(RE)DEVELOP THE FUTURE

An instrument to develop and implement the concept of circularity for the redevelopment initiation phase

Delft University of Technology

Faculty of Architecture, Urbanism and Building Sciences
MSc Management in the Built Environment

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Colophon

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All minutes of the interviews conducted during this thesis are available upon request to the author, due to the confidentiality of provided information. The quotes elaborated in this report are to underline certain important insights relevant to this thesis. The responsibility of the translation of these quotes fully lies with the author.

Preface

This report constitutes the final version of my graduation project as part of the master Management in the Built Environment at the Delft University of Technology, where I have studied for the past three years. After having completed the pre-master's degree in Architecture, Urbanism and Building Sciences, this Masters degree have enabled me to get acquainted with a theoretical body of knowledge and practical skills to apply in the various disciplines of the real estate sector. Especially the conceptual and creative skills from perspective of design thinking, and further to prioritize information and derive logical conclusions are valuable competencies.

I am intrinsically motivated to find innovative ways to enrich the world from real estate perspective. Ever since the emergence of a new ideology referred to as a 'circular economy', it sparked this interest and made me decide to focus on this subject in my graduation research. The title is called '(Re)Building the Future – An instrument to develop and implement the concept of circularity for the redevelopment initiation phase'. From January 2017 until April 2018 I have been working on this thesis. Since the beginning of November 2017 I started an internship at 'Rijksvastgoedbedrijf' (Government Real Estate Agency) in The Hague, which enabled me to get access to a broad network of expertise and acquiring relevant information.

Within the first phase of the graduation project, I was involved in the Adaptive Reuse Laboratory at the TU Delft led by Hilde Remøy. During this stage, I defined the scope of my research, focussing on heritage depletion. Hilde has enabled me to specifying the research towards circular redevelopment of heritage by asking the right questions and triggering valuable discussions. When the research scope was partially defined, Ruud Binnekamp joined as my second mentor, to support with the operationalization. Their supervision and feedback helped me to converge from a broad perspective of a circular economy towards a manageable research topic.

Starting my internship at 'Rijksvastgoedbedrijf' has proven to be the right step. Working with Stef Voermans has led to many fruitful discussions and provided me with sufficient insights to improve my thesis further. During the final phase of my thesis, Philip Koppels joined this research with full commitment, and enabled me to finalize my thesis without any delay.

I am grateful for the pleasant cooperation with Hilde, Ruud, Philip and Stef, for which they provided me sufficient supervision, support an guidance throughout the process. Moreover I would like to thank my colleagues at 'Rijksvastgoedbedrijf' for their support when I had specific questions. In addition, I would also like to thank Woud Jansen from Alba Concepts, for his expertise and technical guidance during the final phase. Finally, I want to thank all the professionals with which I have had the pleasure of interviewing.

On a personal note, I would like to thank my girlfriend Lisanne for her patience and support during the process. She encouraged me to stay ambitious and to get the most out of this graduation experience, as well as reminding me to take some time to relax when needed. I want to thank Jos, Saskia, Roelof and Lieneke for their sincere interest and support during my studies. Finally, I want to thank my fellow students with whom I have shared a wonderful time back in the days in Utrecht, and more recently at the department of Management in the Built Environment.

After three years at the Delft University of Technology, I am at the end of my student career. It started with HBO Bouwkunde in Utrecht and after an interval, working abroad, I continued studying. Finally, through the pre-master in Architecture, Urbanism and Building Sciences I achieved the final step towards my master's degree Management in the Built Environment.

It has been quite an experience and I am proud to look back at a wonderful student career.

I hope you find this report enjoyable and informative.

Abstract

Context - The current environmental situation as a result of human life reflects the demand for more consciousness on the embedded energy of buildings. Moreover, due to the recent economic crisis the perceived naturalness to demolish existing buildings for new development is outdated. Hence, new functions should be accommodated in existing buildings, through sustainable adaptive reuse. However, traditional approaches are failing. New, innovative business models are needed to enable maintenance and adaptive reuse of heritage buildings in order to finally rebuilding the future.

Objective - This explorative and design-oriented research aims to have insight on the circular redevelopment potential of elements within the existing built environment. This research focused on two central themes, respectively adaptive reuse of societal heritage projects and circular economy. These central themes represent the theoretical framework. The overarching objective was to accelerate a transition from a linear economy towards a circular economy through circular redevelopment.

Methods - This thesis is structured from both an empirical and operational perspective. Literature study is used to summarize prior research, critically examine contributions, explain results of prior research and clarify differences in alternative views of the past. The conclusion extracted from the empirical study will be used as input for the operational model, together with unstructured expert interviews, and a case study research.

Results - The CRP indicator comprises 6 consecutive strategies which are assessed for each component; respectively (1) Reuse, (2) Repair, (3) Refurbish, (4) Remanufacture, (5) Repurpose and finally (6) Recycle. Identifying the degree of circularity starts with the assessment of applied material characteristics (Bill Of Materials) and their relation and interfaces with all elements in the system (Disassembly Determining Factors). By combining this factor with the actual condition on site (NEN 2767), the applicable reutilization potential of an element could be developed. In accordance with the preferred representability of predefined spaces specific components are categorized if applicable. Altogether, this reflects the degree of circularity of a building (Building Circularity Indicator) for a particular intervention.

Conclusion - The CRP Indicator is a useful tool for the assessment of properties to implement circularity during the redevelopment process. Building inspectors can provide property managers/ owners with objective data about the applied material characteristics and corresponding condition status of building elements. It supports principals to identify preconditions, in order to specify their ambition on circularity and provide the sufficient information to actually enable contractors to differentiate from their competitors during tenders. The assessment model is not intended as a certificate or label, however could be used as supportive instrument to substantiate any classification on this matter.

Key Words - Adaptive reuse, circular economy, building circularity indicator, condition assessment, reutilization potential, circular redevelopment, assessment model

Management Summary

Introduction

Ever since the Industrial Revolution, a series of innovations led to ever-increasing productivity and growth of the global economy. In particular, average income and population began to exhibit unprecedented growth. Technological changes enabled a tremendously increased use of natural resources and the mass production of manufactured goods. Nowadays, the earth is increasingly suffering due to growth in both global population and human welfare. The world population is predicted to be 9.2 billion in 2050, and is expected to be centered to urban areas by 66 per cent in 2050 (United Nations, 2014). A growing population with higher average income requires more food, more industrial products, more energy and more water.

The current environmental situation as a result of human life reflects the demand for more consciousness on the embedded energy of buildings, because in this way the earth cannot keep up with the rate of consumption. Research have shown that around half of all non-renewable resources mankind consumes are used in construction, making it one of the least sustainable industries in the world. In Europe, the built environment accounts for 40% of the energy and material consumption and waste generation, and further contributes around 35% of all CO_2 emissions (UNEP, 2009; Dixon 2010; Schoolderman et al., 2014). These assumptions are heavily alarming, knowing that our planet is not growing simultaneously. Therefore offering consumers a way to meet their needs and aspiration, with respect to the limits of the capacity the world has to offer, is the challenge in the future.

Vacancy in the Netherlands

Numerous types of societal heritage like churches, municipal monuments, schools or industrial buildings, are all illustrative examples of real estate with architectural, emotional or historical value. Due to their representative functions it is out of question to be eligible for demolishment. However, despite the emphasis on the importance of aforementioned societal value, the vacancy and dilapidation issues are remarkable. Currently this amount includes 2 million m2 of heritage buildings the Netherlands, and that the number is growing (AMS, 2016; BOEI, 2016).

Put in a different perspective, the real estate market is characterized by its static appearance, and the recent credit crisis accelerated consciousness to preserve the built environment. The ideology to improve the energy performance of heritage aims to provide a solution for global warming. Moreover new insights for redevelopment methods of intangible assets from perspective of the society help to accelerate new initiatives in a collaborative way.

Sustainability Context in the Netherlands

Traditional linear consumption patterns known as ‘take-make-dispose’ (Ellen MacArthur Foundation, 2015) are coming up against constraints on the availability of resources. The resource side is challenged to comply with rising demand from the world’s growing population and increasing welfare. Resources are mined without thinking about future generations of people and animals that need to survive on this planet. Calculations using ‘Ecological Footprint’ illustrate that the world is already using around 60% more biocapacity than the global ecosystems can provide in a sustainable manner (Global Footprint Network, 2017). A realistic prediction is that the global consumption of materials will triple by 2050 (UNEP, 2011). The result would be global resource depletion. Therefore, the main challenge for this research is to create a sustainable business concept based on circular redevelopment, in order to contribute to a sustainable environment.

Economic Context in the Netherlands

In addition to the aim for a solution to prevent climate change, the economic benefits provide an opportunity as well. While the idea of a circular economy is around for decades the current situation seems now more favorable than ever to take action. With the research ‘Kansen voor de circulaire economie in Nederland’ TNO stated that the circular economy potentially saves €7.3 billion and creates an opportunity for 54.000 jobs for the Dutch economy (Bastein et al., 2013).

By introducing a new perspective for redevelopment purposes, circularity from perspective of the current situation could benefit by diminishing the financial threshold. The second part of this thesis will elaborate a new approach for circular redevelopment.

Problem Statement

To move towards a circular economy for redevelopment opportunities, a lot of research still has to be done. This research focuses on the applicability of circular business concept in order to accelerate the reuse potential of societal heritage.

Currently the Dutch heritage is reluctant to participate in new investment alternatives for redeveloping real estate. Solutions to prevent vacancy and dilapidation like renovation and conversion regularly fail due to numerous reasons, for example due to the complex and inefficient redevelopment process and financial constraints. It is helpful to investigate the potential of available resources in buildings to reinvest during redevelopment of heritage. The phenomenon 'circular economy' could contribute and accelerate adaptive reuse of societal heritage.

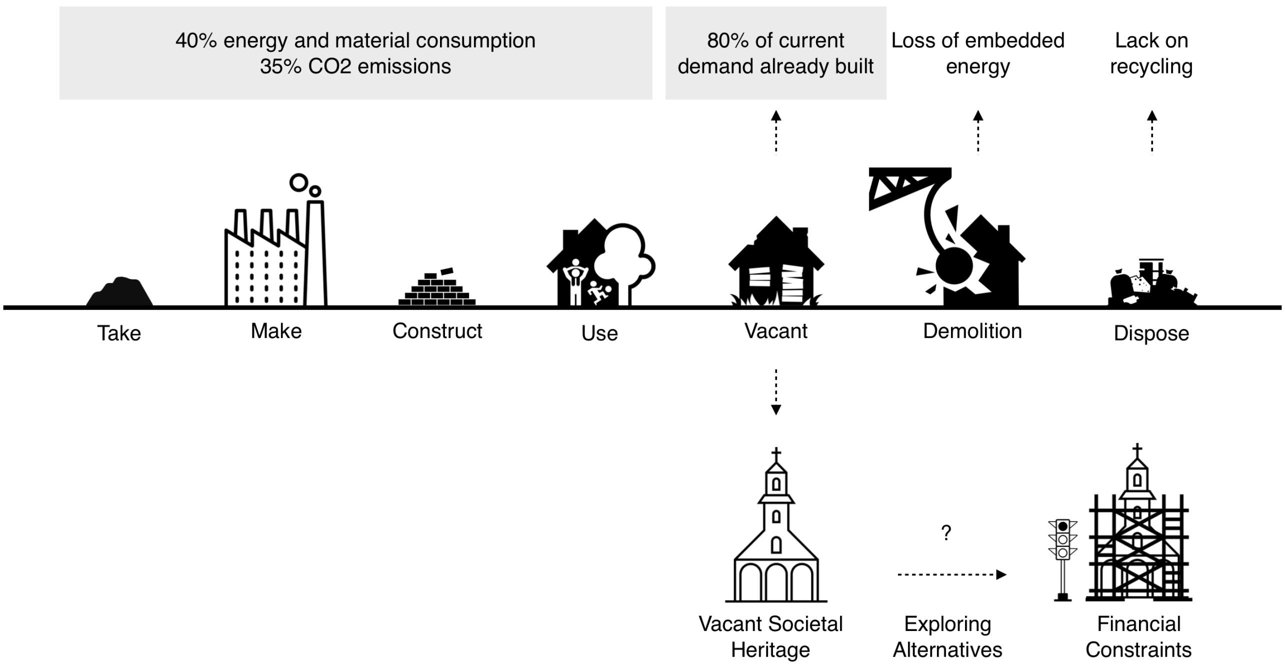

Figure 2.1: Visual explanation of problem statement (own illustration)

The term Circular Economy is a holistic approach and is subject to different meanings over time. Due to the complexity and the interrelations of the circular economy, no single definition or method to initiate circularity during the construction process could be given. The research of Circle Economy & IMSA (2013) recommends: ensure the circular economy is a simple measure of achievement as a first step for succeeding circular economy. This allows organizations to give incentives to their (chain) partners to become more circular in a large number of application, such as tracking progress (e.g. Key Performance Indicators (KPI's)), procurement decision, supporting internal decision-making or informing investments choices.

Until date, there is no unambiguous way to measure the reuse potential in the built environment. So, all initiatives, which are related to the transition from a linear to a circular economy, can't be compared to each other due to the lack of standardization of circularity.

Main Question

As defined in the problem statement, a widely recognized method for measuring circularity in the built environment is lacking. Therefore, the main objective of this explorative and design-oriented research is to assess circular redevelopment potential in order to initiate circularity during the redevelopment process. Within this perspective the comprehensive aim is to develop a tool which can be used as an instrument for principals (i.e. the client, searching for a highest and best use for the upcoming exploitation phase of the property) and identify a performance indicator within the built environment. Derived from the problem definition and objectives, the main question of this research is:

How could principals develop and implement the concept of circularity as a decision support instrument for the redevelopment initiation phase?

The sub questions are divided over both the current situation and future opportunities for redevelopment projects. In order to answer the main question, following sub-questions are formulated:

1. *What is the potential for circular economy in the built environment?*
2. *Which indicators are recognized to influence the reuse value of buildings' level of circularity?*
3. *How would de conditions for circular reutilization indicators be determined?*
4. *How to set up a circular redevelopment performance indicator assessment model?*
5. *What are the weighted variables for each indicator?*

Research Methodology

This thesis will be structured from both an empirical and operational perspective. Therefore several research methods will be used during the graduation process. With an exploratory approach, current strategies and determinants of the circular economy will be identified. Insights regarding new redevelopment opportunities in relation to organizational aspects will be presented according to the acquainted knowledge. Subsequently, the possible solutions will be explained through an operational model. Finally, the potential future alternative situation will be tested through a case study. The resulting research design is shown in figure 2.2.

Literature research will be used in order to identify the current situation - referred to as the status quo - in which redevelopment projects and circular economy are perceived two separated aspects within the built environment. Literature study is used to summarize prior research, critically examine contributions, explain results of prior research and clarify differences in alternative views of the past.

The conclusion extracted from the empirical study will be used as input for the operational model. This operational research provides insight for a possible future solution. The design of an operational model based on the circular redevelopment process is used to provide a guide for principals. The operational model is elaborated more thoroughly in Chapters 6 and 8.

Research Design

This research is structured in four different phases (Figure 2.2). The first phase is elaborating on various literature regarding adaptive reuse in the built environment and the fundamentals of the circular economy, and subsequently the applicable system integration among others.

The information gathered from the first phase will be set-up in a conceptual instrument. This second phase is about circular redevelopment in the built environment and the important indicators on which circularity could be assessed in the future. A circular redevelopment assessment model which is taking into account the indicators derived from the literature review and expert interviews is set-up.

Subsequently the validity of the model will be reviewed in phase three. Case studies will form an representative audit. The given indicators will be used to specify the buildings/products/materials reuse value based on its circularity. In addition, validation of the indicators can be extracted from these audits.

Finally, reflection on the final concept, and further the conclusions and recommendations for further research are elaborated. This research will be a small part of many other researches, but the strength is to verify the model and the outcomes from the research model.

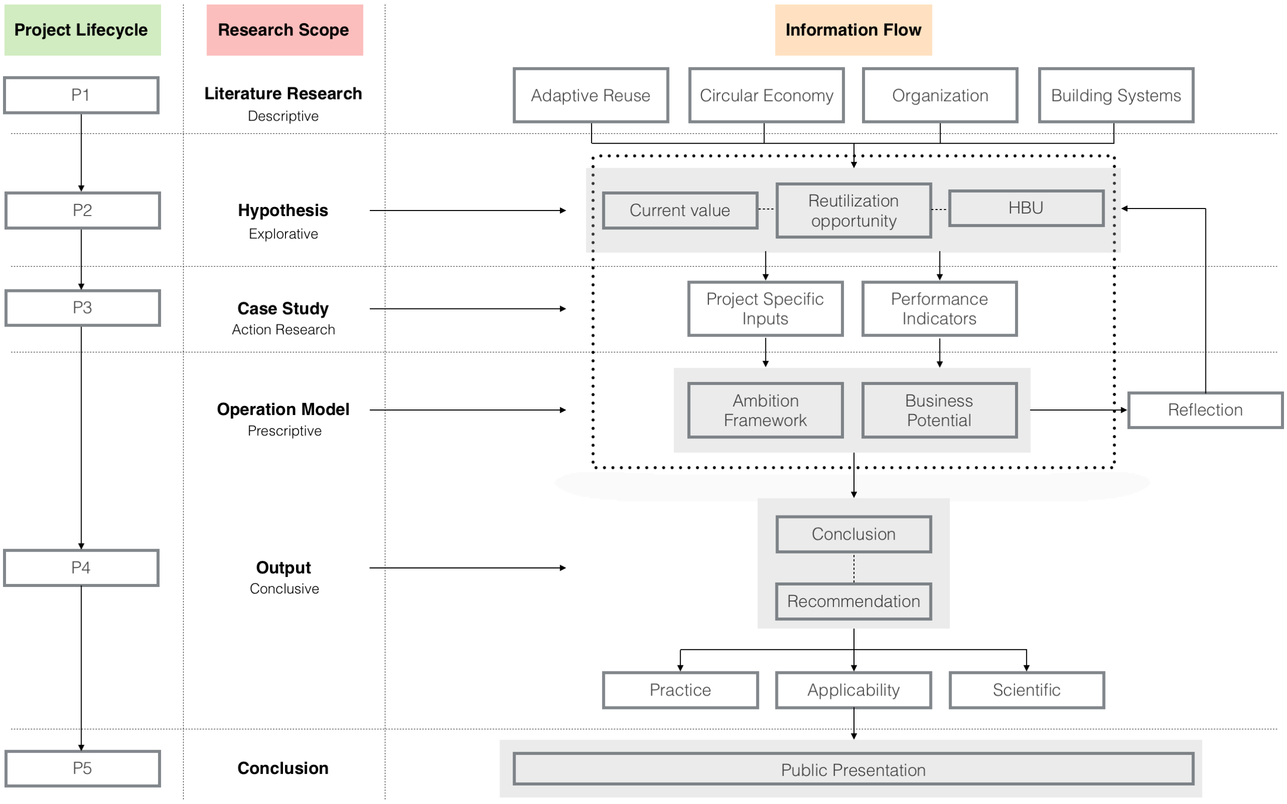

Figure 2.2: Research Design (own illustration) Introduction

Theoretical framework

This research focuses on two central themes, respectively the redevelopment projects and circular economy. These central themes represent the theoretical framework. The overarching aspect is to accelerate a transition from a linear economy towards a circular economy. The transition creates opportunities and threats to encounter.
Since the circular economy is about systems thinking and all interrelations between information, materials and processes, the creation of an analytic methodology and assessment tool requires a more narrow defined perspective:

- This building circularity index is based on the circular assessment method of the Ellen MacArthur Foundation & Granta (2015a) model, further developed by Verberne (2016) and is translated towards practical relevance;
- This instrument aims to identify the circular redevelopment potential based on the NEN 2767 condition rating wherein reutilization plays a role.
- The considered type of real estate for this instrument is limited to existing buildings due to their necessity to be handled accordingly. The outcomes will be reflected in terms of the applicability for other types of real estate later on;
- The focus of this research is limited to the technical cycles as per definition of the Ellen MacArthur Foundation (2015), defined by which products, components, materials are returning back in the highest quality as possible.

Main Research Outcomes

Literature Study

The role of adaptive reuse is important in this thesis. Adaptive reuse of buildings is a form of sustainable urban regeneration, as it extends the building's life and avoids demolition waste, encourages reuse of the embodied energy and furthermore provides significant social and economic benefits to the society. Adaptive reuse deals with the issues of conservation and heritage policies. Whilst old buildings become unsuitable for their programmatic requirements - since technology innovations, politics and economics are more dynamic than the built environment - adaptive reuse is seen as a suitable alternative to improve the financial, environmental and social performance of buildings (Wilkinson et al., 2014). Thus, it embraces the different dimensions of sustainability. Many authors have described definitions of adaptive reuse. Bullen (2007) stated it was “rehabilitation, renovation or restoration works that do not necessarily involve a change of use”, and that adaptive reuse “extends the useful life and sustainability in a combination of improvement and conversion”.

Working with existing buildings, repairing and restoring them for continued use has become a creative process and the main task of the architectural discipline. Nowadays, conversions and upgrades account for between 50 and 70 percent of all construction works (Cramer and Breitling, 2007, in Plevoets & Van Cleempoel, 2011) and due to economical and ecological conditions, adaptive reuse has gained importance ever since. The initiation phase of a redevelopment process needs more research and specific knowledge on technical aspects and the opportunities and constraints embodied by all materials and components of a building. Within this framework, the perception of a circular economy could be reflected in various degrees upon these factors.

Another important theoretical concept for this research relates to the circular economy. The circular economy outlines the capacity to rebuild capital, whether this is financial, manufactured, human, social or natural (Ellen MacArthur Foundation, 2015), and hereby aims to minimize waste cycles and downcycling materials. This means that the first step is repair and prolong the lifecycle, and subsequently reuse, refurbish, and recycling as shown in figure 3.1 below. The EMF splits both cycles into:

- Biological cycles; in which non toxic materials are restored into the biosphere while rebuilding natural capital, after being cascaded into different applications;
- Technical cycles; in which products, components and materials are restored into the market at the highest possible quality and for as long as possible, through repair and maintenance, reuse, refurbishment, remanufacture and ultimately recycling.

The central axis represents the linear production process, in which mining, production, manufacturing, transportation, consumption and finally waste are sustained. In addition to this current process, the ‘circular’ loops are enabling the potential of circularity with respect to maintenance, reuse, remanufacture, recycle, and minimizing the leakage of waste accordingly. In this way the dependency on depletable resources and the amount of construction and demolition waste can be minimized.

Derived from numerous research, various definitions of circular economy represent the notion of a circular economy, namely ‘the way of interpreting’ (the economic system red.). The open-ended system of a linear economy converts to a circular system when the relationship between resource use and waste residuals is considered, or in more general terms: output is input. This change in perspective towards circularity is important to address many of today’s fundamental challenges.

As mentioned above, the ‘butterfly model’ describes the loops returning to its origin in several consecutive phases in the system, respectively the biological and technical cycles. Due to the focus of this thesis, the redevelopment of existing built environment, most materials are not biodegradable in construction industry. Therefore this thesis will only focus on respectively the latter, technical side of the spectrum.

The necessity for an integrated network of information, materials and processes is crucial. A major consequence of taking insights from these integrated systems (networks) is the notion of optimizing systems rather than components, which can also be referred to as ‘systems thinking’ (Ellen MacArthur Foundation, 2015).

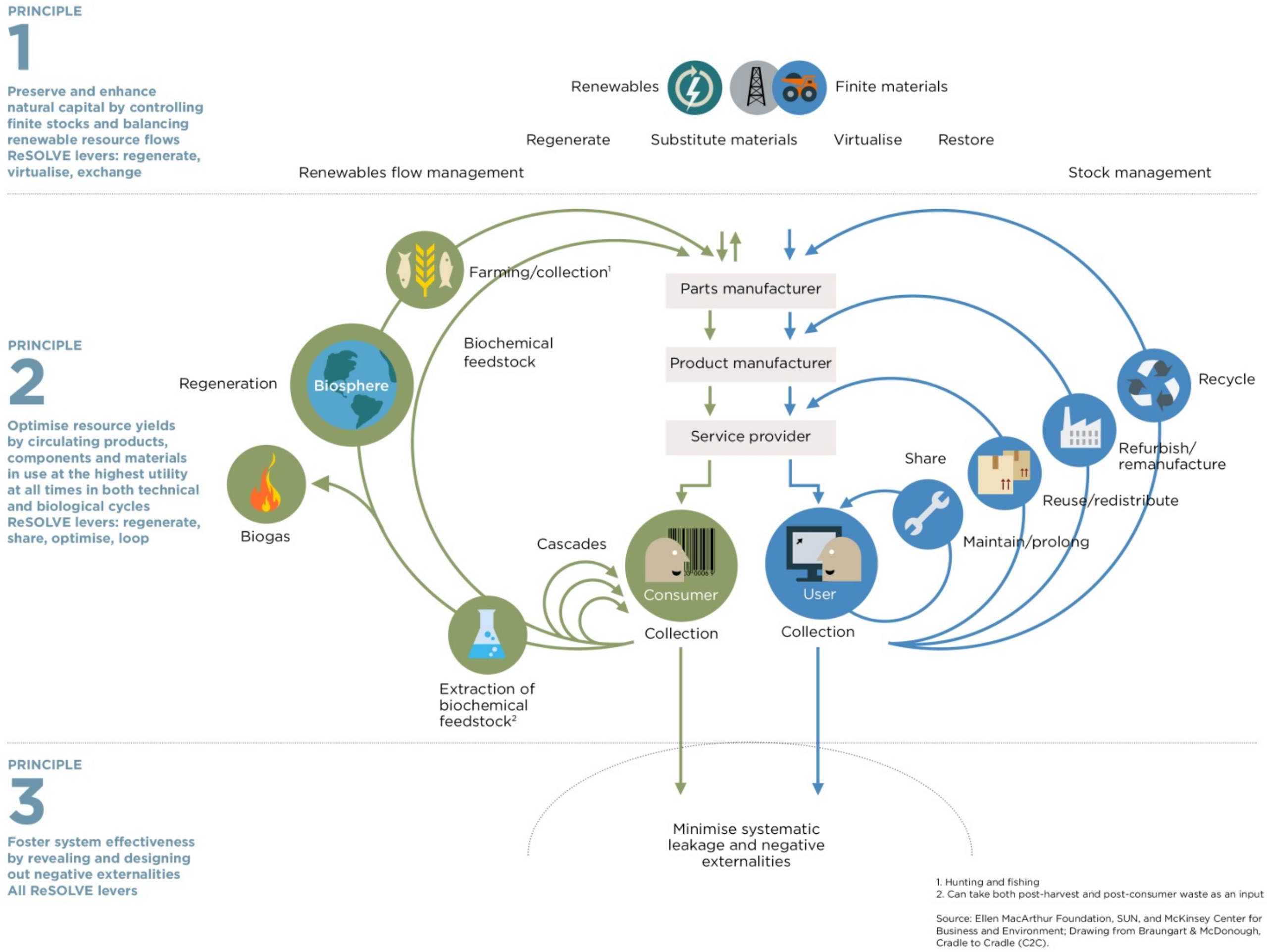

Figure 3.1: Outline of a circular economy (Ellen MacArthur Foundation, 2015).

From this perspective, currently available reutilization lists are structured. A distinction is made between various gradations of circularity. This starts with the highest level of 'refuse' and ends with the lowest level 'landfill'. It is perceived useful to indicate three main categories during implementation of reutilization within projects. Each indicator refers to a category 'to use and make products smarter (R0-R2), 'prolong the lifecycle of products and components' (R3-R7), and 'useful application of materials' (R8-R9). This will enable to distinguish the progress in terms of recycling in comparison with the progress on lifecycle enhancement and innovations for smarter applications of products.

Within the environment of strategic reutilization, another important insight of importance for this research is given. The discrepancy between the intended design resilience and technical performance is difficult to align in current industry. The notion of a building as a whole is still the common way of thinking (Beurskens & Bakx, 2015). However, on the longterm, the buildings are constantly adapting due to the changing user needs and changing environmental conditions. The "Shearing Layers" of Brand (1994), extended by Gibb et al. (2011) propose the following layers and corresponding default lifetimes:

- Surroundings: External influences, neighborhood, infrastructure, natural elements.
- Site: geographical setting, urban location, and legally defined lot (eternal);
- Structure: foundation and load-bearing elements (30-300 years);
- Skin: exterior surfaces (20 years);
- Services: installations; communication wiring, sprinkler, MEP, HVAC (7-15 years);
- Space plan: interior layout; walls, ceilings, floors and doors (3-30 years);
- Stuff: furniture; chairs, desks, phones, pictures, lamps (< 1 year).
- Social: People who actually use the building, function of the building as the people define it.

Each layer represents a conglomerate of building components with similar service lives, requiring change or replacement simultaneously. Generally, the proposed reutilization strategies of all similar components could be classified according to the above mentioned relevant building layer.

Another fundamental aspect is the circular assessment method of the Ellen MacArthur Foundation & Granta (2015a) model, further developed by Verberne (2016). The general idea behind the BCI is to look at two aspects, respectively the material index, and subsequently the way in which the materials and products are linked within the system. One of the main benefits for calculating with the BCI is the quantifiable data. Subjective factors that are related to the aesthetics of materials and products are not included in the assessment model.

The final part of the literature study relates to the use of condition assessment in the built environment. The NEN 2767 standard provides two aspects, respectively an assessment methodology, and a list of classification of faults. This standard aims to provide unambiguous and reliable information.

Integration of systems

Buildings are considered to be very complex products, which comprise numerous different materials, components, products and systems (site, structure, skin, services, space plan, and stuff) hierarchically structured with each a specific lifespan. They are initiated, designed, constructed and used as entities. However, over time, buildings are constantly adapting due to changing needs, user preferences and environmental conditions. Therefore, circularity indicators should be able to change indefinitely, from the present to the future. Resource efficiency and effective reuse strategies gradually improve due to innovations. Ultimately, an open and robust system for assessment is recommended, with the objective to ‘value’ available resources simultaneous to use it circularly. This ‘value’ (e.g. financial, physical or technical) - in which this research focuses on the technical value of product - will embrace the principles of the circular economy: (1) Design out waste, (2) Build resilience through diversity, (3) Rely on energy from renewable resources, and (4) Think in systems.

Circularity regards to the choices in terms of virgin material resources, the organization of modularity, the reusability of material and finally linked with either a sufficient information passport, bill of materials (BOM) or building information model. The collection, management and exchange of resource-related information is related to the fourth principle and prerequisite for the achievement of the other three principles.

Herewith, indicators that assess the influence on the buildings’ level of circularity could be created. These indicators could be divided in four different categories: (1) technical indicators, (2) functional indicators, (3) perception indicators and (4) economic indicators. Important is that the circular economy as per definition is about an economic value (as a driver), to provide balance between supply and demand (e.g. scarce resources) (Jansen, 2018). On the contrary, circularity on itself is mainly focused on the technical, functional and perception values. Within this perspective, technical indicators are related to the origin of material (virgin or reused materials), utility (lifetime and (dis)assembly) and material waste scenarios (level of reuse). The functional indicators refer to the applicability of materials such as location, availability, and accessibility. This could be defined as ‘attractiveness to use’. Finally, the perception indicator relates to the ‘attractiveness for the state of mind’ (aesthetical, exposure, comfort, acoustic, and light).

Due to the strong influence of one individual’s perception, the ‘attractiveness for the state of mind’ is highly subjective and therefore difficult to quantify. Moreover, this qualitative indicator aims to maximize the utility based on perceived prosperity or health, which is contradicting the effective (re)use of available resources at any time. Despite the recognized productivity of the materials by stimulating the state of mind and the utility which would both be beneficial for the buildings’ level of circularity, this indicator is excluded from this research.

In conclusion, the intended model yields two categories, which are respectively the technical values and functional values. The model integrates the information of BCI, NEN condition rating and representability weighting of spaces, and finally presents the resulting reutilization strategy for intervention. Within these categories, data of the applicable materials (BOM), their interfaces and connections (DDF) are categorized into 6 product-specific building layers for industry purpose (Brand, 1994).

The indicator is referred to as the 'Circular Redevelopment Potential Indicator' and could enable the first step towards a circular economy, starting with the existing environment. The application of this indicator provides structure and overview in order to enable the most beneficial strategy during the initiative for intervention. By dismantling the building in the applicable layers and specify the reutilization potential, the redevelopment of a building as a whole is manageable.

Literature studies and expert interviews showed specific interest for the functional process behind reuse. It was considered to be an interesting step in changing the way we deal with adaptive (component) reuse. One major benefit could be the reuse of intrinsic material values that lie enclosed in buildings. It was said that; 'even though it is not common practice, it is at least very helpful to know what the values are we are dealing with. A case study is executed to validate the assessment model and information necessary to accelerate circular redevelopment projects.

Final concept

The CRP indicator comprises 6 consecutive strategies which are assessed for each element; respectively (1) Reuse, (2) Repair, (3) Refurbish, (4) Remanufacture, (5) Repurpose and finally (6) Recycle. The first input of the CRP Indicator is the initiative for intervention. A principal or owner has a building in his portfolio which is either at its end-of-life or end-of-use phase. Intervention is needed in order to facilitate a new exploitation phase. From this perspective, the owner of a building will have to decide at what level the building/products/materials could be reutilized, i.e. respectively reused, repaired, refurbished, remanufactured, repurposed or recycled. The required information is provided through a Bill Of Materials. Identifying the degree of circularity starts with the assessment of applied material characteristics (BOM) and their relation and interfaces with all elements in the system (DDF). By combining this factor with the actual condition on site (NEN 2767), the applicable reutilization potential of an element could be developed. In accordance with the preferred representability of predefined spaces specific components are categorized if applicable. Altogether, this reflects the degree of circularity (BCI) of a building for a particular intervention. Figure A presents the overall concept of this assessment model, and further the resulting sequence of activities to clarify the assessment model of this research in one overview.

