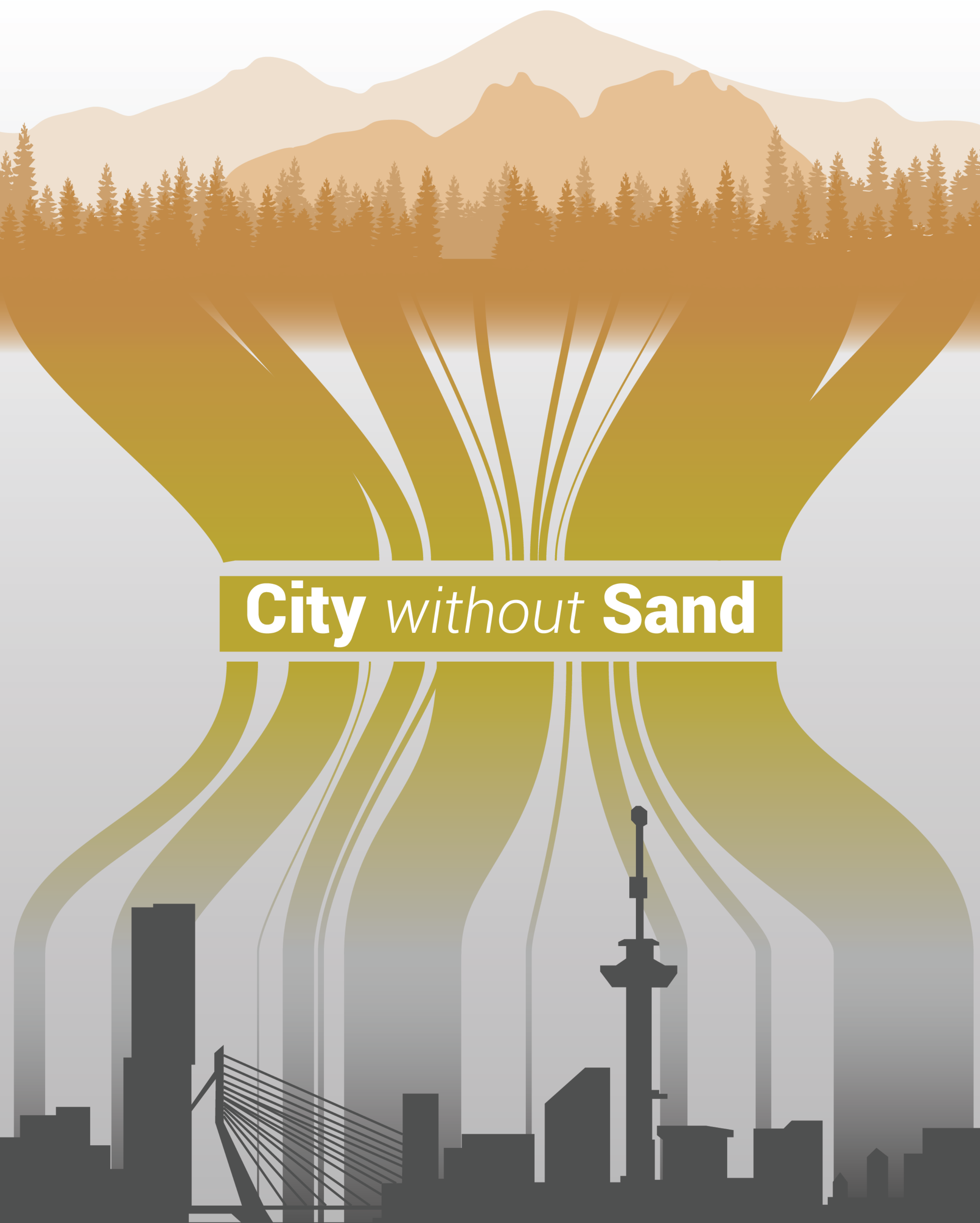

City *without* Sand

MSc Thesis of
Wouter ter Heijden

TU Delft

Final report
June 2019

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City without Sand

A material conscious approach for the urban construction metabolism of sand and gravel in the Rijnmond-Drechtsteden region

Wouter ter Heijden

Delft University of Technology
Faculty of Architecture and the Built Environment
MSc Urbanism | Urban Metabolism

June, 2019
Delft, the Netherlands

Colophon

City without **Sand**

A material conscious approach for the urban construction metabolism of sand and gravel in the Rijnmond-Drechtsteden region

P5 report
MSc Urbanism Thesis
June, 2019

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Part of the IABR 2018-20 'Design with Sediment Lab' initiated by TU Delft DIMI, WWF and Delta platform.
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IABR–2018+2020
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Preface

The P5 report is the final version of the graduation thesis for the Master Architecture, Urbanism and Building Science with the Track Urbanism. The project is part of the graduation studio Urban Metabolism of the research group Urban Metabolism and Smart Cities.

I would like to thank my first mentor Ulf Hackauf for the supervision, feedback and guidance during the entire project. This really helped me to remain the control and overview of the project. I would also like to thank my second mentor Henk Jonkers from the Faculty of Civil Engineering and GeoScience. Although I had never met you before the start of the graduation project, the first respond and meetings were immediately fruitful. Your input and expertise from civil engineering really helped me in understanding the topic and to embrace the interdisciplinary aspect of the project.

Furthermore, I would like to thank Peter van Veelen from Buro Waterfront for the chance to join the Designing with Sediment Lab (part of the IABR 2018-20). It was nice to link the graduation project with other ongoing research and that my results can have a contribution to the living lab. I would also like to thank Marco Hoogvliet from Deltares for his time and effort to guide and send me information and data about the topic.

A special thanks for everyone who supported me during the graduation year; Marjolein Pauly for the support, advice and listening ear about everything that was on my mind about my graduation process; Math Smeets, Rob Kleijnen, Frank ter Heijden, Lian ter Heijden and Nahir Haber for their time and effort in reading and checking my writing and grammar; and everyone from the MSc Urbanism who gave advice or their thought on my graduation topic.

All images are created by the author unless otherwise specified.

Table of Content

Executive summary / Samenvatting

Background: Material consumption of urban development and their impact

Urban development is accompanied with resource depletion and environmental impact of the Earth's ecosystem, with sand and gravel as the most consumed construction materials.

Sand and gravel are key ingredients in the built environment, especially in lowland delta regions such as the Rhine-Meuse estuary in the Netherlands. These materials are used in the urban constructions of concrete, asphalt, as fill sand for site raising and building site preparation or for flood protection through dikes or beach nourishment. This consumption is globally at a such high rate that sand has become the second most consumed material, after water. This consumption results in resource depletion of the stock reservoir and environmental impact such as erosion or decline of flood protection. Concrete has also a significant environmental impact due to the cement production which contribute to the emission of CO2. Urban design and planning deals with urban development which causes the consumption of material. However, the notion of material consumption and the related impact within the profession of urbanism is currently lacking.

The challenge is to meet the urban development demand in the Rijnmond-Drechtsteden region within the scope of circular economy and consumption reduction.

Material consumption is related to construction demand and activities. The Netherlands has a demand for 1 million housing to construct until 2040, with the majority situated in the western Randstad region where the Rhine-Meuse estuary is located with the conurbation of the Rijnmond-Drechtsteden (RMDS). Next to the demand for new housing, replacement of the current stock is also an activity which occurs in the urban ecosystems. All of these activities drive the metabolism of the urban constructions which is currently consumed according the linear model of produce, consume and disposal. On both national and local governmental level, the ambition is set to shift towards a circular consumption of material with a reduction of primary material consumption of 100% until 2050. The challenges lies within the two ambition of housing construction and circular consumption and their relation to the profession of urban design. This is the problem statement within this graduation research for the Master Urbanism at the TU Delft.

Consumption of construction materials is part of the construction metabolism within the urban metabolism concept of an urban ecosystem.

The concept of urban metabolism 'describes how material, food, water and energy flow through an urban ecosystem , and are consumed to support its metabolism, then grow and reproduce, consequently generating products and by-products' (Zhang et al., 2018). This concept can be applied on the construction ecosystem where sand and gravel are primarily integrated. Construction metabolism relates to the construction and demolition activities within urban ecosystem which causes material flow from and towards products/stocks.

Within the Dutch context, sand and gravel are important for the construction of the urban environment in order to secure its durability, accessibility and safety.

Within the construction metabolism, the sand and gravel framework can be highlighted. As mentioned above, these materials are integrated within several urban constructions. These constructions contribute to the purpose of housing opportunities in the environment through durability, accessibility and safety. The different constructions are also linked with each other within the metabolic framework where waste

Achtergrond: Materiaalconsumptie en de impact van stedelijke ontwikkeling

Stedelijke ontwikkeling gaat gepaard met het uitputten van grondstoffen en de milieu-impact op het aardse ecosysteem, waarbij zand en grind, de op een na meest geconsumeerde materialen, voornamelijk gebruikt wordt in de stedelijke bouwwerken.

Zand en grind zijn belangrijke ingrediënten binnen de gebouwde omgeving, vooral in laaggelegen deltaregio's, zoals de Rijn-Maas monding in Nederland. Deze materialen worden toegepast in stedelijke constructies, zoals in beton, asfalt, bij het ophogen en bouwrijp maken, in waterkeringen als dijken of kustsuppletie. De consumptie van, voornamelijk beton, is wereldwijd zo enorm dat zand het op één na (na water) meest geconsumeerde materiaal is. Deze consumptie put de voorraad van de grondstof uit en zorgt voor verschillende milieu-impacts, zoals erosie en aantasting van de natuurlijke waterbescherming. Beton heeft ook een aannemelijke milieu-impact door de uitstoot van CO2 tijdens de productie van cement. De consumptie van deze materialen wordt veroorzaakt door stedelijke ontwikkelingen die binnen de discipline van stedelijk ontwerp en ruimtelijke planning vallen. Het besef van de materiaalconsumptie en de gerelateerde impact binnen deze disciplines is echter afwezig.

De uitdaging is om de benodigde stedelijke ontwikkeling te realiseren in de Rijnmond-Drechsteden regio binnen de ambitie van circulariteit en materiaalvermindering.

Materiaal consumptie is gerelateerd aan de vraag naar constructies en zijn activiteiten, zoals de vraag naar huisvesting. In Nederland is de vraag om 1 miljoen huizen te realiseren voor 2040, waarbij deze huizen grotendeels in de Randstad gerealiseerd moet worden. Deze regio is ook de casestudy locatie van Rijnmond-Drechtsteden (RMDS), gelegen in Rijn-Maas delta. Naast de woningvraag is vervanging van het huidige woningaanbod ook een activiteit die binnen de stedelijke constructie ecosysteem voorkomt. Deze activiteiten volgen het lineair consumptiemodel van produceren, consumeren en storten. Op zowel nationaal als lokaal bestuurlijk niveau is er de ambitie voor een circulaire consumptie van materialen met een reductie van primaire grondstoffen van 100% in 2050. De opgave ligt in het samenbrengen van de twee ambities van de woningvraag en circulaire consumptie in relatie tot het vakgebied stedenbouwkundig ontwerp. Dit is ook de probleemstelling binnen dit afstudeeronderzoek voor de Master Urbanism aan de TU Delft.

De consumptie van constructiematerialen is onderdeel van het constructie-metabolisme binnen het stedelijke metabolisme concept.

Het concept van stedelijk metabolisme beschrijft 'hoe materiaal, voedsel, water en energie door het stedelijke ecosysteem stroomt en hoe het geconsumeerd wordt voor het ondersteunen van zijn metabolisme, waarna het groeit of reproduceert, waarbij het producten en bijproducten genereert'. Dit concept kan op het constructie ecosysteem worden toegepast waar zand en grind in geïntegreerd zijn. De constructie-metabolisme is gerelateerd aan constructie-en sloopactiviteiten binnen het stedelijk ecosysteem. Deze activiteiten veroorzaken materiaalstromen van en naar producten/stocks.

Zand en grind zijn belangrijk voor de constructie van de stedelijke leefomgeving binnen de Nederlandse context, waarbij het zorgt voor goede levensduur, draagkracht van de grond en veiligheid.

Binnen het constructie metabolisme kan zand en grind worden uitgelicht in een systematisch kader. Zoals hierboven is genoemd zijn deze materialen from one stock is recycled in another stock. This process means that sand and gravel never leaves the anthropocentric urban ecosystem which can result in the saturation of some stocks. On the other hand, the construction ecosystem has a continuous demand for primary material.

The notion of durability in the complex urban system is an important character of construction metabolism where internal and external factors can be distinguished which affect the flux of a stock.

The durability and lifespan of a stock depends on when an activity of construction or demolition occurs within the construction metabolism (the so called flux) These stocks have a very low dynamic within the urban environment which means that their lifespan are long, between the 75-125 years and sometimes even infinite. The durability can be affected through internal or external factors which results in the activity of demolition with its outflow and sometimes new construction. Internal factors might be material degradation which are set within the projected lifespan of a construction when it is designed. External factors are unforeseen at the moment of design, which can be policy/land use change or hazards Within the complex urban ecosystem, the durability and its external factors are quite difficult to forecast.

Purpose: Material reduction through urban design

The research aims to find ways to reduce the demand of primary construction sand through urban design.

The research relates to the challenges around construction metabolism, material consumption, the environmental impact of consumption, and urban design within the case study area of RMDS region. The aims in the research project can be summed up as follows:

geïntegreerd in verschillende stedelijke constructies. Deze constructies zorgen er onder andere voor dat de waterveiligheid van het gebied gewaarborgd wordt (door dijken en kustsuppletie), dat een gebied begaanbaar en bouwrijp is (door het op te hogen met zand) of dat gebouwen voor een lange periode blijven staan (door beton). Al deze eigenschappen zorgen ervoor dat huisvesting in een gebied mogelijk kan zijn. De verschillende constructies zijn ook met elkaar verbonden, waarbij afval van de ene constructie hergebruikt wordt in de andere. Dit is het geval bij sloopafval van woning- of utiliteitsbouw dat gebruikt wordt als funderingsmateriaal bij het ophogen van onder andere wegen. Dit fenomeen zorgt ervoor dat zand en grind het 'antropocentrische' stedelijke ecosysteem nooit verlaten wat kan leiden tot een verzadiging van sommige stocks. Aan de andere kant heeft het constructie ecosysteem ook een continue vraag naar primair materiaal.

