, *International Journal of Technology Management* 60(1/2), 96-113, doi: 10.1504/IJTM.2012.049108

Wu, H.q., Shi, Y., Xia, Q. & Zhu, W.D. (2014). Effectiveness of the policy of circular economy in China: A DEA-based analysis for the period of 11th five-year-plan. *Resources, Conservation and Recycling*, 83, 163-175.

Yuan, Z., Jiang, W., Liu, B. & Bi, J. (2008). Where will China go? A viewpoint based on an analysis of the challenges of resource supply and pollution*, Environmental Process and sustainable energy*, 27(4), 503-514.

Zhijun, F. & Nailing, Y. (2007). Putting a circular economy into practice in China. *Sustainability Science*, 2(1) 95-101.

APPENDIXES

Appendix A- Consent form

Introduction Key Components

Thank you: I want to thank you for taking the time to participate in this interview and that you are willing to take part in my master thesis research.

Name: My name is Fatemeh Korminouri and I am a master student of Environmental and Energy Management at the University of Twente.

Purpose: I would like to talk to you about climate change adaptation measures with regard to construction sector and the integration of circular economy where it is feasible in these measures.

Confidentiality: Your interview responses will be only used for the purposes of this research and your participation can be anonymous if preferred. Also, you do not have to talk about anything you do not want, and you may end the interview at any time

Duration: The interview should take about an hour.

How interview will be conducted: We can discuss via phone, Skype or on paper (the questions will be answered directly on interview sheet). If that is all right with you, I will be taping the interview to do not miss any of your comments. Although I will be taking some notes during the session, I cannot possibly write fast enough to get it all down. Because we are on tape, please be sure to speak up so that we do not miss your comments.

After the interview the transcription of the interview will be sent to the interviewees to review, validate the accuracy of the information, necessary updates and approval.
Interview results can be reported anonymously upon the interviewee's preference, in terms of both name and position.

I agree to take part in this interview.

Name of participant	Date	Signature

My contacts are as followings:

Fatemeh Korminouri
Master of Environmental and Energy Management
University of Twente
E-mail: f.korminouri@student.utwente.nl
Skype: fatemeh.nouri.64
Phone No: (+31) 684474189

Appendix B- Interview guide and questions

June 2018

Dear Sir/Madam,

I am a student of the Master Program "Environmental and Energy Management" at the University of Twente, Department of Governance and Technology for Sustainability (CSTM). Currently, I am undertaking a research as part of my master thesis which aims to study the potential of circular economy in climate change adaptation for construction sector in cities (grey and green infrastructures such as dikes, water squares, blue corridor etc.), focusing on Rotterdam. The research is under supervision of Dr. Gül Özerol and Dr. Yoram Krozer.

I would like to obtain your opinion and thoughts as an expert in subjects related to my research. The information you provide will be of great value and will be systematically analyzed and only used for the purposes of this research and your participation can be anonymous if preferred.

I would be thankful to schedule a one-hour appointment. The interview can be conducted via phone Skype or on paper (you can directly write your answers on interview sheet).

Thank you in advance for your willingness to contribute to this research. I hope to hear from you soon.

With Best Regards,

Fatemeh Korminouri
Master of Environmental and Energy Management
University of Twente
E-mail: f.korminouri@student.utwente.nl
Skype: fatemeh.nouri.64
Phone No: (+31) 684474189

Interview questions:

1-Mr. Marco Hoogvliet (Deltares, Project Manager and Senior advisor. Research program manager resilient cities)

1. Could you introduce yourself and your position at Deltares? For how long have you been involved in this position?
2. How Deltares is involved in implementing climate change adaptation measures, specifically grey/green adaptation measures in Rotterdam? (Which activities/project do you do for climate change adaptations)?
3. In your opinion which sector within climate change adaptation measures (grey or green infrastructure) has more potential to apply circular economy principles? Please explain the reason.
4. In your opinion, how the existing construction regulations in the Netherlands stimulate the way towards adopting circular economy?
5. Is there any need for shift in Dutch government policy and economic systems to support and enable the implementation of circular economy in construction measures?
6. What are the main concerns of using reused/recycled materials for the construction activities/ maintenance and renovation grey/green adaptation measures in the Netherlands?
7. What kind of research is required to inform and motivate cities to better understand the potential of circular economy and adopting it into construction measures?
8. What are some of the important short-term and long-term instruments required in transition to a circular model in construction sector? (for example, decreasing costs for permit etc.)
9. What do you think are the main current barriers of technology, finance and legislation and regulations at the moment for applying circular principles to the grey/green adaptation measures in the Rotterdam?
10. Are there any more comments you would like to add?