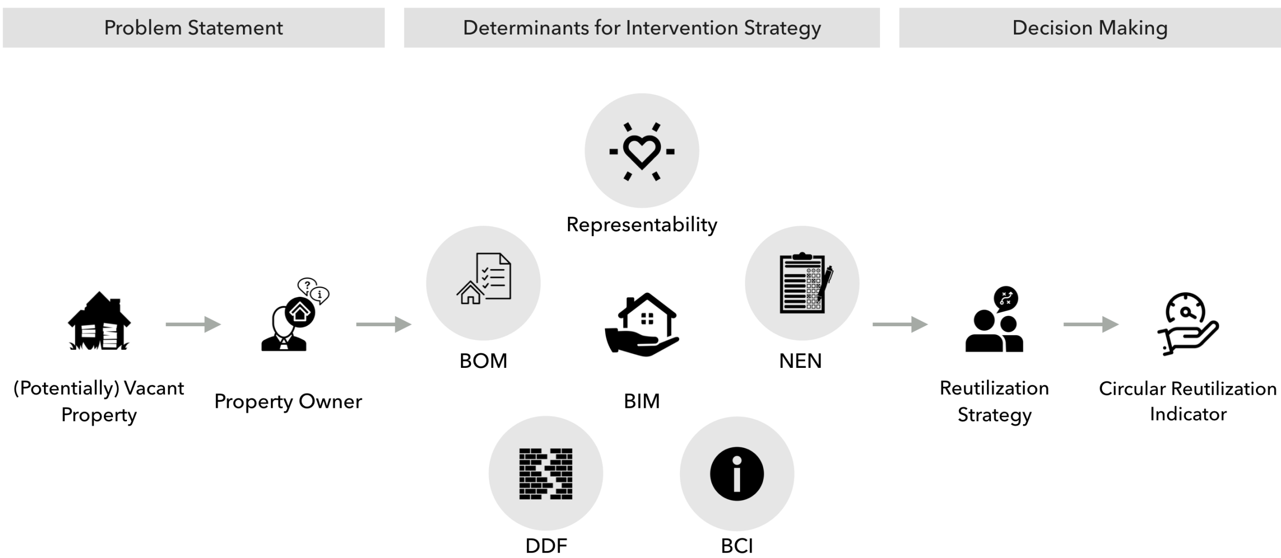

Figure 6.3: Visual presentation of the concept for circular redevelopment potential (own illustration)

Based on above mentioned information, the CRP Indicator is designed following a five step approach. The first step of the program relates to the '**information gathered into a BOM'**. All material characteristics and their configuration are employed in order to specify the applicable MCI (material level) and their relation and interfaces within the system (DDF), to combine into a

PCI for each element (product level). The second step for the actor is to ‘**classify any defects observed on site**’ according to the checklist as per the integrated ‘NEN 2767 Stappenplan’, and provide the associated ‘**representability factor**’ for the elements within each space.

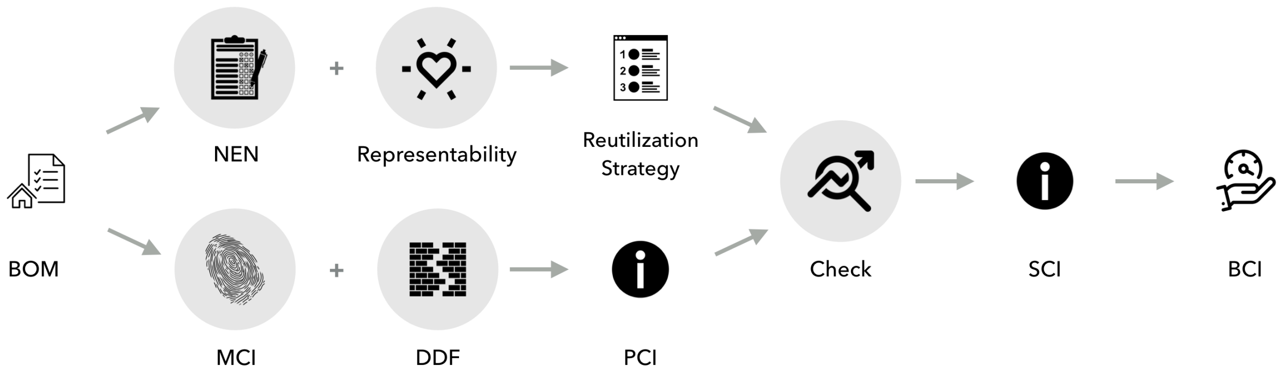

Figure A: Schematic overview of the information flow of the CRP Indicator (own illustration)

The applicable intervention strategies are subject to above mentioned aspects. This selection is based on the following options:

R3: Reuse the whole product;
R4: Repair and maintain to reuse the whole product in its current function;
R5: Refurbish and improve the old product for use in an improved version of its original function;
R6: Remanufacture the components into a new product with the same function;
R7: Repurpose the products or components for use in a new product with another function;
R8: Recycle materials in order to utilize them into new (preferably higher) qualitative products;
R9: Recover the embedded energy in materials by incineration.

Step 3 includes the adjustment of weighting to user preferences through a ‘**check on representability**’. For an organization the first step would be to clarify why the integration of circular initiatives (i.e. reuse of existing components and products) should be implemented, and on what areas this could be applied. These aspects could be related to function related criteria (e.g. the characteristics of an employees office or client-/ customer-specific appearance of an foyer). These criteria could help to determine the circularity potential or exclude one another by veto. The chosen decision for a certain intervention is a combination of circularity potential and the actor’s preferences .

Subsequently, step 4 provides the ‘**result on six strategies**’ for all products/elements within each building layer (SCI). Finally, the last step of the process relates to the **‘reutilization performance indicator’** (BCI). Based on the applicable elements, together with the given condition ratings and reutilization strategy, the indicator to what extent the intervention is circular is extracted.

The BCI incorporates the level of importance for circularity for all different systems. Deviant strategies can be pursued. Whenever elements are either linear or not demountable it is possible to determine a strategy to ‘upcycle’ the applicable element, and thereby resulting to ‘prolong the lifecycle’. The gradual increase of linearity and/or demountability of elements reflect on the attractiveness to either Repair, Refurbish, Remanufacture or Repurpose in between the two most extreme strategies (i.e. Reuse & Recycle). The extreme strategies will always be used to their assigned ‘excellent condition’ and ‘very bad condition’. However, on the contrary, other strategies could result less favorable due to the embodied energy in these products, despite their ‘acceptable’ or ‘moderate’ condition. For the purpose of this research, however, distinction is left out of the calculation method.

Conclusions and Recommendations

In order to solve the challenge discussed in literature, and further the situation in practice, the proposed CRP Indicator will help to provide insights for multiple actors during the redevelopment process and accelerate circular adaptive reuse. For example to which extent elements are integrated within the technical cycle and possible to further exploit by integrating waste as input for new business. Derived from literature study and expert interviews, the simple notion to reuse products to exploit its full technical lifecycle could be remarked perfectly circular at the moment of intervention. Herewith, the level of circularity is distinguished by different strategies.

Adaptive reuse is a form of sustainable urban regeneration, as it extends the building's life and avoids demolition waste, encourages reuse of the embodied energy and furthermore provides significant social and economic benefits to the society. Within this perspective, for a transition towards circularity - by means of the relationship between resource use and waste residuals - it is mandatory to gain insight into applied resources and embodied energy in existing built environment, opportunities of material flows, design of a product, and products' treatment.

Herein, the CRP Indicator is a useful tool for the assessment of properties to implement circularity during the redevelopment process. Building inspectors can provide property managers/owners with objective data about the applied material characteristics and corresponding condition status of building elements. Detailed surveyor manuals and the eyes of well-educated and experienced building inspectors remain important in getting condition data. To make use of the standard more reliable it might be necessary to provide references of the listed defects and intensities by visual examples.

The CRP Indicator is not designed as a goal in itself, but as an instrument to provide guidance in the decision making process. It supports principals to identify preconditions, in order to specify their ambition on circularity and provide the sufficient information to actually enable contractors to differentiate from their competitors during tenders. The assessment model is not intended as a certificate or label, however could be used as supportive instrument to substantiate any classification on this matter. In the end, the theoretical results of the model are compared with the results in practice via the case study of circular pavilion 'The Green House'.

The CRP Indicator is moreover not designed to benchmark circular redevelopment in order to compare projects with each other. Whilst this CRP Indicator focuses on circular redevelopment of a single building, additional methods regarding environmental sustainability and transformation strategies are focusing on a broader perspective of the real estate market, which in addition have nothing to do with circularity on its own.

Further research that builds upon this study can be for instance the operationalization of this assessment model. A study can be conducted that optimizes between investment costs, circularity and present component or material value of an asset. This way the ideal design can be obtained within the set by feasibility parameters. Another possible study could be empirical research on lifetimes of building elements/layers. From perspective of the derived values of reutilization strategies, the result from the stated condition ratings are manually provided. Additional research on weighting these variables and the sensitivity of stated cross references should be executed.

On terms of technology innovations, the use of advanced performance measurements, sensor technology and intelligent decision support systems to monitor and report on changes in the performance of building components is still in its infancy. Moreover performance profiles of building components depend on the local circumstances.

This model could fundamentally change the way in which chain partners communicate during the redevelopment process. Aligning interests, by focusing on the embodied energy of buildings, an accelerated shift towards circularity in the built environment could be achieved.

Table of content

Terminology

Before starting to read this research, it is perceived useful to clarify some terminology. A misinterpretation of these definitions could cause confusion while reading. This misinterpretation concerns the definitions explained below.

Definition of Condition Ratings

Abbrevation	Definition	Explanation
	(Natural) resource / virgin materials / raw materials / commodities	An output of what can be provided by planet Earth
	Material (e.g. Wood, Glass)	The outcome of which the input is a/are natural resource(s), subjected to energy/labour during the process.
	Component (e.g. Window frame)	The outcome of which the input is a/are material(s), subjected to energy/labour during the process.
	Element (e.g. Window)	The outcome of which the input is a/are component(s), subjected to energy/labour during the process.
	Product (e.g. Building)	The outcome of any of the previously mentioned processes, at the moment of it being transmissible. A collective term for either resource, material, part or component.
	Consumer product	The outcome of which the input is/are component(s) subjected to energy and labour during the process. This is the final result of the production process ready for consumption
BOM	Bill of Materials	A list of the raw materials, sub-assemblies, intermediate assemblies, sub-components, parts and the quantities of each needed to manufacture an end product
MCI	Material Circularity Index	The extent to which linear flows have been minimized and restorative flows maximized for the applicable material.
PCI	Product Circularity Index	
BCI	Building Circularity Index	The extent to which linear flows have been minimized and restorative flows maximized for the building's component systems, products and materials.
CRP	Circular Redevelopment Potential Indicator	Measures what level of reutilization of components, products and materials are applicable during adaptive reuse
DDF	Disassembly Determining Factor	Quantifies the interrelation of components within the system as a whole
DfD	Design for Disassembly	Design process that allows easier access to the materials, parts and products of a builidng when it is renovated and/or disassembled
DfAD	Design for Adaptability	A measurement of how well a design handles change.
NEN	Nederlandse Norm (Netherlands Standardization Institute)	Development of international and European standards and promotion of the use of standards and standardization within the Netherlands

Part I: An introduction for circular redevelopment

1. Research Background

1.1. INTRODUCTION

The first section illustrates the initiative and further background information of this thesis. First, the research context for this subject will be elaborated, followed with the research objective and problem statement. Conclusively the research questions are identified, to conclude with the research design, expected results.

1.2. RESEARCH BACKGROUND

The current environmental situation as a result of human life reflects the demand for more consciousness on the embedded energy of buildings. Moreover, due to the economic crisis the perceived naturalness to demolish existing buildings for new development is outdated.

With 80% of next century's building demand already built, it is essential to provide a sustainable solution by reusing this stock, and avoid vacancy and dilapidation. Hence, new functions should be accommodated in existing buildings, through sustainable adaptive reuse. However, traditional approaches are failing. Currently the feasibility studies for redevelopment projects do not consider the societal benefits related to heritage, which might be the solution for accelerating reuse potential. New, innovative business models are needed to enable maintenance and adaptive reuse of heritage buildings in order to fill up this 'investment gap'.

The knowledge regarding financing as well as business models is rather limited. Until date no clear and specific key indicators are identified (Van Velzen, 2009). Furthermore it was not possible to determine the market value of renovated heritage (in the Hague)(Barentsen, 2015). However, in order to enable politicians and the public to recognize the scale of the opportunity, the change it might bring will have to be put in perspective of health and safety.

The earth is increasingly suffering due to growth in both global population and human welfare. The world population is predicted to be 9.2 billion in 2050, and is expected to be centered to urban areas by 66 per cent in 2050 (United Nations, 2014). A growing population with higher average income requires more food, more industrial products, more energy and more water. The OECD shows that material use likely remains around 62 Gt today and is projected to reach 100 Gt by 2030 (OECD, 2017). These assumptions are heavily alarming, knowing that our planet is not growing simultaneously. Therefore offering consumers a way to meet their needs and aspiration, with respect to the limits of the capacity of the planet, is the challenge in the future.

Especially the environmental and societal benefits of heritage could be of major importance for the city's future. An attractive environment contributes to the joyful living of residents and ensures an healthy and safe environment. Therefore this research is limited to the extent of political and public intentions in relation to the private developer, and furthermore specifically focused on the sustainable innovations during redevelopment projects.

1.3. MARKET CONTEXT

The real estate market is characterized by its static appearance, and the recent credit crisis accelerated consciousness to preserve the built environment. The ideology to improve the energy performance of heritage aims to provide a solution for global warming. Moreover new insights for redevelopment methods of intangible assets from perspective of the society help to accelerate new initiatives in a collaborative way.

Given the previous mentioned aspects for a future sustainable environment, both the current market, sustainability interventions and valuation methods of societal heritage will be investigated.

1.3.1. Vacancy in the Netherlands

Numerous types of societal heritage like churches, municipal monuments, schools or industrial buildings, are all illustrative examples of real estate with architectural, emotional or historical value. Due to their representative functions it is out of question to be eligible for demolishment.
The societal value captured within cultural heritage is recognized by Jacobs since 1960: "New ideas occur in old buildings."(Jacobs, 1961). Multiple other authors validate the importance of cultural heritage (Florida, 2002; Marlet, Ponds, Poort, & Woerkens, 2015; Tallon, 2013).

Despite the emphasis on the importance of aforementioned societal value, the vacancy and dilapidation issues are remarkable. Currently this amount includes 2 million m2 of heritage buildings the Netherlands, and that the number is growing (AMS, 2016; BOEI, 2016).

Another issue to deal with is the so-called modern heritage. How to preserve this type of heritage, to guarantee accessibility for society and the opportunity to asses their value? Contrary to the available resources to preserve traditional heritage, a sufficient approach for this modern heritage is lacking (Scholte, 2015).

Local authorities could potentially fulfill a more decisive role in the solution for aforementioned vacancy and dilapidation issues. Due to the so-called 'participation society', which emerged from governmental policies, local authorities and public agencies are challenged to innovate and deal with smaller budgets. Further, the decentralization of responsibilities illustrate the spectrum in which municipalities have to deal. Cultural heritage could be deployed as incubator for more economic growth. Until date, the majority of renovation- or transformation projects fail due to multiple reasons like procedures or financial constraints (BOEI, 2009). The main question to be answered, how to act on the societal heritage which face the above mentioned vacancy and dilapidation issues?

1.3.2. Sustainability Context in the Netherlands

In the current linear economy we take, make, use, and dispose. Resources are mined without thinking about the future generations of people and animals that need to survive on this planet. Especially in the 20th century the increasing population and the simultaneous prosperity increase led to a massive growth in the mining and usage of building materials. Research shows that it has increased by a factor of 34 since the beginning of the 20th century (Bastein, Roelofs, Rietveld, & Hoogendoorn, 2013). In our current, linear economy, approximately 80 % of what we use is directly discarded after usage (Sempels & Hoffmann, 2013). Other research even concludes that over 99% of the total material flow generated in order to produce consumer goods ends up in waste disposal within 6 months (Hawken, 1999).

Traditional linear consumption patterns ('take-make-dispose')(Ellen MacArthur Foundation, 2015) are coming up against constraints on the availability of resources. The resource side is challenged to comply with rising demand from the world's growing population and increasing welfare. Nowadays, unsustainable overuse of resources, higher price levels and fluctuation on the markets are recognized. These findings are supported with research on the so-called 'biocapacity'. Whether further economic growth and increased consumption of resources will be possible is determined by this crucial factor: the limited capacity of the global ecosystems to provide us with biotic resources (e.g. cereals, fish and timber) and to absorb the waste and emissions we generate through our resource use. This capacity is called 'biocapacity' (WWF, 2008).

Calculations using 'Ecological Footprint' illustrate that the world is already using around 60% more biocapacity than the global ecosystems can provide in a sustainable manner (Global Footprint Network, 2017). The Ecological Footprint warns us that with our current level of resource consumption, we are already overusing the biological capacities of the global ecosystems. As shown in figure 1.1 below, the predictions for the 'Earth Overshoot Day' based on the current way of consumption - referred to as the day on which the global consumption is equal to 200% of the earth's bio capacity - is estimated on June 28th 2030. In other words: we are liquidating the 'natural capital' of the planet, instead of living on the sustainable interest from this capital.

A realistic prediction is that the global consumption of materials will triple by 2050 (UNEP, 2011). This way the earth cannot keep up with the rate of consumption. The result is global resource depletion. Therefore, the main challenge for this research is to create a sustainable business concept based on circular redevelopment, in order to contribute to a sustainable environment.

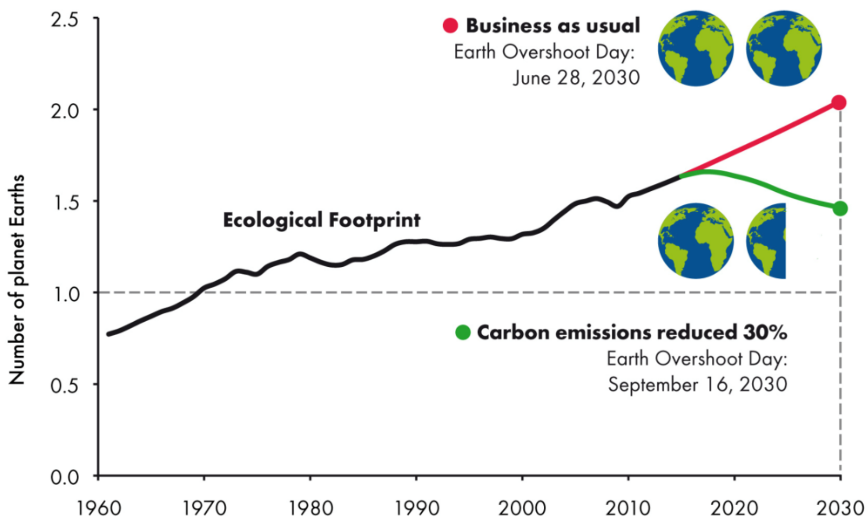

Figure 1.1: Global Ecological Footprint and forecasted Earth Overshoot Day (Global Footprint Network, 2017)

Beerda states that the problems that are occurring in the building sector are due to the long life/use cycle of buildings, ineffective leadership, and a poor organization. People and companies are afraid to change what is, in their eyes, already working fine (Beerda, 2014).

To move towards a circular economy for redevelopment opportunities a lot of research still has to be done. This research focuses on the applicability of circular business concept in order to accelerate the reuse potential of societal heritage.

1.3.3. Economic Context in the Netherlands

In addition to the aim for a solution to prevent climate change, the economic benefits provide an opportunity as well. While the idea of a circular economy is around for decades the current situation seems now more favorable than ever to take action. With the research 'Kansen voor de circulaire economie in Nederland' TNO stated that the circular economy potentially saves €7.3 billion and creates an opportunity for 54.000 jobs for the Dutch economy (Bastein et al., 2013). In a recent report to the World Economic Forum the Ellen MacArthur Foundation and McKinsey & Company concluded that the transition to a circular economy would create an opportunity in excess of 1 trillion USD for the global economy (Ellen Macarthur Foundation, 2014). These calculations created a huge awareness for the topic as many corporations seized their chance to get a part of this potential revenue opportunity.

Most research is done by investigating the so-called 'willingness to pay' with regards to cultural heritage. Within this perspective the notion to contribute to preservation by investing in cultural heritage is perceived beneficial for society. However there is a much wider spectrum than solely the buildings that should be preserved in their original state for future generations. According to Barentsen (2015), in the Netherlands new views on heritage preservation state that heritage should no longer be seen as isolated parts of society which should be protected from change.

'The new opinion about heritage preservation stimulates heritage to be an integrated and dynamic part of society. In this way heritage is believed to be an important catalyst for local economy. This change allows for buildings with a special cultural historic character to be re-designed or transformed after they lose function' (Barentsen, 2015).

Why do redevelopment- and renovation projects fail to be viable? The commonly known bottlenecks are complexity, uncertainty and significant risks related to redevelopment projects. These hazards are especially applicable for redevelopment projects, by changing the characteristics of an existing building to fit purpose for new functions. Therefore, redevelopment projects are perceived expensive and time consuming, even compared to renovation projects. However, this does not imply that renovation is always the best alternative. The best solution is subject to the equation of acquisition and investment necessary for the new function, together with the future value of this new function. The recurring bottleneck here is the financial feasibility of redevelopment or renovation.

"*A project is financially not feasible when the required returns on acquisition and necessary investments for redevelopment and exploitation are not met in a reasonable time frame with revenues of future use."* - Schmidt, 2012

Unfortunately the discrepancy of estimated value between property owners and redevelopers currently withholds the reuse potential of cultural heritage. From perspective of a property owner the estimated market value is usually based on the income approach, i.e. the generated income when fully functional. Contrary, the redevelopers calculate the potential of a property based on residual land value. As long as these two methods of calculating are not equivalent, the investment gap between perceived minimum price level for the property owner and maximum investment by redevelopers could hardly be closed.

By introducing a new perspective for redevelopment purposes, circularity from perspective of the current situation could benefit by diminishing the financial threshold. The second part of this thesis will elaborate a new approach for circular redevelopment.

2. Research Objective

2.1. PROBLEM STATEMENT

The previous introduction to the context enumerates the current situation of cultural heritage regarding the behavior on the real estate redevelopment market, sustainability interventions and valuation methods in the Netherlands. Important is the emergence of the consciousness to improve energy performance and financing structures to accelerate new initiatives in the future. Altogether, this leads to the following problem statement.

The current vacancy and dilapidation issues of heritage is widely recognized. The Netherlands' vacant cultural heritage, and simultaneously the quest for a more sustainable world has never been more urgent. Within this perspective the preservation of cultural heritage results with numerous societal benefits. Adapting cultural heritage to fit the changing needs of the society would increase the viability of heritage in use, and contribute to preserving heritage sustainably.

Currently the Dutch heritage is reluctant to participate in new investment alternatives for redeveloping real estate. Solutions to prevent vacancy and dilapidation like renovation and conversion regularly fail due to numerous reasons, for example due to the complex and inefficient redevelopment process and financial constraints. It is helpful to investigate the potential of available resources in buildings to reinvest during redevelopment of heritage. The phenomenon 'circular economy' could contribute and accelerate adaptive reuse of societal heritage.

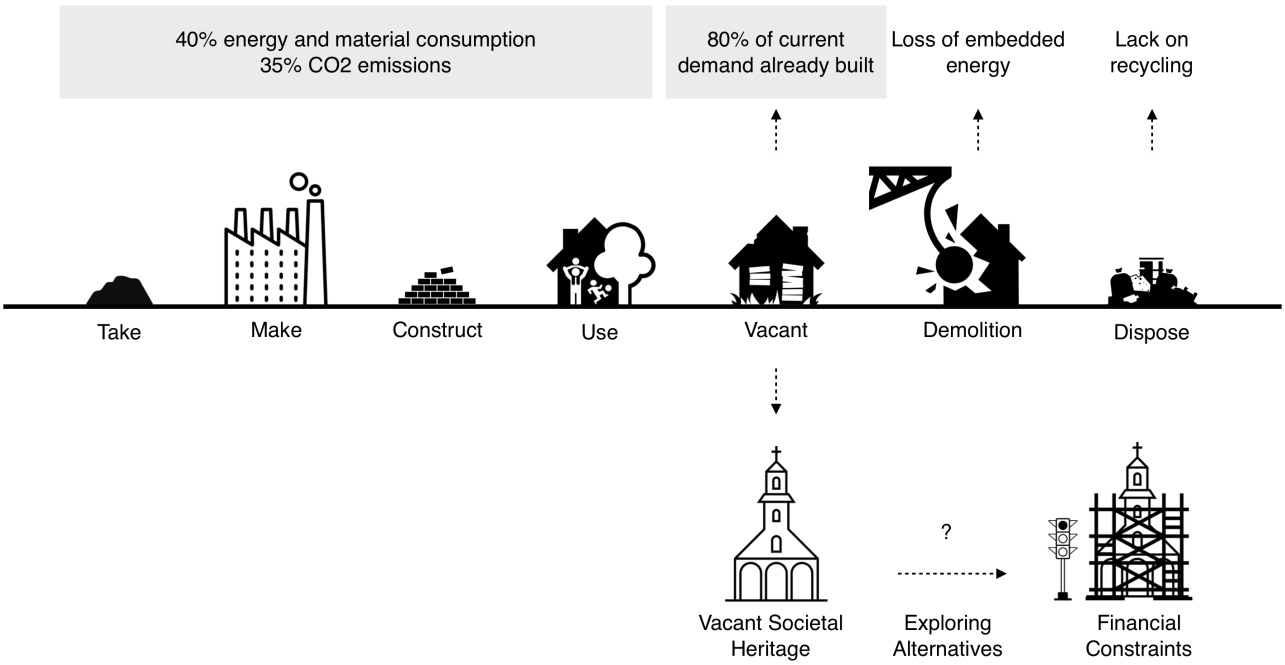

Figure 2.1: Visual explanation of problem statement (own illustration)

2.1.1. Towards Circular Cultural Heritage

The term Circular Economy is a holistic approach and is subject to different meanings over time. Due to the complexity and the interrelations of the circular economy, no single definition or method to initiate circularity during the construction process could be given. The research of Circle Economy & IMSA (2013) recommends: ensure the circular economy is a simple measure of achievement as a first step for succeeding circular economy. This allows organizations to give incentives to their (chain) partners to become more circular in a large number of application, such as tracking progress (e.g. Key Performance Indicators (KPI's)), procurement decision, supporting internal decision-making or informing investments choices. These various applications will require different types of metrics, based on different sets of data (Ellen MacArthur Foundation & Granta, 2015). Until date, there is no unambiguous way to measure the reuse potential in the built environment. So, all initiatives, which are related to the transition from a linear to a circular economy, can't be compared to each other due to the lack of standardization of circularity.

2.2. RESEARCH QUESTIONS

2.2.1. Main Question

As defined in the problem statement, a widely recognized method for measuring circularity in the built environment is lacking. Therefore, the main objective of this explorative and design-oriented research is to assess circular redevelopment potential in order to initiate circularity during the redevelopment process. Within this perspective the comprehensive aim is to develop a tool which can be used as an instrument for principals (i.e. the client, searching for a highest and best use for the upcoming exploitation phase of the property) and identify a performance indicator within the built environment. This allows principals to give incentives to their contractors to become more and more circular using a 'standardized language'. Through a transparent circularity assessment and a standardized language, contractors are encouraged to innovate their process and distinguish their product performance classification.

Derived from the problem definition and objectives, the main question of this research is:

How could principals develop and implement the concept of circularity as a decision support instrument for the redevelopment initiation phase?

2.2.2. Sub questions

In order to be able to understand above mentioned main question, first, the term 'circular economy' will be explained. Furthermore the motivation for redevelopment projects should be clarified. Subsequently, insight on the alternative decision-making instrument will be given, and ultimately the potential future situation can be identified according to the presented model. The sub questions are divided over both the current situation and future opportunities for redevelopment projects. In order to answer the main question, following sub-questions are formulated:

1. What is the potential for circular economy in the built environment?
2. Which indicators are recognized to influence the reuse value of buildings' level of circularity?
3. How would de conditions for circular reutilization indicators be determined?
4. How to set up a circular redevelopment performance indicator assessment model?
5. What are the weighted variables for each indicator?

2.3. METHODOLOGY

2.3.1. Project Scope

Since the circular economy is about systems thinking and all interrelations between information, materials and processes, the creation of an analytic methodology and assessment tool requires a more narrow defined perspective:

- This building circularity index is based on the circular assessment method of the Ellen MacArthur Foundation & Granta (2015a) model, further developed by Verberne (2016) and is translated towards practical relevance;
- This instrument aims to identify the circular redevelopment potential based on the NEN 2767 condition rating wherein reutilization plays a role.

- The considered type of real estate for this instrument is limited to existing buildings due to their necessity to be handled accordingly. The outcomes will be reflected in terms of the applicability for other types of real estate later on;
- The focus of this research is limited to the technical cycles as per definition of the Ellen MacArthur Foundation (2015), defined by which products, components, materials are returning back in the highest quality as possible.

2.3.2. Research Methodology

This thesis will be structured from both an empirical and operational perspective. Therefore several research methods will be used during the graduation process. With an exploratory approach, current strategies and determinants of the circular economy will be identified. Insights regarding new redevelopment opportunities in relation to organizational aspects will be presented according to the acquainted knowledge. Subsequently, the possible solutions will be explained through an operational model. Finally, the potential future alternative situation will be tested through a case study. The resulting research design is shown in figure 2.2.

2.3.3. Literature Research

Literature research will be used in order to identify the current situation - referred to as the status quo - in which redevelopment projects and circular economy are perceived two separated aspects within the built environment. Literature study is used to summarize prior research, critically examine contributions, explain results of prior research and clarify differences in alternative views of the past (Schwarz, Johnson, & Chin, 2007). This literature study is necessary in order to:

- Identify the context and current constraints of the linear redevelopment in the built environment
- Clarify the circular economy principles, and the beneficial aspects of such business models.
- Provide insights for an future alternative situation, on which the beneficial elements could provide a solution for the constraints of traditional redevelopment projects.
- Be able to compare the potential future alternative with the current situation.

During literature research the organizational aspects reflect the difficulties to provide a viable solution for reuse in order to understand the current situation. Directly related to the these difficulties, the determinants influencing the principals to reject the business opportunity are investigated.

In addition, the principles of a circular economy are investigated. By identifying an circular economy business concept, the outlines for an alternative future situation could be determined. Expert interviews are used to obtain exploratory information, systematically reconstruct the expert's experiential and professional knowledge and theory-generating information (Littig & Pochhacker, 2014). Eventually the key performance indicators related to redevelopment projects will help to define objectives to be considered within the operational model later on.

The model is based on multiple reports, respectively the material circularity indicators of the Ellen MacArthur Foundation & Granta (2015a), elaborated into a building circularity indicator by Verberne (2016), combined with the NEN 2767 (Netherlands Standardization Institute) condition assessment and developed into a decision support tool. The assessment model will give insights in the reuse potential value of circularity and will indicate how circular the building/product/material is.

2.3.4. Operational Research

This research will make use of a case study in which the redevelopment project is related to a circular business model. Operations research or management science is concerned with the science of decision and its application. In this domain the term *model building* refers to the process of putting together of symbols representing objects according to certain rules, to form a structure, *the model*, which corresponds to a system under study in the real world.

The conclusion extracted from the empirical study will be used as input for the operational model. This operational research provides insight for a possible future solution. The process related to operational research fundamentally deviates from empirical research. The empirical research focuses on the observations from the past, and 'describes' the situation. Contrary, the operational research results from a design process and 'prescribes' the improved future situation (Barendse, P., Binnekamp, R., De Graaf, R., Van Gunsteren, L., & Van Loon, P., 2012). This operational research is however supported with conclusions of aforementioned literature study and case study.

There is a wide range of problem-solving techniques and models applied in the pursuit of improved decision-making and efficiency, such as simulation, mathematical optimization multi-criteria analyzation models, such as the cost-benefit analysis, the multi-criteria analysis and the optimization analysis through lineair programming. The design of an operational model based on the circular redevelopment process is used to provide a guide for principals. It enables to verify the consequences of a certain decision on a particular moment in time (Rotmans et al., 1996; in Brouwer & Van Ek, 2004). Within this research the most applicable method would be the mathematical optimization. The operational model is elaborated more thoroughly in chapter 6 and 8.

The validation for the indicators will have a significant added value for the model and conclusions can be drawn of what the circularity is in the current status quo of the built environment and which information needs to be conducted in the future to accelerate circularity toward 2050.

2.4. PROJECT DESIGN

2.4.1. Research Design

This research is structured in four different phases (Figure 2.2). The first phase is elaborating on various literature regarding adaptive reuse in the built environment and the fundamentals of the circular economy, and subsequently the applicable system integration among others.

The information gathered from the first phase will be set-up in a conceptual instrument. This second phase is about circular redevelopment in the built environment and the important indicators on which circularity could be assessed in the future. A circular redevelopment assessment model which is taking into account the indicators derived from the literature review and expert interviews is set-up.

Subsequently the validity of the model will be reviewed in phase three. Case studies will form an representative audit. The given indicators will be used to specify the buildings/products/materials reuse value based on its circularity. In addition, validation of the indicators can be extracted from these audits.

Finally, reflection on the final concept, and further the conclusions and recommendations for further research are elaborated. This research will be a small part of many other researches, but the strength is to verify the model and the outcomes from the research model.

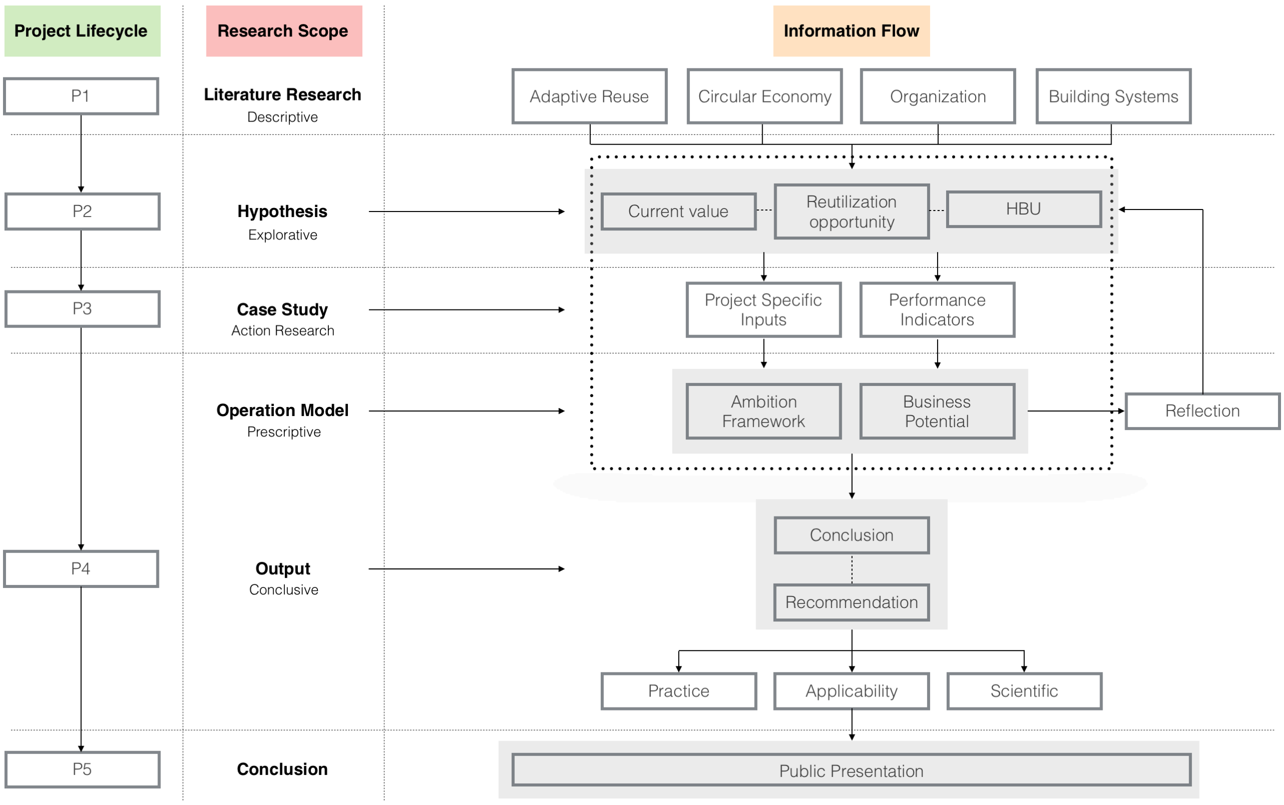

Figure 2.2: Research Design (own illustration)

2.4.2. Theoretical framework

This research focuses on two central themes, respectively the redevelopment projects and circular economy. These central themes represent the theoretical framework. The overarching aspect is to accelerate a transition from a linear economy towards a circular economy. The transition creates opportunities and threats to encounter.