Levensduur van stedelijke constructie binnen het complexe stedelijke systeem is een belangrijke eigenschap van het constructie metabolisme, waarbij er een onderscheid gemaakt kan worden tussen interne en externe factoren die de 'flux van een stock' beïnvloeden.

De levensduur van een constructie (of stock) is afhankelijk van wanneer er een activiteit binnen het constructie ecosysteem plaatsvindt (de flux). Deze constructies hebben een erg lage dynamiek binnen de gebouwde omgeving wat betekent dat ze een lange levensduur hebben. Deze levensduur ligt tussen de 75 en 125 jaar en is soms zelfs oneindig. De levensduur kan beïnvloed worden door interne en externe factoren die constructie- en/of sloopactiviteiten veroorzaken met de gerelateerde materiaalstromen. Onder interne factoren vallen de verouderingsprocessen van het materiaal. Deze factor is meegenomen in het ontwerp van een constructie. De externe factoren daarentegen, zijn onbekend op het moment van

Image A

Construction sand and gravel metabolism within the Dutch context.

(original on page 43)

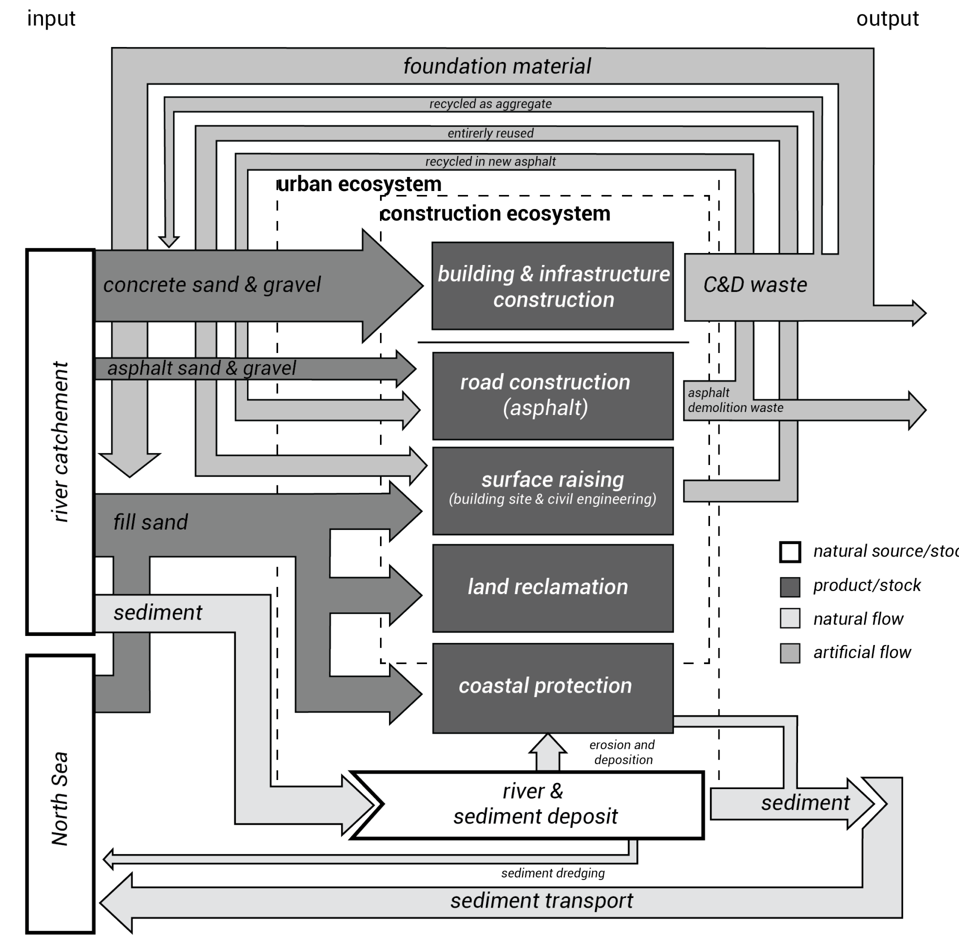
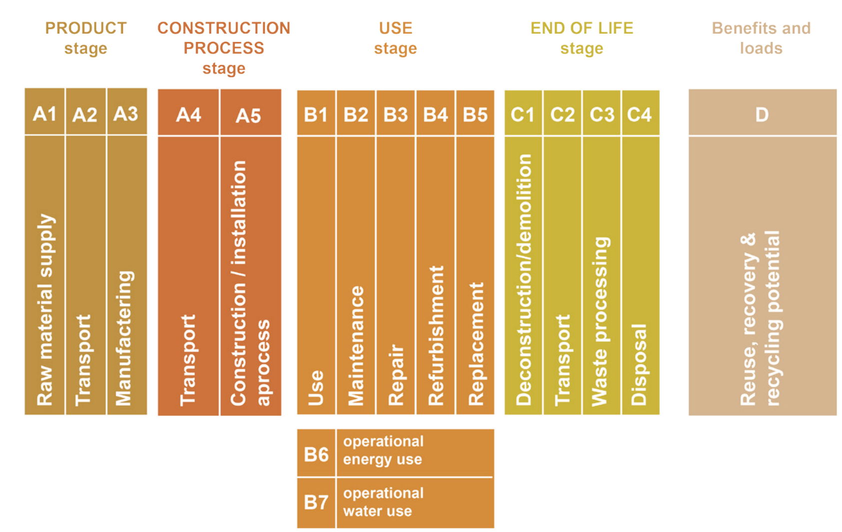


Image B

NEN-EN 15804:2012+A1

LCA scheme

(original on page 68)



(1) Improve the sand and gravel metabolic balance in the RMDS region by minimising the consumption
(2) Clarify the drivers behind the construction sand and gravel in order to understand its ecosystem
(3) Improve the metabolic balance by applying solutions in spatial and urban planning which requires less primary sand and gravel.
(4) Develop an approach in urban design where material impact and application is better exposed in the design process.

The aims are translated in the main research question:

"How can **urban design** reduce the **consumption of primary construction sand and gravel** in the **construction ecosystem** of the Rijnmond-Drechtsteden region?"

The research question is divided in four main sub-questions which are discussed in the method paragraph. The scientific relevance of the research is that urban consumption and impact of urban design and development are underexposed in both urbanism and urban metabolism studies. The social relevance is that urban consumption reduction is a major challenge within the circular economy ambitions on different governance levels.

Method: A sand-sensitive experiment

The research is a systematic experiment where construction possibilities will be assessed according to their impact on the consumption of primary construction sand and gravel within the urban metabolism. A division in three topics can be made which are; understanding the construction metabolism, exploration of improvements and urban design practice which reduces the consumption of sand and gravel.

ontwerp. Onder deze factoren vallen veranderingen binnen de landpolitiek of -gebruik en natuurrampen. De levensduur en externe factoren zijn, binnen het complexe stedelijke systeem, lastig te voorspellen.

Doel: Materiaalreductie door stedenbouwkundig ontwerp

Het onderzoek richt zich op het verkennen van methodes om de vraag naar primair constructiezand te verminderen door middel van stedenbouwkundig ontwerp.

Het onderzoek is gerelateerd aan de uitdagingen rondom het constructie metabolisme, materiaal consumptie met zijn impact en stedenbouwkundig ontwerp in context van de RMDS regio. De doelen van het onderzoek zijn als volgt geformuleerd:
(1) Het verbeteren van de balans in het zand- en grind-metabolisme in de RMDS regio door de consumptie te minimaliseren.
(2) Het verhelderen van de drijfveer achter de consumptie van constructiezand en -grind om vervolgens het achterliggende ecosysteem te begrijpen.
(3) Het verbeteren van het metabolische balans door het toepassen van ruimtelijke en strategische oplossingen die minder primair zand en grind nodig hebben.
(4) Het ontwikkelen van een aanpak binnen stedenbouwkundig ontwerp, waarbij de impact en toepassing van materiaal beter geïntegreerd zijn in het ontwerpproces.

Deze doelen kunnen vertaald worden in de volgende hoofdvraag:

"Hoe kan **stedenbouwkundig ontwerp** de **consumptie van primair constructiezand en -grind** reduceren binnen het **constructie-ecosysteem** van de Rijnmond-Drechtsteden regio?"

The construction sand and gravel metabolism will be explained through an analysis of the current system by developing a business as usual scenario for the material flow analysis, extended with a dynamic stock model and a material intensity study.

In order to reduce the consumption of primary sand and gravel within the construction metabolism of RMDS region, an analysis of this current system needs to be made. This analysis tackles the sub-questions: 'What is the construction sand & gravel metabolism of RMDS region until 2040?' and 'What is the impact of the construction sand & gravel metabolism of RMDS region until 2040?'. The sand and gravel metabolism is based on the theoretical metabolic framework as mentioned above and the related internal and external factors in the region which cause flows and activities. This is done by constructing a material flow analysis (MFA) which is extended to a dynamic stock model. The dynamic stock model includes the internal and external factors and their systematic impact. The internal factor is further explored through a material intensity study in the region with parameters such as expected end-of-life of buildings and its amount of concrete. The results of the MFA will be translated into a Life-Cycle Analysis (LCA) model where the environmental impact is transparent and made explicit for the constructed business as usual scenario of the region.

Improvements for reduction of material consumption within the urban design context are explored through the development of a Catalogue of Solutions for sand-sensitive solutions.

The problem statement mentions the lack of the notion of material consumption within the profession of urban design. This problem is tackled according the sub-question: 'How can urban design reduce the material consumption and impact of construction sand & gravel?'. The possible improvements are explored through literature review and will eventually be used to develop an approach for material sensitive design.

De hoofdvraag is verdeeld in vier deelvragen die in de methode behandeld zullen worden. Het onderzoek is zowel wetenschappelijk als maatschappelijk relevant. Wetenschappelijk gezien is de stedelijke consumptie van bouwmateriaal en de impact van stedelijke ontwikkeling nog onderbelicht binnen de studies van zowel stedenbouw als stedelijke metabolisme. Maatschappelijk gezien is het verminderen van de consumptie gerelateerd aan stedelijke constructie en ontwikkeling een belangrijke uitdaging voor het behalen van een circulaire economie.

Methode: een zandsensitief experiment

Het onderzoek is een systematisch experiment, waarbij constructiemogelijkheden worden geëvalueerd en verbeterd volgens de impact van de consumptie van primair constructie zand en grind binnen het stedelijk metabolisme. Het onderzoek is onderverdeeld in drie onderdelen; het begrijpen van het constructie metabolisme, het verkennen van verbeteringen en het reduceren van materiaal binnen het stedenbouwkundig ontwerpproces.

Het constructie zand en grind metabolisme zal worden verklaard aan de hand van een analyse van het huidige systeem door middel van een business as usual scenario van een materiaalstromen analyse, met onderbouwing van een dynamisch stockmodel en materiaalintensiteit studie.

Een analyse van het huidige systeem is van belang om de consumptie van primair zand en grind binnen het constructie metabolisme van de RMDS regio te reduceren. Deze analyse pakt de volgende twee deelvragen aan: "Wat is het constructiezand en -grind metabolisme van de RMDS regio tot 2040?" en "Wat is de impact van de constructie zand en grind metabolisme in de RMDS regio tot 2040?". Het zand

The improvements are collected in the Catalogue of Solutions where the link between space, system and environment are studied and stated. The study also explores the relation between material consumption and urban design which the foundation for the new approach.

Based on the business as usual scenario of the consumption of construction sand and gravel and the Catalogue of Solutions, a research by design is carried out where urban design example will reduce their material consumption.

The aim is to reduce the consumption of sand and gravel within the current scenario for the RMDS region. The final sub-question in order to answer the main research question is: 'How can the construction sand & gravel metabolism of RMDS region be improved?'. This part is tackled through research by design where urban design studies will be used to improve its material consumption. This improvement is based on the input from the Catalogue of Solutions. This design study will affect the system and urban environment which can be used in the extrapolation towards the regional system.

Findings 1/3: Analysis of the current sand system

The Rijnmond-Drechtsteden region requires an enormous amount of primary material for the different construction activities but also needs to deal with a high amount of waste material which needs to be integrated in the urban ecosystem.

The future urban development of the RMDS region can be distinguished in different drivers, related to urban design, causing flows. Drivers can be the urban development activities (densification, retrofitting, transformation and greenfield development) or maintenance activities (due to subsidence, sea level rise, dredging or infrastructure status) within

en grind metabolisme is gebaseerd op het hierboven benoemde theoretisch metabolisch kader en de gerelateerde interne en externe factoren in de regio die activiteiten en materiaalstromen veroorzaken. Dit kader is praktisch toegepast door middel van een materiaalstromen analyse (MFA) dat uitgebreid is met een dynamisch stock model. Dit model bevat de interne en externe factoren en de impact ervan op het metabolisch systeem. De interne factoren zijn verder verkend aan de hand van een materiaalintensiteit studie voor de regio met parameters zoals de verwachte levensduur van een gebouw en zijn materiaalvoorraad. De resultaten van de MFA worden gebruikt om een levenscyclusbeoordeling (LCA) model op te zetten, waarbij de milieutechnische impact zichtbaar wordt van het business as usual scenario voor de regio.

Verbeteringen voor het reduceren van de materiaalconsumptie binnen de context van het stedenbouwkundig ontwerp worden verkend aan de hand van het ontwikkelen van een oplossingencatalogus.

Onderdeel van de probleemstelling is het ontbreken van de effecten op materiaalconsumptie binnen het vakgebied stedenbouwkundig ontwerpen. Dit onderdeel wordt behandeld in de deelvraag: "Hoe kan stedenbouwkundig ontwerp de materiaalconsumptie van constructie zand en grind en zijn impact reduceren?". De verbeteringen worden verkend aan de hand van een literatuurstudie en uiteindelijk gebruikt om een materiaalsensitieve aanpak te formuleren. De oplossingen worden verzameld in de oplossingencatalogus, waarbij het verband tussen ruimtelijk, systematische en milieutechnische inpassingen wordt behandeld. De studie behandelt ook het verband tussen materiaalconsumptie en stedenbouwkundig ontwerp, wat uiteindelijk toegepast wordt in de nieuwe aanpak.

the construction ecosystem. These drivers mainly require primary sand and gravel but there is also an outflow of demolition waste from building which reach their assumed end-of-life. As the diagram in image C shows, most material mains within the urban ecosystem where it is recycled. An exception is the coast and river related activities such as beach nourishment and dredging. These activities are still influenced by the natural sediment ecosystem of sand and gravel. The diagram is an assumption based on a business as usual scenario. The large quantities and related transport affect the environment the most. Concrete has a manufacturing process which also has an environmental impact. The metabolism can be characterised by its continuous and large demand for material but also has several opportunities for recycling and reduction.