2-Mr. Nanco Dolman (Royal HaskoningDHV, Leading Professional in Urban Flood & Water Resilience)

1. Could you please introduce yourself and your position at Royal Haskoning DHV? For how long have you been involved in this position?
2. How your associated organization is involved in implementing infrastructural and construction climate change adaptation measures, specifically grey/green adaptation measures in the Netherlands? (Which activities/project do you do for infrastructural and construction adaptations)?
3. In your opinion which sector within the infrastructural and construction adaptation measures (grey or green infrastructure) has more potential to apply circular economy principles? Please explain the reason.
4. what way are you concerned with circular economy concepts in infrastructural and construction adaptation measures?

5. To what extent is financial support provided for adopting circularity in infrastructural and construction adaptation projects and how does it cover the risk related to innovative projects?
6. In your opinion, do the existing construction regulations in the Netherlands stimulate the way towards adopting circular economy in infrastructural and construction adaptation measures?
7. What are the existing challenges/barriers for applying circular principles to the infrastructural (grey/green) adaptation measures?
8. Are there any more comments you would like to add?

3-Mr. Luca Sittoni (EcoShape/Deltares, Programme manager)

1. Could you introduce yourself and your position? For how long have you been involved in this position?
2. How your associated organization is involved in implementing climate change adaptation measures, specifically grey/green adaptation measures? (Which activities/project do you do for climate change adaptations in term of construction?
3. Have you applied the circular economy concepts in infrastructural and construction adaptation projects? specifically grey/green adaptation measures (Please explain how).
4. What are the main current challenges/barriers of technology, finance and legislation and regulations for applying circular principles to the grey/green adaptation measures?
5. To what extent is financial support provided for adopting circularity in your projects and how does it cover the risk related to innovative projects?
6. In your opinion which sector within climate change adaptation measures (grey or green infrastructure) has more potential to apply circular economy principles? Please explain the reason.
7. What are some of the important short-term and long-term instruments required in transition to a circular model in infrastructural and construction adaptation measures? (for example, decreasing costs for permit etc.)

4-Interview 1 (Rebel)

1. Could you introduce yourself and your position at Rebel and for how long have you been involved in this position?
2. How does Rebel incorporate circular economy into grey/green adaptation measures in Netherlands and specifically Rotterdam? Are there any specific tools, resources and/or plans you need for integrating circular economy into the projects?
3. Which sector within climate change adaptation measures (grey or green infrastructure) has more potential to apply circular economy principles? Please explain the reason.

4. What are the main concerns of using reused/recycled materials for the construction sector?
5. What do you think are the main, presenting barriers of technology, finance and legislation and regulations at the moment for applying circular economy principles in the grey/green adaptation measures?
6. Is there any short-term and/or long-term instrument to support the transition towards circularity in Rotterdam in adaptation measures in construction sector? (for example, decreasing costs for permit etc.)
7. How the policies and regulations in the Netherlands support implementation of circular economy in construction sector in the Netherlands?

5-Mr. Charlie Spork (Drift, Dutch Research Institute for Transitions, Researcher and Advisor)

1. Could you introduce yourself and your position at Drift? For how long have you been involved in this position?
2. How Drift is involved in implementing grey/green climate change adaptation measures in the Netherlands? (Which activities/project do you do for climate change adaptations)?
3. In your opinion which sector within climate change adaptation measures (grey or green infrastructure) has more potential to apply circular economy principles? Please explain the reason.
4. What kind of research is required to inform and motivate cities to better understand the potential of circular economy and adopting it into construction sector?
5. What do you think are the main, presenting barriers of technology, finance and legislation and regulations at the moment for applying circular principles to the grey/green adaptation measures in the Netherlands?
6. To what extent is financial support provided for adopting circularity in your projects and how does it cover the risk related to innovative projects?
7. How could the other parties (stakeholders) better support your project for integration of circular economy?

6-Mr. Ardi Dortmans (TNO, Director of Circular Economy and Environment)

1. Could you introduce yourself and your position at TNO, for how long have you been involved in this position?
2. How your associated organization is involved in implementing climate change adaptation measures, specifically grey/green adaptation measures in the Netherlands and Rotterdam?

3. What is the role of technology in improving circular construction? (in terms of facilitating to move infrastructure towards circular practices or execution)

4. Which sector within climate change adaptation measures (grey or green infrastructure) has more potential to apply circular economy principles? Please explain the reason.
5. What are the main, presenting challenges/barriers of technology, finance and legislation and regulations for applying circular principles to the grey/green adaptation measures?
6. In your opinion is there any need for shift in government policy and economic system to improve implementation of circular economy in construction sector in the Netherlands?

7-Mr. Albert Jan Kerssen (BTL Advies B.V., Project leader and manager for building green and climate adaptive cities)

1. Could you introduce yourself and your position at BTL? For how long have you been involved in this position?
2. How BTL is involved in implementing climate change adaptation measures, specifically grey/green adaptation measures? (Which activities/project do you do for climate change adaptations)
3. What are the main concerns of using reused/recycled materials for the design phase/construction activities/ maintenance and renovation?
4. Have you applied the circular economy concepts in infrastructural and construction adaptation projects? (Please explain how). Are there any specific tools, resources and/or plans you need for integrating circular economy into your projects?
5. Which sector within climate change adaptation measures (grey or green infrastructure) has more potential to apply circular economy principles? Please explain the reason.
6. What is the role of technology in facilitating towards circular practices in infrastructural and construction adaptation projects?
7. To what extent is financial support provided for adopting circularity in your projects and how does it cover the risk related to innovative projects?
8. What are the main, presenting challenges/barriers for applying circular principles to the grey/green adaptation measures?
9. How could the other parties like public sector (regulators) and private sector (engineers, urban planners, construction companies) optimize the transition to circular procurement?