Due to the intervention, new opportunities to develop circular projects arise. For example to which extent element are integrated within the technical cycle and used to further exploit the concept by integrating waste as input for new business. One of the conditions would be the limited investment capital, by reusing materials, referred to as 'urban mining'. The aim of this research is to contribute to the transition towards a circular economy, by starting with the currently existing situation and initiate circular redevelopment.

2.5. EXPECTED RESULTS

Since the vacancy and dilapidation of heritage concerns the socio-economic environment, most relevant target group to consider is the public. However, in order to solve this problem this research aims on the circular business model and moreover will be focused on incentives for the principal to initiate reutilization during the redevelopment project. Therefore research aims to identify and evaluate the circularity during redevelopment projects, and further to compare this set-up with traditional redevelopment projects in order to define the future financial and societal opportunities. The effect of the resulting decision support model will be observed through a case study.

2.5.1. Deliverables

The first and underlying objective of this research is to provide an alternative for demolition and new built. With a new reutilization concept based on the circular economy, a network of local economies could function more efficiently and result into a beneficial alternative for redevelopment.

Second objective is to clarify circularity in redevelopment projects from perspective of the organization. The most important part of this aspect is doing research into setting up a decision making tool for the principal. This tool needs to guide towards circular redevelopment with the emphasis on translation into performance indicators, which are more and more requested to stimulate innovation and to let contractors think about the optimization of the production and embracing collaboration in or between other industries. As a result of this performance indicator, current challenges and status of processing from a linear towards a circular economy could be measured. With the integration of waste of old production process into capital for new products a building can be the link between the two production lines.

One beneficial outcome could be the contribution to a better understanding for principals and governmental authorities how to optimize future redevelopment projects, and avoid further dilapidation and vacancy of heritage. Another favorable result would obviously be the environmental sustainability due to adaptive reuse of existing stock, and simultaneously to diminish disposal of waste from the built environment.

Due to the complexity and required knowledge for the reutilization of societal heritage and the use of circular economies as an aid, some criteria in terms of circular thinking have to be established. The same has to be done for the redevelopment process more specifically. These criteria will be given in the chapter results.

Part II: Theoretical Framework

3. Adaptive Reuse in the Built Environment

Ever since the Industrial Revolution of the 19th century and the great commercial building boom of the 20th century, numerous large, masonry buildings were created in order to facilitate the economic welfare. From brick factories to skyscrapers, these commercial buildings had specific purposes for their time and place. As society continued to change these buildings were left behind. In the late 20th century, many of these old buildings were simply demolished in order to enable new developments. However, perspectives on how to reflect on the existing built environment has changed. The economic crisis, demographic changes and increasing vacancy of real estate in the city urged society to question how to cope with the changing requirements in relation to the existing environment.

Adaptive reuse of buildings is a form of sustainable urban regeneration, as it extends the building's life and avoids demolition waste, encourages reuse of the embodied energy and furthermore provides significant social and economic benefits to the society. Thus, it embraces the different dimensions of sustainability. Many authors have described definitions of adaptive reuse. Bullen (2007) stated it was “rehabilitation, renovation or restoration works that do not necessarily involve a change of use”, and that adaptive reuse “extends the useful life and sustainability in a combination of improvement and conversion”. Bullen and Love (2011) define the concept as “[...] the process that changes a disused or ineffective item into a new item that can be used for a different purpose”. On the contrary, Douglas (2006) adopts a broader perspective on adaptive reuse by stating that adaptive reuse is “[...] any building work and intervention to change its capacity, function or performance to adjust, reuse or upgrade a building to suit new conditions or requirements.”

Adaptive reuse deals with the issues of conservation and heritage policies. Whilst old buildings become unsuitable for their programmatic requirements - since technology innovations, politics and economics are more dynamic than the built environment - adaptive reuse is seen as a suitable alternative to improve the financial, environmental and social performance of buildings (Wilkinson et al., 2014).

The types of buildings which most likely become subject of adaptive reuse are: industrial buildings, as gentrification transforms cities and the industry moves away from the centers; political buildings, such as palaces and buildings which cannot support current and future visitors of the site; and community buildings such as churches or schools where the use has changed over time among others.

3.1. ADAPTATION

Buildings follow a cyclical sequence. First the building is created in the initial phase. During operation phase the building’s future utility and value have to be assessed. Vacancy may occur in this phase when the building’s technical or functional characteristics are insufficient or if the cost in use exceeds the benefits of occupation. At this point a possible solution is to initiate a new process; converting the building and conduct major adaptations (Remøy, 2010). To state the definition of adaptation from the dictionary: ‘serving or able to adapt; showing or contributing to adaptation, like the adaptive coloring of a chameleon.

Generally, there are two types of adaptation of buildings: ‘within use’ and ‘across use’. Within use is defined as adaptation process a building undergoes to accommodate the original function. Across use adaptation occurs when a building is adapted to accommodate a different function (e.g. from office to residential functions). A complete overview of the options for adaptation is shown in Figure 2.1 below.

There are several factors identified which influence the decision-making to perform building adaptation. These are considered to be social, economic, environmental, legislative, location and physical factors. Figure 2.2 below shows a model to show all these factors and their relationship with building adaptation and each other (Wilkinson et al., 2014, pp. 21-22).

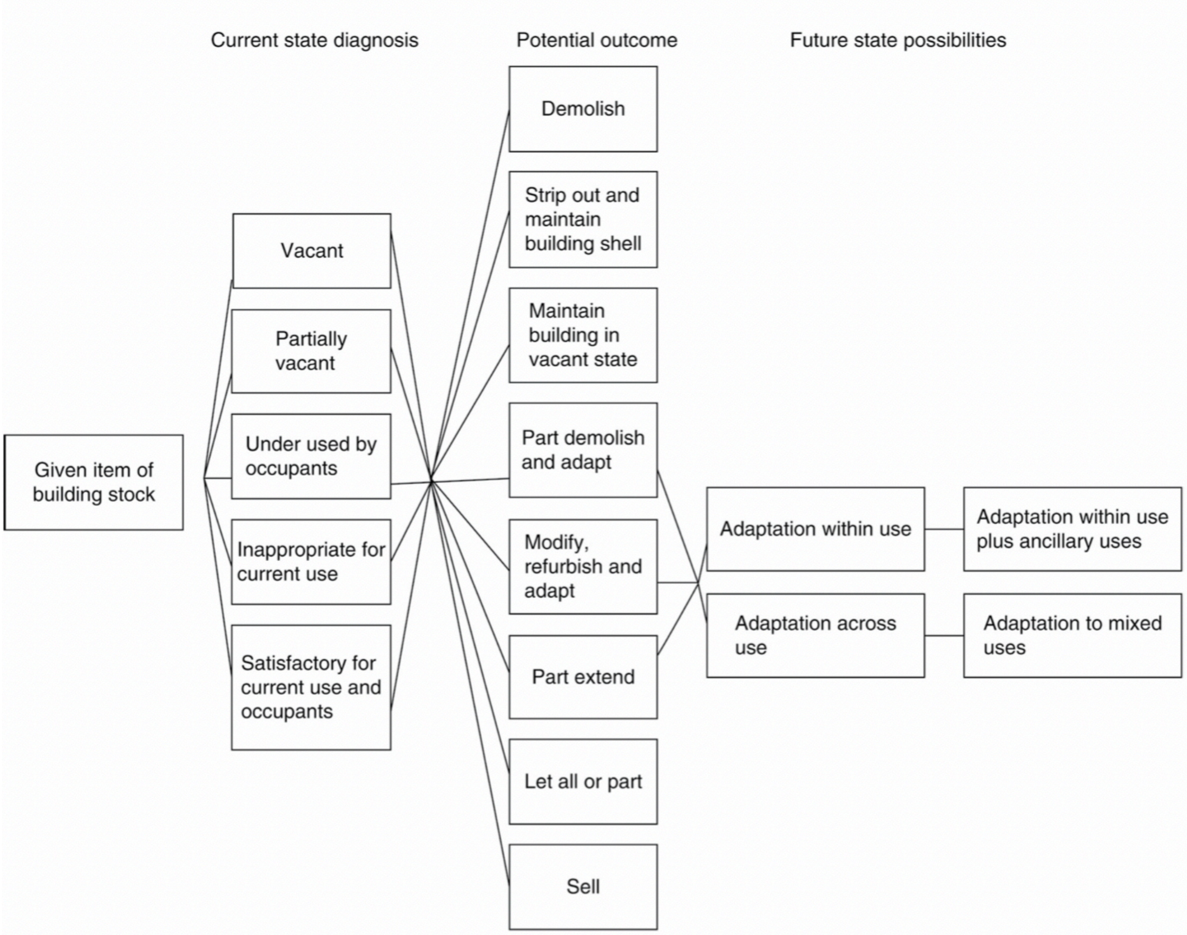

Figure 2.1 Options for adaptation (Wilkinson et al., 2014, p. 12)

3.2. SUSTAINABILITY PERSPECTIVE

Working with existing buildings, repairing and restoring them for continued use has become a creative process and the main task of the architectural discipline. Nowadays, conversions and upgrades account for between 50 and 70 percent of all construction works (Cramer and Breitling, 2007, in Plevoets & Van Cleempoel, 2011) and due to economical and ecological conditions, adaptive reuse has gained importance ever since.

Increasing the lifecycle of a building through reuse might lower the impact on material resources, transport costs and impact on the environment. Therefore it is perceived a contribution to sustainability (Bullen & Love, 2011). With global recognition of the considerable contribution adaptive reuse can make to sustainability (Bullen & Love, 2011; Douglas, 2006; Latham, 2000; Mısırlısoy & Günçe, 2016; Strumiłło, 2016; Van Giezen, 2013; Wong, 2016, in Slits, 2017), the practice of adaptive reuse has been placed in a primary position in the formulation of strategies for future-proof cities (Slits, 2017).

Moreover, to reduce environmental degradation and problems associated with resource depletion, it is necessary to identify the appropriate methods of dealing with aging building stocks in cities (Eames et al., 2014, in Udawatta et al., 2018). According to Wilkinson and Remøy (2011), there are social issues associated with structurally vacant buildings. Moreover, Bullen and Love (2010) pointed out that buildings should only be demolished if those cannot be converted due to technical or physical incapability. However, there are differences because a conversion process is more complex than a new build process due to the existing building and conditions. The increased complexity of adaptive reuse projects could potentially prolong project duration and increase uncertainty associated with the actual cost/value (Kurul, 2007, p.555). According to Kurul (2007) project complexity is one of the crucial barriers to participate in this sector of project development. Therefore, in order to resolve the issues at hand, this research aims to identify a new approach for circular redevelopment of the built environment.

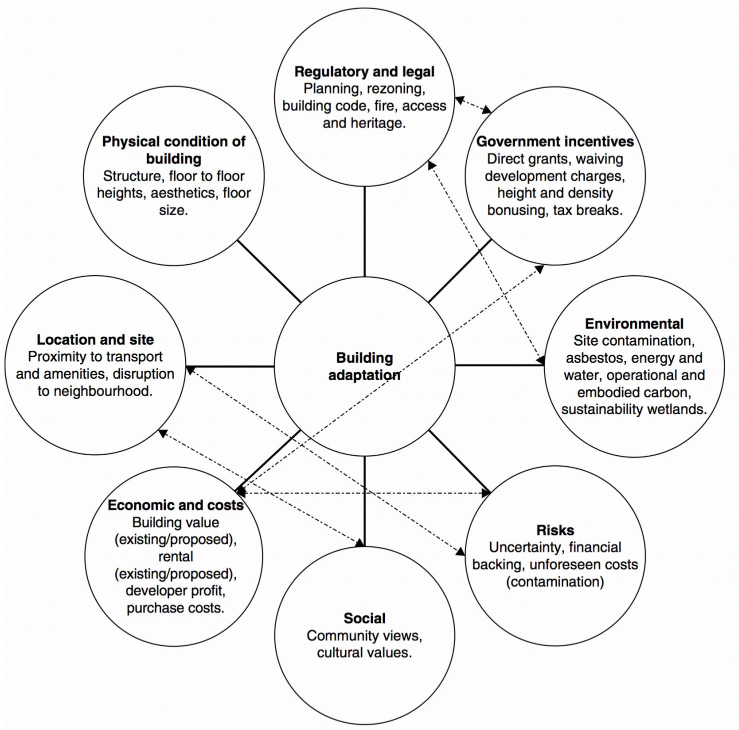

Figure 2.2 Model of decision-making factors in building adaptation (Wilkinson et al., 2014, p. 22)

Conclusion Adaptive Reuse

Adaptive reuse of the built environment is a complex process, consisting of many interrelated parts and involving many different actors, each with their own interest. Project complexity may be even a barrier for actors to participate in this segment of project development. This complexity has a strong influence on investment decisions. Due to the constant evolving development process with new, innovative methods, it is difficult to prescribe a set of specifications and preconditions to work with sequence of events. However, there are some opportunities to combine sets of data into a decision support model, to cope with the uncertainties. Walker (2003) created a conceptual framework to systematically handle the uncertainty in the decision-making process. Walker (2003) defines uncertainty as “any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system” and feels that a good decision support model has to provide the necessary (scientific) assistance.

The initiation phase of a redevelopment process needs more research and specific knowledge on technical aspects and the opportunities and constraints embodied by all materials and components of a building. Within this framework, the perception of a circular economy could be reflected in various degrees upon these factors. As highlighted by Wilkinson and Remøy (2011), there are number of attributes associated with adaptive reuse of buildings, such as: age, condition, envelope, structure, building services, internal layout, location, heritage, size, accessibility, parking and character/aesthetics. All these aspects could be divided under aforementioned social, economic, environmental, legislative, location and site and physical categories. From this perspective, circularity is an integral system and a holistic approach that focuses on the future by means of closing material and resources cycles, for which this research is limited to the technical cycles, in which products, components, materials are returning back in the highest quality as possible.

4. Circular Economy

The term circular economy has many definitions, of which are many different interpretations. Kirchherr et al (2017) defined no less then 114 definitions. This chapter elaborates on the definition of a circular economy used throughout this research. The first section enumerates the original notions, widely recognized by different researchers and subsequently a global perspective on the definition will be given. In the third part, the principles of a circular economy are elaborated. Subsequently inherent business models are elaborated in a various ways of thoughts.

4.1. ORIGIN OF THE CIRCULAR ECONOMY

The term circular economy emerged quite recently in 2010, but already established itself as the new revolution to improve our society for the future generation. The Dutch Government-wide program for a Circular Economy is aimed at developing a circular economy in the Netherlands by 2050 (Dutch Government, 2016). The concept has complex deep-rooted origins, for which cannot be traced back to one author or publication. For that reason, more than one definition of a circular economy exists. This paragraph provides an overview of the most common definitions in order to clarify the perspective on the circular economy used during this research.

It gained public momentum in the late 1970s with the research report of Stahel and Reday-Mulvey '*Jobs for tomorrow: The potential for substituting manpower for energy*' to the European Commission. There are various schools of thought that follow, partially overlap and reinforce each other in refining and developing the concept of the circular economy. The most extensively researched and widespread schools of thought are Industrial Ecology and C2C, for which this research will be elaborate more thoroughly.

The first concept of a circular economy has its conceptual roots in **industrial ecology**. There is no standard definition of Industrial Ecology, however it envisions the benefits of recycling residual waste materials and by-products through the development of interrelated projects. The notion of 'Industrial Ecology' was defined by Ayres, Frosch & Gallopoulos (1989) and seeks the opportunities for waste- and pollution reduction in the material-intensive industries through:

- Waste mining
- Dematerialization
- Repair, re-use, remanufacture and recycle
- Design for the environment: Products should be designed for disassembly, reuse and minimal impact on the environment
- Substitute scarce materials by renewable materials
- Reduce, and with time eliminate heavy use of non-biodegradable materials

According to Andersen: "Benefits will be obtained, not only by minimizing use of the environment as a sink for residuals but more importantly by minimizing the use of virgin materials for economic activity" (Andersen, 2006). In industrial ecology, it is implied that a circular economy will be beneficial to society and to the economy as a whole. Its principles have been applied to products, organizations and regions. It examines societal issues and their relationship with both technical systems and the environment. Within this perspective, Industrial Ecology recognizes that solving problems must involve understanding the connections and interfaces that occur between systems, various aspects cannot be viewed in isolation.

McDonough & Braungart (2002) defined in their publication 'Cradle to Cradle: remaking the way we make things', a new concept referred to as **Cradle to Cradle (C2C)**. This is a new approach for designing intelligent products, processes and systems taking into account the entire life cycle of the products, optimizing material health, recyclability, renewable energy use, water efficiency and quality, and social responsibility. They made a distinction between the biological nutrients, designed to re-enter the biosphere safely and technical nutrients, which are designed to circulate at high quality without entering the biosphere.

As long as human beings are regarded as "bad", zero is a good goal. But to be less bad is to accept things as they are, to believe that poorly designed, dishonorable, destructive systems are the best humans can do. This is the ultimate failure of the "be less bad" approach…" - McDonough & Braungart (2002, p. 67).

According to McDonough & Braungart doing less bad isn't good enough (2002), and stated that current sustainability focus isn't enough to really protect the planet. Therefore they introduced a new strategy of eco-effectiveness. The concept moves from the perspective of incremental change and 'doing more with less' (eco-efficiency) towards the designing of industrial systems to be "commercially productive, socially beneficial and ecologically intelligent" (eco-effectiveness).

It should not be the aim to use less fossil fuel (eco efficiency) to no fossil fuels, but switching to renewable sources. By merely diminishing problems whilst simultaneously an enormous growth of the world population, it's still not tenable. Eco-effectiveness is fundamentally based on a cyclic approach of an integrated system like nature, and is therefore the equivalent to the circular economy. An eco-effectiveness approach pursues a positive footprint for social- and environmental economics, which also applies to the circular economy principles.

Other, rather early notions of circular systems are representing the underlying schools of thought of a circular economy, but are less extensively researched and therefore described briefly:

The **regenerative design** was defined by Lyle in the early nineties. The concept of regenerative design is a process-oriented systems theory. The term "regenerative" describes processes that restore, renew or revitalize their own sources of energy and materials, creating sustainable systems that integrate the needs of society with the integrity of nature. The following principles could be derived (Lyle, 1994):

- Operational integration with natural processes and by extension with social processes;
- Minimum use of fossil fuels and man made chemicals except for backup applications;
- Minimum use of non-renewable resources except where future reuse or recycling is possible and likely;
- Use of renewable resources within their capacity for renewal;
- The environment should be able to absorb the composition and volume of waste without damage.

The model is meant to be applied to many different aspects of human society such as urban environments, buildings, economics, industry and social systems (Lyle, 1994).

The **functional economy** as defined by Stahel (1997) aims for optimization of the use value of goods and services for the longest possible period of time while consuming as few material resources and energy as possible.

- The smaller the lifecycle loop of a product or material, the more economically pro table and resource efficient it will be: The more a product or material could be re-used after it expires its original use, the more the material's productivity and longevity will be.
- Product or material loops have no beginning and no end: Waste does not exist. The stock of existing goods within the loop should be constantly monitored and optimized in order to maintain value.
- Reduction of the speed of the resource flows: Long life goods increase the efficiency of managing the existing stock of materials. Through cascading and cannibalizing, new product could be derived from waste.
- Reduction of volume of the resource ow: Goods should be modular and multifunctional.
- Reduction of the volume and speed of the resource ow: Selling service instead of goods.

Benyus (1997) defined the concept of **biomimicry** which is derived from nature. The core idea is that nature has already solved many of the problems we are dealing with. Animals, plants, and microbes are the consummate engineers. So biomimicry contains the study of what we can learn from the nature instead of what we can extract from it of which following principles could be found:

- Evolve to survive: Strategies that are proven to work, should be replicated and improved.
- Be resource (material and energy) efficient: The use of multi-functional design and low energy processes should be stimulated. All used materials have to be recycled.
- Adapt to changing conditions: Maintain integrity through self-renewal, and embody resilience through variation, redundancy, and decentralization
- Use life-friendly chemistry
- Be locally attuned and responsive
- Integrate development with growth: build from the bottom-up

The **blue economy** is a philosophy defined by Pauli (2010) of alternative business models by using cascading systems in which waste forms the input to create new cashflows. It is an open-source movement bringing together concrete case studies. One recent example in practice is BlueCity in Rotterdam, the Netherlands. Blue economy has a total of 21 principles, of which the most important ones have been listed below:

- Substitute something with nothing: Question any resource regarding its necessity for production.
- Natural systems cascade nutrients, matter and energy, by means waste does not exist. Every by-product could be the beginning for a new product.
- Use what locally is available
- Nature provides room for entrepreneurs who do more with less: Nature is contrary to monopolization.
- Nature is constant in change: Innovations take place in every moment.
- Natural systems are interconnected and evolve towards symbiosis.

The four principles and typical characteristics are shown in Figure 3.2 below (Djoegan & Van Reek 2016). This shows how the different schools of thought are related to each other within the concept of a circular economy. This relation will be discussed further during the next section.

4.2. THE DEFINITION

“A circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the end-of-life concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse and return to the biosphere, and aims for the elimination of waste through the superior design of materials, products, systems and business models.“ - Ellen MacArthur Foundation (2012)

The Ellen MacArthur Foundation was launched in 2010 to accelerate the transition to a circular economy. The developed concept of ‘Circular Economy’ refers to a new economic and industrial system in which (raw) materials and components are kept on their highest value. Ellen Macarthur Foundation illustrates the continuous flow of technical and biological materials through the ‘value circle’. The circular economy outlines the capacity to rebuild capital, whether this is financial, manufactured, human, social or natural (Ellen MacArthur Foundation, 2015). This means that the first step is repair and prolong the lifecycle, and subsequently reuse, refurbish, and recycling as shown in figure 3.1 below.

The circular economy is in principle a industrial economy with the intention to strive for resilience. She is based on the closure of chains and realization of (infinite) recursive cycles. The circular economy invites to extract from renewable energy, minimizes the burden on the ecological system, eliminates emissions of toxic substances and assumes waste could be the start of a successive lifecycle, and reuse is initiated during the design phase.” - Schoolderman et al. (2014, p. 17).

As presented, the EMF splits both cycles into:

- Biological cycles; in which non toxic materials are restored into the biosphere while rebuilding natural capital, after being cascaded into different applications;
- Technical cycles; in which products, components and materials are restored into the market at the highest possible quality and for as long as possible, through repair and maintenance, reuse, refurbishment, remanufacture and ultimately recycling.

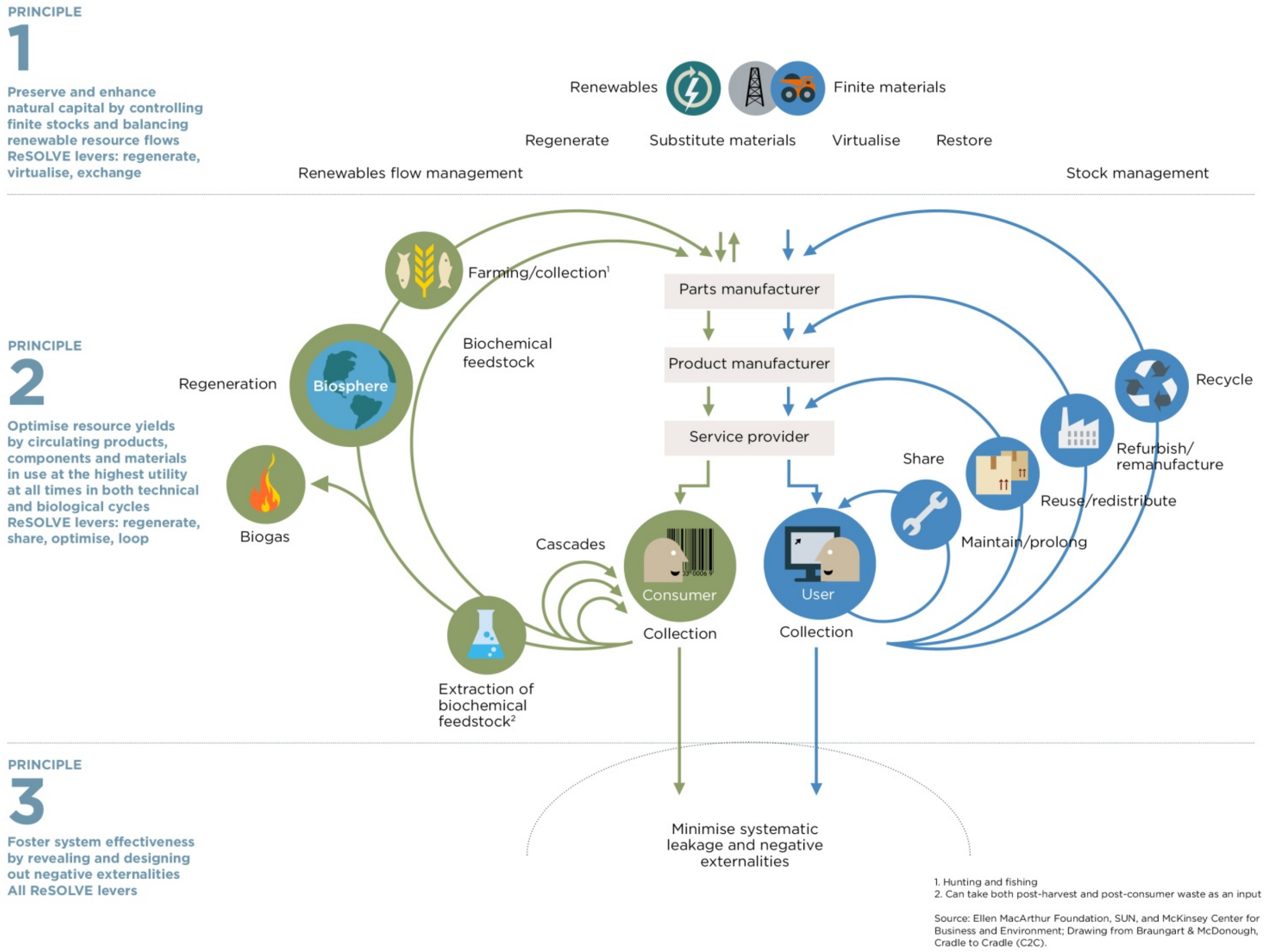

Figure 3.1: Outline of a circular economy (Ellen MacArthur Foundation, 2015).

The central axis represents the linear production process, in which mining, production, manufacturing, transportation, consumption and finally waste are sustained. In addition to this current process, the 'circular' loops are enabling the potential of circularity with respect to maintenance, reuse, remanufacture, recycle, and minimizing the leakage of waste accordingly. In this way the dependency on depletable resources and the amount of construction and demolition waste can be minimized.

Ever since the Ellen MacArthur Foundation (EMF) introduced their report '*Towards the Circular Economy Vol I'* (2012), it has been the leading reference in defining the term circular economy. Many definitions of the circular economy are derived from the one stated by the EMF, a selection of the more common definitions is given:

"The circular economy is an economic and industrial system that uses the reusability of products and materials, and the regenerative ability of natural resources as starting point, minimizes the value destruction in the complete system, and pursues value creation in every loop or chain of the system." - Bastein et al., (2013)

“A circular economy builds on stock optimisation, decoupling wealth and welfare from resource consumption while creating more work. It tackles many of the issues from the linear economy in a bottom-up approach by introducing new private sector business models of the circular economy, such as ‘reuse, repair and remanufacture instead of replace’, and ‘selling goods as services’.” - Stahel (2012)

As can be noted in previously stated definitions by the several authors, various definitions of circular economy represent the simplistic notion of a circular economy, namely ‘the way of interpreting’ (the economic system red.). The open-ended system of a linear economy converts to a circular system when the relationship between resource use and waste residuals is considered, or in more general terms: output is input.

As mentioned above in Figure 3.1, the ‘butterfly model’ describes the loops returning to its origin in several consecutive phases in the system, respectively the biological and technical cycles. Due to the focus of this thesis, the redevelopment of existing built environment, most materials are not biodegradable in construction industry. Therefore this thesis will only focus on respectively the latter, technical side of the spectrum.

The necessity for an integrated network of information, materials and processes is crucial. A major consequence of taking insights from these integrated systems (networks) is the notion of optimizing systems rather than components, which can also be referred to as ‘systems thinking’ (Ellen MacArthur Foundation, 2015). To compute a more comprehensive clarification of the circular economy, the principles will be elaborated further.

4.3. PRINCIPLES

The principles of the circular economy have derivative characteristics based on various schools of thoughts such as *Industrial Ecology* (Forsch & Gallopoulos, 1989), *Regenerative design* (Lyle, 1994), *Functional economy/Performance economy* (Stahel, 1998, 2010), *Biomimicry* (Benyus, 1997, 2002), *Cradle to Cradle* (Braungart et al., 2002) and the *Blue Economy* (Pauli, 2010).

Djoegan en Van Den Reek (2016) have clarified the relation of the concept of Ellen MacArthur foundation with the six aforementioned, earlier schools of thought. The principles described by the EMF can all be directed to the principles of these six schools of thought (figure 3.2).

Four principles are defined. The first principle ‘**design out waste/ waste equals food**’ relates to the notion of diminishing waste streams during the design process. Waste does not exist when the biological and technical components of a product are designed by intention to fit within a biological or technical materials cycle, designed for disassembly and refurbishment. The principle indicates that every product follows a path where it starts, for instance, as building material and after it’s full technical life cycle returned as resource material for something else and therefore is ‘food’ for new purposes. The product continually makes new starts, implying the closed material loops. Materials are by definition not toxic or harmful for the environment, in which biological substances could be given back to earth, and contrary, all technical substances are designed in order to remain recursive indefinitely.

The second principle ‘**build resilience through diversity**’ refers to resilience. It concerns the adaptivity and modularity of systems (e.g. resources, components, products) and reflects the capacity of a system to recover from disturbances. The degree in which a system is adaptable determines which ways it can be utilized. For example, a product is easier to be reused when it can be disassembled to the level of resources or materials, than a product that can only be disassembled into parts. A circular economy benefits from this diversity and derives its strength. Modularity, versatility, and adaptively are prized features that need to be prioritized in an uncertain and fast-evolving world (Ellen MacArthur Foundation, 2015).

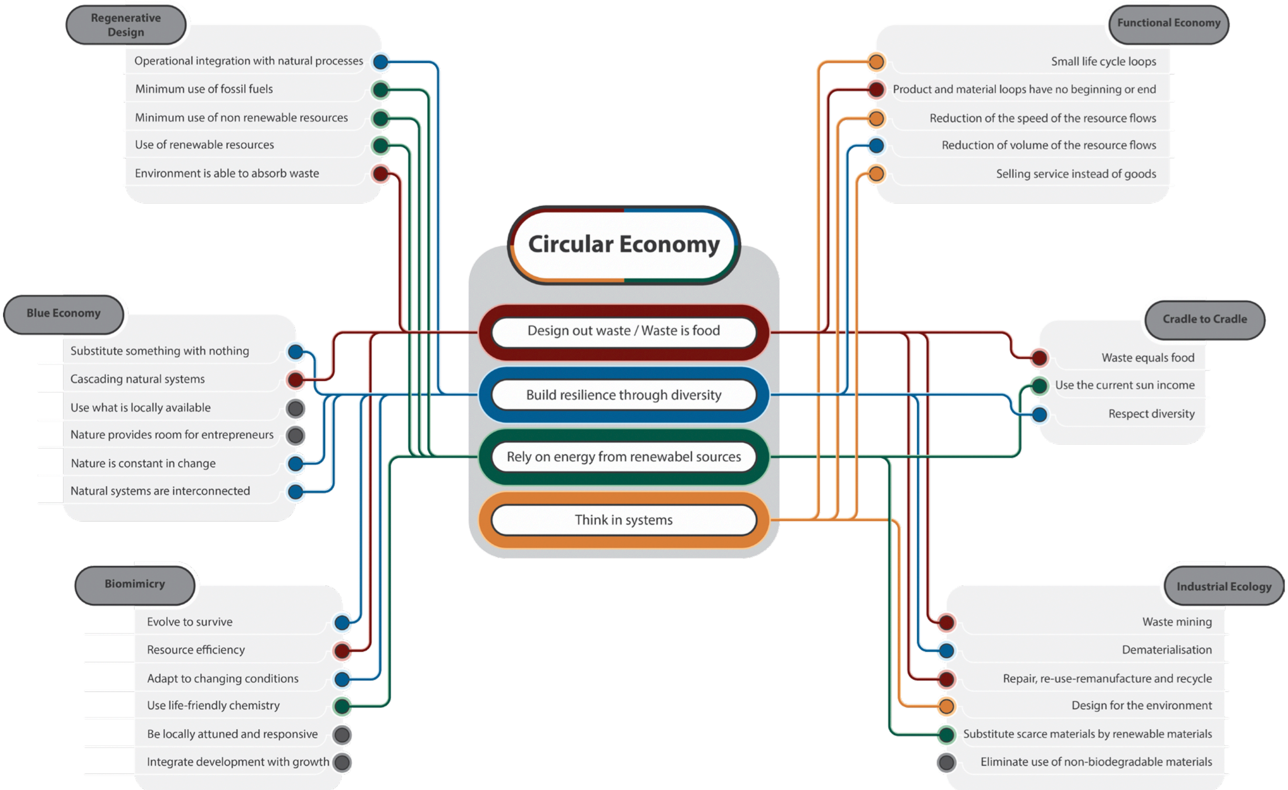

Figure 3.2: Principles of a circular economy (Djoegan, C.E.S., Van Reek, D.L., 2016).