In order to reduce the material consumption within the sand and gravel metabolism of the Rijnmond-Drechsteden region, options need to be found in alternatives for the continuous demanding drivers such as fill sand for subsidence and for recycling opportunities of waste flows from dredging or demolition waste.

Findings 2/3: Material conscious approach

Derived from the analysis of the current system, it is stated that consciousness of material consumption needs to be integrated within urban design process. The research aims to find both practical and systematic solutions or methods which have an impact on the material consumption. The results can be divided in the material conscious approach and the Catalogue of Solutions.

Aan de hand van het business as usual scenario van de constructiezand- en grindconsumptie en de oplossingencatalogus zal een ontwerpend onderzoek worden uitgevoerd, waarbij stedenbouwkundig ontwerpvoorbeelden inzicht geven in hoe het materiaalgebruik verminderd kan worden.

Het doel van het onderzoek is om de consumptie van zand en grind te reduceren binnen het huidige scenario voor de RMDS regio. De laatste deelvraag is: "Hoe kan het constructie zand en grind metabolisme van de RMDS worden verbeterd?". Voor deze kwestie wordt een ontwerpend onderzoek uitgevoerd met kleinschalige stedenbouwkundig ontwerpstudies om de materiaalconsumptie te verbeteren door middel van input vanuit de oplossingencatalogus. De ontwerpstudie heeft een systematische impact op regionale schaal door middel van extrapolatie.

Bevindingen 1/3: Analyse van het huidige zand systeem

De verschillende constructie activiteiten in de Rijnmond-Drechsteden regio vragen om een enorme hoeveelheid aan primaire grondstoffen maar moeten ook een aannemelijk deel van het sloopafval integreren binnen het stedelijk ecosysteem.

De toekomstige stedelijke ontwikkelingen van de RMDS regio kunnen worden gekenmerkt door verschillende drijfveren die aan stedenbouwkundig ontwerp gerelateerd zijn en dus materiaalstromen veroorzaken. Deze drijfveren zijn de vier verschillende stedelijke ontwikkelingstypes (verdichten, herstructureren, transformatie en uitleg) en het onderhoud van gebieden (vanwege bodemdaling, zeespiegelstijging, bageren of infrastructure status). Deze drijfveren hebben voornamelijk zand en grind nodig, maar veroorzaken soms ook een materiaalstroom van sloopafval, afkomstig van afgeschreven gebouwen. Het merendeel van de gebruikte materialen blijft binnen het stedelijke

Material conscious approach for urban design integrates the four stages of a construction process from the lifecycle perspective (situation, construction, maintenance and end-of-life) with its related material consumption for each construction where the material efficiency strategies will be applied on; prevention, reuse, recycle.

The study of construction ecology aims to improve the current linear material consumption pattern towards a more circular one. This improvement can be achieved by becoming more efficient with our materials. Material efficiency can be done by applying the three related strategies (from highest to lowest priority); prevention or reduction of material consumption, reuse of products or elements, and recycling of materials. These strategies also requires a life-cycle perspective, which relate to the LCA (according the NEN-EN 15804:2012+A1), of the design product in order to

ecosysteem door middel van recycling, zoals weergegeven in afbeelding C. De enige uitzonderingen hierop zijn de activiteiten die gerelateerd zijn aan de rivier of kust, zoals baggeren en kustsuppletie. Het diagram is een aanname gebaseerd op het business as usual scenario. De grote materiaalhoeveelheden, het transport en de productie van beton hebben het grootste effect op het milieu. Het metabolisme kan gekenmerkt worden door zijn continue en grote vraag naar materiaal maar er zijn ook enkele kansen voor recyclen en reductie.

Oplossingen zijn nodig om de materiaalconsumptie binnen het zand en grind metabolisme van de RMDS regio te reduceren. Deze oplossingen moeten betrekking hebben op de continue vraag naar materiaal (zoals ophoogmateriaal tegen bodemdaling) en voor recycle opties van afvalstromen (van het baggeren of slopen).

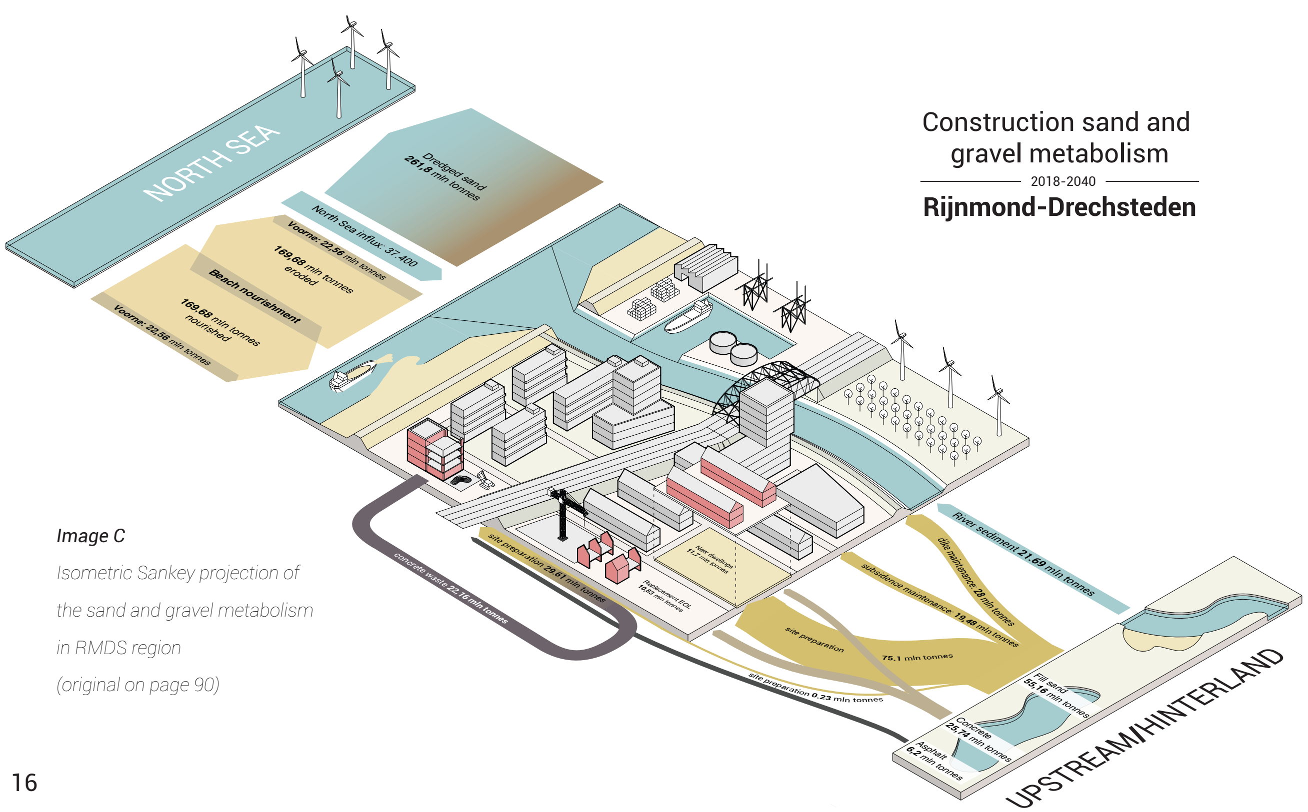


Image C

Isometric Sankey projection of the sand and gravel metabolism in RMDS region (original on page 90)

include the overall environmental impact. The life-cycle perspective for urban development includes: situation, construction, maintenance and end-of-life/demolition. Each process is related to material consumption where the material efficiency strategies can be applied on. For an urban designer, it is important to become aware of the conditions (based on drivers of the construction ecosystem) where material consumption occurs.

Spatial intervention regarding material consciousness are integrated in the Catalogue of Solutions where each intervention contributes to a material efficiency strategy within the construction ecosystem.

In order to strengthen the link between material consumption or reduction and urban design, the Catalogue of Solution is developed through an exploration of spatial interventions. These spatial interventions and their impact relate to the material efficiency strategies. Three solutions will be explained in order to clarify this relation. (1) Reduction of material consumption can be done by the development of buildings on water because this does not requires fill sand for building site preparation. (2) Reuse can be the transformation of non-residential building to a residential one. (3) Recycling of material can be done by linking demolished buildings as secondary resources for new construction (also known as urban mining). The solutions can be applied within different urban conditions which affect the consumption of material.

Findings 3/3: Design research

Three locations are chosen in the region which represent the different urban development types and conditions. The locations are; Ommoord in Rotterdam (transformation of non-residential areas and subsidence maintenance), Vliesland in Spijkenisse (greenfield development) and Spoorzone in Dordrecht (densification and retrofitting). The material conscious

Bevindingen 2/3: Materiaalbewuste aanpak

De analyse van het huidige systeem laat zien dat een bewustwording van materiaalconsumptie geïntegreerd moet worden binnen het stedenbouwkundig ontwerpproces. Het onderzoek streeft ernaar om zowel praktische als systematische oplossingen of methodes te vinden die impact hebben op het materiaalgebruik. Deze resultaten kunnen verdeeld worden in de materiaalbewuste aanpak en de oplossingencatalogus.

De materiaalbewuste aanpak voor stedenbouwkundig ontwerp integreert vier stappen van de levenscyclus van een constructie (situatie, constructie, onderhoud en deconstructie) en ieders relatie met materiaalconsumptie, waarbij de materiaalefficiënte strategieën (voorkomen, hergebruiken en recyclen) worden toegepast.

De studie naar constructie ecologie streeft naar het verbeteren van de huidige lineaire materiaalconsumptie naar een circulaire consumptie. Deze verbeteringen kunnen worden behaald door efficiënter met onze materialen om te gaan. Materiaalefficiëntie is gerelateerd aan een drietal strategieën (van hoogste naar laagste prioriteit); voorkomen of reduceren van materiaalconsumptie, hergebruik van producten of onderdelen en het recyclen van materialen. De strategieën vereisen ook een perspectief op de levenscyclus (gerelateerd aan de LCA volgens de NEN-EN 15804:2012+A1) binnen een ontwerp, zodat de milieu impact meegenomen kan worden. De levenscyclus van stedelijke ontwikkelingen bevatten: situatie, constructie, onderhoud en deconstructie. Iedere stap is gerelateerd aan materiaalconsumptie, waarbij de materiaalefficiënte strategieën toegepast kunnen worden. Voor een stedenbouwkundig ontwerper is het ook belangrijk om bewust te worden van de condities (afgeleid van approach is applied in every location where first a business as usual design (BaU) is constructed. This BaU design is accompanied with a spatial and material consumption impact. The consumption impact is integrated in a territorial metabolic life-cycle (TM-LCA) scheme which embodied the core of the material conscious approach.

The designs seek to reduce material demand, reuse structures or recycle material through spatial solutions where each design option has an different spatial, systematic and environmental impact.

Based on the BuA, solutions from the Catalogue of Solutions are applied at each situation which results in three improved concepts. The results from the improvements are quite different from each other. Alternative or recycled material from demolished buildings can be used for the new construction to reach the same spatial conditions as the BaU or the current buildings can be completely transformed and elevated with new structure. Another improvement is done by creating a complete new urban environment built on stilts above a green landscape. These improved designs reduce the primary material consumption but are sometimes depended on regional interventions or activities such as secondary resources or treatment plants. Some designs also affect the built environment which might conflict with current standards.

Circular sand metabolism is a multiscalar system where regional demand and supply is embedded in the local urban designs. These improvements require new flows and supplies which results in industrial spatial transformation of environments elsewhere.

On the regional scale, supply from demolishment and demand from construction needs to be linked in order to facilitate recycling potentials for both concrete and fill sand. Storage and manufacturing need to be located on available and suitable locations such as tidal parks for dredged sediment as fill sand substitute

de drijfveren van het constructie metabolisme) waar materiaalconsumptie plaatsvindt.

Ruimtelijke interventies met betrekking tot materiaalbewustzijn zijn geïntegreerd in de oplossingencatalogus waarin iedere oplossing bijdraagt aan een materiaalefficiënte strategie binnen het constructie ecosysteem.

Om de link tussen materiaalconsumptie, reductie en stedenbouwkundig ontwerp te versterken, is de oplossingencatalogus ontwikkeld door middel van een verkenning naar ruimtelijke interventies. Deze interventies en de impact zijn gerelateerd aan de materiaalefficiënte strategieën. Deze relatie zal worden verduidelijkt aan de hand van drie voorbeelden. Als eerste kan de reductie van de materiaalconsumptie worden gerealiseerd door woningen op water te ontwikkelen, zodat er geen ophoogzand nodig is voor het bouwrijp maken. Een tweede voorbeeld van hergebruik is de transformatie van utiliteitsgebouwen naar woningen. Het laatste voorbeeld is het recyclen van materiaal dat gedaan kan worden door het vrijgekomen sloopmateriaal uit afgedankte gebouwen te verbinden met nieuwe constructies waar het als grondstof gebruikt kan worden . De oplossingen kunnen binnen verschillende stedelijke condities worden toegepast die uiteindelijk een impact hebben op de materiaalconsumptie.