8-Christophe Brière (Deltalings, Senior Advisor Coastal Adaptation to Climate Change expert)

1. Could you introduce yourself and your position at Deltares? For how long have you been involved in this position?
2. How your associated organization is involved in implementing grey/green climate change adaptation measures, specifically grey/green adaptation measures in the Netherlands and specifically Rotterdam?

3. What are the current adaptation measures in terms of infrastructural and construction in Rotterdam (grey/green adaptation measures)?
4. In your opinion which sector within the infrastructural and construction adaptation measures (grey or green infrastructure) has more potential to apply circular economy principles? Please explain the reason.
5. In your opinion, do the existing construction regulations in the Netherlands stimulate the way towards adopting circular economy in infrastructural and construction adaptation measures?
6. To what extent is financial support provided for adopting circularity in infrastructural and construction adaptation projects and how does it cover the risk related to innovative projects?
7. What are the main, presenting challenges/barriers in terms of technology, finance or regulation for applying circular principles to the infrastructural (grey/green) adaptation measures?

9-Bouke Bakker (Municipality of Rotterdam, Consultant & Entrepreneur in Circular Economy)

1. Could you introduce yourself and what is your position at the Municipality of Rotterdam and for how long have you been involved in this position?
2. What are the current practices of the municipality of Rotterdam in grey/green adaptation measures to climate change in Rotterdam?
3. How is the municipality of Rotterdam adopting the concepts of circular economy in infrastructural and construction adaptation measures?
4. Who are the stakeholders involved in implementing circularity concepts in infrastructural and construction adaptation measures and what are their roles?
5. What kind of resource are needed for transition towards circularity for infrastructural and construction adaptation measures in Rotterdam? (Like the material, finance, or legislation)
6. Does the municipality offer any incentives to stakeholders to implement circular economy concepts/initiatives in infrastructural construction adaptation measures? (for example, decreasing costs for permit etc.)
7. What are the main incentives/drivers (short-term/long-term) to support Rotterdam in transition towards circularity in infrastructural and construction adaptation measures?
8. In your opinion which sector within climate change adaptation measures (grey or green infrastructure) has more potential to apply circular economy principles? Please explain the reason.
9. What do you think are the main existing barriers of technology, finance and legislation and regulations at the moment for applying circular principles to the grey/green adaptation measures in the Rotterdam?

10-Johannes de Groot (Ardadis, Specialist Geotechnical Engineering and Flood Protection)

1. Could you introduce yourself and your position in this company. For how long have you been involved in this position?
2. How your associated organization/company is involved in implementing climate change adaptation measures, specifically infrastructural (grey/green) adaptation measures? (Which activities/project do you do for climate change adaptations)
3. What are the main concerns of using reused/recycled materials for the design phase/construction activities/ maintenance and renovation?
4. How does your organization/company incorporate circular economy into adaptation measures? Are there any specific tools, resources and/or plans you need for integrating circular economy into your projects?
5. Which sector within climate change adaptation measures (grey or green infrastructure) has more potential to apply circular economy principles? Please explain the reason.
6. To what extent is financial support provided for adopting circularity in your projects and how does it cover the risk related to innovative projects?
7. What are the main, presenting challenges/barriers for applying circular principles to the infrastructural (grey/green) adaptation measures?
8. In your opinion, do the existing construction regulations stimulate the way towards adopting circular economy?

11- Jacqueline Cramer (University of Utrecht, Professor in Sustainable Innovation at Utrecht University. Member of the Amsterdam Economic Board in charge of Circular Economy.)

1. Could you please introduce yourself and your position? For how long have you been involved in this position?
2. How do you see circular economy in relation to adaptation measures in terms of construction sector (green/grey infrastructures)?
3. What kind of research is required to inform and motivate cities to better understand the potential of circular economy and adopting it into infrastructural and construction adaptation measures in the Netherlands?
4. What is the role of technology in facilitating to move towards circular practices in the infrastructural and construction adaptation measures?
5. Which organizations are most influential in terms of facilitating circularity implementation in the infrastructural and construction adaptation measures?
6. Will there be a need for shift in government policy and economic systems to support and enable the implementation of circular economy in the Netherlands for the infrastructural and construction adaptation measures?

7. What do you think are the barriers of technology, finance and legislation and regulations at the moment for a circular economy in the infrastructural and construction adaptation measures in the Netherlands specifically Rotterdam?