As per the third principle, to ‘**rely on energy from renewable sources**’, the required energy for all systems should ultimately aim to run on renewable sources, since energy also has a material footprint. Fossil fuels and other non-renewable energy sources cannot restore their original sources. Contrary, wind mills or PV panels can be restored to elementary material flows and ultimately used for other energy production systems in the future, which explains the need to shift sooner or later to renewable energy use (Mentink, 2014).

Further elaborations to the energy issue and the resilience issue are beyond the scope of this thesis.

The notion to '**think in systems**’ is widely recognized within the concept of a circular economy. A system is a set of interrelated parts that make a unified whole. The fundamental importance is well illustrated in Figure 3.1 (CE butterfly diagram). Closing a material loop involves some five to six economic activities, which includes several stages of production, the consumer, and one or more recovery activities. In reality this can increase to tens or hundreds of activities for very complex products. To successfully close a loop , one should get an understanding of how these parts affect one another within the whole system. Elements are considered in relationship with infrastructure, environment, and social context. In order to achieve the transition towards a circular economy, according to the fourth principle it is crucial to consider and understand how parts influence one another within a whole, and the relationship of the whole to the parts (Ellen MacArthur Foundation, 2015).

4.4. CIRCULAR VALUE CREATION

The principles of the circular economy provide not only a description of how it should work as a whole, but moreover an outline of specific sources of economic value creation potential (Ellen Macarthur Foundation, 2015). The authors define four concepts of circular value creation which hold true from perspective of all available interpretations for a circular economy (Figure 3.3 below):

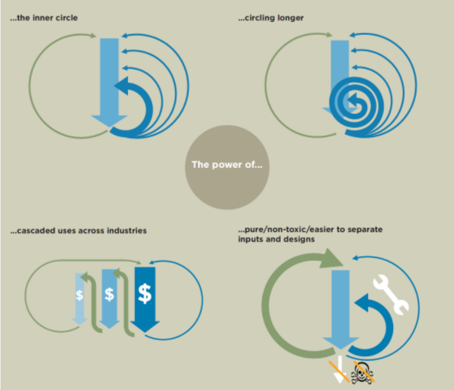

Figure 3.2: Sources of value creation (Ellen MacArthur Foundation, 2015).

The ‘**power of the inner circle**’ refers to minimising comparative material usage vis-à-vis the linear production system. The tighter the circle, i.e., the less a product has to be changed in reuse, refurbishment and remanufacturing and the faster it returns to use, the higher the potential savings on the shares of material, labour, energy, and capital embedded in the product and on the associated rucksack of externalities (such as greenhouse gas (GHG) emissions, water, toxicity).

The ‘**power of circling longer**’ refers to maximising the number of consecutive cycles (be it reuse, remanufacturing, or recycling) and/or the time in each cycle.

The ‘**power of cascaded use**’ refers to diversifying reuse across the value chain, as when cotton clothing is reused first as second-hand apparel, then crosses to the furniture industry as fibre-fill in upholstery, and the fibre-fill is later reused in stone wool insulation for construction—in each case substituting for an inflow of virgin materials into the economy—before the cotton fibres are safely returned to the biosphere.

The ‘**power of pure circles**’, finally, lies in the fact that uncontaminated material streams increase collection and redistribution efficiency while maintaining quality, particularly of technical materials, which, in turn, extends product longevity and thus increases material productivity.

These four ways to increase material productivity are perceived not merely one-off effects that will reduce resource demand for a short period of time during the initial phase of introduction of these circular setups. Their lasting power lies in changing the run rate of required material intake (Ellen Macarthur Foundation, 2015).

Within this respect, numerous research is conducted recently in order to estimate the overall value of the circular economy. These outcomes have shown different results such as European Commission (2014a, 2014c), Ellen MacArthur Foundation (2013, 2014), OPAi & MVO (2014), Rijksoverheid (2014, 2016) and RLI (2015). As can be seen from the given researches, the urge for governmental bodies to identify the value of a circular economy is significant. With the aim ‘Nederland circulair in 2050’ the official ambition towards a circular economy is evident.

Conclusively, certain aspects covered by the given definitions are not relevant for this research, and therefore not necessary to consider for the purpose of this thesis. Within the boundaries of this research, the aspect concerned would be resource scarcity as the fundamental driver for a circular economy, in which the ‘power of loops’ (explained in section 3.4 ‘Circular Value Creation’) as the method used to prevent this resource scarcity. Looking at the definition by EMF, which provides the most advanced and extensive explanation regarding a circular economy, the first sentence of the definition will be focused on: “A circular economy is an industrial system that is restorative or regenerative by intention and design” – (Ellen MacArthur Foundation, 2012)

5. Potential of Circular Redevelopment Projects

In accordance with both adaptive reuse and the circular economy, the built environment is perceived to change its perspective in the way products are produced, services are provided and processes are orchestrated. The integration and collaboration of all stakeholders within this economic system is evident in order to preserve the highest possible quality of raw materials and achieve aforementioned minimized waste disposal. According to the Ellen MacArthur Foundation (2015) a circular design as 'improvements in material selection and product design (e.g. standardization/modularization of components, purer materials flows, and design for easier disassembly) are at the heart of the circular economy'. Therefore, this chapter will look into the implementation of the circular economy within the built environment, an more specifically to individual buildings, in order to enable the use of circularity indicators and determine decision-making strategies.

The first paragraph will look into the material waste potentials currently available in the built environment. The second paragraph introduces the appropriate system in which the assessed components could be classified. Subsequently, the third paragraph identifies the actual condition assessment method for the application of circularity during the initiation of redevelopment. Finally, the fourth paragraph elaborates on the strategic implementation of actual condition assessment with reutilization strategies.

5.1. WASTE POTENTIAL IN CONSTRUCTION AND DEMOLITION

The physical life of a building is mostly perceived as a linear process. It starts with extracting materials, processing, manufacturing and then exploit the building as a product. The industry does not consider the designation of these resources when the buildings are designed. When the building is no longer of use, it is discarded into the environment. This process results into pollution, depletion of resources, loss of cultural history and energy consumption. Usually this demolition waste is either used for incineration with energy recovery or dumped in landfills. Some recycling and reuse takes place, but this is mostly based on the economic value of the materials.

In some countries, like the Netherlands, high recycling is achieved, but this recycling of materials is mostly subject to down-cycling (e.g. hollow-core slabs are used for road base materials, since only 20% can be used for new structural elements). This waste of resources and materials is unsustainable if the world continues to become more prosperous and populated. This section focuses on this waste problem in the building industry by what steps can be taken towards zero-waste.

According to the European Council's Directive on Waste, waste is 'any substance or object which the holder discards or intends or is required to discard'. So, the definition of waste as 'a thing which its holder has discarded' assumes that waste is already there and that the holder intends to dispose of it. Consequently, something has to be done with it. Waste management thus appears to be merely a reaction to waste. However, it has been recognized that the most important tool for resource efficiency, as well as for sustainable waste management, is waste prevention (Pongracz, E., Phillips, P.S., Keiski, R.L., 2004).

The amount of demolition waste is considerably larger than the construction waste. To achieve a more sustainable resource use, the industry should aim for zero-waste. Increasing the lifecycle of a building through reuse might lower the impact on material resources, transport costs and impact on the environment. Therefore it is perceived a contribution to sustainability (Bullen & Love, 2011). In this research a strategy which aims for a closed loop of all materials, referred to as reutilization strategies, will be used.

5.1.1. Reutilization Strategies

A significant focus of the circular economy is to advocate for a product design that optimizes the creation of materials economy that eliminates the concept of 'waste'. This indicator intends to create incentives for industry to eliminate waste through the design process of products with (different) materials that could be recycled to retain their value.

From this perspective, currently available reutilization lists are structured. Basically these schedules find its blueprints from the so-called 'Ladder van Lansink', initiated by Ad Lansink in 1979, with priority sequence for waste management policies. This laser is incorporated in the Environmental Management Law of 1993. Years later, in 2006 it was adopted in the European Framework of Waste as well. A distinction is made between various gradations of circularity. This starts with the highest level of 'refuse' and ends with the lowest level 'landfill'. Internationally this proven concept is a combination of the list of both the RLI (2015) and Vermeulen et al. (2014), provided in today's presented list with nine consecutive levels (PBL, 2016). These different gradations are listed in Figure 4.1 below.

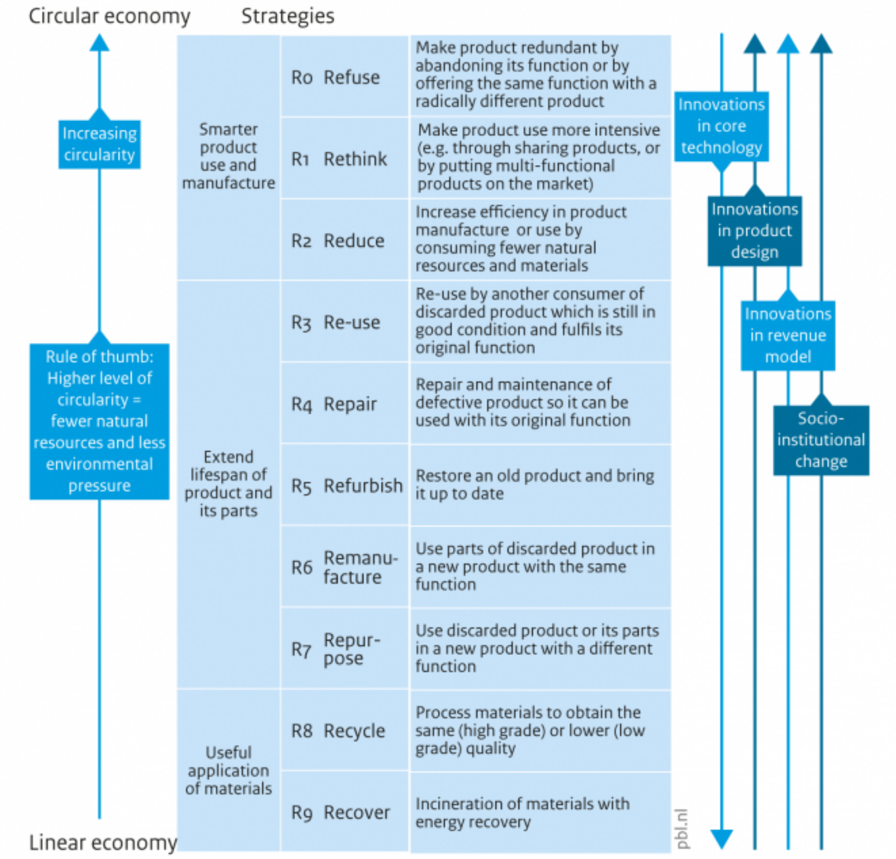

Figure 4.1: Circularity strategies within production chains, in order of priority (Source IRL 2015, edited: PBL, 2016).

It is perceived useful to indicate three main categories during implementation of reutilization within projects. Each indicator refers to a category 'to use and make products smarter (R0-R2), 'prolong the lifecycle of products and components' (R3-R7), and 'useful application of materials' (R8-R9). This will enable to distinguish the progress in terms of recycling in comparison with the progress on lifecycle enhancement and innovations for smarter applications of products. Subsequently, the emphasis for a resilient product resulting from an innovative design process is assigned to designers and suppliers. Furthermore, terms like 'design for repair', 'design for recycling' and 'design for disassembly' occur, for which the latter will be elaborated further below (PBL, 2016).

The reuse of materials that result from demolition provide major opportunities for the building industry. According to Baars and Govers (2015) there is an important financial stimulus involved, costs can be reduced with smart reuse of materials.

5.1.2. Demountability in buildings

The design of buildings is usually intended for a single type of use and at the end of its functional life the building is neglected. The main objective is to optimize and reduce cost and time during construction and use phase. Due to the inefficient and time-consuming process, at the end of life a building is demolished and most of the materials end up in either incineration facilities or landfills, even though the materials are not past the end of their physical life. This is a major waste of materials and thus energy.

According to the circular economy, to minimize the negative environmental impacts of this waste, a design should not only concern construction and service life, but moreover consider the complete life cycle of the building. Blok et al (N.D.) described the three types of life which can be distinguished in a building:

- Design working life: The design working life is the assumed period for which a structure is to be used for its intended purpose (with anticipated maintenance but without major repair).
- Technical service life: The technical service life is the period for which a structure can actually perform according to the structural requirements based on its intended purpose (possibly with necessary maintenance but without major repair).
- Functional working life: The functional working life is the period for which a structure can still meet the demands of its (possibly changing) users (may be with repairs and or adaptations).

In correspondence with the reutilization strategy, zero-waste can be achieved by making use of the method to 'use and make products smarter' through 'design for disassembly' (DfD) or to 'prolong the lifecycle of products and components by 'Design for Adaptability' (DfAD). The first design method is an end of life approach in which the building is a system which is methodically disassembled. Subsequently, the second design method relies on the robust and versatile design, and aims to be able to accommodate alternative use. Ultimately, any disassembled parts can be reused in new buildings or recycled into other products. In addition, down-cycling is avoided and all materials should return to either the technical system or the biological system. Moreover, disassembly methods separate waste streams and eliminate the accumulation of mixed debris, allowing for direct reuse or recycling. Instead of destroying buildings and systems by changing requirements - by means that we cannot predict what the future is requesting - it should be possible to disassemble sections back into components and to reassemble them in the new combination (Durmisevic & Brouwer, 2002).

Demountable buildings have been around a long time and this concepts have been studied in various designs. Several principles can be distinguished in order to design for disassembly (DfD). Nowadays, one of the main design strategies which are generally accepted is DfD as defined by Durmisevic & Brouwer (2002). Three dimensions of transformation are shown in Figure 4.2 below:
1. Spatial transformation: ensures continuity in the exploitation of the space through the spatial adaptability;
2. Structural transformation: which provides continuity in the exploitation of building and its components through replaceability, reuse and recover of building components;
3. Element and material transformation: providing continuity in the exploitation of the materials through recycling of building materials.

The key component of such three-dimensional transformation capacity of building is structural transformation with associated disassembly. Without disassembly spatial systems whose life cycle vary from 2-20 years would not be easy transformable. On the other hand without disassembly the life cycle model of building materials (whose durability vary from 5-75 years) is linear and ends up with demolition and waste disposal (Durmisevic & Brouwer, 2002).

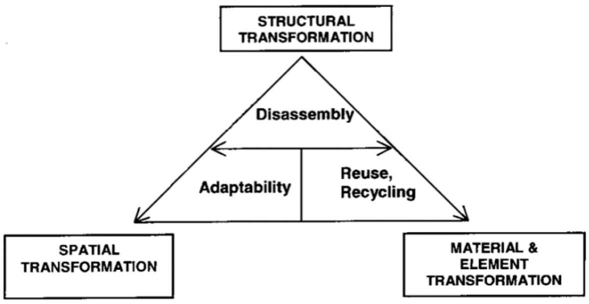

Figure 4.2: Disassembly - the key for building transformation (Elma Durmisevic & Brouwer, 2006)

5.1.3. Material levels hierarchy

The building structure is defined as a hierarchical arrangement of materials and their relations of which the building consist of. It represents the way parts are arranged in the group of parts (components) and the way group of parts are arranged in the whole building. Three levels could be described, whereby the higher levels will dominate the lower level of technical composition (Durmisevic & Brouwer (2006). The hierarchy of material levels should be divided into three levels as shown in Figure 4.3 below:

- Building level represents the composition of systems which are carriers of main building functions (load-bearing, enclosure, partitioning, servicing);
- System level represents the composition of components which are carriers of the system functions (bearing, finishing, insulation, reflecting, distributing);
- Component level represents the layered or frame assembly of component functions which are allocated through the elements and materials at the lowest level of building assembly.

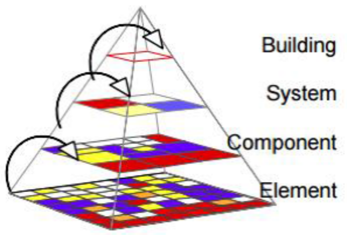

Figure 4.3: Hierarchy of material levels (Durmisevic & Brouwer, 2006)

5.1.4. Disassembly Determining Factor

The notion of material levels hierarchy corresponds with the shearing layers of Brand (1994). In addition, the design for disassembly factors create the opportunity to quantify the interrelation of components within the system as a whole. This aspect is further reviewed by Verberne and there has been a selection initiated by the author in order to keep de BCI assessment model evident (Verberne, 2016). For the purpose of this research, and further due to the applicability of the Building Circularity Indicators this description is used as input for the development of this strategic decision-making tool. Verberne describes a selection of 7 Disassembly Determining Factors (DDF) (Durmisevic, 2002, in Verberne 2016), subdivided into functional, technical and physical decomposition (Figure 4.4 below). The corresponding disseminated weighted variables (Durmisevic et al, 2006) are presented in the concluding overview of the selected DDF in Table 4.1 below.

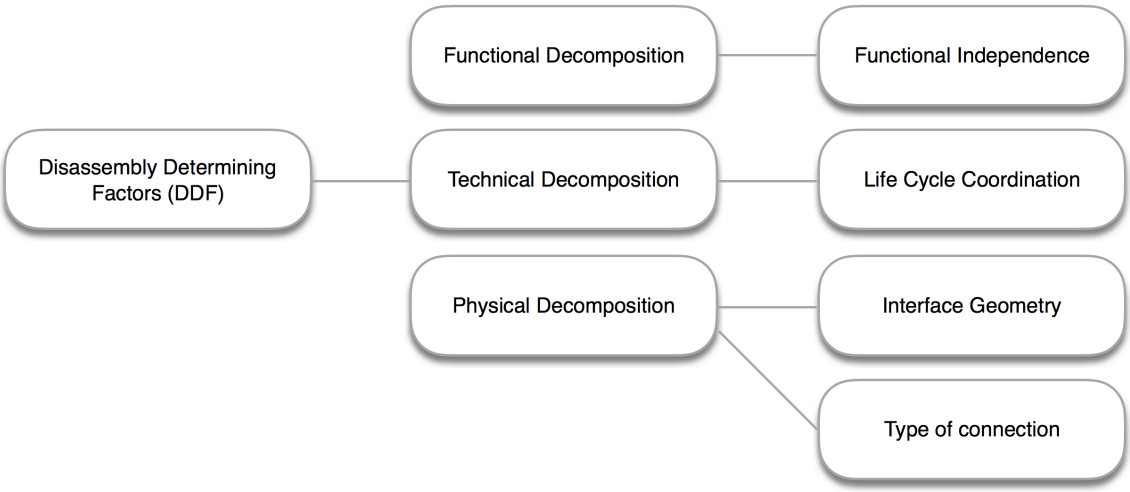

Figure 4.4: Disassembly aspects (own illustration, based on Verberne, 2016, p.65)

Functional decomposition (material level):
This disassembly aspect is about functionality of an assembly, it comprises decomposition of functions and consists of:
- Functional independence; separation of function within one composition; if a product is functional obsolete, it is possible to disassemble components and / or products separately. This prevents unnecessary dismantling;
- Clustering / systematization; the substitution of one element would have considerable consequences on all related parts at connection, the principle of structure for a subsystem aims amongst others at creating modular designs and standardization of elements on sub-assembly and component levels.

Technical decomposition (hierarchy):
This disassembly aspect, technical decomposition, is focused on decomposition of different elements. It is responsible for defining technologies and methods to specify principle solutions for composition of structures and consists of:
- Base element specification; providing independence of elements within one cluster should define its base elements;
- Life cycle coordination; identifying the products lifecycle and assembly sequences determines the relation between a long cycle product and a short cycle product;
- Open versus closed hierarchy; specifying the relation between subsystems for disassembly, the hierarchy within the structure plays an important role.

Physical decomposition (interfaces):
The disassembly aspect, physical decomposition, is focused on the performance of the interfaces of products and materials. It is strongly related to the manufacturing and construction process and the final processing on site. It consists of:
- Assembly sequence; factor for transformable configuration, deconstruction without generating waste, the sequence of assembly between products and components is of highly importance;
- Interface geometry; factor for possibility of disassembling a composition, interpenetrating geometry is less suitable for disassembly than connections that could be removed by (partly) demolition of elements;
- Type of connection; factor for the connections in which the interfaces defines the degree of freedom between component, through design of product edge and specificity of connection type.

Based on all DDF, Durmisevic assigned fuzzy variables as input of a knowledge model. The result is a selection of disseminated weighted variables for each of the DDF, with all relevant aspects shown in table 4.1. Grading is done from one to zero, in order to show respectively the worst impact and the best impact on disassembly (Durmisevic, 2002, in Verberne 2016).

5.1.5. System thinking in the built environment

Within the environment of strategic reutilization, the discrepancy between the intended design resilience and technical performance is difficult to align in current industry. The notion of a building as a whole is still the common way of thinking (Beurskens & Bakx, 2015). However, on the longterm, the buildings are constantly adapting due to the changing user needs and changing environmental conditions. Therefore, buildings should be perceived as a dynamic configuration of elements that is constantly adapting to the needs of the present. The “theory of levels” of Habraken (1961) and subsequently the “Shearing Layers” of Brand (1994) propose a model of a building decomposition. In addition, there have been various proposed modifications to Brand’s framework and terminology (Slaughter, 2001), (Rush, 1986), (Duffy, 1990), (Leupen, Heijne, & Zwol, 2005) and (Gibb et al., 2011).

Gibb et al. (2011) also added a social and a surrounding layer, which influence the building’s adaptability. Especially the surrounding layer reflects the urge to consider the changing needs of society.

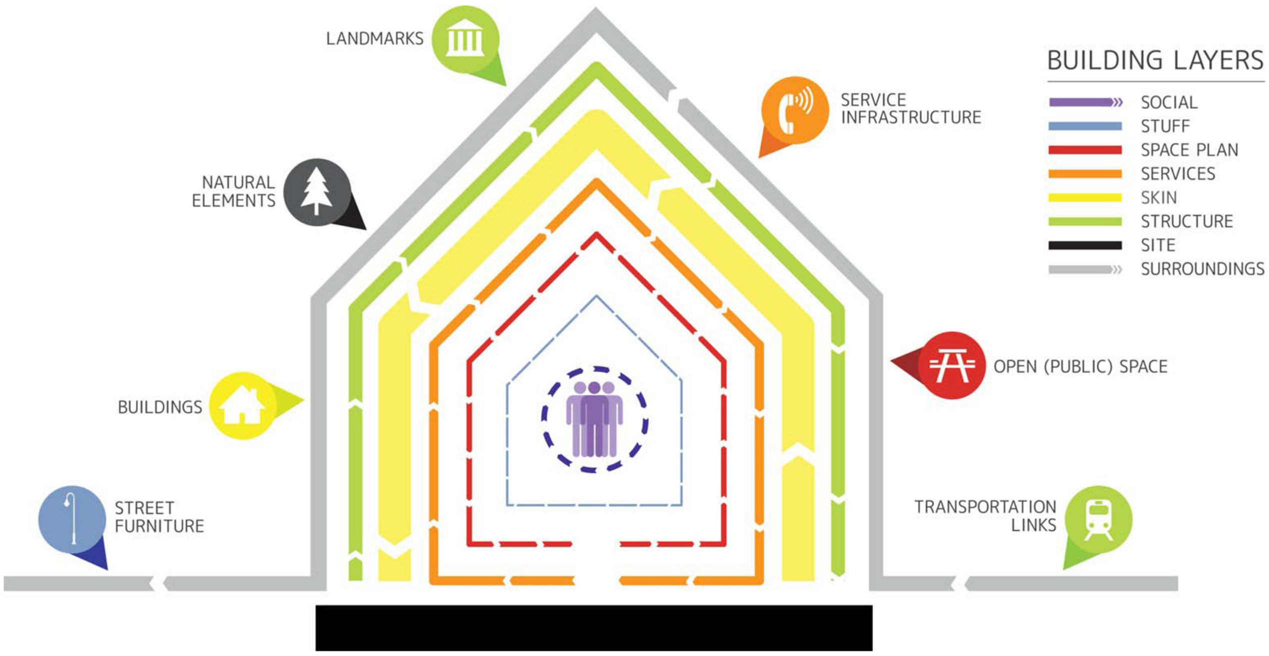

Figure 4.1: Building Layers and time (Gibb et al., 2011).

Following layers and corresponding default lifetimes are defined:
- Surroundings: External influences, neighborhood, infrastructure, natural elements.
- Site: geographical setting, urban location, and legally defined lot (eternal);
- Structure: foundation and load-bearing elements (30-300 years);
- Skin: exterior surfaces (20 years);
- Services: installations; communication wiring, sprinkler, MEP, HVAC (7-15 years);
- Space plan: interior layout; walls, ceilings, floors and doors (3-30 years);
- Stuff: furniture; chairs, desks, phones, pictures, lamps (< 1 year).
- Social: People who actually use the building, function of the building as the people define it.

Each layer represents a conglomerate of building components with similar service lives, requiring change or replacement simultaneously. Generally, the proposed reutilization strategies of all similar components could be classified according to the above mentioned relevant building layer.

Within this perspective, and further the notion to think in systems, the perception of a building as one compact static product is misleading (Duffy, cited in Elma Durmisevic & Brouwer, 2006, p. 6). The goal of circular (re)development is to build more efficiently and profitably by adopting dynamic structures with changing composition, with respect to the interrelation of components within the system.

Product disassembly determining factors		
Functional separation	separation of functions	1,0
	integration of function with same lifecycle into one element	0,6
	integration of function with different lifecycle into one element	0,1
Functional dependence	modular zoning	1,0
	planned interpenetrating for different solutions (overcapacity)	0,8
	planned for one solution	0,4
	unplanned interpenetrating	0,2
	total dependence	0,1
Technical life cycle/coordination	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	1,0
	medium (1) / long (2)	0,5
	short (1) / medium (2)	0,3
	short (1) / long (2)	0,1
Geometry of product edge	open linear	1,0
	symmetrical overlapping	0,8
	overlapping on one side	0,7
	unsymmetrical overlapping	0,4
	insert on one side	0,2
	insert on two sides	0,1
Standardisation of product edge	pre-made geometry	1,0
	half standardised geometry	0,5
	geometry made on the construction site	0,1
type of connections	accessory external connection or connection system	1,0
	direct connection with additional fixing devices	0,8
	direct integral connection with inserts (pin)	0,6
	direct integral connection	0,5
	accessory internal connection	0,4
	filled soft chemical connection	0,2
	filled hard chemical connection	0,1
	direct chemical connection	0,1
Accessibility to fixings and intermediary	accessible	1,0
	accessible with additional operation which causes no damage	0,8
	accessible with additional operation with reparable damage	0,6
	accessible with additional operation which causes damage	0,4
	not accessible - total damage of bought elements	0,1
System layer disassembly dependency factors		
System dependency	Stuff	1,0
	Spaceplan	0,9
	Services	0,8
	Shell	0,7
	Structure	0,2
	Site	0,1

Table 4.1 (own illustration, based on Verberne, 2016, p.67)

In this research, the object of assessment considered is the building. Therefore the layers site, surroundings and social are excluded from this decision support model as alternative, as they are too subjective and difficult to quantify. The six remaining layers will be used in order to classify the components, and define the relevant reutilization strategy for each layer accordingly. Herewith the aforementioned design resilience and technical performance is assigned to the actual components proportionally.

5.2. BUILDING CIRCULARITY INDICATORS

The Building Circularity Indicator (BCI) is defined by research of Verberne (2016) and will make it possible to measure the buildings' level of circularity at a certain moment in time. The goal is to minimize the demand of virgin materials, the impact on the environment, and keep the materials infinite into the chain.

During the assessment of the BCI, the materials and products should be observed separately, and subsequently the interconnections and physical interfaces of the assembly in a building. It is built up of a System Circularity Indicator (SCI), Product Circularity Indicator (PCI), and Material Circularity Indicator (MCI). This is possible with the aforementioned 'Shearing Layers', in which a building is perceived as an configuration of six different systems (Brand, 1994); site, structure, skin, services, space plan, and stuff. In technical cycles, the products, components, and materials are returned to the market at the highest possible quality level and for as long as possible by repair, maintenance, reuse, refurbishment, revision, and ultimately by recycling (Verberne, 2016).

"…circularity, technically, only consists of two components: (1) circular material usage, and (2) circular design. Other indicators such as material health, toxicity and material scarcity are preconditions and drivers, which are not influencing the buildings' level of circularity in any way." - Verberne (2016)

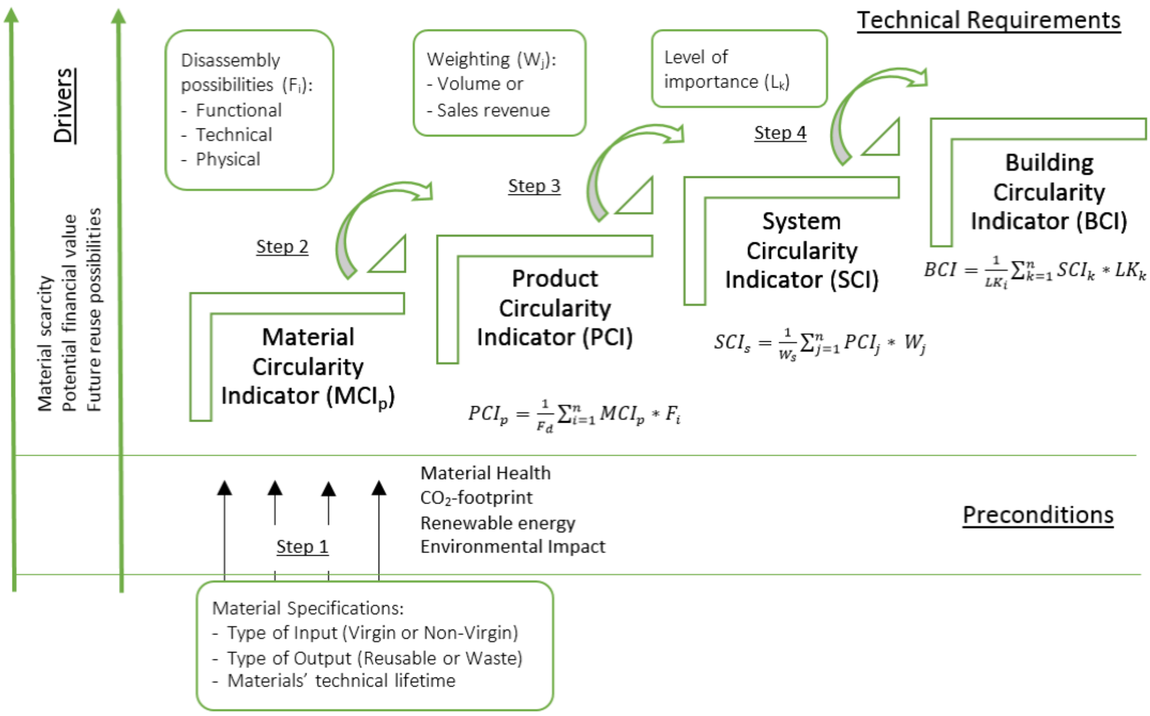

Figure 4.7: Assessment model - conceptual structure for the circularity assessment model of materials within the technical cycle (Verberne, 2016)

The assessment model results from the consecutive indicators, multiplied with the specified variables; the disassembly possibilities F_d for each product material MCI_p, the weight factor W_s for each product, and finally the level of importance LK_i for each system level.

5.2.1. From MCI to BCI

The general idea behind the BCI is to look at two aspects, respectively the material index, and subsequently the way in which the materials and products are linked within the system. The material index is based on the Material Circularity Indicator (MCI) defined by Ellen Macarthur Foundation (2015) and is essentially constructed from a combination of three product characteristics: (1) the mass V of virgin raw materials used in manufacture, (2) the mass W of unrecoverable waste addressed to the product, and (3) a utility factor X that accounts for the length or intensity of the product's use. This first aspect could also be described as the 'theoretical' value of circularity for a product, without any interfaces and merely the product itself. The merged material evaluation MCI of all applicable materials will finally result in a MCI for a product. Figure 4.8 summarizes the different variables influencing the MCI. Where:

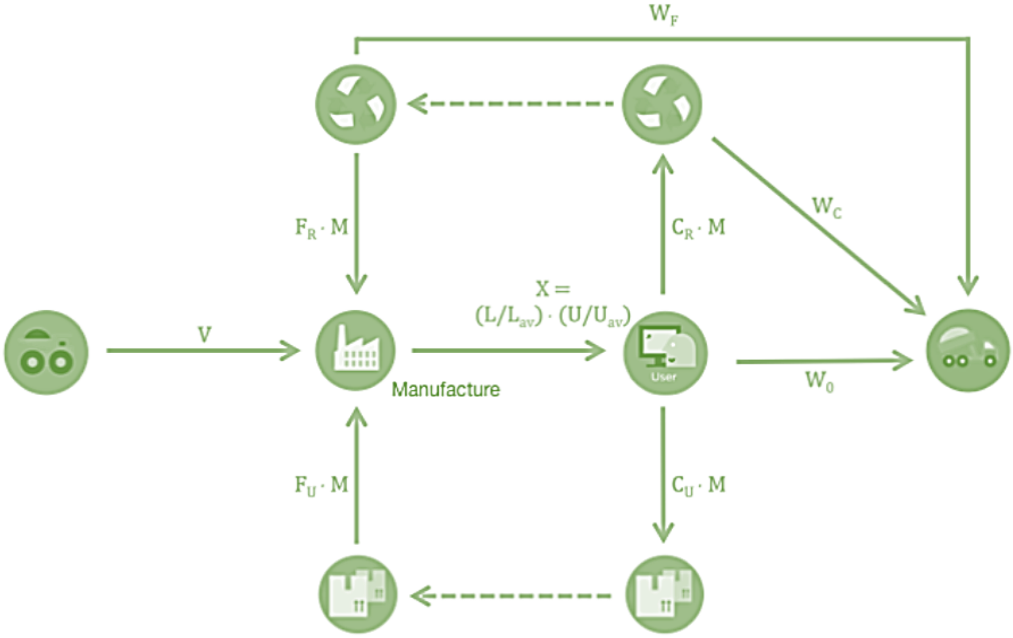

Figure 4.8: Diagrammatic representation of material flows (Ellen MacArthur Foundation, 2015)

V = Mass of virgin feedstock used in a product;
F_R = Fraction of mass of a product's feedstock from recycled sources;
F_U = Fraction of mass of a product's feedstock from reused sources;
M = Mass of a product;
X = Utility of a product;
L = Actual average lifetime of a product;
L_{av} = Actual average lifetime of an industry-average product of the same type;
U = Actual average number of functional units achieved during the use phase of a product;
U_{av} = Actual average number of functional units achieved ruing the use phase of an industry-average product of the same type;
C_R = Fraction of mass of a product being collected to go into a recycling process;
C_U = Fraction of mass of a product going into component reuse;
W_0 = Mass of unrecoverable waste through a product's material going into landfill, waste to energy and any other type of process where the materials are no longer recoverable;
W_C = Mass of unrecoverable waste generated in the process of recycling parts of a product;
W_F = Mass of unrecoverable waste generated when producing recycled feedstock for a product.