Bevindingen 3/3: Ontwerpend onderzoek

Drie locaties zijn gekozen binnen de regio die de verschillende stedelijke ontwikkelingen en condities representeren. De locaties zijn; Ommoord in Rotterdam (transformatie en bodemdaling onderhoud), Vliesland in Spijkenisse (uitleglocatie) en Spoorzone in Dordrecht (verdichting en herstructurering). Op iedere locatie is de materiaalbewuste aanpak toegepast, waarbij eerst een business as usual ontwerp (BaU)

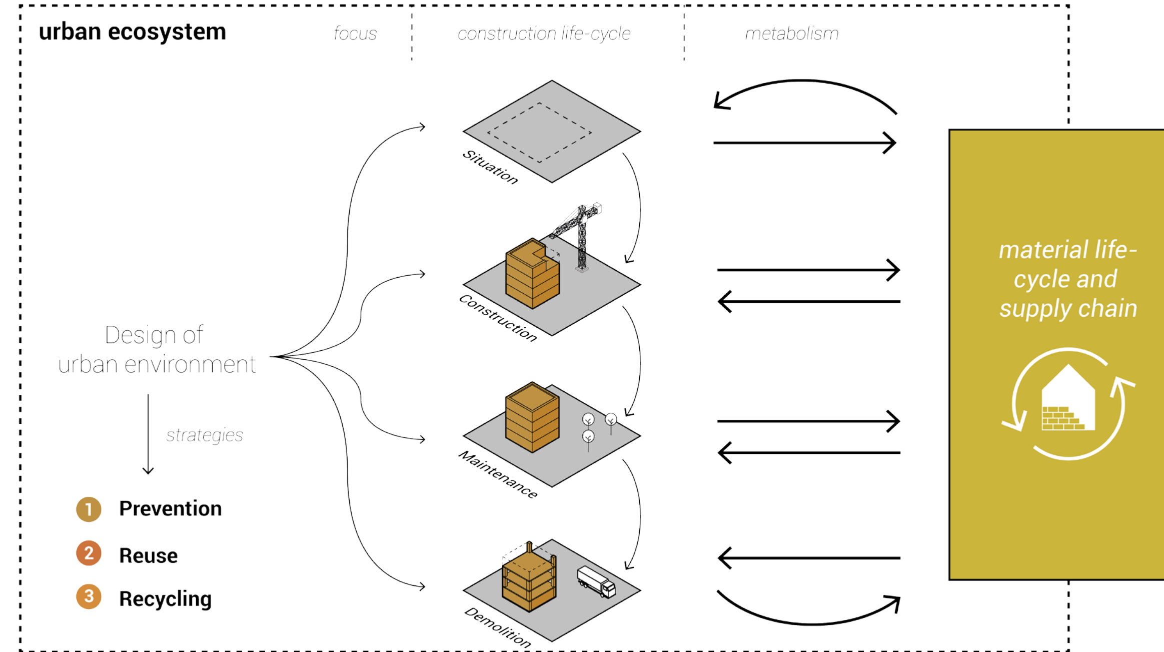
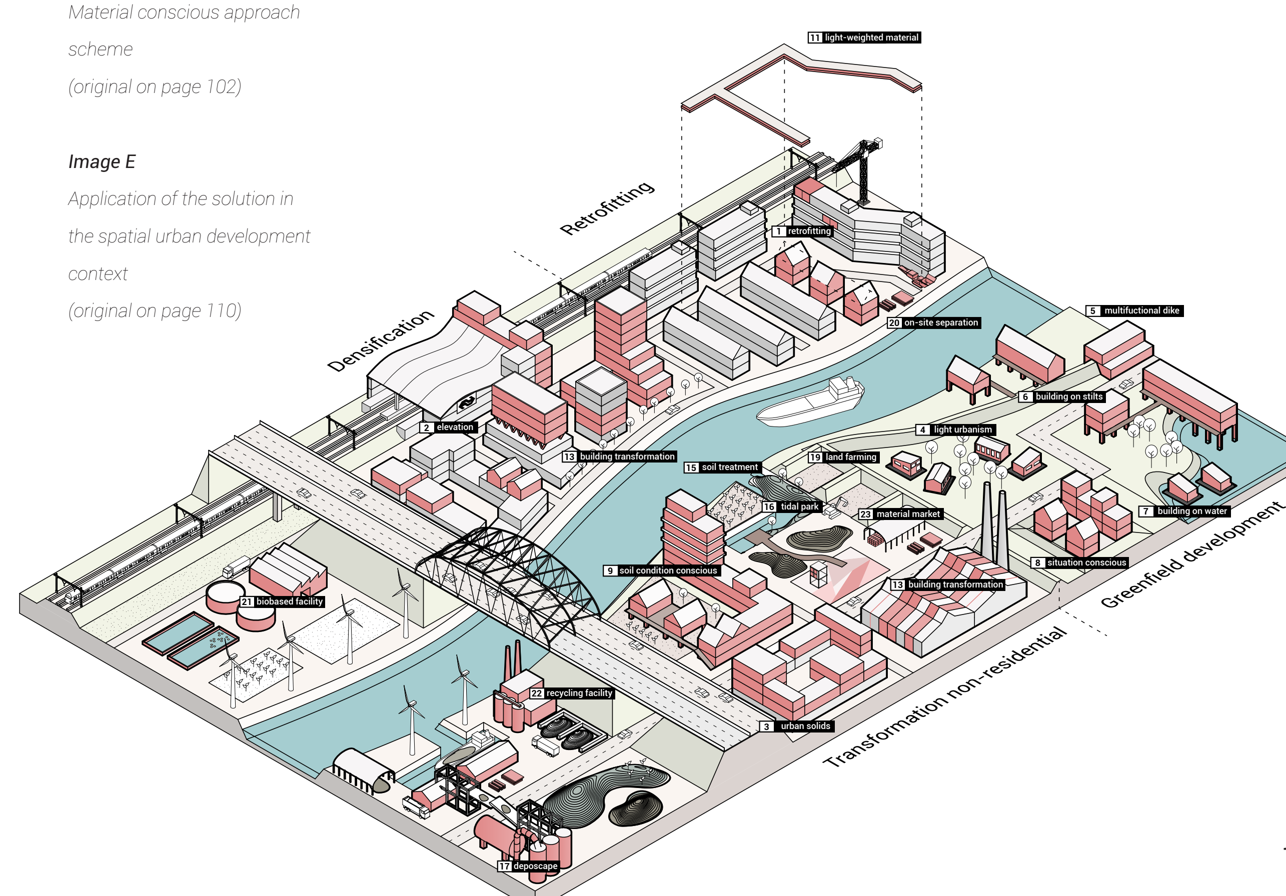
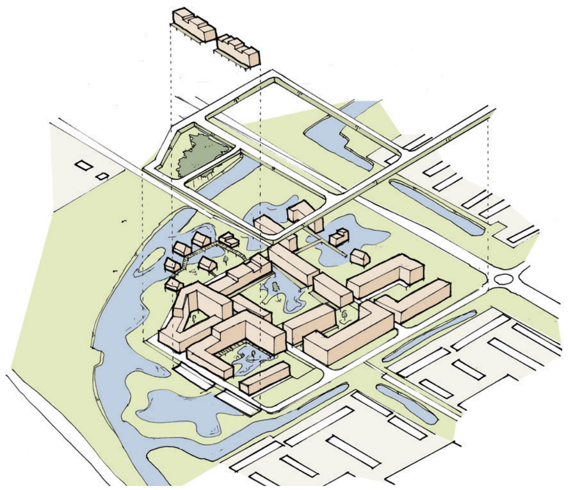


Image D
Material conscious approach scheme
(original on page 102)

Image E
Application of the solution in the spatial urban development context
(original on page 110)





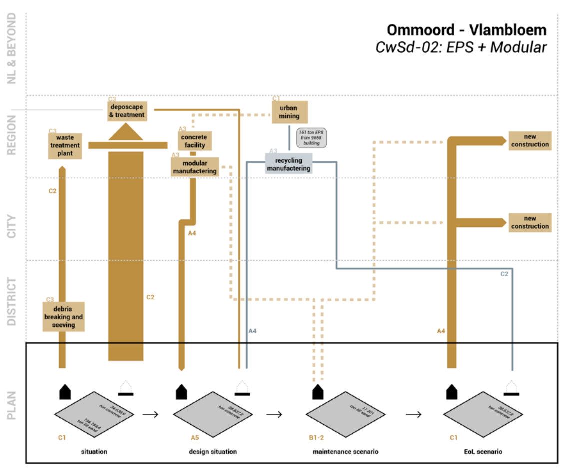


Image F

Example of design intervention

(original on page 126)

is ontwikkeld. Het BaU ontwerp heeft zowel een ruimtelijke als consumptieve impact. De consumptie impact is geïntegreerd in een territoriale metabolisme levenscyclus (TM-LCA) schema dat de kern van de materiaalbewuste aanpak omvat.

De ontwerpen streven ernaar om de materiaalvraag te reduceren, te structuren en te hergebruiken of om materiaal te recyclen met behulp van ruimtelijke interventies, waarbij ieder ontwerp een andere ruimtelijke, systematische en milieutechnische impact heeft.

Oplossingen uit de catalogus zijn toegepast in iedere situatie die resulteren in drie verbeterde concepten op basis van de BaU. De nieuwe concepten zijn erg verschillend van elkaar. Van het gebruik van gerecycled of alternatief materiaal in nieuwe constructies om dezelfde ruimtelijke kwaliteit als de BaU te behalen, het volledig transformeren of verticaal uitbreiden van de huidige constructies tot een compleet nieuwe verhoogde omgeving gebouwd op palen boven een groen landschap. Deze verbeterde ontwerpen reduceren de primaire materiaalconsumptie maar zijn soms ook afhankelijk van regionale factoren of activiteiten, zoals de beschikbaarheid van secundaire grondstofbronnen (gebouwen als stedelijke mijn). Ook veranderen ze de gebouwde omgeving op zo'n manier dat het de afwijkt van de huidige standaarden.

Een circulair zand metabolisme is een systeem dat uit meerdere lagen bestaat, waarbij de regionale vraag enhet aanbod van materiaal is gekoppeld aan stedenbouwkundige ontwerpen op lage schaal. Sommige lokale interventies vereisen nieuwe stromen en faciliteiten die resulteren in transformatie en ontwikkeling op een andere plaats.

Het aanbod van de sloop en vraag uit de constructie moet gelinkt worden aan de regionale schaal om voor zowel beton als voor ophoogzand

or material storage for recyclable material or modular building components. A balance is necessary in order to meet this supply and demand. However, a first estimation based on extrapolation results in a mismatch in the supply and demand. This means that further study is required.

Conclusions and recommendations

Sand and gravel are integrated in the built environment and thus relate to the profession of urban design and planning. The activities which cause consumption of sand and gravel are the core of the urban design profession but its metabolism and flux have a really low dynamic. However, this dynamic is affected by different internal and external factors which can be translated into different kind of conditions. These relate to urban development such as the type of urban development (e.g. densification) or the maintenance demand which relates to climate effects (e.g. subsidence). Based on these conditions, future assumptions and scenarios can be made of the material consumption in the RMDS region. The assumed sand and gravel metabolism in this region requires large quantities which causes transportation and resource depletion and indirect emission from manufacturing. The current recycling process of demolition waste has a chance to become saturated which amplifies the necessity of alternative recycling options.

The conditions causing material flow are important in the integration of material consumption in urban design. The research resulted in a material conscious approach where urban metabolism, urban design and the lifecycle perspective are combined. The approach integrates the entire lifecycle of the constructions (situation, construction, maintenance and end-of-life) in the urban design process and relates these to the consumption of material. This consumption relates to

de faciliteiten voor de recycling te realiseren. Opslag en productie moeten plaatsvinden op beschikbare en geschikte locaties, zoals getijdenparken voor baggersediment als zandvervanger of de opslag van modulaire gebouwelementen in en rondom wijken. Een balans is nodig voor deze vraag en aanbod omdat het mogelijk is dat de huidige strategieën niet goed hierop aansluiten.

Conclusies en aanbevelingen

Zand en grind zijn sterk geïntegreerd binnen de gebouwde omgeving en zijn gerelateerd aan de vakgebieden van stedenbouwkundig ontwerp en ruimtelijke planning. De activiteiten die de consumptie van zand en grind veroorzaken zijn de kern van stedenbouwkundig ontwerp maar het metabolisme en de flux ervan hebben een erg lage dynamiek. Deze dynamiek wordt beïnvloed door verschillende interne en externe factoren die vertaald zijn naar condities. Deze condities hebben betrekking op stedelijke ontwikkelingen, zoals verdichting of op onderhoudsactiviteiten gerelateerd aan het klimaat, zoals bodemdaling. Een toekomstscenario en een aanname zijn gemaakt voor de materiaalconsumptie in de RMDS regio, gebaseerd op de condities. Vanuit de aanname komt naar voren dat er grote aantallen zand en grind metabolisme in de regio nodig zijn die transport en grondstofuitputting (en indirect ook broeikasgassen door betonproductie) veroorzaken. Het huidige recyclingproces van sloopafval zou mogelijk verzadigd kunnen worden wat de belangen van alternatieven vergroot.

De condities die materiaalstromen veroorzaken zijn belangrijk bij de integratie van materiaalconsumptie in stedenbouwkundig ontwerp. In het kader van het onderzoek is een materiaalbewuste aanpak ontwikkeld waarin de consumptie, stedelijk metabolisme en een levenscyclus perspectief in zijn gecombineerd. Deze aanpak omvat de volledige levenscyclus van een the urban ecosystem and its metabolism which are made visible through a TM-LCA scheme. This scheme visualises the consumption during the lifespan of a construction and the origin or impact of the materials. This scheme can be used to evaluate the metabolic impact of a design to eventually apply material efficient strategies of reduce, reuse and recycle. Within the scope of material efficiency, an exploration of spatial solutions is made and combined in the Catalogue of Solutions which give an overview of sand-sensitive interventions related to urban design. These interventions can be linked to the different conditions which relate to both material consumption as urban design.

Three focus locations are used to test the material conscious approach and its solutions. These locations reflect the different conditions according to the urban development types. A two-step method was applied where first a business as usual scenario was designed with a TM-LCA scheme. Based on this design, improvements were made which reduces the material consumptions. Urban design has a significant impact on the consumption of material through the application of the material conscious approach. However, material conscious urban designs have an impact on the standard spatial quality and requires a regional system where material can be recycled and treated. The question remains if the ecosystem can supply both the material and space for production, treatment or storage in order to be able to reuse or recycle everything and to become circular. On the other hand, systematic improvement on the regional scale can contribute to design decisions on the local scale.

The research was a study which aimed to tackle the challenges related to sand and gravel consumption and its reduction from an urban design perspective. The study had an interdisciplinary approach because it covered topics from urbanism and civil engineering. However, this interrelation needs to be further explored for the technical feasibility of the design improvements and their impact on the drivers and the environment (e.g. by the execution of a LCA). The discipline of urban design can continue on exploration towards the relation between spatial composition and material consumption in order to optimise the reduction through a design.

The current designs relate to a regional systematic improvement and integration. Regional and local storage and treatment plants need to be facilitated. This task demands further research from both regional planning and environmental studies. Based on the environmental impact of e.g. transportation, suitable and strategic locations need to be found for these plants, both geographical as governmental.

On a more practical level, research needs to be done based on the quantitative feasibility of recycling possibilities. Some alternative material, for example EPS as a fill sand substitute, are interesting to be recycled and implemented but the quantity originated from secondary stock mismatches the demand. This requires studies towards a balance in circular material consumption and its alternatives which can continue on findings and methods from this research.

stedelijke constructie (situatie, constructie, onderhoud en afdanking) en zijn relatie met materiaalconsumptie. De relatie tussen deze consumptie en het stedelijke ecosysteem of metabolisme worden verduidelijkt door middel van het TM-LCA schema. Dit schema visualiseert de consumptie en de impact van de constructie over zijn volledige levenscyclus. Daarnaast kan het gebruikt worden om de metabolische impact van een ontwerp te evalueren om er uiteindelijk de materiaalefficiënte strategieën (voorkomen, hergebruiken, recyclen) op toe te passen. Een verkenning van ruimtelijke oplossingen zijn samengevat in de oplossingencatalogus die een overzicht geeft van zandsensitieve interventies met betrekking tot stedenbouwkundig ontwerp.

De materiaalbewuste aanpak en de gerelateerde oplossingen zijn toegepast op drie locaties binnen de RMDS regio. Deze locaties vertegenwoordigen de verschillende condities van de stedelijke ontwikkeling. Een methode in twee stappen is toegepast, waarbij eerst een business as usual ontwerp is opgezet vergezeld van een TM-LCA schema. Als tweede worden, gebaseerd op dit ontwerp, verbeteringen gemaakt die de materiaalconsumptie reduceren. Door het toepassen van de materiaalbewuste aanpak kan stedenbouwkundig ontwerp een aanzienlijke en directe impact op de materiaalconsumptie hebben. Echter hebben deze ontwerpen een impact op de standaarden van ruimtelijke kwaliteiten en zijn ze soms afhankelijk van een regionaal systeem voor recycling en reiniging. De vraag blijft of het ecosysteem de vraag naar secundair materiaal kan opvangen en of er genoeg plaats is om de ruimtelijke ingrepen voor productie, reiniging en opslag huis te vesten om zodoende dus circulair te worden. Aan de andere kant kunnen regionale systematische verbeteringen bijdrage aan ontwerpkeuzes voor stedenbouwkundige plannen.

Het onderzoek was gericht op de problemen rondom de zand en grind consumptie en reductie vanuit een stedenbouwkundig ontwerpperspectief. Het onderzoek had een interdisciplinaire aanpak aangezien het op het raakvlak van stedenbouw en civiele techniek ligt. Deze relatie zou verder moeten worden verkend voor de technische haalbaarheid van de ontwerpen en de impact op de drijfveren van de consumptie en omgeving (door middel van het uitvoeren van een LCA). Voor stedenbouwkundig ontwerp ligt er nog de kans om de relatie tussen ruimtelijke compositie en materiaal reductie en optimalisatie verder te verkennen.

De huidige ontwerpen zijn gerelateerd aan regionaal systematische verbetering en integratie. Regionale en lokale opslag- en reinigingslocaties moeten worden gefaciliteerd. Dit vergt verder onderzoek vanuit zowel regionale planning als milieutechnisch perspectief. Gebaseerd op de milieu impact van onder andere transport moeten er geschikte en strategische locaties gekozen worden, zowel ruimtelijk als bestuurlijk.

Vanuit een meer praktisch oogpunt is verder onderzoek nodig naar de kwantitatieve haalbaarheid van de recycling mogelijkheden. Sommige alternatieven, zoals het voorbeeld van EPS als ophoogzandvervanger, zijn recyclebaar en toe te passen maar het aanbod uit secondaire bronnen komt niet overeen met de vraag. Hiervoor zijn studies naar de balans in een circulaire materiaalconsumptie nodig die de bevindingen en methodes uit dit onderzoek kunnen gebruiken als inspiratie en startpunt.

The foundation of modern and future cities

1. Introduction

Annually, we extract enough sand from the earth to cover the entire Netherlands with a layer of 60cm of sand*

"Sand is, after water, the most used raw material on earth [...] and greatly exceeds their natural renewal rates"

Image 1

Impression of 60cm of sand in the Netherlands

Position yourself in a random city. Probably, the buildings around you are built out of concrete and have glass windows, the road under your feet might be asphalt and, especially when you envision a Dutch city, the ground underneath you is artificial raised with the main ingredient of the previous materials; sand (and gravel). This substance is literary the *"main material of which our modern cities are made of"* (Beiser, 2018). This accounts especially for delta areas which are formed by the natural flow of sand; the sedimentation. Urbanised areas, such as the Dutch Delta, are constantly interfering in this process for flood defence, building site preparation or waterway dredging. Including the demand of sand for building construction makes these areas a large consumer of sand and gravel.

Annually, 47 and 59 billion tonnes of material is mined (Steinberger, Krausmann, & Eisenmenger, 2010) of which sand and gravel shares 68 to 85 percent (UNEP, 2014). This amount is enough to cover the entire Netherlands with a sand layer of around 60cm. Or turn it the other way, imagine the area of the Netherlands being excavated with 60cm each year.

Sand, just like almost every substance on earth, is a finite resource and nowadays it is extracted at a faster rate than its renewal (UNEP, 2014). This depletion is causing negative environmental impact on rivers, deltas and coast. (Beiser, 2018; Gavriletea, 2017; Pitchaiah, 2017; Torres et al., 2017; UNEP, 2014). Due to this negative impact, it is stated that sand is becoming scarce.

According to Torres, urban expansion is the main driver of the global sand consumption because of the usage of sand in concrete, asphalt glass and more (2017).Globally, the material consumption of the construction sector is also the largest compared to the consumption of e.g. fossil fuel and biomass (de Wit, Hoogzaad, Ramkumar, Friedl, & Douma, 2018) and is globally causing the most CO2 emission (Huang, Krigsvoll, Johansen, Liu, & Zhang, 2018). Furthermore, the construction and demolishing process is still overall linear where the demolition waste of buildings is recycled but ends up as foundation for infrastructure which is not a circular solution (Circle Economy, 2014; Schut, Crielaard, & Mesman, 2016). In order to reduce the urban metabolic footprint, the consumption of raw materials in the construction of cities should be changed.

*average of +/- 40 billion (40.000.000.000) tonnes
source: United Nations Environment Programme (UNEP)
. *Sand, Rarer Than One Thinks.*

Sand, *our most dependent urban ingredient*

2. Problem Field

This chapter introduces and analyses the problems which are the basis of the research. It shows the relation and characteristics of the domains which conclude in an problem statement. This will be elaborated in the research question and objectives for the entire research.

Source: Fabiton, n.d.

2.1 Urban consumption and resource depletion

The age in which we live is partly defined by the large-scale exploitation of the planet's resource base (McNeill, 2001). Cities are responsible for the consumption of 75% of the natural resources which are transformed into 50% of the global waste (UNEP, 2012). This is remarkable because cities only cover 3% of the Earth's surface. The urban consumption is expected to grow from 40 billion tonnes in 2010 to 90 billion tonnes in 2050 according to the United Nations' International Resource Panel (IRP) (2018).

This resource extraction is not without consequences. The Earth has its limits and our economic consumption pattern is also linear resulting in a depletion of the resources. This notion was already exposed in 1972 when the Club of Rome presented their report 'Limits to Grow' (Meadows & Club of Rome., 1972). Their report predicted that the current economic growth could not continue indefinitely because of the limited availability of natural resources are limited.

Currently, the inexhaustibility of resources is the main challenges in the transition from a linear economy towards a circular economy. In 2018, the Circularity Gap Report was published which stated what needs to be done in order to bridge the circularity gap for the future (de Wit et al., 2018). Key challenges are stopping the extraction of raw materials and stopping the generation of waste by closing the cycle.

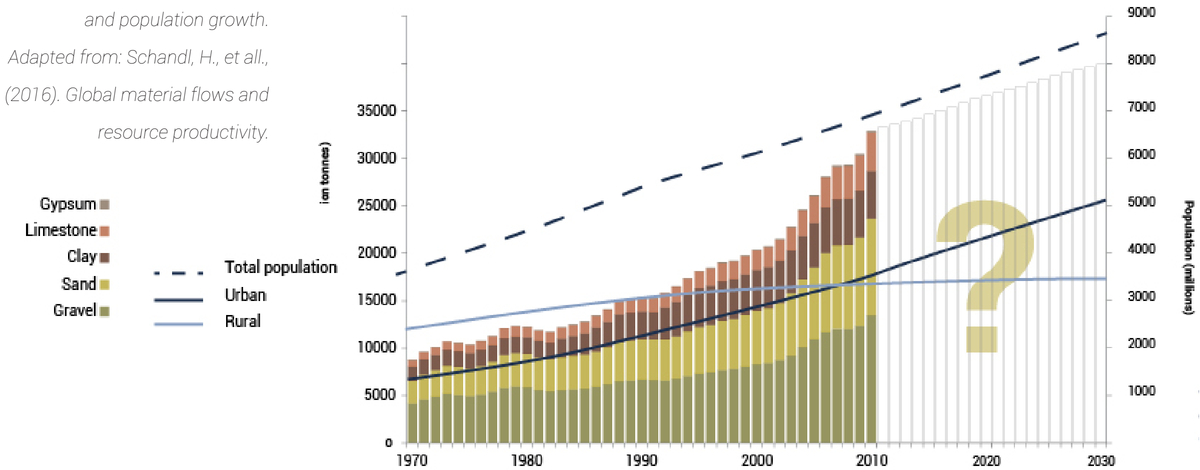
2.1.1 Material consumption in urbanisation

The materialisation, i.e. construction, of the urban structures is mainly responsible for resource depletion and consumption. 40% Of the extracted materials are stored in the buildings and infrastructure of cities (Kibert, Sendzimir, & Guy, 2003). According to Sawin and Hughes (2007), 40% of the global waste stems from the construction industry. The global urbanisation and population growth thus involves resource depletion and waste generation, which will result in a negative impact on the environment.

The construction sector is consuming resources unsustainably. It is based on a linear process where a small quantity of the materials are reused. In some cases, such as the Netherlands, C&D waste is used for foundation material This is an example of a cradle-to-grave process because the material is downcycled and can be compared to landfill (Schut et al., 2016). The linear aspect of the construction industry is nowadays broadly covered by studies of design for deconstruction (DfD) and urban mining (Johansson, Krook, Eklund, & Berglund, 2013; Koutamanis, van Reijn, & van Bueren, 2018; Stephan & Athanassiadis, 2017). However, most of the time these studies focus on materials with a shorter lifespan and non-structural elements. The application of sand and gravel is characterised by a long lifespan and structural elements (Brand, 1994).

Image 2:

Non-metalic mineral consumption and population growth. Adapted from: Schandl, H., et all., (2016). Global material flows and resource productivity.



2.1.2 The 'scarcity' of primary material sand and gravel

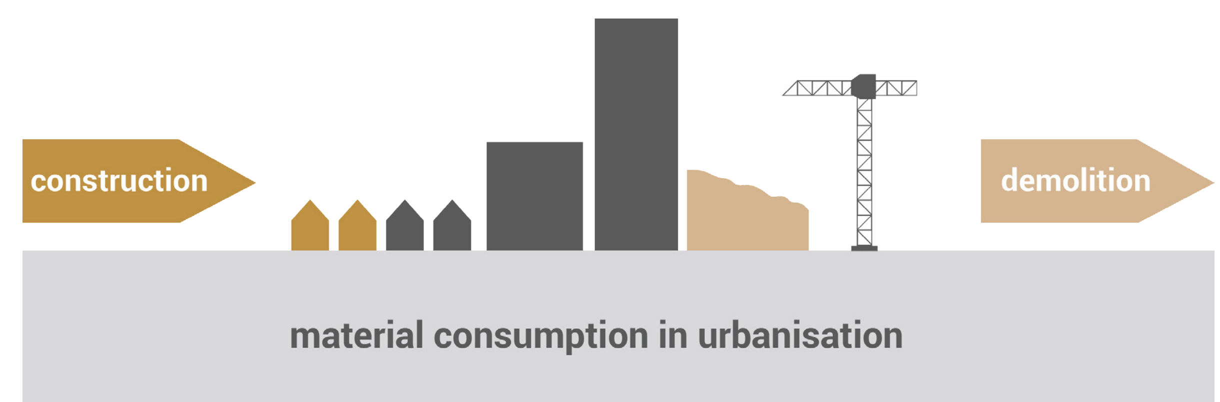
Sand and gravel take a large share in the consumption of construction resources (Krausmann et al., 2009). United Nations Environmental Panel (UNEP) recently published an alarming report that states that these minerals are currently extracted at a greater rate than their natural renewal by erosive processes (2014). Sand and gravel are the second most consumed natural resource, with construction and urbanisation as the main driver (Gavriletea, 2017; Torres, Brandt, et al., 2017). Around 22 billion tonnes of sand and gravel are mined globally (UNEP, 2016) and this extraction rate increases (Krausmann et al., 2009). Sand and gravel are widely applied in products such as concrete, mortar, and glass for buildings and bridges, asphalt for infrastructure, land reclamation and building site preparation, and for flood protection (Beiser, 2018; Gavriletea, 2017; S.-L. Huang & Hsu, 2003; UNEP, 2014). The extraction rate is larger than the renewal of sand and gravel, which is through erosion and sedimentation of natural rock. The extraction volume of sand and gravel is impacting the ecosystem of rivers, deltas, coastal and marine systems. The impacts can be loss of land through erosion and decrease of sediment supply (UNEP, 2014). Next to the impacts of extraction, it should be noted that the linear consumption pattern is permanently removing the sand and gravel from its reservoir, highlighting its finite characteristic.