The second aspect of the assessment model is to develop the product circularity indicator (PCI), including the interfaces and connections between products and materials. The PCI identifies the circularity of products in a system as a whole. The PCI comprises additional and adjusting factors based on the Design for Disassembly (DfD) principles of Durmisevic (2002) including functional, technical, and physical deconstruction. Contrary to the theoretical circularity value of the MCI, the PCI addresses the practical circularity value of a product.

In addition to the first two aspects, the BCI is derived from the summation of the system circularity indicator (SCI), which is the third step in the assessment model. The SCI assesses the circularity of products in a system together based on their weight, and is determined by a separation based on the 'Shearing Layers' defined by Brand in 1994, to compare systems with each other and the different lifetimes of each system.

Finally, the BCI assesses the separate systems as a whole with a factor for the level of importance for each system. It is widely recognized that, due to the velocity of material circulation, the circularity of a system with a short lifetime such as fit-out is considered more important compared to systems with a long lifetime, such as building structures. Therefore, the weighted factor for linearity of building structures results into less influence on the circularity index compared to the fit-out.

One of the main benefits for calculating with the BCI is the quantifiable data. Subjective factors that are related to the aesthetics of materials and products are not included in the assessment model. Moreover, since this assessment model on its own does not answer the research question, additional development on the actual condition is done for an decision-making tool of the most beneficial intervention strategy.

5.3. CONDITION ASSESSMENT IN THE BUILT ENVIRONMENT

5.3.1. Dutch standard for condition assessment of buildings (NEN 2767)

According to Straub, numerous research in order to achieve objectivity during the inspection process, that should result in unambiguous information for maintenance and retrofit strategies is carried out in the past (Straub, 2009, p. 24). Based on this aforementioned research, the Dutch Government Buildings Agency standardized the the process of condition assessment for buildings, called the NEN 2767. The NEN 2767 standard provides two aspects, respectively an assessment methodology, and a list of classification of faults. This standard aims to provide unambiguous and reliable information for the following target groups (NEN 2767, 2013, p.4).:

- (potential) property owners, private owners, housing corporations and investors among others;
- (potential) facility managers;
- (potential) tenants;
- consultants;
- contractors and maintenance providers;
- inspectors of control institutions.

Direct- and indirect application potential may include (NEN 2767, 2013, p.6):

- visualization of the current physical condition;
- long-term maintenance planning;
- prioritizing maintenance budget;
- analyze and control maintenance conditions;
- support the real estate portfolio management and strategy;
- enable and simplify communication regarding the required/preferred condition.

Especially the last application potential (enable and simplify communication regarding the required/preferred condition) would suggest that a well elaborated tool in order to assess both building condition and circularity would be beneficial to accelerate the redevelopment process.

A six-point scale has been taken as the basis for the standardized method. The condition categories are of a chronological order that describe possibly occurring defects without references to remedial work. Table 4.2 gives the general descriptions of the condition ratings.

Definition of Condition Ratings

Condition Rating	Definition	Explanation
1	Excellent condition	Incidental defects
2	Good condition	Incidental, but initial aging
3	Reasonable condition	Locally visible aging; Functionality not threatened
4	Moderate condition	Functionality incidentally threatened
5	Bad condition	Degradation process is irreversible
6	Very bad condition	Technically ready for demolition

Table 4.2 Description of condition rating (in Dutch) (NEN 2767-1, 2013)

5.3.2. Condition assessment process in steps

The condition assessment process follows the framework shown in Figure 4.9. Firstly, identifying the defects will be done in order to formulate any applicable components which are subject to intervention. Secondly the following objectives will be elaborated accordingly: the importance, extent and intensity of defects. Conclusively those three objectives specify the condition rating.

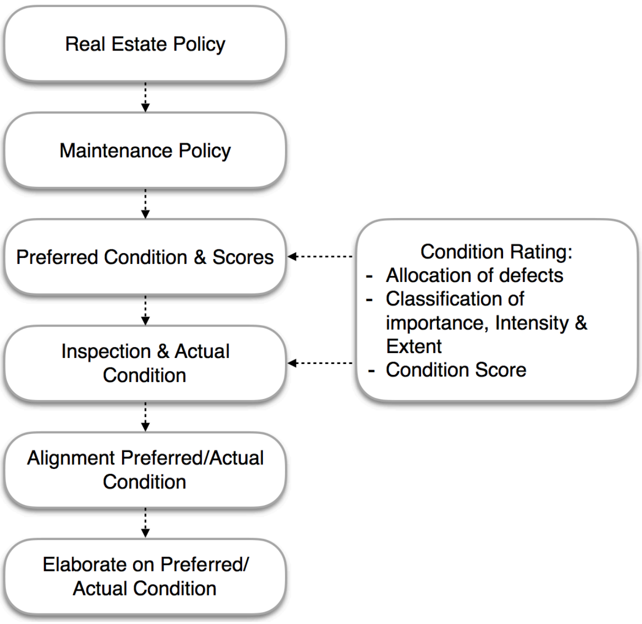

Figure 4.9: Framework of assessment process from perspective of the applicable scope (own illustration, based on NEN 2767-1, 2013)

5.3.2.1. Building components

In order to obtain for an objective visual assessment, the necessity for a clear definition and hierarchical classification of building components is crucial. The list of faults (defects) refers to the first four digits of the so-called Dutch SfB-classification (NL-SfB). In the Netherlands this 'Elementenmethode' is used for the classification of building elements. This method, based on the Swedish SfB, is developed into an object orientated classification, used for ordering building objects in e.g. CAD-systems, building estimations and documentation of related information.

The use of this hierarchical system directly influences the classification of importance of defects. The building component list and corresponding matrix (provided and available for review by NEN 2767-2) cover 80 to 90 per cent of the common building components in housing and real estate, and identifies the assigned importance for each component. For all remaining components the given framework for importance rating should be used.

5.3.2.2. Importance of defects

The importance of defects is divided into three levels, respectively the critical, serious and minor defects. These levels indicate to what extent it influences the building's functionality. As shown in Table 4.3 below, numerous types of defects are identified and categorized within the three levels.

Critical defects significantly affect the functionality of the building component. Generally, this type of defects threaten the building structure, e.g. stability and distortion. Subsequently, serious defects gradually wear down the performance of building components, for example deterioration in the material surface or basic quality issues due to obsolescence of components. Finally, any defects on finishes, for example deterioration or pending maintenance on coatings are referred to as minor defects.

Importance of Defects

Importance	Type of Defect	Explanation
Critical defects	Primary function Constructively primary Material intrinsic Basic quality	Critical defects directly affect the functionality of the building's component or installation part
Serious defects	Secondary function Constructively secondary Material surface Basic quality and aging of components	Serious defects refer to the deterioration of the building's component or installation part, without directly affecting it's functionality
Minor defects	Maintenance Finishing Basic quality and aging of sub-components Deterioration	Minor defects do not affect the functionality of the building's component or installation part

Table 4.3: Definitions of Importance of defects (own illustration, based on NEN 2767, 2013)

5.3.2.3. Extent of defects

Together with the importance of defects, two remaining objectives finally determine the condition rating of components. The first objective regards the extent of defects. The difficulty to estimate the extent and assign the appropriate class is widely recognized, even for an experienced building inspector. Moreover, the defect at hand also influence the inspector's judgement. Therefore it is crucial to distinguish the importance and intensity from the extent to which the defect is calculated. The standard distinguishes five extent categories as shown in Table 4.4 below.

Extent of Defects

extent rating	Percentage	Explanation
Extent 1	<2%	Defect is hardly visible
Extent 2	2%-10%	Defect occurs locally
Extent 3	10%-30%	Defect occurs regularly
Extent 4	30%-70%	Defect occurs frequently
Extent 5	>=70%	Defect occurs generally

Table 4.4: Definitions of Extent of defects (own illustration, based on NEN 2767, 2013)

5.3.2.4. Intensity of defects

In addition to the extent of defects, knowledge regarding the intensity of defects is necessary to determine the condition. The intensity of defects strongly influences the condition of building components. Generally there are two types of defects, respectively degradation or an accidental occurrence. With reference to the degradation, the intensity indicates the status of the process, e.g. material intrinsic defects and defects regarding the material surface develop over a certain period of time and therefore they will gradually occur in several intensities. Contrary, any defects caused by accidents just occur in one moment. Conclusively three intensity categories are defined as shown in Table 4.5 below. The list of faults determines if intensities are applicable for a building component.

Intensity of Defects

Intensity rating	Name	Explanation
Intensity 1	Low (initial stage)	Defect is barely perceptible
Intensity 2	Medium (advanced stage)	Defect is clearly perceptible
Intensity 3	High (final stage)	Defect cannot/ barely increase any further

Table 4.5: Definitions of intensity of defects (own illustration, based on NEN 2767, 2013)

5.3.2.5. Condition ratings

With the three objectives identified, a condition rating can be determined accordingly. The NEN 2767 describes three matrices for the differentiation of respectively, critical, serious and minor defects (refer to Tables 4.6 - 4.8 below). Whenever multiple defects occur on a component, a integrated calculation method should be handled. Within this perspective, separation is made between the combined defects on one object or combined defects on several objects within the component. A step-by-step plan to register defect scores is provided and available for review by NEN 2767-1. The final operational model for this thesis is based on this step-by-step plan in order to register the defects observed from the case study.

Critical Defects

	Extent				
Intensity	<2%	2%-10%	10%-30%	30%-70%	>=70%
Low (initial stage)	1	1	2	3	4
Medium (advanced stage)	1	2	3	4	5
High (final stage)	2	3	4	5	6

Serious Defects

	Extent				
Intensity	<2%	2%-10%	10%-30%	30%-70%	>=70%
Low (initial stage)	1	1	1	2	3
Medium (advanced stage)	1	1	2	3	4
High (final stage)	1	2	3	4	5

Minor Defects

	Extent				
Intensity	<2%	2%-10%	10%-30%	30%-70%	>=70%
Low (initial stage)	1	1	1	1	2
Medium (advanced stage)	1	1	1	2	3
High (final stage)	1	1	2	3	4

5.3.2.6. Prioritization defects

One important sub process of the condition assessment is to prioritize the observed maintenance work. The priority settings enable users to cope with the risks of failure of components. The provided risk-priority matrix (NEN 2767-1) aims to identify the potential risks when no intervention will take place. Finally the available budget could be assigned to the appropriate defects in order to correspond with the stated real estate and maintenance policies. The risks of defects of building components that are not solved are rated on a three-point scale. The risk categories are derived from the policy beforehand.

The introduction of standard lists of defects, condition parameters and condition ratings could mean a clear break of the common working processes of building inspectors. By elaborating on the condition assessment, more beneficial strategies for reuse can be determined. The most difficult part however is to forget about the old fashion way of thinking and working, on site and based on experience which is of major impact for creative solutions during feasibility studies. Well-educated and/or certified building inspectors should have enough knowledge and experience about elements, defects and remedial work. Nevertheless, it is the crucial information architects need to create new products from existing materials. Inspectors are forced to put a lot of effort and time to use it in a rather different way: register the found situation and separately choose for maintenance activities.

5.3.2.7. Preservation of representability due to minor defects

Due to the impact of minor defects on the representability of a space, 'Rijksvastgoedbedrijf' agreed to specify the accepted levels of condition in collaboration with several market parties. Kindly refer to the standardization directive attached in Appendix B.

Based on the 'certificate of compliance' according to the signed contract, the representability of al visible components of the asset, including all fit out works delivered by the contractor should be achieved and maintained. The assessment includes the degradation of all surfaces, classified as minor defects as per the definition of NEN2767-II.

The required conditions are not prescribed according to the NEN 2767. For each space on the contrary, three levels of conditions can be requested:

Conditionlevel A (Highly representative)	Conditionlevel B (Representative)	Conditionlevel C (Low representative)
Visual degradation is not perceptible during exploitation	Visual degradation is not of disturbance during exploitation	Visual degradation is not of disturbance during exploitation
Only further observation close by would reveal minor degradation	Only further observation from distance would reveal degradation	No decay, depletion or impoverishment of the (work) environment

Table 4.7: requirements for each condition level (own illustration, based on appendix xxx, 2015)

All codes for representability (i.e. A, B, C) are integrated with the output specifications during procurement and refer to the applicable space of a building. The spaces and corresponding representability of a building related to 'Rijksvastgoedbedrijf' are defined in a so-called 'space tree' (Ruimteboom). For all external spaces, which are not included in this 'space tree', the following classifications are specified:

- Condition A: Main entrance and direct surrounding;
- Condition B: Facades, outer walls and ceilings; and
- Condition C: Utility functions in outdoor spaces, not visible from public areas of inner spaces with classification A or B.

The first version of this representability classification standardization was equipped with the additional reference to NEN 2767 (Table 4.8), specifying the maximum accepted extent and intensity for the criteria 'utilization' and 'decay' of spaces. The reason it was taken out, was due to different point of views between principal (Rijksvastgoedbedrijf) and contractors. However, since this research intents to specify objective data into reutilization strategies, the classification schedule could be used for assigning the justified importance of representability of minor defects.

Table 4.6: Matrices of resulting condition rating (own illustration, based on NEN 2767, 2013, p.13)

Upper limits for minor defects

Based on table 5 [NEN 2767-1]					
Extent Intensity	Incidentally <2%	Locally 2%-10%	Regularly 10%-30%	Frequently 30%-70%	Generally >=70%
Low (initial stage)	-	A	B	C	-
Medium (advanced stage)	A	B	C	-	-
High (final stage)	B	C	-	-	-

Table 4.8: maximum accepted extent and intensity per condition level (A, B, C) (own illustration, based on appendix xxx).

The extent of defects is assessed for each space, or area for the facades. The functional units refer to aforementioned NL-SfB coding in order to be able to register the data into BIM. A few examples are:
- Architectural: Raised ceiling plate, floor tile;
- Installations: Lighting fixture, light switch;
- Space plan: Pantry, counter, partition wall;
- Stuff: Table, chair; closet.

The weight factor of different spaces within the building and their stated representability influence component reutilization strategies. The stated condition ratings as per the general matrix could result into adjusted references for some components. Therefore, the check on representability for minor defects is integrated in order to guarantee client's satisfaction.

5.4. INTEGRATION OF SYSTEMS

Depending on the strategies concerning circularity (e.g. reuse, recycle, preserve and non- toxic) related to the impact categories (e.g. energy, water, materials, and land), different approaches are required. Each actor in the supply chain only has a small piece of the necessary information to address circularity. There is not a single actor that has the complete picture. Therefore, first it is important to indicate the various stakeholders involved during the different life cycle phases in the built environment in order to align their objective to incorporate circularity from the initial start. The life cycles most commonly acknowledged in industry are respectively: (1) development, (2) planning, (3) design, (4) construction, (5) operation, and (6) deconstruction.

In addition, buildings are considered to be very complex products, which comprise numerous different materials, components, products and systems (site, structure, skin, services, space plan, and stuff) hierarchically structured with each a specific lifespan. They are initiated, designed, constructed and used as entities. However, over time, buildings are constantly adapting due to changing needs, user preferences and environmental conditions. Therefore, circularity indicators should be able to change indefinitely, from the present to the future. Resource efficiency and effective reuse strategies gradually improve due to innovations. Ultimately, an open and robust system for assessment is recommended, with the objective to 'value' available resources simultaneous to use it circularly. This 'value' (e.g. financial, physical or technical) - in which this research focuses on the technical value of product - will embrace the principles of the circular economy: (1) Design out waste, (2) Build resilience through diversity, (3) Rely on energy from renewable resources, and (4) Think in systems.

Circularity regards to the choices in terms of virgin material resources, the organization of modularity, the reusability of material and finally linked with either a sufficient information passport, bill of materials (BOM) or building information model. The collection, management and exchange of resource-related information is related to the fourth principle and prerequisite for the achievement of the other three principles.

Herewith, indicators that assess the influence on the buildings' level of circularity could be created. These indicators could be divided in four different categories: (1) technical indicators, (2) functional indicators, (3) perception indicators and (4) economic indicators. Important is that the circular economy as per definition is about an economic value (as a driver), to provide balance between supply and demand (e.g. scarce resources) (Jansen, 2018). On the contrary, circularity on itself is mainly focused on the technical, functional and perception values. Within this perspective, technical indicators are related to the origin of material (virgin or reused materials), utility (lifetime and (dis)assembly) and material waste scenarios (level of reuse). The functional indicators refer to the applicability of materials such as location, availability, and accessibility. This could be defined as 'attractiveness to use'. Finally, the perception indicator relates to the 'attractiveness for the state of mind' (aesthetical, exposure, comfort, acoustic, and light).

Due to the strong influence of one individual's perception, the 'attractiveness for the state of mind' is highly subjective and therefore difficult to quantify. Moreover, this qualitative indicator aims to maximize the utility based on perceived prosperity or health, which is contradicting the effective (re)use of available resources at any time. Despite the recognized productivity of the materials by stimulating the state of mind and the utility which would both be beneficial for the buildings' level of circularity, this indicator is excluded from this research.

In conclusion, the intended model yields two categories, which are respectively the technical values and functional values. The model integrates the information of BCI, NEN condition rating and representability weighting of spaces, and finally presents the resulting reutilization strategy for intervention. Within these categories, data of the applicable materials (BOM), their interfaces and connections (DDF) are separated into 6 product-specific building layers for industry purpose (Brand, 1994).

The indicator is referred to as the 'Circular Redevelopment Potential Indicator' and could enable the first step towards a CE, starting with the existing environment. First there is the current available products for all that could be reused on site. This is the material reuse value and the component reuse value of the building. And then there is the (expected) future redevelopment of that what is maintained & added. Together these aspects result to the circular development potential.

The application of this indicator provides structure and overview in order to enable the most beneficial strategy during the initiative for intervention. By dismantling the building in the applicable layers and specify the reutilization potential, the redevelopment of a building as a whole is manageable. The relevance for a circular economy is clarified accordingly. What is important for the company? What is achievable? Would the focus be more specifically be reuse or disassembly? Would refuse of material use or the use of non-toxic, pure cycles be more preferable?

The operational research model will be introduced in Chapter 6: 'A Strategic Model for Circular Redevelopment Projects'.

Part III: Approach for new redevelopment potential

6. A Strategic Model for Circular Redevelopment Projects

This chapter describes both the development and the final concept of the Circular Reutilization Potential Indicator. In the first paragraph all decision variables, optimization criteria and constraints will be evaluated through interviews. Most important actor considered is the acting principal of the Central Government Real Estate Agency (Rijksvastgoedbedrijf), giving feedback on the proposed model. Furthermore, market parties are approached with the proposal for further validation. Conclusively, the conclusion, limitations and recommendations for this CRP Indicator will be presented in the second paragraph.

6.1. CONCEPTUAL MODEL

6.1.1. Expert Interviews for the CRP Indicator

So, what critical aspects address the success of the intended CRP Indicator? In order to get a broad perspective, a variety of stakeholders that are involved in the building process (initiative, design, construction, exploitation and deconstruction) with different expertise have been interviewed (principals, consultants, financial departments, construction companies, real estate companies, and engineering companies). In total there have been 13 expert interviews conducted, of which 10 internally, focussing on new insights for key performance indicators, and 3 external interviews for valorization from perspective of the market. A total overview of the interviews, date and location can be found in Appendix C.

During the interviews held internally with 'Rijksvastgoedbedrijf' it became clear that there is a variety of different opinions and definitions about the circular economy and the assessment on circularity. The discrepancies and perspective on the applicability of the model are highly crucial to the intended CRP Indicator. Therefore, it has been decided to use external interviews to acquire a sufficient valorization on the model.

The findings from all expert interviews with persons relevant for the previous mentioned approach (principals, consultants, financial departments, construction companies, real estate companies, and engineering companies) (for details, see Appendix C), are as follows:

- In principle, the existing situation on site could be observed and classified. Indicators differ in two main aspects, qualitative and quantitative factors. Especially the quantitative data is useful for modeling. Then indicators show an reutilization potential. However, there should be some adjustments/additional factors developed, in particularly related to functionality or usage intensity of the current condition.

"The initiation of material reuse from old buildings for new purpose is maximized with the temporary Valkenburg office. It achieves optimal reuse of materials and serves as an example for the environment, to inspire the users and create awareness for the origin and future of these materials. But the knowledge of reused materials and their potential is indispensable" - P. Vermeer, Rijksvastgoedbedrijf

- Despite of the importance of aesthetics, it turns out that something with qualitative, perceptions with the tendency for subjectivity cannot be measured in society. Usually, a building consists of a very long circle and the perception on what we appreciate today could change considerably in the future. Therefore the aesthetics, despite the fact this KPI has great influence, cannot be measured and is ignored.

"Whether a chair is functionally capable and acceptable to reuse in a new exploitation phase, and to determine the reutilization potential is relatively simple. But to agree on the aesthetics of this chair could lead to an endless discussion." - W. Jansen, Alba Concepts, 2018

- The quest for measuring circularity is widely recognized. Parameters influencing on the circularity are considerable. However, whether the conditions for circular reuse are emission

based, economically justified, or any other way affected by, circularity relates to the material intrinsic values.
- The CE could contain different aspects such as functional, economic, cultural and social and is based on the minimization of the waste cycles and downcycling resources and materials. Therefore, it is not primarily about the financial value, but it has to do with the technical value proposition. This means that the process should be organized in a way that a higher intrinsic value is going to be assigned to the current products and materials, gradually downgraded with each following level of reutilization. Within this perspective, the Trias Materia is fundamental: Reduce Reuse Recycle. The Multi-LCA approach is conditional however, due to the technical life of each product.

"Circularity is regarding the full exploitation of the technical lifecycle of products, by designing products modular, robust and reusable in order to enable the full intrinsic value of raw materials." - W. Jansen, Alba Concepts, 2018

- The CRP Indicator should provide a perspective on how to scale up reutilization from component level to building level in order to obtain a certain intervention strategy.
- The ability to test reutilization potential on component level in an easy, affordable and efficient way is lacking. No methodology as it stands now, does allow the insights during initiative phase. Condition ratings could objectively classify the potential for reuse, based on the 'attractivenes to use'. However, an adjustment would be needed for the NEN2767, given the fact that a building is built up out of building layers with each a different mass and lifespan. The addressed conditions of components should relate to the individual layers of the building in order to be able specify the relevant strategy.
- Adaptability is one of the crucial aspects for measuring reutilization potential in the built environment. It can be perceived as the way components are fixed, and the spatial environment in which one or more functions can be enabled. It is a prerequisite of circularity, since a building requires a certain level of demountability in order to provide maintenance and moreover is adaptable enough for a possible, new future function. The latter refers to the aim to prolong the lifetime. By preserving the value of embedded materials and energy during use without any degradation, the building has a potential infinite lifetime, which is perceived perfectly circular. In addition to the technical adaptability, regarding a more broad perspective on the aspects economical, technical and functional efficiency, it is more sufficient to use a building which lasts longer without any adaptations than a building subject to multiple changes. Therefore, robust and functionally adaptable design, at some level, is more important than technical adaptability.

During the interviews conducted experts addressed the desire to incorporate the reutilization values of components into a general strategy of building layers of a building. For instance, a greater material reuse value or a greater component reuse value in a building might result in a more favorable 'exit value' for this specific material or component to another owner. Specific interest for the functional process behind reuse was shown. It was considered to be an interesting step in changing the way we deal with adaptive (component) reuse. The market for secondary components for instance is slowly emerging, with reference to Madaster as one of the more common known platforms. One major benefit could be the reuse of intrinsic material values that lie enclosed in buildings. It was said that; 'even though it is not common practice, it is at least very helpful to know what the values are we're dealing with.

The model assesses how components are built up from materials, respectively their origin, utilization and waste scenario. Note that this is merely an analysis and does not give any preferences of using one material or another.

6.1.2. Design of the CRP Indicator

The design phase is subject to iterative cycles, in which the development and improvements are based on trial and error of the previous cycles. This process has resulted into the final concept of the CRP Indicator and describes how all aspects are implemented in the model. Due to the educational purpose of this research, all preliminary concepts are not described further. All mathematical formulas and the technical description of the model is presented in Appendix A.

6.1.2.1. Objective
The developed CRP Indicator has the objective to help actors in the built environment to determine at what level a building component or material is most suitable to reutilize in order to initiate adaptive reuse. The CRP Indicator is mainly focused on circularity. Therefore, economic, societal and sustainability are excluded from this method. The model is designed to use without the necessity of a high level of expertise and should therefore encourage more actors in the built environment to use it. All implemented aspects are either data inputs, or widely accepted procedures to fulfill observation.

6.1.2.2. Strategies
The CRP indicator comprises 6 consecutive strategies which are assessed for each component; respectively (1) Reuse, (2) Repair, (3) Refurbish, (4) Remanufacture, (5) Repurpose and finally (6) Recycle. The strategies are considered here as 'within use' adaptation, and in this case the circular pavilion remains in its function. The decision for either transformation or demolish and new built is not applicable for the simplicity of circularity measurement on building level. Transformation as a strategy considers any intervention necessary to adjust, reuse or upgrade the building, which is covered by the lower three reutilization strategies accordingly. The demolish and new built option refers to the strategy 'recycle', for materials to be retrieved into new cycles.

The CRP Indicator is designed for decision support on various moments. The main objective however is to integrate during initiative for redevelopment, at the end of use phase of previous cycle. The necessary information in order to use the CRP Indicator should at least be:
- Information regarding material characteristics; layouts, (bill of) materials, circularity index;
- (Dis)assembly information;
- Condition assessment.

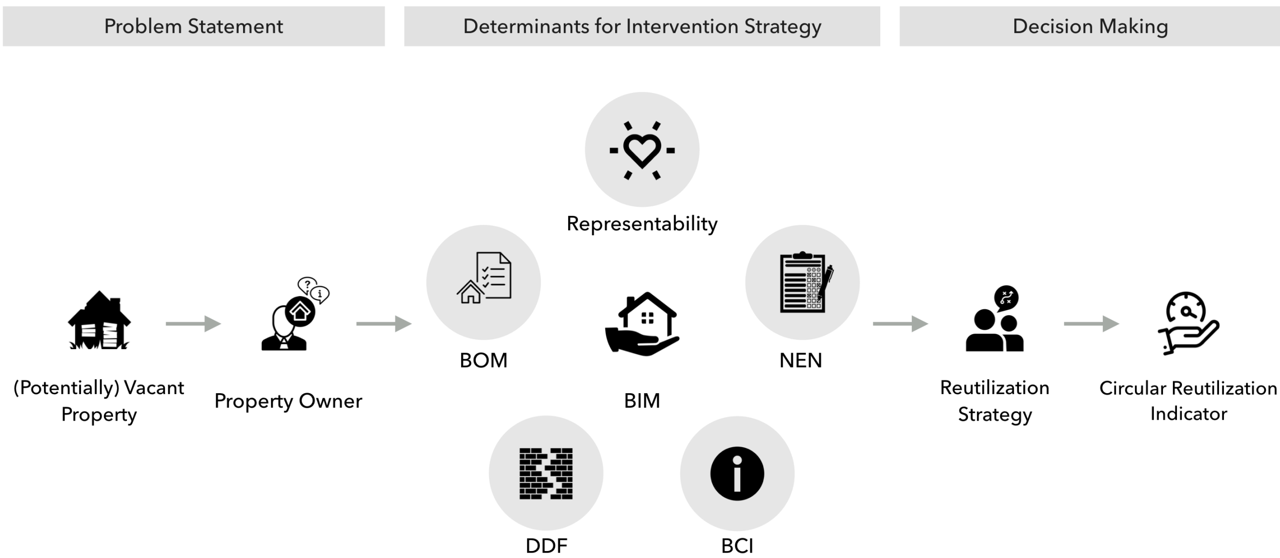

Figure 6.3: Visual presentation of the concept for circular redevelopment potential (own illustration)

6.1.2.3. Included aspects
The relevance of included aspects within the CRP Indicator are derived from the literature studies, interviews and simulations. A brief summation is provided below, for which Figure 6.3 presents the sequence of activities to clarify the assessment model of this research in one overview. An overview of the applicable aspects and their relation is shown in Figure 6.4 below.

The BCI covers two aspects, respectively the material characteristics, and subsequently the way in which the materials and products are linked within the system. This is necessary to identify the possibilities to reuse the components for a new cycle, without affecting surrounding systems. Given the systematic BCI assessment model of Verberne, it is necessary to quantify the applicable building elements, systems, products and materials. The BOM provides an overview of both the resource of feedstock and technical value and further the circular reutilization potential. The summation of all Material Circularity Index further defines the circularity index for the building as a whole. In addition, the DDF identifies the interfaces and connections between products and materials. Based on this information the potential for disassembly strategies in order to accelerate circular redevelopment could be subtracted.

The third element of this model is the analysis of the current condition. Observation on site provides insight on the actual condition of systems and products. Whenever the product is perceived not acceptable for another exploitation phase (i.e. reuse), the model could either refer to repair, refurbish remanufacture or repurpose on product level on another location, or focus on the most appropriate recycling or recovery methods.

The representability classification is used to define the impact of minor defects (i.e. degradation/ decay as a consequence of normal usage) on the representability of a component. ‘Rijksvastgoedbedrijf’ agreed to specify the accepted levels of condition in collaboration with several market parties to assign the justified importance of representability of minor defects.

The last part of this conceptual model is the elaboration of all gathered knowledge into the CRP Indicator. With the combination of stated representability, the building characteristics from BIM and the observation on site it is possible to classify the most beneficial strategy of each component In addition to the insights provided for the principal, this strategy could furthermore be helpful for contracting parties to get objective prescribed information for an fair allocation during tenders, among others.

6.1.2.4. Step-by-Step approach

Based on above mentioned information, the CRP Indicator is designed following a five step approach. The first input of the CRP Indicator is the initiative for intervention. A principal or owner has a building in his portfolio which is either at its end-of-life or end-of-use phase. Intervention is needed in order to facilitate a new exploitation phase. From this perspective, the owner of a building will have to decide at what level the building/products/materials could be reutilized, i.e. respectively reused, repaired, refurbished, remanufactured, repurposed or recycled. The required information is provided through a Bill Of Materials. The first step of the program relates to the ‘**information gathered into a BOM’**. All material characteristics and their configuration are employed in order to specify the applicable MCI (material level) and their relation and interfaces within the system (DDF), to combine into a PCI for each element (product level). The second step for the actor is to ‘**classify any defects observed on site**’ according to the checklist as per the integrated ‘NEN 2767 Stappenplan’, and provide the associated ‘**representability factor**’ for the elements within each space.

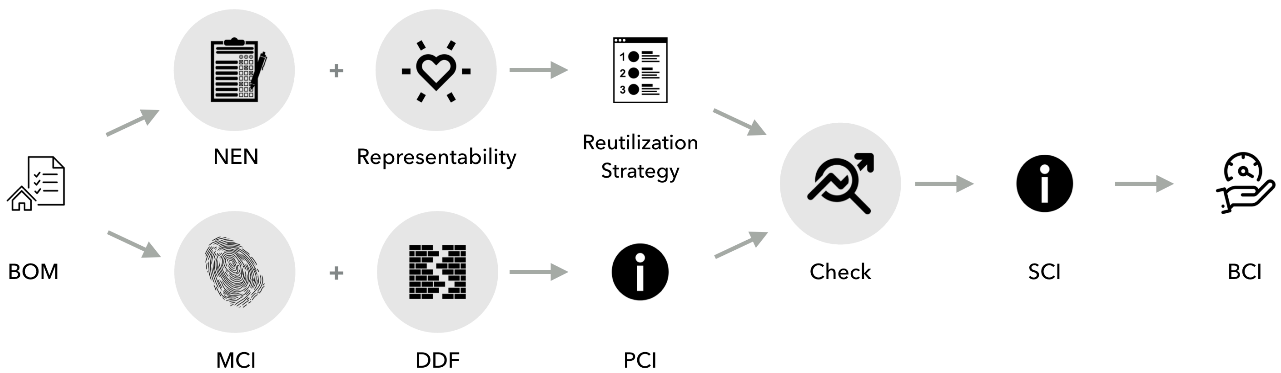

Figure 6.4: Schematic overview of the information flow of the CRP Indicator (own illustration).

The applicable intervention strategies are subject to above mentioned information aspects. This selection is based on the following options:

R3: Reuse the whole product;
R4: Repair and maintain to reuse the whole product in its current function;
R5: Refurbish and improve the old product for use in an improved version of its original function;
R6: Remanufacture the components into a new product with the same function;
R7: Repurpose the products or components for use in a new product with another function;
R8: Recycle materials in order to utilize them into new (preferably higher) qualitative products;
R9: Recover the embedded energy in materials by incineration.

Step 3 includes the adjustment of weighting to user preferences through a '**check on representability**'. For an organization the first step would be to clarify why the integration of circular initiatives (i.e. reuse of existing components and products) should be implemented, and on what areas this could be applied. These aspects could be related to function related criteria (e.g. the characteristics of an employees office or client-/ customer-specific appearance of an foyer). These criteria could help to determine the circularity potential or exclude one another by veto. The chosen decision for a certain intervention is a combination of circularity potential and the actor's preferences .

Subsequently, step 4 provides the '**result on six strategies**' for all products/elements within each building layer (SCI). Finally, the last step of the process relates to the **'reutilization performance indicator'** (BCI). Based on the applicable elements, together with the given condition ratings and reutilization strategy, the indicator to what extent the intervention is circular is extracted.

The CRP Indicator is designed in Excel to be used in practice. If the decision for a certain intervention is made, the indicator should address to the performance on circularity during the redevelopment process. With regards to the relevant level of intervention, reutilization of applicable products would create the least disposal of waste to the environment.

When the score for each strategy is presented, it is possible to continue with LCA modeling as a possible subsequent step in the decision-making process to calculate the environmental load.

6.1.2.5. Important notes
The default weighting of the representability aspects in the CRP Indicator are derived for company-specific purpose, thereby focussing on large assets and offices. Despite the opportunity to calculate the performances for circular redevelopment within this sequence, the applicability for other type of real estate should be taken into account.