2.1.3 Circular ambition of the Netherlands

Circularity and waste reduction are global challenges in every sector, as well as the construction industry (Adams, Osmani, Thorpe, & Thornback, 2017; de Wit et al., 2018). The vast extraction of natural resources is also noted by the Dutch Government. In 2016 the Dutch government published a report stating their ambition to become circular in 2050 (Ministerie van Infrastructuur en Milieu & Ministerie van Economische Zaken, 2016). Their aim is to reach 30% of circularity in 2030 and 100% in 2050. This ambition is split into different agendas focusing on different topics such as construction and consumables. In 2017, a Resource Agreement is concluded which led to the transition agenda for the construction industry (RVO, 2018). Half of all resources that the Netherlands uses is consumed by the construction sector (Schut et al., 2016). The Dutch government acknowledge the negative environmental impact of resource extraction, manufacturing and transportation in the construction sector which needs to be changed towards a more bio-based and less waste-generation sector. The challenge is complex and unknown but the Dutch Government is stimulating various organisations to experiment and research the possibilities to become 100% circular in 2050.

Image 3:

Consumption of construction material in urban areas



Primairy construction resource extraction: the Netherlands *2016*
(in tonnes)

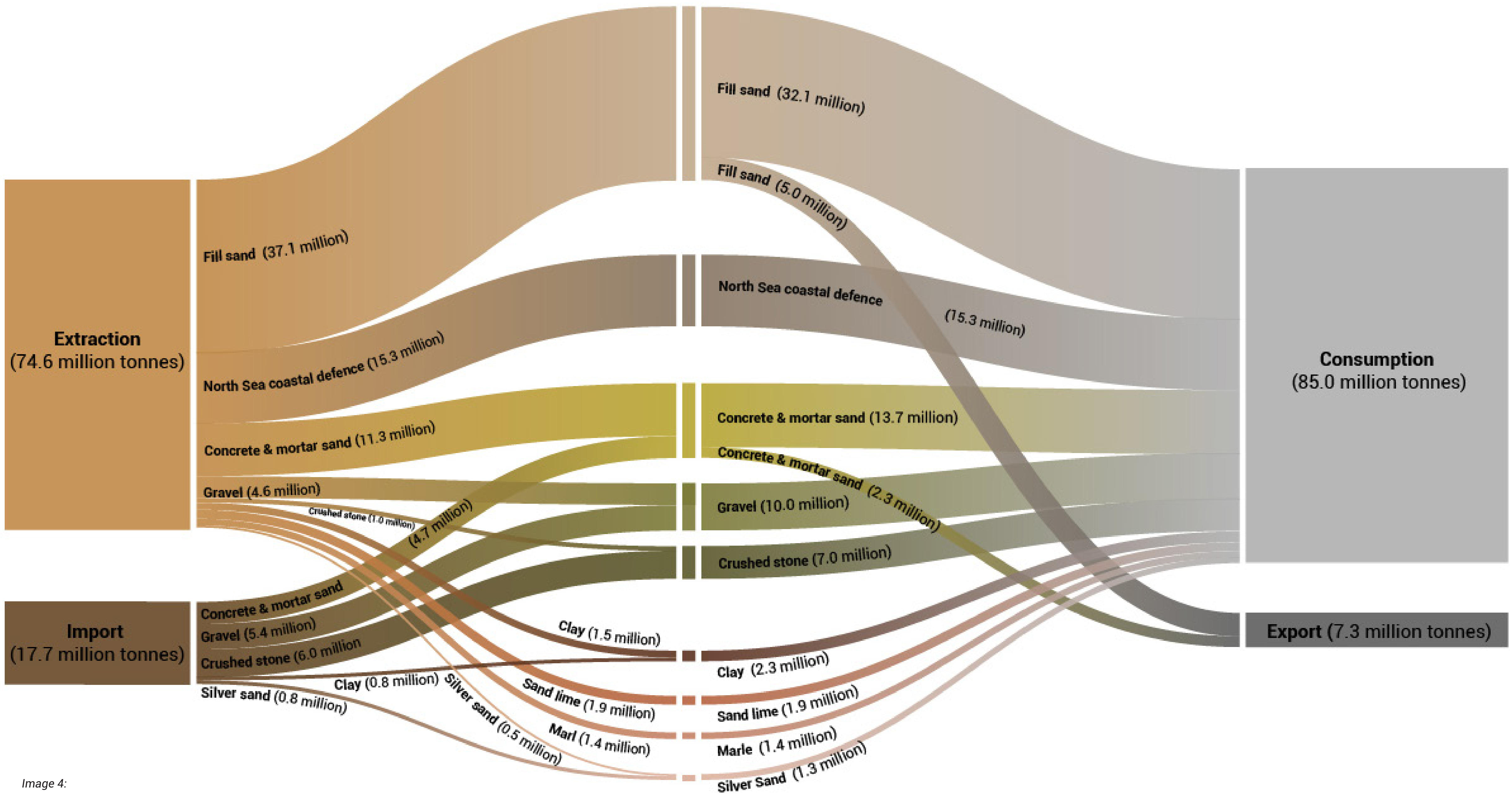


Image 4:

Flow diagram of the consumption of non-metal minerals in the Netherlands.

Based on 't Hoen, 2017.

2.2 One million dwellings to construct in the Netherlands

The Netherlands is facing a challenge of realising around 1 million dwellings until 2040 (Alkemade, Strootman, & Zandbelt, 2018). The current annual production of dwellings is 50.000 which is not enough to reach to goal. This urbanisation and production of dwellings is linked with challenges in mobility, energy transition and climate adaptation. The current discussion is where the 1 million dwellings shall be built, either in urban or rural area. Apart from the final location, urbanisation will demand raw material with sand and gravel assumedly as the key resource. The urgent housing challenge is not directly linked or mentioned with the circular ambition and documents but they share the same task. In order to reach the circular ambition, these two challenges should be combined.

2.2.1 Urbanisation in the Rijnmond-Drechtsteden region

Sand and deltas are closely related to each other. The sediment flows through the rivers and (trans)forms the deltas by sediment deposit (van Veelen, Jansma, & Kalogeropoulou, 2018). When deltas are urbanised, the geomorphological dynamics of sediment is disturbed but also a closer relation with sand is created. In the Dutch case, sand and gravel are used as a building material, fill sand for building site preparation and land reclamation and sand for coastal protection. The Rhine-Meuse estuary is an example of this relation between urban area and sediment. In the Rhine-Meuse estuary, cities such as Rotterdam and Dordrecht shape the Rijnmond-Drechsteden (RMDS) conurbation. The sand and gravel consumed in the region is mined in the North Sea or upstream on the Rhine or the Meuse ('t Hoen, 2017). On the other hand, sediment flowing through and eventually deposit in the Nieuwe Maas and Nieuwe Waterweg (harbour of Rotterdam) is dredged and transported towards the North Sea in order to maintain the waterways for economic activity (van Veelen et al., 2018). Other activities also affected the sediment balance and its related ecosystems such as the Haringvliet, a storm surge barrier.

Sand and gravel is linked with urbanisation, which is also occurring in the RMDS region. Until 2040, the region needs to build 88.300 houses (Provincie Zuid-Holland, 2016) but the Dutch national government stated that the city of Rotterdam needs to replace 100.000 houses in their current stock (Ministry of Infrastructure and the Environment, 2012). These events will cause major in- and outflow of construction material.

Next to activities around housing construction, the area is also demanding sand for flood and coastal protection (van Veelen et al., 2018). Sand is the key material for the beach nourishment of the Dutch coast and its dunes. A recent study by Deltares on the effects of climate change and rising sea level on the flood safety concluded that in the status quo coastal maintenance will demand more sand related to the projected sea level rise (2018). These events in the urban region will increase the consumption of sand and gravel for urban constructions.

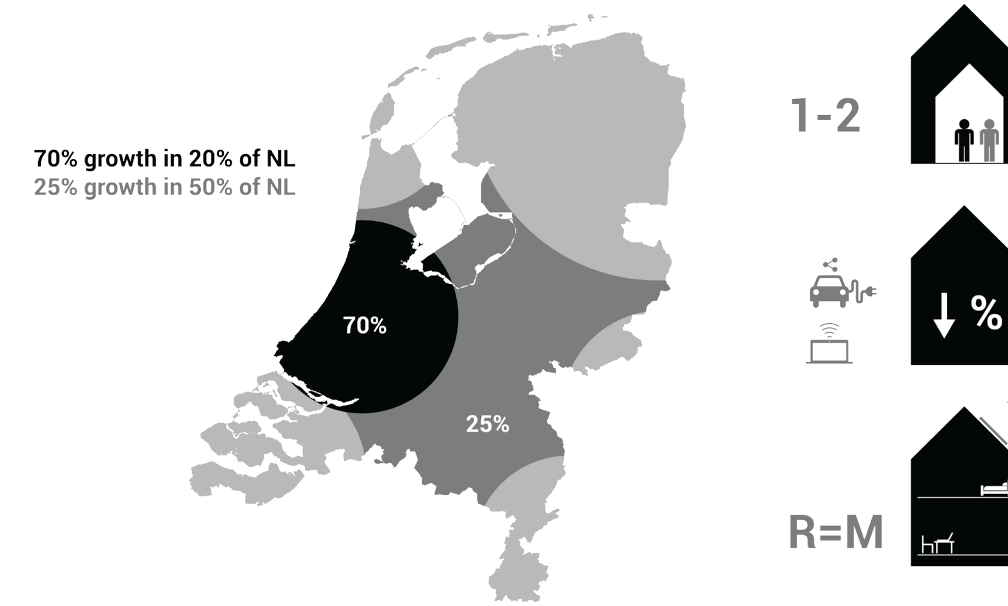


Image 5:
Housing challenge in the Netherlands.
based on CRA, 2018

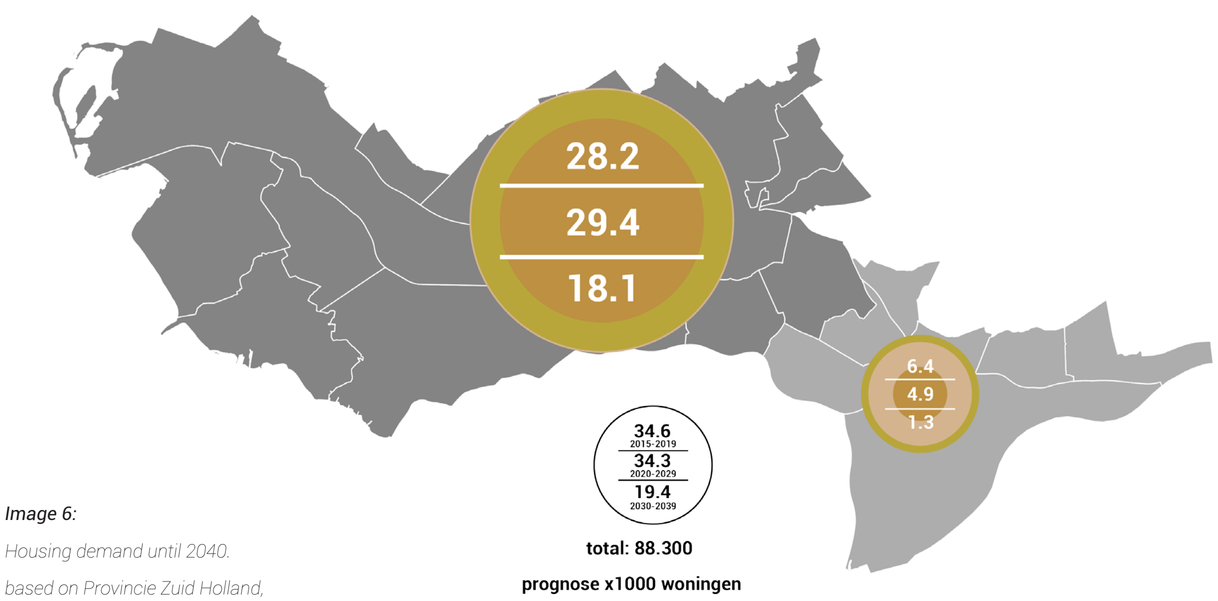


Image 6:
Housing demand until 2040.
based on Provincie Zuid Holland, 2016

2.2.2 Urbanisation vs. Materialisation

Torres et al. stated that urbanisation is the driver of the depletion of sand and other minerals which are transformed through construction activities into our urban construction (2017). The urbanisation is a task for spatial planners and urban designers. As mentioned before, the urbanisation challenge is not (yet) combined with the circular construction ambition. The gap also lies in the discipline of urban planning and design. Urban design and planning locate and structure the shape of environments, which eventually results in materialisation of urban constructions (e.g. buildings or roads) but the disciplines only mention detailed materialisation when talking about legibility or identity of an environment (Meyer, Josselin de Jong, Hoekstra, Harteveld, & Cosijn, 2006). The impact of the material choice and their related flows are neglected.

Torres et al. (2017) criticizes the current approach of planning and construction in relation to sand and gravel consumption as: *"While scientists are making a great effort to quantify how infrastructure systems such as roads and buildings affect the habitats that surround them, the impacts of extracting construction minerals such as sand and gravel to build those structures have been overlooked."* . Assessment methods concerning material consumption and impact such as Life Cycle Assessment (LCA) are applied on urban scale and projects in some studies (Albertí, Balaguera, Brodhag, & Fullana-i-Palmer, 2017; Lotteau, Loubet, Pousse, Dufrasnes, & Sonnemann, 2015; Mastrucci, Marvuglia, Leopold, & Benetto, 2017) but these applications are either incomplete or focussing on energy.

Still, if future urbanisation wants to reduce the environmental impact of its materialisation, urban design and planning needs to integrate the material choice and flows in their discipline.

2.3 Problem statement

Globally, the construction and demolition sector is accountable for high consumption of primary materials and generation of waste. The sector is also responsible for the materialisation of urbanisation, which is a trend expected to continue. The most important material in the construction sector is sand and gravel as it is fundamental for urban constructions. The consumption of sand and gravel is linear resulting in a constant input of primary material and output which is downcycled.