Moreover, the derived values of reutilization strategies as the result from the stated condition ratings are manually provided. Additional research on weighting these variables should be executed. The CRP Indicator is not designed to benchmark circular redevelopment in order to compare projects with each other. Due to the purpose of this model to inform the principal at first hand during initiation phase, several elements are excluded. First, it is too time consuming to develop a model which also includes lifecycle costs, economic reuse values and environmental impact. Whilst this CRP Indicator focuses on circular redevelopment of a single building, additional methods regarding environmental sustainability and transformation strategies are focusing on a broader perspective of the real estate market, which in addition have nothing to do with circularity on its own.

The focus is put on the reutilization potential of building products/components as set by PBL (2016). Moreover, due to the situation of redevelopment of existing buildings, only the second main category 'prolong the lifecycle' of the Circularity Ladder is considered crucial, and in addition the combined step of the third main category 'useful application of materials'; 'R8: Recycle & R9: Recover'.

In order to express circularity in a measure of units during procurement, a holistic and systematic approach is required. This starts with the maximum use from resources depot that is currently available on site, and expands towards the more abstract levels of the project scope. For this type of redevelopment, different categories of the project scope should be introduced in order to be able to classify the most appropriate alternative. During the expert interviews, Alba Concepts defined 4 types of categories for their procurement strategies (Appendix C):

1. Assessment of the building and it’s site. All reutilized components are rewarded 1 points;
2. Core business of the considered company. Products and components which are perceived insufficient for their initial purpose and reused during intervention are rewarded 1/2 points;
3. Products and components mined from the business related sector are rewarded 1/4 points; and
4. Any reutilized product or component within the redevelopment project is rewarded 1/8 points.

7. Case Study Analysis: Circular Pavilion ‘The Green House’

The proposed results of CRP Indicator are compared to the results in practice. The difference learns us how the business case can be improved or what the limitations in practice could be from the model. The CRP Indicator is applied to the case of ‘The Green House’ in Utrecht, adjacent to the Government office ‘De Knoopkazerne’. First, the input variables are presented, which are followed by the results as output of the model. Finally, the results are evaluated and the conclusions are given.

7.1. INTRODUCTION

In the middle of Utrecht a new, circular pavilion arises. The location, next to the redevelopment of government office ‘De Knoopkazerne’, enables to exploit the concept as a hotspot for social interferences and catering services for a period of 10 to 15 years. Afterwards, the pavilion is expected to fulfill another designation, for which new development could emerge on this location. ‘The Green House’ is the title for this temporary, circular and gas free realization. A visual representation of the future situation is shown in Figure 7.1 below. The initiative was based on the ambition to optimize circularity. The aim to realize a sustainable building within the conditions of a temporary designation resulted with the opportunity to calculate circularity. Consequently the project contains the necessary information to do so. Therefore this case study will be used to validate the proposed decision support model. The context of the case is given by a description of its location, the dynamics of the decision-making process and determining conditions.

Figure 7.1: Circular Pavilion ‘The Green House’ Utrecht (The Green House, 2018)

7.2. ORIGIN OF 'DE KNOOPKAZERNE’ UTRECHT

In 1934 the formerly ‘Willemskazerne’ in Utrecht was renamed in "Lt.-gen. Knoopkazerne". Utrecht always have had a ‘Knoopkazerne’ ever since. In 1989 a new facility was built along the Croeselaan, which was the temporary head quarter for the Royal Dutch Military in 2005. Years later, after their relocation towards ‘Galgenwaard’, the premises became obsolete due to overcapacity. As a result of an interdisciplinary strategy, in which multiple government agencies merge into one shared facility, the former government building department ‘Rijksgebouwendienst’ took over the property from Ministry of Defense in 2012.

7.2.1. Location

The premises and the office building are located West from the Central Station and inner city center of Utrecht, in between the 'Beatrix Theater' and the headquarters of Rabobank. The area is part of the 'CU 2030' masterplan, aimed to renew the city center. This masterplan is a guideline for the future developments in the area. It describes potential new functions, the accessibility and improved quality of the public space. The preconditions are supported by research on environmental impact, economic effects and safety. More information on this matter is available (CU 2030, 2018).

7.2.2. Development of Knoopkavel spatial planning

The Government Real Estate Agency and Municipality of Utrecht signed a collaboration agreement. This collaboration structure was used to orchestrate and initiate the spatial planning procedures. This agreement was based on a long-term vision and aims to develop in accordance with the preferences of all (future) stakeholders, respectively the Government Real Estate Agency, Municipality, future users, and NS. One product is the 'uitgangspuntenkaart', which contains the agreed spatial configuration on the plot (refer to Figure 6.2 below).

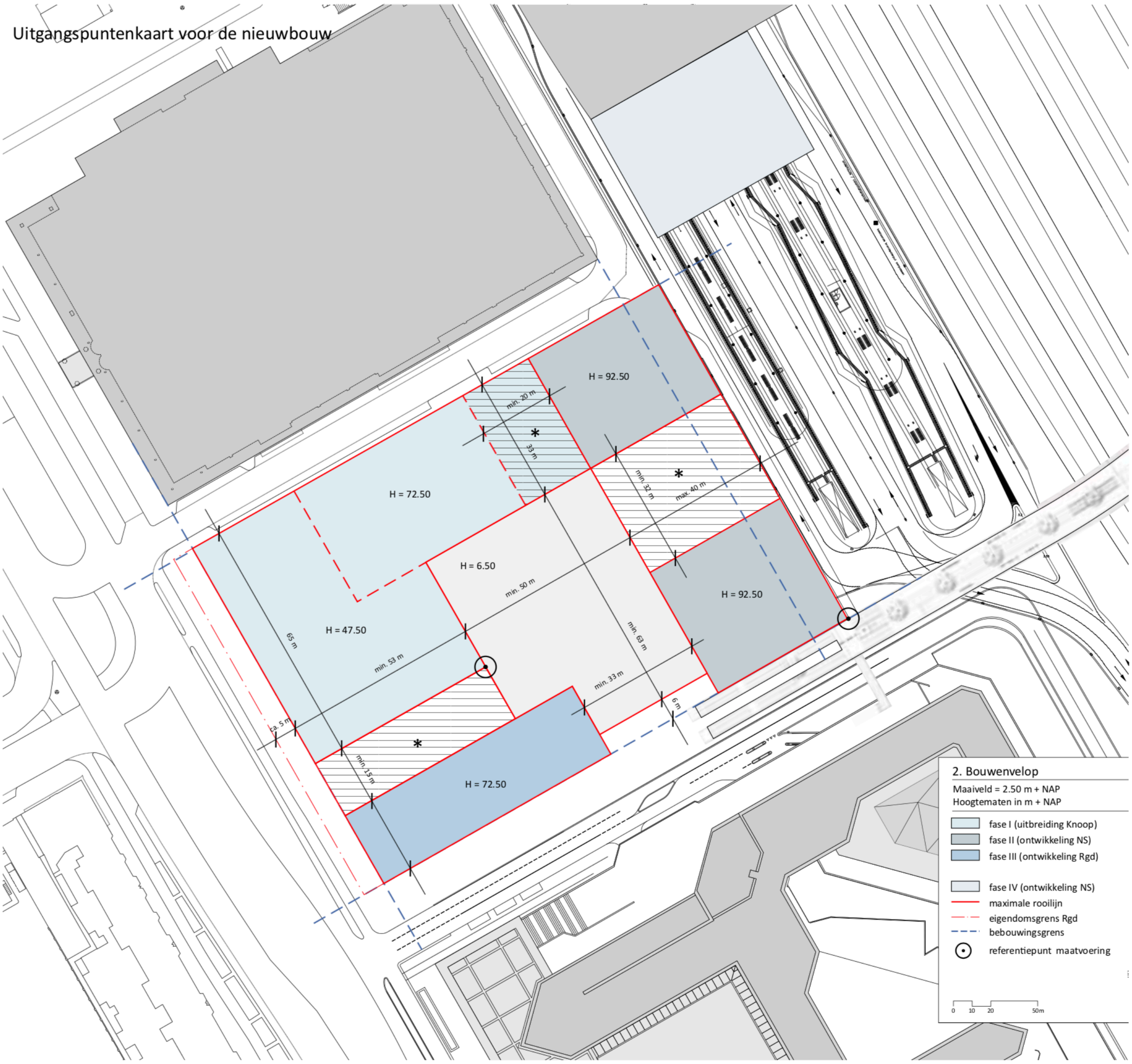

Figure 7.2: Land use plan 'Knoopkazerne' plot Utrecht (Rijksvastgoedbedrijf, 2013)

7.2.2.1. First phase

The government office is a first step in the realization of the long-term vision and the ambitions for a vivid urban implementation. The plot will initially be used as parking lot. Later on the pedestrian area will connect the Central Station and city center with the new developed southwest urban area.

In order to fulfill a successful implementation of the building within the final situation, the plot is equipped with a gradual, transitional infill between the elevated 'Forum' of the central station and the surrounding level of the Croeselaan. The 'Forum' is at level of 6,5 meter above height gauge, shown in light grey in Figure 7.2 above. This platform functions as a forecourt with connections into several directions. Underneath this platform, space for bicycle storage, car parking and expedition.

7.2.3. Reuse

The existing built environment and surrounding requested for a thorough redevelopment. The building was developed in the period 1988-1990 by the 'Office of Buildings Works and Terrains' [Dienst Gebouwen Werken en Terreinen] of Ministry of Defense [Ministerie van Defensie], which later merged into the Government Real Estate Agency [Rijksvastgoedbedrijf]. The building did not have any cultural heritage value and involved approximately 20.850 m2 GFA. The basement underneath the former building was approximately 2.350 m2 GFA.

7.2.3.1. Optimized reutilization

The office building is fully redeveloped and expanded. The ambition was to realize an affordable, sustainable and healthy working environment. Due to the ambition of sustainability, demolition of technical sufficient elements and new built would not have been acceptable. The majority of the structure, which is in-situ concrete work, was kept during redevelopment. Due to innovative developments and concepts, the fit out, services and facade were fully replaced.

7.3. CIRCULAR PAVILION 'THE GREEN HOUSE'

The opportunity for the circular pavilion was initiated due to the acting masterplan of this area. Phase 2, 3 and 4 are scheduled to be developed towards 2030. The direct reason for the building of the pavilion is the aim of 'Rijksvastgoedbedrijf' to avoid an urban gap at the location of the Green House, and to create an opportunity that contributes to social liveliness and social security. The municipality of Utrecht participated in a temporary enlightenment of an important and busy city-center hub. Subsequently, 'Rijksvastgoedbedrijf' has chosen to make the pavilion part of the tender for the redevelopment of the former neighboring Knoopkazerne.

7.3.1. Disassembly potential

Since the building is ought to be relocated after 10-15 years, the objective was to design for disassembly potential. Cepezed and Alba Concepts realized this ambition into practice. Steel construction and wood flooring elements are dismountable. The building is constructed 100% circular on this matter. This is from perspective of functionality of the extracted elements. For example, the foundation is created from so-called 'stelcon' plates and similar concrete blocks. After disassembly, the elements could be reused for different purposes.

The shell and core of The Green House is constructed within three months. The former 'Knoopkazerne' was used as donor. Subsequently, the fit out was implemented. All elements were chosen with respect to sustainability. Triple glazed windows, residual heat from the adjacent government office 'De Knoop', and 500 m2 solar panels. Conclusively, the measures resulted into an energy neutral building.

7.3.2. Involved stakeholders

The joint venture ‘R Creators’ is responsible for the development, which is scheduled to open this spring 2018. Together with Albron; Strukton, Ballast Nedam and Facilicom aimed for optimized on circularity. This was agreed by the joint development, construction and operation of the circular catering and meeting pavilion 'The Green House' nearby Utrecht Station. The process was safeguarded by Alba Concepts, which assessed the circularity and the circular ambition level, and further supported the procurement. Cepezed was the architect, responsible for the design for this circular pavilion. Fokkema & Partners was the interior architect. Rijnboutt elaborated on the urban fitting, DGMR was responsible for the climate, and to conclude Pieters Bouwtechniek calculated on the construction. There were numerous other parties involved, with reference to Figure 6.1.

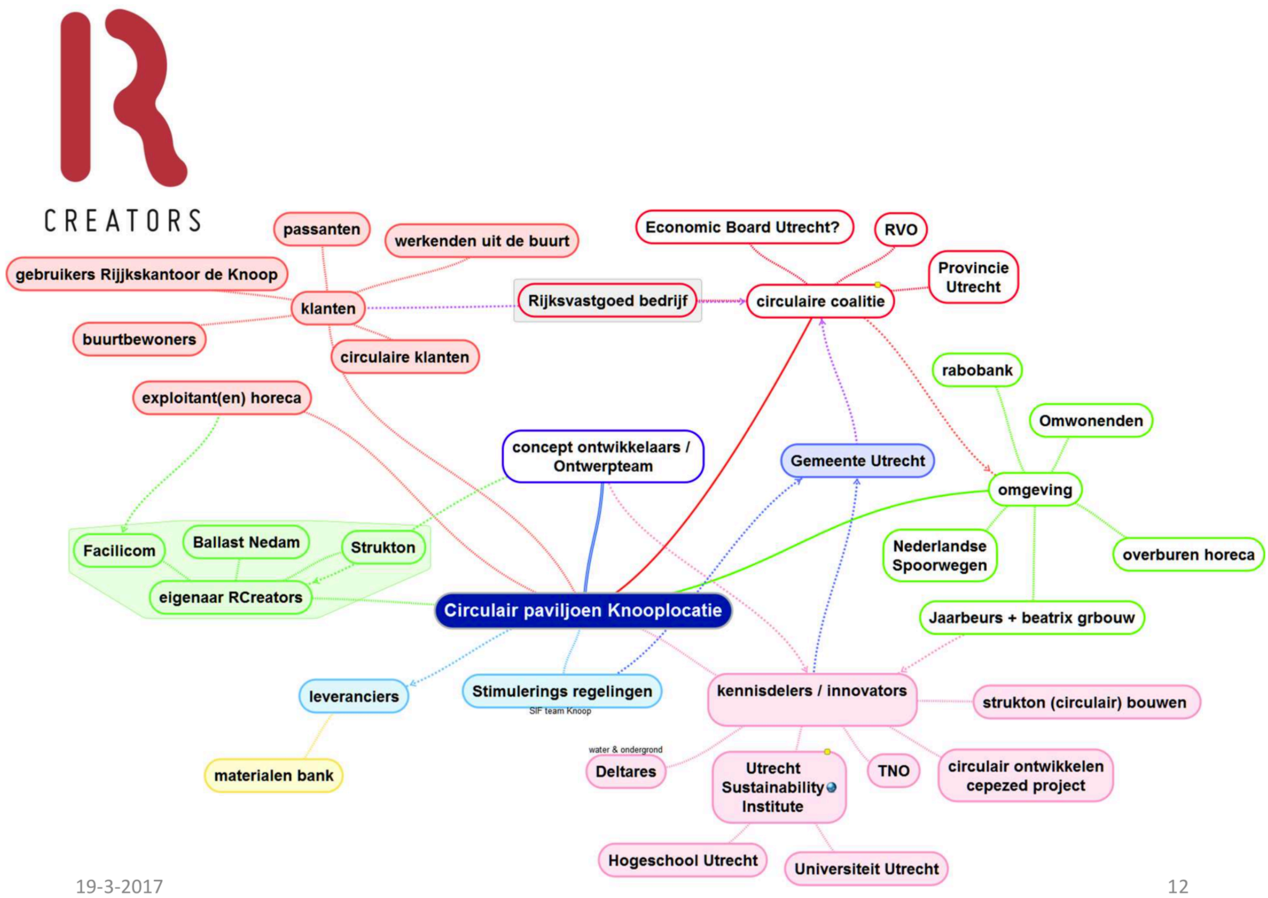

Figure 7.3: Stakeholders map Circular Pavilion ‘The Green House’ Utrecht (R Creators, 2017)

8. CPR Indicator for The Green House Pavilion

In this chapter the CRP Indicator based on The Green House Pavilion is used to answer the main question. Firstly, the final design will be presented. A scenario for intervention is clarified in paragraph two. Subsequently the data is implemented and all relevant strategies with associated objectives and conditions are presented, based on the given results regarding the project The Green House Pavilion. After evaluation of the design, the last paragraph presents the final conclusion.

8.1. INFORMATION FLOW OF CRP INDICATOR

Aforementioned problem analyses have shown the possible relation between the problem of dilapidation issues of existing real estate and the alternative solution, to change towards a circular economy. The CRP Indicator combines these two aspects into one reutilization potential indicator. The model comprises in total 6 worksheets, for which a brief overview is presented below:

Circular Pavilion The Green House

#	Worksheet	Functionality	Description
1	Bill Of Materials (BOM)	Data collection & assessment	To identify elements & assess MCI
2	Condition (NEN 2767)	Assessment form	To assess condition rating
3	Reutilization Potential	Derived aggregation	To aggregate information and determine most beneficial strategy
4	Building Circularity Index Calculations	Derived performance indicator	To derive BCI
5	Tables & Disassembly Determining Factors	Reference Tables	To support formulas

Table 8.1: CRP Indicator Worksheet description (own illustration)

8.1.1. Worksheet Bill Of Materials

The 'Bill Of Materials' Worksheet presents the circularity characteristics of all applied elements of the building. Kindly refer to Appendix A for a full overview based on the case study. Firstly, the columns A-H provide general information regarding the elements. The information refers to the location and gives the inspector the opportunity to get acquainted with the building configuration:

Information of applied elements for MCI calculation

Column	Value	Description
B	Applicable Building Layer	Used to determine Technical Lifetime
C	NL-SfB Coding	Used to determine applicable Building Layer
D & E	Product Description & Comprised Materials	Characteristics
F & G	Technical & Functional Lifetime	Used to derive utility function
H	Total Volume	Used to determine weighted score on BCI

Table 8.2: Columns A-H 'Bill Of Materials' Worksheet description (own illustration)

In addition, the material characteristics should be filled in (Colums I-N). All elements have to clarify their origin and waste scenario of the embodied materials. The required information respectively address the following amounts (%):

Input variables for MCI calculation

#	Input related	#	Output related
I	Reused feedstock	L	Reused output
J	Recycled feedstock	M	Recycled output
K	Recycling efficiency	N	Recycling efficiency

Table 8.3: Columns I-N 'Bill Of Materials' Worksheet description (own illustration)

Subsequently, the derived MCI for each element is presented based on the formulas in columns O-W. The following sequence is handled accordingly:

MCI calculation

Column	Value	Description
O	Virgin feedstock	Sum of 1 unit deducted by reused and recycled feedstock
P	Unrecoverable waste	Sum of 1 unit deducted by reused and recycled output
Q	Unrecoverable waste recycled feedstock	Sum of waste from efficiency losses of recycled feedstock
R	Unrecoverable waste from recycling	Sum of waste from efficiency losses of recycled output
S	Total Waste	Sum of all waste flows after full cycle
T	Utility of the product	Functional life / industry benchmark (Brand, 1994)
U	Eco-efficiency impact	Impact function of utility factor
V	Linear Flow Index (LFI)	Sum of linear flows after full cycle
W	Material Circularity Index (MCI)	Aggregated circularity of materials

Table 8.4: Columns O-W 'Bill Of Materials' Worksheet description (own illustration)

After the MCI is calculated, all interfaces of the elements are determined. Based on the 7 DDF factors (reference worksheet 'Disassembly Determining Factors'), the impact of demountability on circularity for the elements is derived in columns X-AS:

Disassembly Determining Factors

Column	Value	Description
X	Functional Separation	Separation of function within one composition
Y	Functional Dependence	Factor of the principle of a subsystem at creating modular design
Z	Technical Lifecycle	Relation between a long cycle product and a short cycle product
AA	Geometry of product edge	Factor for possibility of disassembly a composition
AB	Standardization of product edge	Relation between subsystems for disassembly
AC	Type of connection	Factor in which the interfaces defines the degree of freedom between component
AD	Accessibility	Factor for transformable configuration
AE - AK	W DfD	Derived factors from worksheet 'Disassembly Determining Factors'
AL - AR	W DfD × MCI	Aggregated impact of DDF on elements
AS	Product Circularity Indicator (PCI)	Aggregated circularity of elements within the system

Table 8.5: Columns X-AS 'Bill Of Materials' Worksheet description (own illustration)

8.1.2. Worksheet Condition (NEN 2767)

The ‘Condition (NEN 2767)’ Worksheet comprises a step-by-step plan for the inspector to observe and classify any defects on site. The worksheets basically consists of two sections, respectively the provided information by the inspector (up until Step 3c, if applicable), and the calculation model on the second part (Step 4a until Step 7). The assessment on the applied elements should be filled in (Colums B-I). All elements have to be classified into their configuration categories (B). Moreover, any combined defects on a single component should be addressed accordingly (C). Choices have to be made on the importance, extent and intensity of defects. The process and definitions of these aspects is described in Paragraph 5.3: ‘Condition Assessment in the Built Environment’. The assessment address to the following information:

Condition rating (NEN 2767) Step-by-Step plan

Column	Value	Description
B	Configuration element/product	Single elements or combined components [yes/no/remaining elements]
C	Multiple defects on 1 component	One or more defects on one component [yes/no]
D	Element	Element title
E	Location Specifications	Representability (in case of minor defects) [A/B/C]
F	Defects observed	Brief description of defect (unless remaining elements, these are rated ‘excellent condition’)
G	Importance	Factor to indicate to what extent it influences the building’s functionality
H	Extent	Factor to indicate to what extent it is considered noticable
I	Intensity	Factor to indicate the status of the process

Table 8.6: Columns B-I ‘Condiition (NEN 2767)’ Worksheet description (own illustration)

Whenever components are merged and one or multiple defects occurred, the assessment model requires the weighted variable to be provided in order to differentiate the importance of defects based on their volumetric parameters. The amounts (%) have to be provided by Step 3b & 3c (columns K & L). This will become visible if the model cannot return the condition ratings, and no “n/a” is returned in the related cells of aforementioned columns. After the fully provided information, the consecutive calculation of Step 4a - Step 7 (columns N-R) is handled accordingly:

Condition rating (NEN 2767) Step-by-Step plan

Column	Value	Description
N	Step 4a	Condition of the component
O	Step 4b	Condition on the spot of defect (merged components/multiple defects)
P	Step 5	Correction factor for merged components with different conditions
Q	Step 6	Corrected total extent for merged components
R	Step 7	Aggregated condition ratings for (merged) components

Table 8.7: Columns N-R ‘Condiition (NEN 2767)’ Worksheet description (own illustration)

8.1.3. Worksheet Reutilization Potential

The aggregation of the two aspects above is presented in the worksheet ‘Reutilization Potential’. This overview provides an answer to optimize reutilization during the intervention of a building. The worksheet is divided into two sections. Firstly, all gathered information is summarized in columns A-E:

Reutilization Potential

Column	Value	Description
A	ID #	Element ID
B	Product	Product description
C	MCI	Aggregated circularity of materials
D	PCI	Aggregated circularity of elements within the system
E	Condition Rating	Condition of the element

Table 8.8: Columns A-E 'Reutilization Potential' Worksheet description (own illustration)

Conclusively, based on given information it is possible to determine the most beneficial or preferred strategy for all elements. By retrieving the circularity and demountability characteristics (G & H) of the elements, in combination with the assessed condition rating (F), the reutilization potential is given (I).The preferred strategy and the relevant level are presented in columns I & J accordingly. Finally, column K checks whether reuse (i.e. on location) is sufficient for current purpose. Whenever the strategy does not correspond, it is necessary to consider disassembly and relocation to reuse the element properly.

Reutilization Potential

Column	Value	Description
F	Circularity	Intrinsic material circularity of element
G	Demountability	Disassembly potential for waste scenario's
H	Reutilization Potential	Aggregated level reutilization potential
I	Preferred Strategy	Preferred reutilization strategy
J	Level	Level of intervention [product/component/material]
K	Check on representability	Checks whether reuse (i.e. on location) is sufficient for current purpose

Table 8.9: Columns F-K 'Reutilization Potential' Worksheet description (own illustration)

Important note
Deviant strategies can be pursued. Whenever elements are either linear or not demountable it is possible to determine a strategy to 'upcycle' the applicable element, and thereby resulting to 'prolong the lifecycle'. The gradual increase of linearity and/or demountability of elements reflect on the attractiveness to either Repair, Refurbish, Remanufacture or Repurpose in between the two most extreme strategies (i.e. Reuse & Recycle). The extreme strategies will always be used to their assigned 'excellent condition' and 'very bad condition'. However, on the contrary, other strategies could result less favorable due to the embodied energy in these products, despite their 'acceptable' or 'moderate' condition. For the purpose of this research, however, distinction is left out of the calculation method. This is possible to adjust manually in the worksheet 'Tables' section 'B78:N131'.

8.1.4. Worksheet Building Circularity Indicator Calculations

To conclude the proposed intervention, the worksheet 'BCI Calculations' provides an overview of the resulting Building Circularity Index, based on the chosen strategy. For each Building Layer the applicable elements are summarized into the System Circularity Indicator (SCI), given their Volume, Reutilization level, MCI and PCI. The SCI provides both the 'theoretical' and 'practical' circularity index, for which the latter is known as the factor of interfaces within the system. This The weighted variables are continued into the final BCI.

Reutilization Potential

Column	Value	Description
C	Products	Element title
D	Volume	Used to determine weighted score on BCI
E	Reutilization Level	Aggregated level of reutilization
F	MCI	Aggregated circularity of materials
G	PCI	Aggregated circularity of elements within the system
H	MCI x V	Weighted factor of all summarized elements into applicable building layer
I	PCI x V	Weighted factor of all interfaces of applicable building layer
J	SCI_T	Theoretical circularity index of assigned building layer
J	SCI_P	Practical circularity index of assigned building layer
J	BCI_T	Theoretical circularity index of assigned building
J	BCI_P	Practical circularity index of assigned building

Table 8.10: Columns C-I 'BCI Calculations' Worksheet description (own illustration)

The main difference with the original SCI and BCI assessment model regards the 'practical' circularity index. Whilst the original calculation is merely based on the interfaces of products within the system, this step is redefined in order to adapt reutilization strategies which potentially withhold component or material relocations, and therefore would likely result into a perfectly circular strategy. Based on this theory, the model relies on the terms 'reuse' and 'repair' on the total product level, as shown in the worksheet 'Tables' section 'J69:M75'. The four remaining reutilization levels are respectively on component (i.e. refurbish and remanufacture) and material level (i.e. repurpose and recycle). For the purpose of this research, further distinction on the gradual decreasing factors is left out of the calculation method. This is possible to adjust manually in the worksheet.

8.2. CRP INDICATOR APPLIED TO 'THE GREEN HOUSE'

8.2.1. Data collection

The information was gathered from drawings and reports submitted by the PPS team 'Rijksvastgoedbedrijf' & 'R Creators' and the consultants responsible for the circularity performance indicator of the circular pavilion, Alba Concepts. The listed components and resulting BCI were classified into a building layer category, and identified within a subcategory in each layer (e.g. partition wall is a subcategory of space plan). The simulation for condition ratings will be based on the future relocation of the pavilion, approximately 2032. This is done due to the recent completion, which will result into a condition score equivalent to 'excellent'. The simulation will result into a condition score, and is recorded accordingly.

Based on the BCI calculation method of Alba Concepts, the circularity of the pavilion could be assessed. In addition, the condition assessment will give the opportunity to assess the most beneficial strategy for an intervention in the future, set for 2032. The majority of this case study will consider the structure and façade of the building. A detailed overview of the case study assessment can be found in appendix C. A brief overview of the room specifications can be found in Table 8.11 below.

Circular Pavilion The Green House	
Description	Area
Restaurant (Ground Floor)	392 m^2
Conference Rooms (2nd Floor)	221 m^2
Green House (2nd Floor)	80 m^2

Table 8.11: Room division and characteristics (own illustration)

8.2.2. Description Case Study: Keep the pavilion for extended duration

For this suggested case the pavilion is required to remain on this location. In 2032 the structure and facade of the building are maintained at highest possible level. Only the additions made by Allbron ('Stuff' and 'Spaceplan' for operation-specific fit outs) are removed and excluded in this case study. The fictitious condition scores are based on traces of use up until intervention. Severe weather conditions deteriorated the glass and some cracks on the greenhouse glazing occured. Due to the intensive catering and conference meetings, the partition walls are roughed up considerably. The foundation built up from stelcon plates and Legio blocks are slightly settled. The upper ground structure is made up of steel, supplemented with wooden hollow core slabs, and reused at highest possible level as well. The façade and curtain glazing is removed due to cracks and reused as materials.

A full summary of the assessment can be found in Appendix A.

8.2.3. Data Input for the Case Study

The input variables for this case are largely determined by the availability of information of applied elements and their interfaces, for which a concept version of the BCI assessment is provided by Alba Concepts. The specifics for this case are subject to the confidentiality agreement by means of the current status of the project in this 'conceptual' phase. Therefore, more detailed information is available upon request with regards to the rightful owner, Alba Concepts. All presented results elaborated during this case study are underline certain important insights relevant to this thesis. The responsibility of these result fully lies with the author. The basic characteristics are shown in Table 8.12 below. The general input data for this case is already discussed in Paragraph 8.1 above and the related Appendix A.

8.2.4. Bill of Materials

An overview of the elements employed for this case study is presented below. It is assumed that all elements added during initial development in 2017 obtain for a full technical lifecycle, which is supposed to reach beyond the functional lifetime of the pavilion itself. The status quo of recycling, however, is set for the destination of their waste when discarded due to the simulated condition.

Applied Elements for Pavilion The Green House

#	Description	NL-SfB	Building Layer (Brand, 1994)	Functional Lifetime
1	Foundation structure	16.1 - 16.2	Structure	75
2	Main structure	28.2	Structure	50
3	Kerto Ripa Floor	23.1	Structure	75
4	SIPS Panels	21.1	Structure	75
5	Stairs	24.2	Structure	50
6	Roof plates	27.1	Shell	50
7	Second skin facade 1	31.1	Shell	30
8	Second skin facade 2	31.1	Shell	75
9	Curtain wall 1	31.2	Shell	30
10	Curtain wall 2	31.2	Shell	100
11	Windows	31.2	Spaceplan	100
12	Doors	32.1	Spaceplan	100
13	Partition wall 1	42.1	Spaceplan	50
14	Partition walls 2	22.1	Spaceplan	50
15	Floor finishing	42.2	Spaceplan	75
16	Roof 1	47.1	Shell	75
17	Roof 2	47.1	Shell	50
18	Roof 3	47.1	Shell	50
19	Roof 4	47.1	Shell	75
20	Roof 5	47.1	Shell	75
21	Roof 6	47.1	Shell	100
22	Greenhouse Roof 1	47.1	Shell	75
23	Greenhouse Roof 2	47.1	Shell	75
24	Greenhouse Roof 3	47.1	Shell	75
25	Greenhouse Roof 4	47.1	Shell	20
26	Plumbing	51.1	Services	75

Table 8.12: Bill of Materials for The Green House (own illustration, based on Alba Concepts, 2018)

Based on the data provided within the BOM worksheet, briefly summarized in the table above, the MCI & PCI can be computed for the 26 elements.

8.2.5. List of defects

Based on aforementioned scenario, the simulation of all observed defects should be determined. Validating the condition ratings requires additional data when comparing to the BOM. As described in paragraph 5.3, the required data is observed on site, clarifying the importance, extent and intensity of defects. An overview of the defects employed for this case study is presented below, for which the NEN 2767-2 Matrix is used as Normative Reference List.

#	Description	Defect	Importance	Extent	Intensity
1.1	Stelcon plates	02.11: settlement	Critical	Locally	Advanced
1.2	Legioblok concrete	02.09: Cracks	Critical	Regularly	Advanced
2	Main structure	61.31: cracks not structural	Serious	Locally	Advanced
3.1	Wooden Ribs	37.16: Wood rot	Critical	Generally	Advanced
3.2	Underlayment	Degradation	Minor	Incidentally	Advanced
3	Kerto Ripa Remaining	-	-	-	-
4.1	SIPS Panels (Chipboard)	12.27: Deformation	Serious	Frequently	Advanced
4.2	SIPS EPS	12.27: Deformation	Serious	Generally	Advanced
4.2	SIPS EPS	Cracks	Serious	Generally	Initial
4	SIPS remaining	-	-	-	-
5	Stairs	46.57: Dirt, Tarnish	Minor	Frequently	Advanced
6	Roof plates	05.22: Moisture	Critical	Frequently	Advanced
7	Second skin facade 1	Cracks	Critical	Frequently	Final
8	Second skin facade 2	65.54: Algae, Moss	Minor	Locally	Initial
9	Curtain wall 1	Dirt, Tarnish	Minor	Frequently	Advanced
10	Curtain wall 2	65.54: Dirt, Tarnish	Minor	Regularly	Final
11	Windows	Coloring	Minor	Incidentally	Initial
12	Doors	69.27: Deformation	Serious	Generally	Final
13	Partition wall 1	109.57: Dirt, Tarnish	Minor	Locally	Initial
14.1	Metal Stud Steel	29.36: Damage	Serious	Frequently	Advanced
14.2	Metal Stud Gypsum	Damage	Serious	Frequently	Final
14	Partition wall 2	-	-	-	-
15	Floor finishing	124.41: Loose finish	Serious	Incidentally	Advanced
16	Roof 1	Damaged	Serious	Locally	Advanced
17	Roof 2	189.23: loose seams	Critical	Regularly	Final
18	Roof 3	Coloring	Minor	Frequently	Initial
19	Roof 4	Loose fixings	Minor	Locally	Initial
20	Roof 5	Loose fixings	Minor	Incidentally	Initial
21	Roof 6	186.39: Erosion	Serious	Frequently	Initial
22	Greenhouse roof 1	186.54: Algae, Moss	Minor	Generally	Initial
23	Greenhouse roof 2	Algae, Moss	Minor	Generally	Initial
24	Greenhouse roof 3	185.57: Dirt, Tarnish	Minor	Locally	Initial
25	Greenhouse roof 4	188.10: anchoring	Critical	Frequently	Advanced
26	Plumbing	-	-	-	-

Table 8.13: List of defects for The Green House (simulation)(own illustration)

8.2.6. Output

In order to validate the associated reutilization levels, the two aspects ‘element circularity’ and actual ‘condition rating’ have been established. These are aggregated into the worksheet ‘Reutilization Potential’, which addresses the preferred strategy as per the summarized overview of the results in Table 8.14 below. Due to the comprehensive list of materials and defects, a full detailed overview is presented in Appendix A.