The Rijnmond-Drechtsteden (RMDS) region is also expected to continue in urbanisation. With a demand for almost 88.300 dwellings to build and 100,000 to replace, the construction metabolism of the region will undertake many in- and outflow of primary sand and gravel. This process is still in the business-as-usual perspective still traditionally and not circular. This is also a missing ambition in the urban design profession for housing development.

Image 7

Construction activity in the RMDS region due to urbanisation

Construction materials in urbanism

3. Theoretical Framework

The problem statement is related to a certain field of study and concepts which are collected and explained in the theoretical framework chapter. The hierarchy and structure of the theoretical framework is explained in image 8. As introduced in the previous chapter, the ***background*** *of the research the resource depletion and consumption. The research focus on the consumption of resources in the construction sector, in the* ***context*** *of construction metabolism. Construction metabolism is a concept which explains the construction ecosystems consisting of certain* ***attributes & processes****. These are distinguished in civil engineering as well in urban design respectively. Although, these two disciplines are closely related to each other and even overlap. They will be described separately.*

Source: Dekker Groep, n.d.

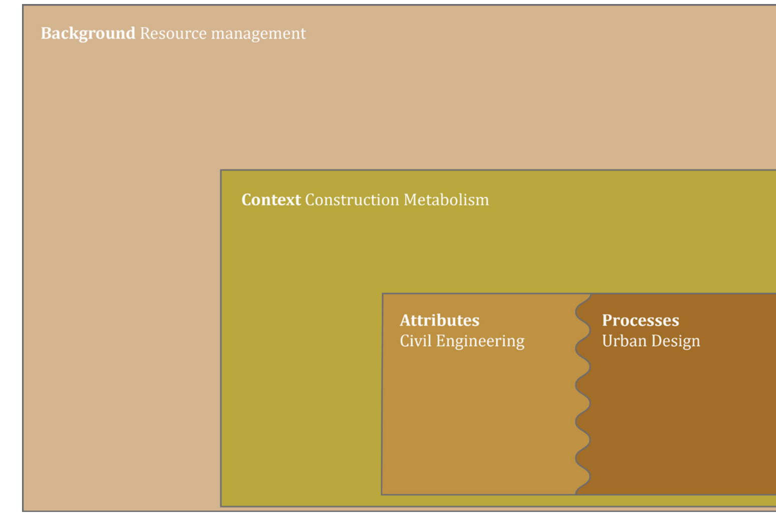


Image 8:

Theoretical framework

3.1 Background: Resource depletion and consumption

Current society is dependent on the resources the Earth supplies. A resource is something human society attaches value to. In other words, a resource can thus gain or lose its (level of) value as society changes, which is visible in our historical determination of the Stone Age, Bronze Age and the Iron Age. This change is an important factor in how our relationship between human society and the natural environment is shaped (Daniels & Sidaway, 2012). The resources are stocked in the resource base which can be defined as the finite stock of resources the Earth holds. The resources can be divided into non-renewable or stock resources and renewable or flow resources (Daniels & Sidaway, 2012). Stock resources are those that have taken millions of years to form and with a limited availability, e.g. minerals. Flow resources are naturally renewed within the short time-span of human society, e.g. wind or biomass.

3.1.1 Sustainability & circularity

As the division shows, not all resources are usable without harming or influencing the resource base. Resource management aims to "ensure that exploitation of a particular renewable resource does not damage its capacity to replace itself" (Daniels & Sidaway, 2012). This means that some material become scarce or affects the environment which the material is related to. The current consumption pattern of materials is linear based which means that products result in waste but also demands raw material for production. Recent strategies become more efficient in the material consumption (Allwood, Ashby, Gutowski, & Worrell, 2011). According to Allwood et al. (2011) material efficiency means "providing material services with

non-renewable/stock		
Consumed by use	Theoretically recoverable	Recyclable
Oil	All elemental minerals	Metalic minerals
Gas		
Coal		

renewable/flow	
Critical zone	Non-critical zone
Fish	Solar energy
Forests	Tides
Animals	Wind
Soil	Waves
Water in aquifers	Water
	Air

Flow resources used to extinction

Critical zone resources become stock once regenerative capacity is exceeded

Image 9

Classification fo resource types

(Daniels & Sidaway, 2012)

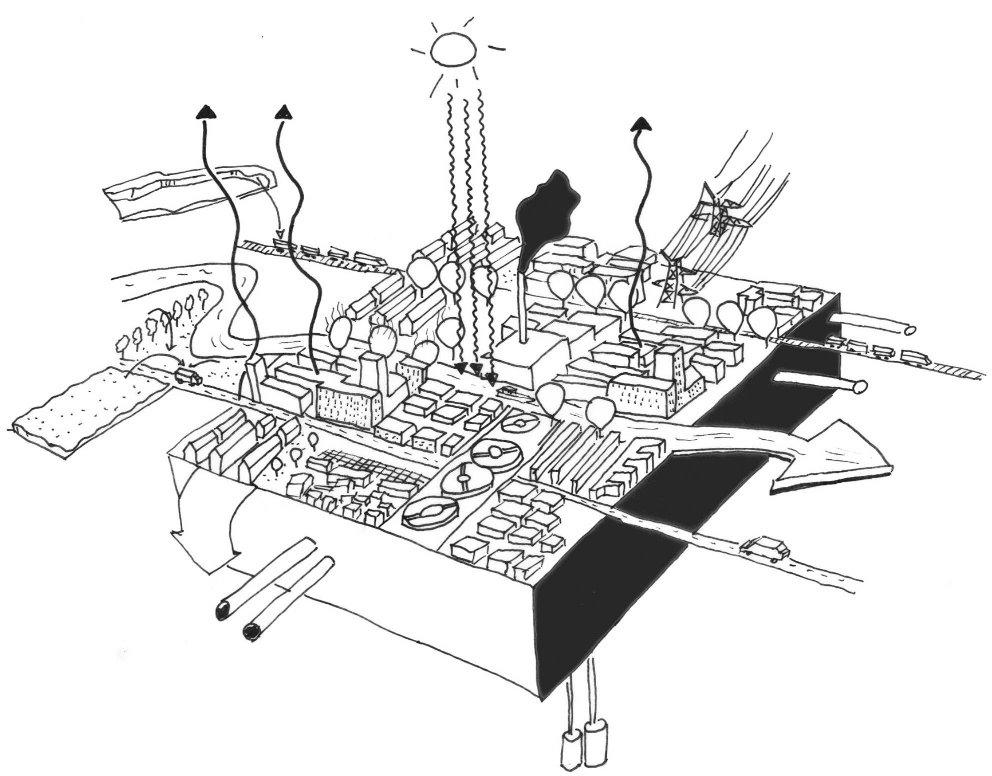


Image 10:

Urban metabolism concept Dirk Sijmons and Jurra Raith.

(Brugmans et al. 2014.)

less material production and processing". The strategies are: longer-lasting products; modularisation and remanufacturing; component re-use; designing products with less materials. These strategies prevent and reduce the change that materials will run out and a sustainable future can be assured. How materials are consumed in urban areas is research in the field of urban metabolism. The specific section within that field is construction metabolism, which will be described in the next paragraph.

3.2 Context: Construction metabolism

Urban metabolism has become an important perspective in order to achieve urban sustainability (less resource consumption and waste generation), (Fischer-Kowalski & Haberl, 1998; Gandy, 2004; Haberl, 2001; Kibert, Sendzimir, & Guy, 2000; Newman, 1999). Urban metabolism can be defined as ***"the sum total of technical and socioeconomic processes that occur in cities, resulting in growth, production of energy and elimination of waste"*** (Christopher Kennedy, Cuddihy, & Engel-Yan, 2007). Zhang et al. (2018) explain it further as ***"to describe how material, food, water and energy flow through an urban ecosystem, and are consumed to support its metabolism, then grow and reproduce, consequently generating products and by-products (e.g. GHG, pollutants, and waste)"*** . Zhang et al (2018). also note that the industrial ecosystems of urban metabolism, including the construction industry, have received little attention in urban metabolism studies. Construction is key for urban environments because it is responsible for the materialisation. This construction industry is also responsible for a large share of the resource consumption and generation of greenhouse gasses (GHG), pollutants, and construction and demolition (C&D) waste (de Wit et al., 2018; Shen, Tam Vivian, Tam, & Drew, 2004; Tam & Tam, 2008).

3.2.1 Origin of the urban metabolism concept

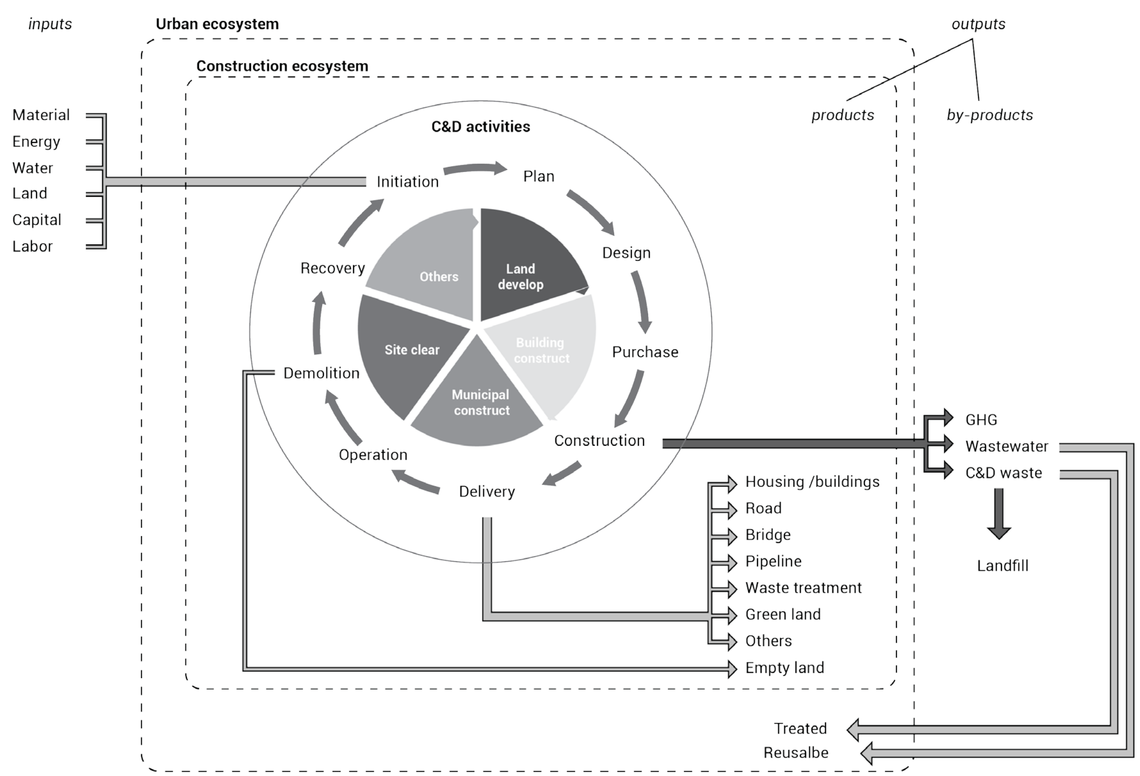
The concept of urban metabolism was introduced by Wolman (1965). Ayres and Knees continued on this concept within industrial ecology whereby nature serves as a model for the analysis of existing industrial systems and for guiding new forms (Newell & Cousins, 2015). The industrial metabolism was further developed when the analogy was made between industrial systems and organisms in terms of energy and waste. Urban metabolism thus became a discipline within the industrial metabolism defined by Kennedy et al. (2007) as per the definition cited earlier in this paper. Important to notice is that nature is used as a model for man-made systems because waste does not exist in natural systems and cycles. Cities are thereby seen as linear metabolism which should be shifted more towards a circular metabolism based on lessons from nature (Broto, Allen, & Rapoport, 2012).

3.2.2 Construction metabolism in urban metabolism

Although the construction can be considered as the most relevant system in materializing the urban, most urban metabolism studies rarely focus on the physical construction and life-span of the city (Zhang et al., 2018). Kennedy et al. (2011) reviewed the studies in the field of urban metabolism but only four of the 47 considered studies focussed on the materialisation of cities. Recently Zhang et al. (2018) took notion of the fact that, despite its relevance, studies on the integration of urban metabolism and construction ecosystem are rare. They developed an urban metabolism framework of the construction ecosystem consisting of the components of input, output and urban ecosystem (see Fig. 11.). This framework can be seen as a development of the construction ecology by Kibert et al (2000, 2003). He used the concept of industrial ecology on the construction industry in order to learn lessons from nature to achieve sustainability. This is related to the construction and demolition (C&D) activities which are key in the construction ecosystem, which is part of the greater urban ecosystem. The C&D activities in the context of flows and stock links the construction process with the metabolic context. Notable is that Zhang et al. (2018) did not include C&D waste in the demolition part of C&D activities, which is important for sustainable and ecological construction.

Image 11:

Construction metabolism. Adapted from Zhang et al. 2018



The study by Huang et al. (2003) of the metabolism in the urban construction in Taipei, Taiwan is highly notable because of the inclusion and emphasis on sand and gravel. The urban construction includes; road, bridge, mass railway transit, dike and levee for flood prevention, and storm drainage and sewerage pipes, and buildings, which are products in the construction metabolism. This notion will be discussed further in the next part which continues on developing the sand and gravel metabolism framework.

3.2.3 Sand and gravel metabolism

Input of construction sand and gravel

The input for construction sand and gravel are the natural or artificial sources of the substance (Padmalal & Maya, 2014). These sources are mined from their natural geological cycle, which are terrestrial (including rivers) and marine (Gavriletea, 2017). Rivers, sand pits and oceans are most common source. The source also relates to the application. Marine sand for example is less suitable for concrete because of chemical composition and silt ('t Hoen, 2017).

Artificial sources include manufactured sand or crushed rock sand by drilling, blasting, washing, and sieving (Padmalal & Maya, 2014). Also recycled sand is considered an artificial source. This type of source is still minimal. In the Dutch context less than 3% of aggregates in construction comes from recycled aggregate (Schut et al., 2016).