#	Description	MCI	PCI	Condition	Reutilization
1	Foundation	0,922	0,895	2	repair
2	Main structure	1,000	0,943	1	reuse
3	Kerto Ripa Floor	0,716	0,635	5	repurpose
4	SIPS Panels (Chipboard)	0,902	0,606	3	refurbish
5	Stairs	1,000	0,857	2	repair
6	Roof plates	1,000	0,786	4	remanufacture
7	Second skin facade 1	0,894	0,894	4	remanufacture
8	Second skin facade 2	0,975	0,891	1	reuse
9	Curtain wall 1	0,770	0,770	2	repair
10	Curtain wall 2	0,957	0,875	2	repair
11	Windows	0,957	0,875	1	reuse
12	Doors	0,955	0,873	5	repurpose
13	HSB (Partition 1)	0,583	0,441	1	reuse
14	Metal Stud (Partition 2)	0,716	0,542	3	refurbish
15	Floor finishing	0,922	0,922	1	reuse
16	Roof 1	0,942	0,713	1	reuse
17	Roof 2	0,802	0,596	4	remanufacture
18	Roof 3	0,855	0,610	1	reuse
19	Roof 4	0,915	0,915	1	reuse
20	Roof 5	0,894	0,728	1	reuse
21	Roof 6	0,955	0,750	2	repair
22	Greenhouse roof 1	0,991	0,835	2	repair
23	Greenhouse roof 2	0,894	0,868	2	repair
24	Greenhouse roof 3	0,968	0,885	1	reuse
25	Greenhouse roof 4	0,156	0,145	4	remanufacture
26	Plumbing	0,982	0,982	1	reuse

Table 8.14: Aggregated reutilization levels for The Green House (simulation)(own illustration)

Subsequently the associated levels will be integrated with the final BCI calculation. Within this worksheet, the elements and reutilization levels are merged into the SCI and BCI. Therewith the possibility to define both ‘theoretical’ (i.e. material intrinsic potential) and ‘practical ‘ (i.e. intervention specific) strategies are determined.

#	System & Building	Theoretical	Weighted Importance	Practical	Weighted Importance
1	SCI Structure	0,960	0,192	0,910	0,182
2	SCI Shell	0,922	0,645	0,982	0,687
3	SCI Services	0,982	0,785	1,000	0,800
4	SCI Spaceplan	0,718	0,646	0,682	0,613
5	SCI Stuff	0,000	0,000	1,000	0,000
6	SCI Site	0,956	0,000	1,000	0,000
-	BCI	-	0,873	-	0,878

Table 8.15: Determined BCI performance for The Green House (simulation)(own illustration)

Kindly note the higher level of 'practical' BCI score compared to the 'theoretical' value. The main reason is related to the actually realized intervention for this case study. For example, 'Element 1' has a potential reusable and recyclable output, resulting into a theoretical MCI of 0,922. However, due to the reuse strategy for this element, no additional action has to be taken. This results into perfectly circular reuse and this is promoted by the model.

8.3. DISCUSSION

The core objective of this research was to have insight in the circular redevelopment potential of elements within the existing built environment. The CRP indicator is based on a model for assessing both the Building Circularity Indicator (BCI) and condition ratings (NEN) on site, providing valuable information on the intended intervention. Herewith, the assessment model is made up of: BOM (type of input, type of output, materials' technical lifetime and disassembly possibilities), NEN (normalizing condition rating), and finally the CRP (level of reutilization). Finally a resulting BCI is presented. Each element should be discussed individually in order to keep the assessment procedure manageable.

With respect to the case study analysis, overall impression on the applicability is positive. The BCI incorporates the level of importance for circularity for all different systems. Deviant strategies for individual elements can be pursued (discussed in § 8.1.3). Whenever elements are either linear or not demountable it is possible to determine a strategy to 'upcycle' the applicable element, and thereby resulting to 'prolong the lifecycle'. The gradual increase of linearity and/or demountability of elements reflect on the attractiveness to either Repair, Refurbish, Remanufacture or Repurpose in between the two most extreme strategies (i.e. Reuse & Recycle). The extreme strategies will always be used to their assigned 'excellent condition' and 'very bad condition'. However, on the contrary, other strategies could be less favorable due to the embodied energy in these products, despite their 'acceptable' or 'moderate' condition. For the purpose of this research, however, further distinction between the two is left out of the calculation method.

Derived from literature study and expert interviews, it appeared that the notion to reuse products to exploit the full technical lifecycle could be defined perfectly circular during intervention. Therefore, the level of circularity is distinguished by the different strategies. For this research the 'reuse' and 'repair' (i.e. whole elements) levels are awarded fully circular. The remaining levels are subject to further actions and therefore relate to the disassembly procedures. However, the sensitivity of the allocated variables may be disputable. For example, the theoretical BCI of the intervention is 0.873 and for the practical intervention 0.878 on the contrary. So, it does influence the BCI, but it is for the principals to decide how to value this guiding principle towards reuse.

Finally, during the validation process of this case study it appeared that the building layer 'site' is not relevant for the assessment model to indicate. Based on the 'eternal' lifespan according to Brand, and further the intention to include functional indicators such as facilities, infrastructure, accessibility, etc., importance for this research is irrelevant. These aspects are excluded due to the difficulty to quantify the 'soft' parameters. Future relevance of the Brand/Gibbs 'building layers’ model should be reviewed. For example to elaborate on additional information, focusing on toxicity and resulting soil remediation (‘recycling’) for sites. Apart from the applicable reutilization potential of the ‘site’ due to pollution, the stated theoretical lifespan to distinguish building layers usually deviates from actual conditions. This deviation does influence the actual circularity, by representing a longer (stuff is less than one year) or, by definition shorter (site is eternal) utilization in practice.

9. Conclusions & Recommendations

This chapter elaborates on the added value of the CRP Indicator as described and validated in the previous chapters and provides an answer on the main research question:

How could principals develop and implement the concept of circularity as a decision support instrument for the redevelopment initiation phase?

The aim of this explorative, design-oriented research is to develop an assessment tool which can be used as an instrument for principals to implement circularity during the adaptive reuse process.

From perspective of the global economy, earth is increasingly suffering due to growth in both global population and human welfare. The world population is predicted to reach 9.2 billion in 2050, and threatening signs of resource depletion emphasize that the quest for a more sustainable economic model has never been more urgent. The international discussion regarding sustainability has made significant progress due to the emergence of the circular economy.

The circular economy outlines the capacity to rebuild capital, whether this is financial, manufactured, human, social or natural (Ellen MacArthur Foundation, 2015), and hereby aims to minimize waste cycles and downcycling materials. The open-ended system of a linear economy converts to a circular system when the relationship between resource use and waste residuals is considered, or in more general terms: output is input.

With 80% of next century's building demand already built, it is essential to provide a sustainable solution by reusing this stock, and avoid vacancy and dilapidation. Hence, new functions should be accommodated in existing buildings, through sustainable adaptive reuse. Adaptive reuse is a form of sustainable urban regeneration, as it extends the building's life and avoids demolition waste, encourages reuse of the embodied energy and furthermore provides significant social and economic benefits to the society. Thus, it embraces the different dimensions of sustainability. Within this perspective, for a transition towards circularity - by means of the relationship between resource use and waste residuals - it is mandatory to gain insight into applied resources and embodied energy in existing built environment, identifying the opportunity of material flows, design of a product, and the products' treatment.

Identifying the degree of circularity starts with the assessment of applied material characteristics (BOM) and their relation and interfaces with all elements in the system (DDF). By combining this factor with the actual condition on site (NEN 2767), the applicable reutilization potential of an element could be developed. In accordance with the preferred representability of predefined spaces specific components are categorized if applicable. Altogether, this reflects the degree of circularity (BCI) of a building for a particular intervention.

The CRP Indicator is not designed as a goal in itself, but as an instrument to provide guidance in the decision making process. It supports principals to identify preconditions, in order to specify their ambition on circularity and provide the contractors the objective procedure to actually differentiate from their competitors. The assessment model is not intended as a certificate or label, however could be used as supportive instrument to substantiate any classification on this matter. In the end, the theoretical results of the model are compared with the results in practice via the case study of circular pavilion 'The Green House'.

9.1. RESEARCH RELEVANCE

9.1.1. Societal Relevancy

This research aims to connect written literature, about both adaptive reuse of societal heritage and circular economy principles, with the challenges decision makers in practice currently face. In order to solve the challenge discussed in literature, and further the situation in practice, the proposed framework could help to diminish the risks for multiple actors during the redevelopment process and accelerate circular adaptive reuse. Despite numerous research papers to accelerate the reuse of heritage, and additionally the benefits of a circular economy, until date it is not possible to relate these aspects to redevelopment opportunities in practice. By providing a assessment tool based on the circular economy, the sustainable approach could help to prevent highly appreciated property from demolition and depletion.

This change in perspective towards circularity is important to address many of today's fundamental challenges. Traditional linear consumption patterns known as 'take-make-dispose' (Ellen MacArthur Foundation, 2015) are coming up against constraints on the availability of resources. The resource side is challenged to comply with rising demand from the world's growing population and increasing welfare. Nowadays, unsustainable overuse of resources, higher price levels and fluctuation on the markets are recognized. These findings are supported with research on the so-called 'biocapacity'. This aspect reflects whether further economic growth and increased consumption of resources will be possible is determined by this crucial factor: the limited capacity of the global ecosystems to provide us with biotic resources (e.g. cereals, fish and timber) and to absorb the waste and emissions we generate through our resource use (WWF, 2008). Calculations using 'Ecological Footprint' illustrate that the world is already using around 60% more biocapacity than the global ecosystems can provide in a sustainable manner (Global Footprint Network, 2017). The Ecological Footprint warns us that with our current level of resource consumption, we are already overusing the biological capacities of the global ecosystems. The predictions for the 'Earth Overshoot Day' based on the current way of consumption - referred to as the day on which the global consumption is equal to 200% of the earth's bio capacity - is estimated on June 28th 2030. In other words: we are liquidating the 'natural capital' of the planet, instead of living on the sustainable interest from this capital. Therefore, the main challenge for this research is to create a sustainable approach for redevelopment based on the circular economy, in order to contribute to a sustainable environment.

In addition to the aim for a solution to prevent climate change, the economic benefits provide an opportunity as well. While the idea of a circular economy is around for decades the current situation seems now more favorable than ever to take action. With the research 'Chances for the circular economy in the Netherlands' ('Kansen voor de circulaire economie in Nederland') TNO stated that the circular economy potentially saves €7.3 billion and creates an opportunity for 54.000 jobs for the Dutch economy (Bastein et al., 2013). In a recent report to the World Economic Forum the Ellen MacArthur Foundation and McKinsey & Company concluded that the transition to a circular economy would create an opportunity in excess of 1 trillion USD for the global economy (Ellen Macarthur Foundation, 2014). These calculations created a huge awareness for the topic as many corporations seize their chance to get a part of this potential revenue opportunity.

9.1.2. Scientific Relevancy

Until date the available research on circular economy to contribute and possibly accelerate redevelopment of societal heritage is limited. Moreover, despite some examples in practice (e.g. BlueCity010 in Rotterdam, the Netherlands) the common knowledge to combine circular economy principles with redevelopment projects is currently lacking. Unfortunately a thorough scientific-based evaluation from development perspective for further elaboration is missing. In addition, there has been no established way of measuring how effective an organization is in making the transition from 'linear' to 'circular' production models. Therefore the main focus of this research is to address this gap and to create a assessment model that identifies how well a building performs in the context of circular redevelopment.

Insight on technical 'value' of material flows and the relationship between resource use and waste residuals will help to identify main differences between the traditional and circular process. Based on the positive outcomes for circular redevelopment a new business concept provides knowledge regarding this disruptive approach on redevelopment of the built environment. The business concept is supported by the CRP Indicator in order to guide circular thinking, circular designing and circularity in the business network of redevelopment during the construction and exploitation phase of any building. There are still great opportunities in this field of research that could be investigated. This research is a small part of the broader topic of circular economy and the beginning of further research.

This research is validated by using literature study on respectively the assessment methodology of the Ellen MacAthur Foundation & Granta (2015) & Verberne (2016), and provides the additional aspect regarding the actual conditions on site through the NEN 2767 standardization procedures. This study gives an indication of the circularity value of a building. Subsequently, the developed methodology has been validated through a case study with respect to the reliability and sensitivity of the assessment model.

9.1.3. Applicability and Future Research

This research provides insight on the technical aspects which will help to guide circular thinking, circular design and circularity in the business network of redevelopment during construction and exploitation phase of any building. The CRP Indicator is a useful tool for the assessment of properties to implement circularity during the redevelopment process. Building inspectors can provide property managers with objective data about the applied material characteristics and corresponding condition status of building elements. Detailed surveyor manuals and the eyes of well-educated and experienced building inspectors remain important in getting condition data. To make the use of the standard more reliable there might be a need for references of the listed defects and intensities by examples of pictures.

Whilst information of the composed material characteristics and circularity potential are gathered, actors become more aware of the environmental impact. For instance toxic substances in paint on window frames. The affect on health draws the line on effective reuse. Additionally, energy performance is always prioritized above circularity. These dilemma's represents the relationship of circularity with impact of sustainability and energy.

Further research that builds upon this study can be for instance the operationalization of this assessment model, such as the derived reutilization levels from condition ratings and additional variables from perspective of feasibility or environmental impact. A study can be conducted that optimizes between investment costs, circularity and present component or material value of an asset. This way the ideal design can be obtained within the framework set by parameters. Another possible study could be empirical research on lifetimes of building elements/layers. From perspective of the derived values of reutilization strategies, the result from the stated condition ratings are manually provided. Additional research on weighting these variables and the sensitivity of stated cross references should be executed.

The CRP Indicator is not designed to benchmark circular redevelopment in order to compare projects with each other. Whilst this CRP Indicator focuses on circular redevelopment of a single building, additional methods regarding environmental sustainability and transformation strategies are focusing on a broader perspective of the real estate market, which in addition have nothing to do with circularity on its own.

On terms of technology innovations, the use of advanced performance measurements, sensor technology and intelligent decision support systems to monitor and report on changes in the performance of building components is still in its infancy. Moreover performance profiles of building components depend on the local circumstances.

This research focused on technical cycles. Moreover, due to the situation of redevelopment of existing buildings, only the second main category 'prolong the lifecycle' of the Circularity Ladder is considered crucial, and in addition the combined step of the third main category 'useful application of materials'; 'R8: Recycle & R9: Recover'. An important consecutive step would be to identify the first category 'to use and make products smarter (R0-R2), respectively 'refuse', 'rethink' and reduce resource demand during the initiation and design of new development procedures.

Another approach could be to identify the financial feasibility during redevelopment procedures. This might emphasize the adjustments of assessment procedures, to consider the aspect of conversion of end-of-use materials into energy (e.g. via biofuels or burning wood) in relation to the necessary energy inputs to enable repurposing.

The assessment model could also be further refined, for example:

- Developing the implementation with LCA procedures in order to relate each reutilization strategy to environmental impact;
- Developing a comprehensive approach on downcycling and upcycling, taking into account the level of material quality loss in the recycling process;
- Investigating the weighting variable of the derived reutilization strategies from condition assessment.
- The default weighting of the representability aspects in the CRP Indicator are derived for company-specific purpose, thereby focussing on large assets and offices. Despite the opportunity to calculate the performances for circular redevelopment within this sequence, the applicability for other type of real estate should be taken into account
- Improving the validation process with the involvement of the market in relation to transformation potential.

This assessment model has not been developed to function as a new certification or labelling methodology. However, it could be developed to be incorporated in one existing method, as supportive in the field of material lifecycle assessment methodologies. It is to be expected that as a result of the standardization, condition surveys will become more reliable and as a consequence more popular among principals and other property owners.

Finally, a considerable amount of information is necessary in order for the assessment model to function properly. For example, as mentioned through this research, Building Information Modelling (BIM) could support the assessment model and keep track of materials and all the characteristics.

This model could fundamentally change the way in which chain partners communicate during the redevelopment process. Aligning interests, by focusing on the embodied energy of buildings, an accelerated shift towards circularity in the built environment could be achieved.

Part IV: Reference List & Appendices

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11. Appendices

Appendix A: Case Study The Green House Utrecht
Appendix B: Preservation of representability minor defects directive (RVB)
Appendix C: Minutes of Expert Meetings 'Towards Initial Concept'

APPENDIX A: CASE STUDY THE GREEN HOUSE UTRECHT

ID #	Kolom1	System	Product	Materials	Technical Lifetime	Utility/functional lifetime	Total Volume (m^3)	Reused feedstock [%]	Recycled feedstock [%]	Recycling efficiency [%]	reusable output [%]	recyclable output [%]	Recycling efficiency [%]2	Virgin feedstock [%]	Unrecoverable waste (Wo)	Unrecoverable waste from recycled feedstock	Unrecoverable waste from recycling	Total sum of waste after full cycle	Utility of the product (P lifespan ÷ S lifespan)	Eco-efficiency impact function of utility factor	Linear Flow Index	Material Circularity Indicator
														V	W_o	W_f	W_c	W	X	F(x)	LFI	MCI
100000		**Structure**																				
Element 1	Services		Funderingsconstructie		15	75	97	30%	0%	100%	0%	90%	100%	70%	0,100	0,000	0,100	0,150	5,000	0,180	0,436	0,922
Element 1.1	Services	16.1		Stelconplaten 2x2x0,2 m1	15	75	34	30%	0%	100%	0%	90%	100%	70%	0,100	0,000	0,100	0,150	5,000	0,180	0,436	0,922
Element 1.2	Services	16.2		Legioblok beton 0,8x0,8x1,6 m1	15	75	63	30%	0%	100%	0%	90%	100%	70%	0,100	0,000	0,100	0,150	5,000	0,180	0,436	0,922
Element 2	Services		Hoofddraagconstructie		15	50	235	100%	0%	100%	0%	100%	100%	0%	0,000	0,000	0,000	0,000	3,333	0,270	0,000	1,000
	Services	28.2		Staalconstructie	15	50	235	100%	0%	100%	0%	100%	100%	0%	0,000	0,000	0,000	0,000	3,333	0,270	0,000	1,000
Element 4	Services		Sips panelen		15	75	98,5	0%	0%	100%	0%	95%	100%	100%	0,050	0,000	0,050	0,075	5,000	0,180	0,544	0,902
Element 4.1	Services	21.1.1		Spaanplaat	15	75	9,4	0%	0%	100%	0%	95%	100%	100%	0,050	0,000	0,050	0,075	5,000	0,180	0,544	0,902
Element 4.2	Services	21.1.2		EPS	15	75	89,1	0%	0%	100%	0%	95%	100%	100%	0,050	0,000	0,050	0,075	5,000	0,180	0,544	0,902
Element 5	Services		Trappen		15	50	0,5	100%	0%	100%	0%	100%	100%	0%	0,000	0,000	0,000	0,000	3,333	0,270	0,000	1,000
	Services	24.2		Houten treden	15	50	0,5	100%	0%	100%	0%	100%	100%	0%	0,000	0,000	0,000	0,000	3,333	0,270	0,000	1,000
200000		**Shell**																				
Element 6	Services		Dakplaten		15	50	0,75	100%	0%	100%	0%	100%	100%	0%	0,000	0,000	0,000	0,000	3,333	0,270	0,000	1,000
	Services	27.1		Stalen dakplaten sendzimir verzinkt	15	50	0,75	100%	0%	100%	0%	100%	100%	0%	0,000	0,000	0,000	0,000	3,333	0,270	0,000	1,000
Element 7	Services		Voorhanggevel 1		15	30	7,5	100%	0%	100%	0%	71%	100%	0%	0,290	0,000	0,290	0,435	2,000	0,450	0,235	0,894
	Services	31.1.1		Beglazing	15	30	7,5	100%	0%	100%	0%	71%	100%	0%	0,290	0,000	0,290	0,435	2,000	0,450	0,235	0,894
Element 8	Services		Voorhanggevel 2		15	75	0,41	100%	0%	100%	0%	82%	100%	0%	0,180	0,000	0,180	0,270	5,000	0,180	0,141	0,975
	Services	31.1.2		Traliespant/vakwerkliggers	15	75	0,41	100%	0%	100%	0%	82%	100%	0%	0,180	0,000	0,180	0,270	5,000	0,180	0,141	0,975
Element 9	Services		Vliesgevel 1		15	30	4,72	10%	0%	100%	0%	93%	100%	90%	0,070	0,000	0,070	0,105	2,000	0,450	0,511	0,770
	Services	31.2.1		Glas	15	30	4,72	10%	0%	100%	0%	93%	100%	90%	0,070	0,000	0,070	0,105	2,000	0,450	0,511	0,770
Element 10	Services		Vliesgevel 2		15	100	0,66	45%	0%	100%	0%	95%	100%	55%	0,050	0,000	0,050	0,075	6,667	0,135	0,316	0,957
	Services	31.2.2		Aluminium vliesgevel	15	100	0,66	45%	0%	100%	0%	95%	100%	55%	0,050	0,000	0,050	0,075	6,667	0,135	0,316	0,957
Element 16	Services		Dak 1		15	75	65	35%	0%	100%	0%	100%	100%	65%	0,000	0,000	0,000	0,000	5,000	0,180	0,325	0,942
	Services	47.1		EPS isolatie	15	75	65	35%	0%	100%	0%	100%	100%	65%	0,000	0,000	0,000	0,000	5,000	0,180	0,325	0,942
Element 17	Services		Dak 2		15	50	1,3	0%	0%	100%	0%	75%	100%	100%	0,250	0,000	0,250	0,375	3,333	0,270	0,733	0,802
	Services	47.2		EPDM dakbedekking	15	50	1,3	0%	0%	100%	0%	75%	100%	100%	0,250	0,000	0,250	0,375	3,333	0,270	0,733	0,802
Element 18	Services		Dak 3		15	50	0,1	10%	0%	100%	0%	90%	100%	90%	0,100	0,000	0,100	0,150	3,333	0,270	0,538	0,855
	Services	47.3		PE-folie	15	50	0,1	10%	0%	100%	0%	90%	100%	90%	0,100	0,000	0,100	0,150	3,333	0,270	0,538	0,855
Element 19	Services		Dak 4		15	75	12	5%	0%	100%	0%	100%	100%	95%	0,000	0,000	0,000	0,000	5,000	0,180	0,475	0,915
	Services	47.4		Steenwol	15	75	12	5%	0%	100%	0%	100%	100%	95%	0,000	0,000	0,000	0,000	5,000	0,180	0,475	0,915
Element 20	Services		Dak 5		15	75	0,8	0%	0%	100%	0%	90%	100%	100%	0,100	0,000	0,100	0,150	5,000	0,180	0,590	0,894
	Services	47.5		PIR Isolatie	15	75	0,8	0%	0%	100%	0%	90%	100%	100%	0,100	0,000	0,100	0,150	5,000	0,180	0,590	0,894
Element 21	Services		Dak 6		15	100	0,17	45%	0%	100%	0%	93%	100%	55%	0,070	0,000	0,070	0,105	6,667	0,135	0,333	0,955
	Services	47.6		Aluminium Dakrand	15	100	0,17	45%	0%	100%	0%	93%	100%	55%	0,070	0,000	0,070	0,105	6,667	0,135	0,333	0,955
Element 22	Services		Kasdak 1		15	75	0,26	90%	0%	100%	0%	100%	100%	10%	0,000	0,000	0,000	0,000	5,000	0,180	0,050	0,991
	Services	47.7.1		Aluminium Roeden	15	75	0,26	90%	0%	100%	0%	100%	100%	10%	0,000	0,000	0,000	0,000	5,000	0,180	0,050	0,991
Element 23	Services		Kasdak 2		15	75	0,26	0%	0%	100%	0%	90%	100%	100%	0,100	0,000	0,100	0,150	5,000	0,180	0,590	0,894
	Services	47.7.2		Glas	15	75	0,26	0%	0%	100%	0%	90%	100%	100%	0,100	0,000	0,100	0,150	5,000	0,180	0,590	0,894
Element 24	Services		Kasdak 3		15	75	0,51	80%	0%	100%	0%	90%	100%	20%	0,100	0,000	0,100	0,150	5,000	0,180	0,179	0,968
	Services	47.7.3		Stalen Goten	15	75	0,51	80%	0%	100%	0%	90%	100%	20%	0,100	0,000	0,100	0,150	5,000	0,180	0,179	0,968
Element 25	Services		Kasdak 4		15	20	0,26	20%	0%	100%	0%	20%	100%	80%	0,800	0,000	0,800	1,200	1,333	0,675	1,250	0,156
	Services	47.7.4		Nok (kunststof)	15	20	0,26	20%	0%	100%	0%	20%	100%	80%	0,800	0,000	0,800	1,200	1,333	0,675	1,250	0,156
300000		**Services**																				
Element 26	Services		Riolering		15	75	3	95%	0%	100%	0%	90%	100%	5%	0,100	0,000	0,100	0,150	5,000	0,180	0,103	0,982
	Services	51.1		PVC Riolering	15	75	3	95%	0%	100%	0%	90%	100%	5%	0,100	0,000	0,100	0,150	5,000	0,180	0,103	0,982
400000		**Spaceplan**																				
Element 3	Services		Kerto Ripa vloer		15	75	33,75	0%	0%	100%	0%	6%	100%	100%	0,940	0,000	0,940	1,410	5,000	0,180	1,575	0,716
Element 3.1	Services	23.1.1		Balken 0,4x0,1 m1 GL24h	15	50	25,2	0%	0%	100%	0%	8%	100%	100%	0,920	0,000	0,920	1,380	3,333	0,270	1,545	0,583
Element 3.2	Services	23.1.2		Underlayment 18 mm	15	50	8,55	0%	0%	100%	0%	0%	100%	100%	1,000	0,000	1,000	1,500	3,333	0,270	1,667	0,550
Element 11	Services		Kozijnen		15	100	0,07	45%	0%	100%	0%	95%	100%	55%	0,050	0,000	0,050	0,075	6,667	0,135	0,316	0,957
	Services	31.2.3		Kozijnen	15	100	0,07	45%	0%	100%	0%	95%	100%	55%	0,050	0,000	0,050	0,075	6,667	0,135	0,316	0,957
Element 12	Services		Deuren		15	100	0,13	45%	0%	100%	0%	93%	100%	55%	0,070	0,000	0,070	0,105	6,667	0,135	0,333	0,955
	Services	32.1		Deuren vzv HPL afwerking	15	100	0,13	45%	0%	100%	0%	93%	100%	55%	0,070	0,000	0,070	0,105	6,667	0,135	0,333	0,955
Element 13	Services		Binnenwanden 1		15	50	2,9	0%	0%	100%	0%	8%	100%	100%	0,920	0,000	0,920	1,380	3,333	0,270	1,545	0,583
	Services	42.1		HSB gips 10 mm	15	50	2,9	0%	0%	100%	0%	8%	100%	100%	0,920	0,000	0,920	1,380	3,333	0,270	1,545	0,583
Element 14	Services		Binnenwanden 2		15	50	0,15	70%	0%	100%	0%	11%	100%	30%	0,890	0,000	0,890	1,335	3,333	0,270	1,051	0,716
Element 14.1	Services	22.1		Ms Staalprofielen	15	50	0,01	100%	0%	100%	0%	95%	100%	0%	0,050	0,000	0,050	0,075	3,333	0,270	0,038	0,990
Element 14.2	Services	42.2		MS gipsplaten	15	25	0,14	0%	0%	100%	0%	5%	100%	100%	0,950	0,000	0,950	1,425	1,667	0,540	1,590	0,141
Element 15	Services		Vloerafwerking		15	75	2	30%	0%	100%	0%	90%	100%	70%	0,100	0,000	0,100	0,150	5,000	0,180	0,436	0,922
	Services	43.1		Betontegels 300x300x50mm	15	75	2	30%	0%	100%	0%	90%	100%	70%	0,100	0,000	0,100	0,150	5,000	0,180	0,436	0,922
500000		**Stuff**																				
Element 27	Services		Component		15	5	0,0001	1%	1%	1%	1%	1%	1%	98%	0,980	0,990	0,010	1,480	0,333	2,700	0,988	0,000
500101	Services			Material	15	5	0,0001	1%	1%	1%	1%	1%	1%	98%	0,980	0,990	0,010	1,480	0,333	2,700	0,988	0,000
500102	Services			Material	15	5	0,0001	1%	1%	1%	1%	1%	1%	98%	0,980	0,990	0,010	1,480	0,333	2,700	0,988	0,000
Element 28	Services		Component		15	5	0,0001	1%	1%	1%	1%	1%	1%	98%	0,980	0,990	0,010	1,480	0,333	2,700	0,988	0,000
500201	Services			Material	15	5	0,0001	1%	1%	1%	1%	1%	1%	98%	0,980	0,990	0,010	1,480	0,333	2,700	0,988	0,000
500202	Services			Material	15	5	0,0001	1%	1%	1%	1%	1%	1%	98%	0,980	0,990	0,010	1,480	0,333	2,700	0,988	0,000
600000		**Site**																				
Element 29	Services		Component		15	300	0,0001	1%	1%	1%	1%	1%	1%	98%	0,980	0,990	0,010	1,480	20,000	0,045	0,988	0,956
600101	Services			Material	15	300	0,0001	1%	1%	1%	1%	1%	1%	98%	0,980	0,990	0,010	1,480	20,000	0,045	0,988	0,956
600102	Services			Material	15	300	0,0001	1%	1%	1%	1%	1%	1%	98%	0,980	0,990	0,010	1,480	20,000	0,045	0,988	0,956
Element 30	Services		Component		15	300	0,0001	1%	1%	1%	1%	1%	1%	98%	0,980	0,990	0,010	1,480	20,000	0,045	0,988	0,956
600201	Services			Material	15	300	0,0001	1%	1%	1%	1%	1%	1%	98%	0,980	0,990	0,010	1,480	20,000	0,045	0,988	0,956
600202	Services			Material	15	300	0,0001	1%	1%	1%	1%	1%	1%	98%	0,980	0,990	0,010	1,480	20,000	0,045	0,988	0,956

Functional separation	Functional dependence	Technical lifecycle	geometry of product edge	standardization of product edge	type of connection	accessibility to fixings	$W_{DfD\,1}$	$W_{DfD\,2}$	$W_{DfD\,3}$	$W_{DfD\,4}$	$W_{DfD\,5}$	$W_{DfD\,6}$	$W_{DfD\,7}$	MCI × WDfD 1 12	MCI × $W_{DfD\,2}$	MCI × $W_{DfD\,3}$	MCI × $W_{DfD\,4}$	MCI × $W_{DfD\,5}$	MCI × $W_{DfD\,6}$	MCI × $W_{DfD\,7}$	PCI
separation of functions	planned interpenetrating for different solutions (overcapacity)	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	open linear	pre-made geometry	accessory external connection or connection system	accessible	1,0	0,8	1,0	1,0	1,0	1,0	1,0	0,922	0,737	0,922	0,922	0,922	0,922	0,922	0,895
separation of functions	modular zoning	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	open linear	pre-made geometry	direct connection with additional fixing devices	accessible with additional operation which causes no damage	1,0	1,0	1,0	1,0	1,0	0,8	0,8	1,000	1,000	1,000	1,000	1,000	0,800	0,800	0,943
integration of function with same lifecycle into one element	modular zoning	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	insert on one side	half standardised geometry	direct connection with additional fixing devices	accessible with additional operation with reparable damage	0,6	1,0	1,0	0,2	0,5	0,8	0,6	0,541	0,902	0,902	0,180	0,451	0,722	0,541	0,606
separation of functions	planned interpenetrating for different solutions (overcapacity)	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	symmetrical overlapping	pre-made geometry	direct connection with additional fixing devices	accessible with additional operation with reparable damage	1,0	0,8	1,0	0,8	1,0	0,8	0,6	1,000	0,800	1,000	0,800	1,000	0,800	0,600	0,857
separation of functions	planned interpenetrating for different solutions (overcapacity)	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	symmetrical overlapping	half standardised geometry	direct connection with additional fixing devices	accessible with additional operation with reparable damage	1,0	0,8	1,0	0,8	0,5	0,8	0,6	1,000	0,800	1,000	0,800	0,500	0,800	0,600	0,786
separation of functions	modular zoning	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	open linear	pre-made geometry	accessory external connection or connection system	accessible	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,894	0,894	0,894	0,894	0,894	0,894	0,894	0,894
separation of functions	modular zoning	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	open linear	pre-made geometry	direct connection with additional fixing devices	accessible with additional operation with reparable damage	1,0	1,0	1,0	1,0	1,0	0,8	0,6	0,975	0,975	0,975	0,975	0,975	0,780	0,585	0,891
separation of functions	modular zoning	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	open linear	pre-made geometry	accessory external connection or connection system	accessible	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,770	0,770	0,770	0,770	0,770	0,770	0,770	0,770
separation of functions	modular zoning	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	open linear	pre-made geometry	direct connection with additional fixing devices	accessible with additional operation with reparable damage	1,0	1,0	1,0	1,0	1,0	0,8	0,6	0,957	0,957	0,957	0,957	0,957	0,766	0,574	0,875
integration of function with same lifecycle into one element	planned interpenetrating for different solutions (overcapacity)	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	open linear	half standardised geometry	direct connection with additional fixing devices	accessible with additional operation with reparable damage	0,6	0,8	1,0	1,0	0,5	0,8	0,6	0,565	0,753	0,942	0,942	0,471	0,753	0,565	0,713
integration of function with same lifecycle into one element	modular zoning	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	overlapping on one side	half standardised geometry	direct connection with additional fixing devices	accessible with additional operation with reparable damage	0,6	1,0	1,0	0,7	0,5	0,8	0,6	0,481	0,802	0,802	0,561	0,401	0,642	0,481	0,596
integration of function with same lifecycle into one element	planned interpenetrating for different solutions (overcapacity)	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	overlapping on one side	half standardised geometry	direct connection with additional fixing devices	accessible with additional operation with reparable damage	0,6	0,8	1,0	0,7	0,5	0,8	0,6	0,513	0,684	0,855	0,598	0,427	0,684	0,513	0,610
separation of functions	modular zoning	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	open linear	pre-made geometry	accessory external connection or connection system	accessible	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,915	0,915	0,915	0,915	0,915	0,915	0,915	0,915
separation of functions	planned interpenetrating for different solutions (overcapacity)	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	open linear	half standardised geometry	direct connection with additional fixing devices	accessible with additional operation with reparable damage	1,0	0,8	1,0	1,0	0,5	0,8	0,6	0,894	0,715	0,894	0,894	0,447	0,715	0,536	0,728
integration of function with same lifecycle into one element	modular zoning	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	symmetrical overlapping	half standardised geometry	accessory external connection or connection system	accessible with additional operation with reparable damage	0,6	1,0	1,0	0,8	0,5	1,0	0,6	0,573	0,955	0,955	0,764	0,478	0,955	0,573	0,750
separation of functions	planned interpenetrating for different solutions (overcapacity)	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	symmetrical overlapping	half standardised geometry	direct connection with additional fixing devices	accessible	1,0	0,8	1,0	0,8	0,5	0,8	1,0	0,991	0,793	0,991	0,793	0,496	0,793	0,991	0,835
separation of functions	modular zoning	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	open linear	pre-made geometry	direct connection with additional fixing devices	accessible	1,0	1,0	1,0	1,0	1,0	0,8	1,0	0,894	0,894	0,894	0,894	0,894	0,715	0,894	0,868
separation of functions	planned interpenetrating for different solutions (overcapacity)	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	symmetrical overlapping	pre-made geometry	direct connection with additional fixing devices	accessible	1,0	0,8	1,0	0,8	1,0	0,8	1,0	0,968	0,774	0,968	0,774	0,968	0,774	0,968	0,885
separation of functions	modular zoning	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	overlapping on one side	pre-made geometry	direct connection with additional fixing devices	accessible	1,0	1,0	1,0	0,7	1,0	0,8	1,0	0,156	0,156	0,156	0,109	0,156	0,125	0,156	0,145
separation of functions	modular zoning	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	open linear	pre-made geometry	accessory external connection or connection system	accessible	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,982	0,982	0,982	0,982	0,982	0,982	0,982	0,982
integration of function with same lifecycle into one element	planned interpenetrating for different solutions (overcapacity)	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	symmetrical overlapping	pre-made geometry	accessory external connection or connection system	accessible	0,6	0,8	1,0	0,8	1,0	1,0	1,0	0,430	0,573	0,716	0,573	0,716	0,716	0,716	0,635
separation of functions	planned interpenetrating for different solutions (overcapacity)	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	symmetrical overlapping	pre-made geometry	direct connection with additional fixing devices	accessible	1,0	0,8	1,0	0,8	1,0	0,8	1,0	0,957	0,766	0,957	0,766	0,957	0,766	0,957	0,875
separation of functions	planned interpenetrating for different solutions (overcapacity)	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	symmetrical overlapping	pre-made geometry	direct connection with additional fixing devices	accessible	1,0	0,8	1,0	0,8	1,0	0,8	1,0	0,955	0,764	0,955	0,764	0,955	0,764	0,955	0,873
integration of function with same lifecycle into one element	planned interpenetrating for different solutions (overcapacity)	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	open linear	half standardised geometry	direct connection with additional fixing devices	accessible with additional operation with reparable damage	0,6	0,8	1,0	1,0	0,5	0,8	0,6	0,350	0,466	0,583	0,583	0,291	0,466	0,350	0,441
integration of function with same lifecycle into one element	planned interpenetrating for different solutions (overcapacity)	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	open linear	half standardised geometry	direct connection with additional fixing devices	accessible with additional operation with reparable damage	0,6	0,8	1,0	1,0	0,5	0,8	0,6	0,430	0,573	0,716	0,716	0,358	0,573	0,430	0,542
separation of functions	modular zoning	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	open linear	pre-made geometry	accessory external connection or connection system	accessible	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,922	0,922	0,922	0,922	0,922	0,922	0,922	0,922
separation of functions	modular zoning	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	open linear	pre-made geometry	accessory external connection or connection system	accessible	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
separation of functions	modular zoning	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	open linear	pre-made geometry	accessory external connection or connection system	accessible	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
separation of functions	modular zoning	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	open linear	pre-made geometry	accessory external connection or connection system	accessible	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,956	0,956	0,956	0,956	0,956	0,956	0,956	0,956
separation of functions	modular zoning	long (1) / long (2) or short (1) / short (2) or long (1) / short (2)	open linear	pre-made geometry	accessory external connection or connection system	accessible	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,956	0,956	0,956	0,956	0,956	0,956	0,956	0,956

# ID	Gebreken aanwezig op meerdere componenten van een bouwdeel	Meerdere gebreken op 1 component	Element	Locatiespecificatie	Stap 1a	Stap 1b	Stap 2a	Stap 2b	Stap 3a	Stap 3b	Stap 3c	Stap 3d	Stap 4a	Stap 4b	Stap 5	Stap 6	**Stap 7**	Kolom2	Controletabel	Kolom3
0				Representativiteit	Gebrek	Ernst	Omvang	Intensiteit	Vervangingswaarde van het component [Volume in m3]	Percentage component t.o.v. bouwdeel o.b.v. vervanginswaarde	Omvang gebrek op component	Omvang van het gebrek t.o.v. bouwdeel	Conditie van de component	Conditie ter plaatse van het gebrek (omvang 100%)	Correctiefactor [Tabel B.1 NEN 2767]	Gecorrigeerde totale omvang * correctiefactor	**Conditieherleiding [Tabel B.2 NEN 2767]**		Stap 2A: als gecombineerd deel, omvang score 5:	Meerdere gebreken op 1 component
1	Nee		Element 2		61.31: cracks not structural	Serieus Gebrek	2. Plaatselijk [2% - 10%]	2. Midden (gevorderd stadium)	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	**1**			
2	Nee		Element 5		46.57: Dirt, Tarnish	Gering Gebrek	4. Aanzienlijk [30%-70%]	2. Midden (gevorderd stadium)	n/a	n/a	n/a	n/a	2	n/a	n/a	n/a	**2**			
3	Ja	Nee	Element 1.1		02.11: settlement	Ernstig Gebrek	2. Plaatselijk [2% - 10%]	2. Midden (gevorderd stadium)	34	34	30	10,2	2	2	1,02	10,404	**0**			
3	Ja	Nee	Element 1.2		02.09: Cracks	Ernstig Gebrek	3. Regelmatig [10%-30%]	2. Midden (gevorderd stadium)	63	63	30	18,9	3	3	1,1	20,79	**0**			
3	Resterende delen		Element 1		Geen gebrek, Sla stap 1B, 2A & 2B over				n/a	n/a	n/a	70,9	1	1	1	70,9	**2**			
4	Nee		Element 6		05.22: Moisture	Ernstig Gebrek	4. Aanzienlijk [30%-70%]	2. Midden (gevorderd stadium)	n/a	n/a	n/a	n/a	4	n/a	n/a	n/a	**4**			
5	Ja	Nee	Element 4.1		12.27: Deformation	Serieus Gebrek	5. Algemeen [>=70%]	2. Midden (gevorderd stadium)	9,4	70	40	28	4	4	1,3	36,4	**0**			
5	Ja	Ja	Element 4.2		12.27: Deformation	Serieus Gebrek	5. Algemeen [>=70%]	2. Midden (gevorderd stadium)	89,1	20	40	8	4	4	1,3	10,4	**0**			
5	Ja	Ja	Element 4.2		Cracks	Serieus Gebrek	5. Algemeen [>=70%]	1. Laag (beginstadium)	89,1	20	40	8	3	4	1,3	10,4	**0**			
5	Resterende delen		Element 4		Geen gebrek, Sla stap 1B, 2A & 2B over				n/a	n/a	n/a	56	1	1	1	56	**3**			
6	Nee		Element 7		Cracks	Ernstig Gebrek	3. Regelmatig [10%-30%]	3. Hoog (eindstadium)	n/a	n/a	n/a	n/a	4	n/a	n/a	n/a	**4**			
7	Ja	Nee	Element 14.1		29.36: Damage	Serieus Gebrek	2. Plaatselijk [2% - 10%]	3. Hoog (eindstadium)	0,01	60	40	24	2	2	1,02	24,48	**0**			
7	Ja	Nee	Element 14.2		Damage	Serieus Gebrek	4. Aanzienlijk [30%-70%]	3. Hoog (eindstadium)	0,14	40	40	16	4	4	1,3	20,8	**0**			
7	Resterende delen		Element 14		Geen gebrek, Sla stap 1B, 2A & 2B over				n/a	n/a	n/a	60	1	1	1	60	**3**			
8	Nee		Element 8		65.54: Algae, Moss	Gering Gebrek	2. Plaatselijk [2% - 10%]	1. Laag (beginstadium)	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	**1**			
9	Ja	Nee	Element 3.1		37.55: Wood rot	Ernstig Gebrek	5. Algemeen [>=70%]	2. Midden (gevorderd stadium)	25,2	95	80	76	5	5	1,7	129,2	**0**			
9	Ja	Nee	Element 3.2		Degradation	Gering Gebrek	1. Incidenteel [<2%]	2. Midden (gevorderd stadium)	8,55	5	80	4	1	1	1	4	**0**			
9	Resterende delen		Element 3		Geen gebrek, Sla stap 1B, 2A & 2B over				n/a	n/a	n/a	20	1	1	1	20	**5**			
10	Nee		Element 9		Dirt, Tarnish	Gering Gebrek	4. Aanzienlijk [30%-70%]	2. Midden (gevorderd stadium)	n/a	n/a	n/a	n/a	2	n/a	n/a	n/a	**2**			
11	Nee		Element 10		65.54: Dirt, Tarnish	Gering Gebrek	3. Regelmatig [10%-30%]	3. Hoog (eindstadium)	n/a	n/a	n/a	n/a	2	n/a	n/a	n/a	**2**			
12	Nee		Element 11		Coloring	Gering Gebrek	1. Incidenteel [<2%]	1. Laag (beginstadium)	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	**1**			
13	Nee		Element 12		69.27: Deformation	Serieus Gebrek	5. Algemeen [>=70%]	3. Hoog (eindstadium)	n/a	n/a	n/a	n/a	5	n/a	n/a	n/a	**5**			
14	Nee		Element 13		109.57: Dirt, Tarnish	Gering Gebrek	2. Plaatselijk [2% - 10%]	1. Laag (beginstadium)	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	**1**			
15	Nee		Element 15		124.41: Loose finish	Serieus Gebrek	1. Incidenteel [<2%]	2. Midden (gevorderd stadium)	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	**1**			
16	Nee		Element 16		Damaged	Serieus Gebrek	2. Plaatselijk [2% - 10%]	2. Midden (gevorderd stadium)	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	**1**			
17	Nee		Element 17		189.23: loose seams	Ernstig Gebrek	3. Regelmatig [10%-30%]	3. Hoog (eindstadium)	n/a	n/a	n/a	n/a	4	n/a	n/a	n/a	**4**			
18	Nee		Element 18		Coloring	Gering Gebrek	3. Regelmatig [10%-30%]	1. Laag (beginstadium)	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	**1**			
19	Nee		Element 19		Loose fixings	Gering Gebrek	4. Aanzienlijk [30%-70%]	1. Laag (beginstadium)	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	**1**			
20	Nee		Element 20		Loose fixings	Gering Gebrek	2. Plaatselijk [2% - 10%]	1. Laag (beginstadium)	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	**1**			
21	Nee		Element 21		186.39: Erosion	Serieus Gebrek	4. Aanzienlijk [30%-70%]	1. Laag (beginstadium)	n/a	n/a	n/a	n/a	2	n/a	n/a	n/a	**2**			
22	Nee		Element 22		186.54: Algae, Moss	Gering Gebrek	5. Algemeen [>=70%]	1. Laag (beginstadium)	n/a	n/a	n/a	n/a	2	n/a	n/a	n/a	**2**			
23	Nee		Element 23		Algae, Moss	Gering Gebrek	5. Algemeen [>=70%]	1. Laag (beginstadium)	n/a	n/a	n/a	n/a	2	n/a	n/a	n/a	**2**			
24	Nee		Element 24		185.57: Dirt, Tarnish	Gering Gebrek	2. Plaatselijk [2% - 10%]	1. Laag (beginstadium)	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	**1**			
25	Nee		Element 25		188.10: anchoring	Ernstig Gebrek	4. Aanzienlijk [30%-70%]	2. Midden (gevorderd stadium)	n/a	n/a	n/a	n/a	4	n/a	n/a	n/a	**4**			
26	Nee		Element 26		-	Gering Gebrek	1. Incidenteel [<2%]	1. Laag (beginstadium)	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	**1**			
27	Nee		Element 27			Gering Gebrek	1. Incidenteel [<2%]	1. Laag (beginstadium)	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	**1**			
28	Nee		Element 28			Gering Gebrek	1. Incidenteel [<2%]	1. Laag (beginstadium)	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	**1**			
29	Nee		Element 29			Gering Gebrek	1. Incidenteel [<2%]	1. Laag (beginstadium)	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	**1**			
30	Nee		Element 30			Gering Gebrek	1. Incidenteel [<2%]	1. Laag (beginstadium)	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	**1**			

ID #	Product	MCI	PCI	Condition Rating	Circularity	Demountability	Reutilization Potential	Preferred Strategy	Level	Check On Representability
100000	Structure									
Element 1	Funderingsconstructie	0,922	0,895	2	(Volledig) Circulair	(Volledig) Demontabel	2	repair	product level	
Element 2	Hoofddraagconstructie	1,000	0,943	1	(Volledig) Circulair	(Volledig) Demontabel	1	reuse	product level	
Element 4	Sips panelen	0,902	0,606	3	(Volledig) Circulair	Goed Demontabel	3	refurbish	component level	
Element 5	Trappen	1,000	0,857	2	(Volledig) Circulair	(Volledig) Demontabel	2	repair	product level	
200000	Shell									
Element 6	Dakplaten	1,000	0,786	4	(Volledig) Circulair	Zeer Demontabel	4	remanufacture	component level	
Element 7	Voorhanggevel 1	0,894	0,894	4	(Volledig) Circulair	(Volledig) Demontabel	4	remanufacture	component level	
Element 8	Voorhanggevel 2	0,975	0,891	1	(Volledig) Circulair	(Volledig) Demontabel	1	reuse	product level	
Element 9	Vliesgevel 1	0,770	0,770	2	Zeer Circulair	Zeer Demontabel	2	repair	product level	
Element 10	Vliesgevel 2	0,957	0,875	2	(Volledig) Circulair	(Volledig) Demontabel	2	repair	product level	
Element 16	Dak 1	0,942	0,713	1	(Volledig) Circulair	Zeer Demontabel	1	reuse	product level	
Element 17	Dak 2	0,802	0,596	4	Zeer Circulair	Goed Demontabel	4	remanufacture	component level	
Element 18	Dak 3	0,855	0,610	1	(Volledig) Circulair	Goed Demontabel	1	reuse	product level	
Element 19	Dak 4	0,915	0,915	1	(Volledig) Circulair	(Volledig) Demontabel	1	reuse	product level	
Element 20	Dak 5	0,894	0,728	1	(Volledig) Circulair	Zeer Demontabel	1	reuse	product level	
Element 21	Dak 6	0,955	0,750	2	(Volledig) Circulair	Zeer Demontabel	2	repair	product level	
Element 22	Kasdak 1	0,991	0,835	2	(Volledig) Circulair	(Volledig) Demontabel	2	repair	product level	
Element 23	Kasdak 2	0,894	0,868	2	(Volledig) Circulair	(Volledig) Demontabel	2	repair	product level	
Element 24	Kasdak 3	0,968	0,885	1	(Volledig) Circulair	(Volledig) Demontabel	1	reuse	product level	
Element 25	Kasdak 4	0,156	0,145	4	(Volledig) Lineair	Niet Demontabel	4	remanufacture	component level	
300000	Services									
Element 26	Riolering	0,982	0,982	1	(Volledig) Circulair	(Volledig) Demontabel	1	reuse	product level	
400000	Spaceplan									
Element 3	Kerto Ripa vloer	0,716	0,635	5	Zeer Circulair	Goed Demontabel	5	repurpose	material level	
Element 11	Kozijnen	0,957	0,875	1	(Volledig) Circulair	(Volledig) Demontabel	1	reuse	product level	
Element 12	Deuren	0,955	0,873	5	(Volledig) Circulair	(Volledig) Demontabel	5	repurpose	material level	
Element 13	Binnenwanden 1	0,583	0,441	1	Goed Circulair	Redelijk Demontabel	1	reuse	product level	
Element 14	Binnenwanden 2	0,716	0,542	3	Zeer Circulair	Goed Demontabel	3	refurbish	component level	
Element 15	Vloerafwerking	0,922	0,922	1	(Volledig) Circulair	(Volledig) Demontabel	1	reuse	product level	
500000	Stuff									
Element 27	Component	0,000	0,000	1	(Volledig) Lineair	Niet Demontabel	1	reuse	product level	
Element 28	Component	0,000	0,000	1	(Volledig) Lineair	Niet Demontabel	1	reuse	product level	
600000	Site									
Element 29	Component	0,956	0,956	1	(Volledig) Circulair	(Volledig) Demontabel	1	reuse	product level	
Element 30	Component	0,956	0,956	1	(Volledig) Circulair	(Volledig) Demontabel	1	reuse	product level	

System Circularity Indicator

Model input | **Model output**

100000 Structure

SCI_T	0,960
SCI_P	0,910

Products	Volume (V)	Reutilization level	MCI	PCI	MCI × V	PCI × V
Element 1	97	repair	0,922	1,000	89,4	97,0
Element 2	235	reuse	1,000	1,000	235,0	235,0
Element 4	98,5	refurbish	0,902	0,606	88,8	59,7
Element 5	0,5	repair	1,000	1,000	0,5	0,5
	431,0				413,7	392,2

200000 Shell

SCI_T	0,922120435
SCI_P	0,982049311

Products	Volume (V)		MCI	PCI	MCI × V	PCI × V
Element 6	0,75	remanufacture	1,000	0,786	0,8	0,6
Element 7	7,5	remanufacture	0,894	0,894	6,7	6,7
Element 8	0,41	reuse	0,975	1,000	0,4	0,4
Element 9	4,72	repair	0,770	1,000	3,6	4,7
Element 10	0,66	repair	0,957	1,000	0,6	0,7
Element 16	65	reuse	0,942	1,000	61,2	65,0
Element 17	1,3	remanufacture	0,802	0,596	1,0	0,8
Element 18	0,1	reuse	0,855	1,000	0,1	0,1
Element 19	12	reuse	0,915	1,000	11,0	12,0
Element 20	0,8	reuse	0,894	1,000	0,7	0,8
Element 21	0,17	repair	0,955	1,000	0,2	0,2
Element 22	0,26	repair	0,991	1,000	0,3	0,3
Element 23	0,26	repair	0,894	1,000	0,2	0,3
Element 24	0,51	reuse	0,968	1,000	0,5	0,5
Element 25	0,26	remanufacture	0,156	0,145	0,0	0,0
	94,7				87,3	93,0

300000 Services

SCI_T	0,981538462
SCI_P	1

Products	Volume (V)	Reutilization level	MCI	PCI	MCI × V	PCI × V
Element 26	3	reuse	0,982	1,000	2,9	3,0
	3,0				2,9	3,0

400000 Spaceplan

SCI_T	0,718267802
SCI_P	0,681594643

Products	Volume (V)	Reutilization level	MCI	PCI	MCI × V	PCI × V
Element 3	33,75	repurpose	0,716	0,635	24,2	21,4
Element 11	0,07	reuse	0,957	1,000	0,1	0,1
Element 12	0,13	repurpose	0,955	0,873	0,1	0,1
Element 13	2,9	reuse	0,583	1,000	1,7	2,9
Element 14	0,15	refurbish	0,716	0,542	0,1	0,1
Element 15	2	reuse	0,922	1,000	1,8	2,0
	39,0				28,0	26,6

500000 Stuff

SCI_T	0
SCI_P	1

Products	Volume (V)	Reutilization level	MCI	PCI	MCI × V	PCI × V
Element 27	0,0001	reuse	0,000	1,000	0,0	0,0
Element 28	0,0001	reuse	0,000	1,000	0,0	0,0
	0,0				0,0	0,0

600000 Site

SCI_T	0,955543965
SCI_P	1

Products	Volume (V)	Reutilization level	MCI	PCI	MCI × V	PCI × V
Element 29	0,0001	reuse	0,956	1,000	0,0	0,0
Element 30	0,0001	reuse	0,956	1,000	0,0	0,0
	0,0				0,0	0,0

Building Circularity Indicator

Model input | **Model output**

	Building system	LK_K	SCI_T	SCI_T × LK
100000	Structure	0,2	0,960	0,192
200000	Shell	0,7	0,922	0,645
300000	Services	0,8	0,982	0,785
400000	Spaceplan	0,9	0,718	0,646
500000	Stuff	0,0	0,000	0,000
600000	Site	0,0	0,956	0,000

Theoretical BCI 0,873

	Building system	LK_K	SCI_P	SCI_P × LK
100000	Structure	0,2	0,910	0,182
200000	Shell	0,7	0,982	0,687
300000	Services	0,8	1,000	0,800
400000	Spaceplan	0,9	0,682	0,613
500000	Stuff	0,0	1,000	0,000
600000	Site	0,0	1,000	0,000

Practical BCI 0,878

Conditiemeting

1. Ernst		
Ernst	Soort gebreken	Toelichting
Ernstig Gebrek	Werking primair Constructief primair Materiaalintrinsiek Basiskwaliteit	Ernstige gebreken doen direct afbreuk aan de functionaliteit van het bouw- of installatiedeel
Serieus Gebrek	Werking secundair Constructief secundair Materiaaloppervlak Basiskwaliteit en veroudering onderdelen	Serieuze gebreken betekenen een degradatie van het bouw- of installatiedeel, zonder de functionaliteit direct aan te tasten
Gering Gebrek	Onderhoud Afwerking Basiskwaliteit en veroudering subonderdelen Verval	Geringe gebreken doen geen afbreuk aan de functionaliteit van het bouw- of installatiedeel

2. Omvang		
Omvangscore	Benaming	Beschrijving
Omvang 1	<2%	Het gebrek komt incidenteel voor
Omvang 2	2% - 10%	Het gebrek komt plaatselijk voor
Omvang 3	10% - 30%	Het gebrek komt regelmatig voor
Omvang 4	30% - 70%	Het gebrek komt aanzienlijk voor
Omvang 5	>= 70%	Het gebrek komt algemeen voor

3. Intensiteit		
Intensiteitscore	Benaming	Beschrijving
Intensiteit 1	Laag (beginstadium)	Het gebrek is nauwelijks waarneembaar
Intensiteit 2	Midden (gevorderd stadium)	Het gebrek is duidelijk waarneembaar
Intensiteit 3	Hoog (eindstadium)	Het gebrek is zeer duidelijk waarneembaar; het gebrek kan niet of nauwelijks toenemen

4. Matrix Resulterende conditiescores

Ernstige Gebreken					
Omvang Intensiteit	1. Incidenteel [<2%]	2. Plaatselijk [2% - 10%]	3. Regelmatig [10%-30%]	4. Aanzienlijk [30%-70%]	5. Algemeen [>=70%]
1. Laag (beginstadium)	1	1	2	3	4
2. Midden (gevorderd stadium)	1	2	3	4	5
3. Hoog (eindstadium)	2	3	4	5	6

Serieuze Gebreken					
Omvang Intensiteit	1. Incidenteel [<2%]	2. Plaatselijk [2% - 10%]	3. Regelmatig [10%-30%]	4. Aanzienlijk [30%-70%]	5. Algemeen [>=70%]
1. Laag (beginstadium)	1	1	1	2	3
2. Midden (gevorderd stadium)	1	1	2	3	4
3. Hoog (eindstadium)	1	2	3	4	5

Geringe Gebreken					
Omvang Intensiteit	1. Incidenteel [<2%]	2. Plaatselijk [2% - 10%]	3. Regelmatig [10%-30%]	4. Aanzienlijk [30%-70%]	5. Algemeen [>=70%]
1. Laag (beginstadium)	1	1	1	1	2
2. Midden (gevorderd stadium)	1	1	1	2	3
3. Hoog (eindstadium)	1	1	2	3	4

Aggregatie

5. Correctiefactor	
Conditie	Correctiefactor
1	1
2	1,02
3	1,1
4	1,3
5	1,7
6	2

7. Conditie herleiding	
uitkomst	conditie
Uitkomst < = 1,01	1
1,01 < Uitkomst <= 1,04	2
1,04 < Uitkomst <= 1,15	3
1,15 < Uitkomst <= 1,4	4
1,4 < Uitkomst <= 1,78	5
Uitkomst > 1,78	6

Samengesteld
Ja
Nee
Resterende

Prioritering Representativiteit

Bovengrens voor geringe gebreken Gebaseerd op tabel 5 uit de NEN 2767-1					
Omvang Intensiteit	1. Incidenteel [<2%]	2. Plaatselijk [2% - 10%]	3. Regelmatig [10%-30%]	4. Aanzienlijk [30%-70%]	5. Algemeen [>=70%]
1. Laag (beginstadium)	-	A	B	C	-
2. Midden (gevorderd stadium)	A	B	C	-	-
3. Hoog (eindstadium)	B	C	-	-	-

Bovengrens voor geringe gebreken Gebaseerd op tabel 5 uit de NEN 2767-1					
Omvang Intensiteit	1. Incidenteel [<2%]	2. Plaatselijk [2% - 10%]	3. Regelmatig [10%-30%]	4. Aanzienlijk [30%-70%]	5. Algemeen [>=70%]
1. Laag (beginstadium)	-	A	B	C	-
2. Midden (gevorderd stadium)	A	B	C	-	-
3. Hoog (eindstadium)	B	C	-	-	-

Aggregatie Hergebruiktpotentie

Circulariteit van elementen		
Uitkomst <	0,17	(Volledig) Lineair
0,17	0,33	Matig Circulair
0,33	0,5	Redelijk Circulair
0,5	0,67	Goed Circulair
0,67	0,83	Zeer Circulair
0,83	< Uitkomst	(Volledig) Circulair

Demontabiliteit van elementen		
Uitkomst <	0,17	Niet Demontabel
0,17	0,33	Matig Demontabel
0,33	0,5	Redelijk Demontabel
0,5	0,67	Goed Demontabel
0,67	0,83	Zeer Demontabel
0,83	< Uitkomst	(Volledig) Demontabel

Gewenste interventie voor element		
1	reuse	product level
2	repair	product level
3	refurbish	component level
4	remanufacture	component level
5	repurpose	material level
6	recycle	material level

PCI
1
1

4. Matrix Resulterende Hergebruikpotentie

1. Uitstekende Conditie

Circulariteit Demontabiliteit	(Volledig) Cirulair [100% >= MCI > 83%]	Zeer Cirulair [83% >= MCI > 67%]	Goed Cirulair [67% >= MCI > 50%]	Redelijk Cirulair [50% >= MCI > 33%]	Matig Cirulair [33% >= MCI > 17%]	(Volledig) Lineair [17% >= MCI > 0%]
Volledig Demontabel [100% >= MCI > 83%]	1	1	1	1	1	1
Zeer Demontabel [83% >= MCI > 67%]	1	1	1	1	1	1
Goed Demontabel [67% >= MCI > 50%]	1	1	1	1	1	1
Redelijk Demontabel [50% >= MCI > 33%]	1	1	1	1	1	1
Matig Demontabel [33% >= MCI > 17%]	1	1	1	1	1	1
Niet Demontabel [17% >= MCI > 0%]	1	1	1	1	1	1

2. Goede Conditie

Circulariteit Demontabiliteit	(Volledig) Cirulair [100% >= MCI > 83%]	Zeer Cirulair [83% >= MCI > 67%]	Goed Cirulair [67% >= MCI > 50%]	Redelijk Cirulair [50% >= MCI > 33%]	Matig Cirulair [33% >= MCI > 17%]	(Volledig) Lineair [17% >= MCI > 0%]
Volledig Demontabel [100% >= MCI > 83%]	2	2	2	2	2	2
Zeer Demontabel [83% >= MCI > 67%]	2	2	2	2	2	2
Goed Demontabel [67% >= MCI > 50%]	2	2	2	2	2	2
Redelijk Demontabel [50% >= MCI > 33%]	2	2	2	2	2	2
Matig Demontabel [33% >= MCI > 17%]	2	2	2	2	2	2
Niet Demontabel [17% >= MCI > 0%]	2	2	2	2	2	2

3. Redelijke Conditie

Circulariteit Demontabiliteit	(Volledig) Cirulair [100% >= MCI > 83%]	Zeer Cirulair [83% >= MCI > 67%]	Goed Cirulair [67% >= MCI > 50%]	Redelijk Cirulair [50% >= MCI > 33%]	Matig Cirulair [33% >= MCI > 17%]	(Volledig) Lineair [17% >= MCI > 0%]
Volledig Demontabel [100% >= MCI > 83%]	3	3	3	3	3	3
Zeer Demontabel [83% >= MCI > 67%]	3	3	3	3	3	3
Goed Demontabel [67% >= MCI > 50%]	3	3	3	3	3	3
Redelijk Demontabel [50% >= MCI > 33%]	3	3	3	3	3	3
Matig Demontabel [33% >= MCI > 17%]	3	3	3	3	3	3
Niet Demontabel [17% >= MCI > 0%]	3	3	3	3	3	3

4. Matige Conditie

Circulariteit Demontabiliteit	(Volledig) Cirulair [100% >= MCI > 83%]	Zeer Cirulair [83% >= MCI > 67%]	Goed Cirulair [67% >= MCI > 50%]	Redelijk Cirulair [50% >= MCI > 33%]	Matig Cirulair [33% >= MCI > 17%]	(Volledig) Lineair [17% >= MCI > 0%]
Volledig Demontabel [100% >= MCI > 83%]	4	4	4	4	4	4
Zeer Demontabel [83% >= MCI > 67%]	4	4	4	4	4	4
Goed Demontabel [67% >= MCI > 50%]	4	4	4	4	4	4
Redelijk Demontabel [50% >= MCI > 33%]	4	4	4	4	4	4
Matig Demontabel [33% >= MCI > 17%]	4	4	4	4	4	4
Niet Demontabel [17% >= MCI > 0%]	4	4	4	4	4	4

5. Slechte Conditie

Circulariteit Demontabiliteit	(Volledig) Cirulair [100% >= MCI > 83%]	Zeer Cirulair [83% >= MCI > 67%]	Goed Cirulair [67% >= MCI > 50%]	Redelijk Cirulair [50% >= MCI > 33%]	Matig Cirulair [33% >= MCI > 17%]	(Volledig) Lineair [17% >= MCI > 0%]
Volledig Demontabel [100% >= MCI > 83%]	5	5	5	5	5	5
Zeer Demontabel [83% >= MCI > 67%]	5	5	5	5	5	5
Goed Demontabel [67% >= MCI > 50%]	5	5	5	5	5	5
Redelijk Demontabel [50% >= MCI > 33%]	5	5	5	5	5	5
Matig Demontabel [33% >= MCI > 17%]	5	5	5	5	5	5
Niet Demontabel [17% >= MCI > 0%]	5	5	5	5	5	5

6. Zeer Slechte Conditie

Circulariteit Demontabiliteit	(Volledig) Cirulair [100% >= MCI > 83%]	Zeer Cirulair [83% >= MCI > 67%]	Goed Cirulair [67% >= MCI > 50%]	Redelijk Cirulair [50% >= MCI > 33%]	Matig Cirulair [33% >= MCI > 17%]	(Volledig) Lineair [17% >= MCI > 0%]
Volledig Demontabel [100% >= MCI > 83%]	6	6	6	6	6	6
Zeer Demontabel [83% >= MCI > 67%]	6	6	6	6	6	6
Goed Demontabel [67% >= MCI > 50%]	6	6	6	6	6	6
Redelijk Demontabel [50% >= MCI > 33%]	6	6	6	6	6	6
Matig Demontabel [33% >= MCI > 17%]	6	6	6	6	6	6
Niet Demontabel [17% >= MCI > 0%]	6	6	6	6	6	6

APPENDIX B: PRESERVATION OF REPRESENTABILITY MINOR DEFECTS DIRECTIVE (RVB)

Document: 'In stand houden Representativiteit'.

versie 7, 28 september 2015

Representativiteit
Vanaf het Beschikbaarheidcertificaat tot aan het Overdrachtcertificaat gelden conditie-eisen voor de instandhouding van de gewenste representativiteit. Het betreft de representativiteit van alle zichtbare onderdelen van de gehele (voor Opdrachtgever bestemde) huisvesting, inclusief de vaste en de losse inrichting welke door de Opdrachtnemer worden geleverd en onderhouden.

Beoordeling
Bij de beoordeling van de representativiteit wordt gekeken naar de visuele aantasting van een oppervlak. Er wordt beoordeeld op 'geringe gebreken' zoals benoemd in de NEN2767-deel II.

Gevraagde conditieniveaus
Er worden geen conditieniveaus gevraagd zoals in de NEN 2767.
Per ruimte kunnen de volgende 3 condities worden gevraagd:

conditieniveau A – hoog (hoog representatief)	**conditieniveau B – normaal** (representatief)	**conditieniveau C – laag** (laag representatief)
Visuele aantasting is tijdens normaal gebruik niet zichtbaar: alleen bij **nadere observatie*** van dichtbij zichtbaar.	Visuele aantasting is tijdens normaal gebruik niet storend: alleen bij **nadere observatie*** van enige afstand zichtbaar.	Visuele aantasting is tijdens normaal gebruik niet storend: geen verval, verpaupering, en/of verarming van de (werk-) omgeving.

Tabel 1: eisen per conditieniveau

*** Nadere observatie:**
Met 'nadere observatie' wordt bedoeld: Wanneer men specifiek op visuele aantasting gaat controleren. Bijvoorbeeld tijdens een periodieke meting of audit op de gevraagde condities.

In de Outputspecificaties
De lettercodes voor representativiteit (A,B,C) zijn in de Outputspecificaties gekoppeld aan de ruimten.

Voor buitenruimten die niet in de ruimteboom zijn gedefinieerd werkt dit niet.
Daar geldt:
- Conditie A: Ter plaatse van de hoofdentree.
- Conditie B: Voor gevels, buitenwanden/-muren en buitenplafonds.
- Conditie C: In utilitaire buitenruimten welke niet zichtbaar zijn vanaf de openbare weg of vanuit binnenruimten met conditiescore A of B.

Storing representativiteit
Daar waar niet aan bovenstaande conditie-eisen wordt voldaan, treedt een storing 'representativiteit' op:
- Voor niet in de ruimteboom gedefinieerde buitenruimten geldt een prestatiekorting.
- Voor gedefinieerde en (A,B,C-) gelabelde ruimten geldt een beschikbaarheidskorting.
- Bij een storing, geconstateerd bij periodieke meting of tijdens een audit (SCB), geldt een korting als beschreven in de outputspecificaties onder resp. de boom
  - [monitoring / periodieke meting] of
  - […. / SCB].

Geen storing representativiteit:
Anders dan bij natuurlijke veroudering, slijtage, verwering, ed. geldt bij een schade-incident (met een oorzaak buiten de aansprakelijkheid van de Opdrachtnemer) dat
kleurverschillen tussen bestaand en nieuw (hersteld werk), niet wordt aangemerkt als een representativiteitgebrek.
Wel zal het Opdrachtnemer zich inspannen om de visuele verschillen tot een minimum te beperken en daar met Opdrachtgever overleg over voeren.

APPENDIX C: MINUTES OF EXPERT MEETINGS
Towards Initial Concept

TABLE OF CONTENT