Ecosystems of construction sand and gravel

Huang et al. (2003) and Zhang et al. (2018) described the ecosystem which is related to the urban construction. The construction sand and gravel ecosystem is part of this construction ecosystem where it is used as material. The framework and analysis of both studies exclude sand ecosystems in building site preparation, land reclamation and flood protection. The ecosystem for flood protection is difficult to clarify because in the Dutch case flood protection is done by beach nourishment, the maintenance of the coastal line with sand (Prins & Hulsman, 2009). This is notable because the natural source is turned by artificial actions into an output which is required for urbanised coastal areas to be safe from natural hazards. This makes construction sand still part of its natural cycle where erosion and disposal along coastal areas is still related. However, human interference is required for flood resilience. In the Dutch case, this will become more important because of rising sea level (Deltares, 2018).

This means that the ecosystem of construction sand is both in the construction ecosystem of the urban ecosystem, as well as part of the natural ecosystem of sedimentation and erosion and deposition.

Output of sand and gravel products

The metabolic process of the construction ecosystem generates products and by-products. The products in which sand is applied are; roads, bridges, dikes and levees for flood prevention, storm drainage and sewage pipes, and buildings (S.-L. Huang & Hsu, 2003). It is important to add that building site preparation and land reclamation are also important sand consumers in the Dutch case, because these activities were important for the construction of large parts of the Netherlands (Hooimeijer et al., 2016; Hooimeijer, 2014) demanding a large amount of sand or gravel ('t Hoen, 2017). The products and by-products are discussed separately in order to clarify the conditions within the metabolic framework.

Output of sand and gravel by-products

The construction ecosystem is also responsible for the production of a massive amount of by-products such as GHG and C&D waste (Zhang et al., 2018). The GHG emission is caused by the production of cement which is substantial in the production of concrete (Copuroglu, 2017). The bitumen used in the asphalt production is a residual product in the oil production (Schut et al., 2016). The C&D waste is notable after the life-span of buildings which can be between the 50 and 100 years, depending on several drivers and maintenance regimes (Sandberg et al., 2016; Stephan & Athanassiadis, 2018). After the demolition of buildings in the Netherlands, most C&D waste is used as foundation material in the site preparation of infrastructure (Schut et al., 2016). This is an end-of-life and downcycle solution because the material remains in this location in a lower quality and is reused on site in renovation and maintenance activities. This is causing the foundation market to become saturated because the rate of generation of C&D waste is higher than the realisation rate of new infrastructure. Some C&D waste is reused in the production of new concrete and asphalt. Respectively less than 3% and 5% (Schut et al., 2016).

The application of fill sand for building site preparation is also an end-of-life process because sand is not manufactured but relocated into a new deposit. Building site preparation is necessary to make the weak soils suitable and stable for constructions. The layer of sand causes weight compression which results in subsidence (F Hooimeijer et al., 2016; van de Ven, 2016). Subsidence also occur due to oxidation of organic material or the loss of upward pressure of the top soil due to water extraction. (Willemse, 2017). Oxidation of organic material contribute to the emission of CO2. This contribution is 2,5% of the Dutch emission, which can be compared to 25% of the emission causes by cars (Willemse, 2017). The subsided surface level of infrastructure needs to be maintained by raising it with sand, which only increases the weight of the sand layer. Subsidence can also damage buildings when they buildings are built on wooden foundation piles or no piles at all (Willemse, 2017). This process suggest that sand applied in building site preparation generated no waste and only demand primary material. However, sand can become

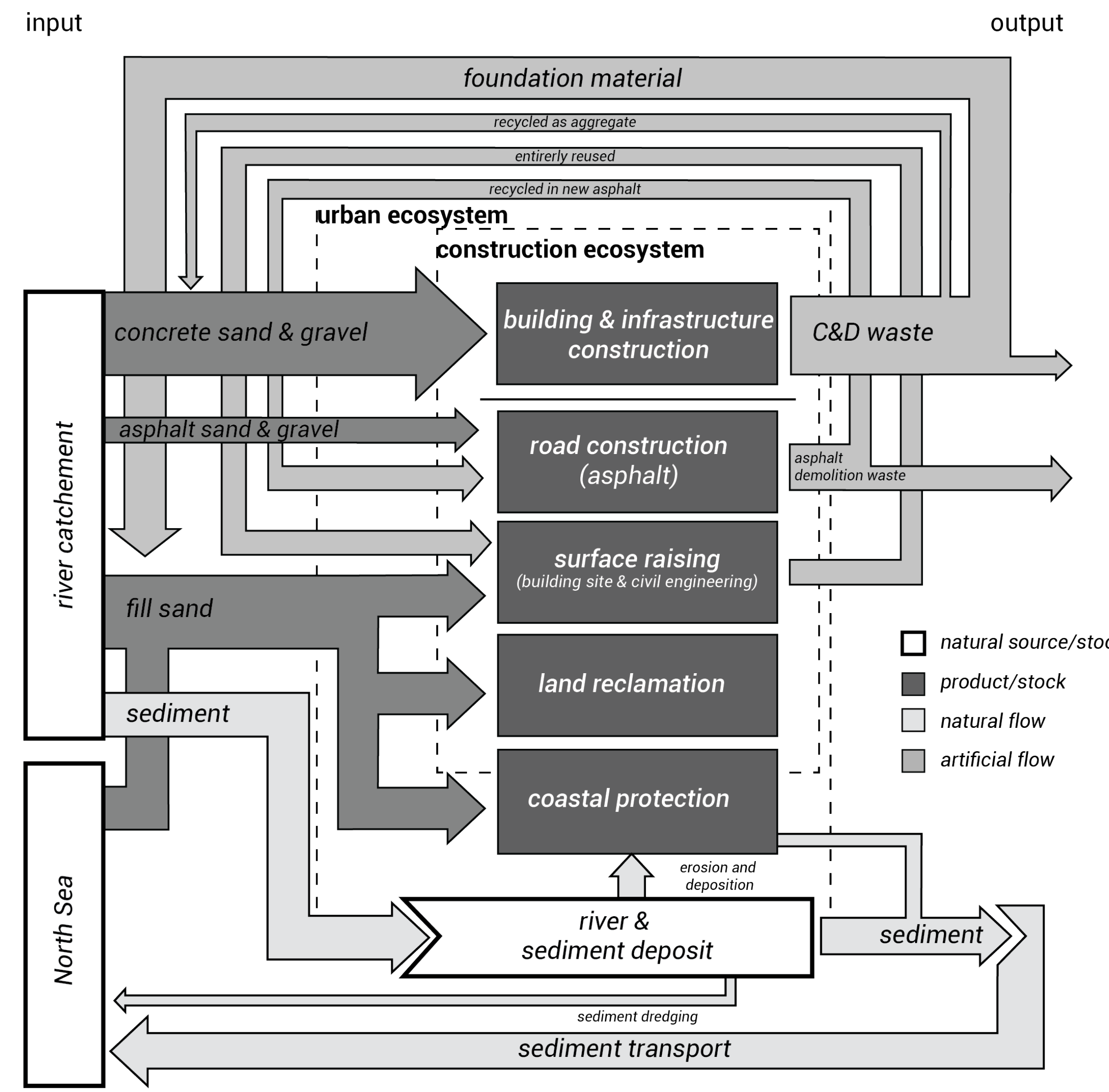


Image 12:

Construction sand and gravel metabolism within the Dutch context.

contaminated during its lifespan (when it is situated under toxic industrial activity). In the Netherlands, contaminated soil needs to be treated and removed by law, after which needs to be deposit (Stichting Kennisontwikkeling Kennisoverdracht Bodem., n.d.). This secure further contamination but it requires clean primary soil for new construction.

The metabolic framework of construction sand and gravel (illustrated in image 12) is constructed around the urban ecosystem and construction ecosystem, similar to the one from Zhang et al. (2018). However, the river ecosystem is part of the urban ecosystem because it crosses through. The framework clarifies the source of sand and gravel (input), the main products in urban construction (products), the destination and flow of waste generation (by-products/output) and their interrelation within the ecosystem. From the model, it can be clarified that the output of C&D waste is depended upon the input capacity and demand, which also results in a continuously growing urban ecosystem in sense of materialisation. Coastal protection is still integrated in the natural system of sediment deposit but is 'fed' by an artificial flow. These events have an impact on the environment which will be discussed in the next part.

3.2.3 Environmental impact

Currently, construction sand and gravel is consumed at a greater rate than its renewal (UNEP, 2014) with significant impact on the environment (Müller, 2006; Kondolf, 1997). The impacts are summarized in table 1. The impacts are not well researched or indicated in every mining location, for example the Netherlands, resulting in insufficient evidence or studies to state that these also occur in the Dutch case.

The report on sand consumption of the UNEP does not take the linear metabolism of the construction into account, which is a contemporary problem and reason for construction ecology and metabolism (Kibert et al., 2000; Zhang et al., 2018). This missing link between consumption in the built environment and recovery of used resources and returning it to natural systems should be added to the environmental impact in order to strengthen and highlight the depletion character of sand and gravel consumption.

Impact on	Description
Biodiversity	Impacts on related ecosystems (for example fisheries)
Land losses	Both inland and coastal through erosion
Hydrological function	Change in water flows, flood regulation and marine currents
Water supply	Through lowering of the water table and pollution
Infrastructures	Damage to bridges, river embankments and coastal infrastructures
Climate	Directly through transport emissions, indirectly through cement production
Landscape	Coastal erosion, changes in deltaic structures, quarries, pollution of rivers
Extreme events	Decline of protection against extreme events (flood, drought, storm surge)

Table 1:
Environmental impacts of sand consumption (UNEP, 2014)

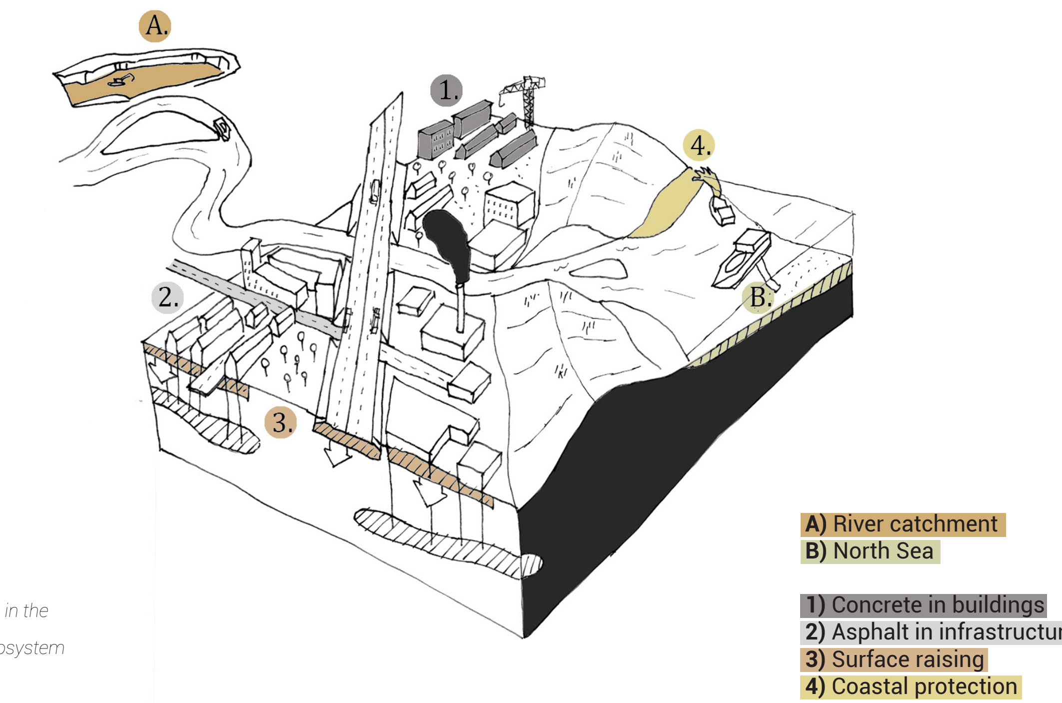
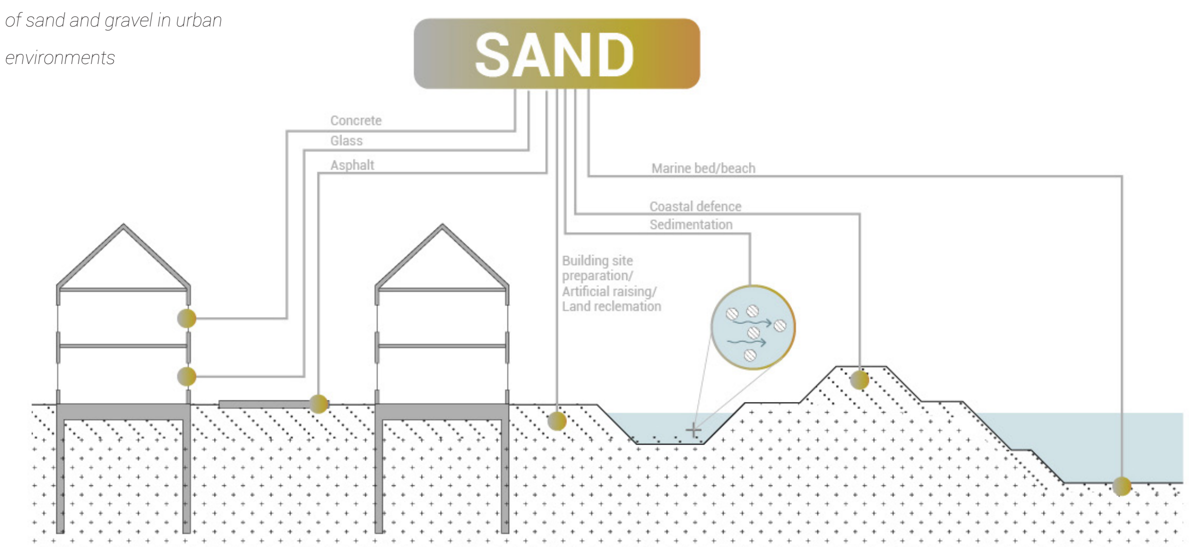


Image 13:
Sand and gravel in the construction ecosystem

Image 14:
Application and integration of sand and gravel in urban environments



3.3 Attributes: Civil engineering

Sand and gravel are natural aggregate formed by rock erosion (Gavriletea, 2017; Kondolf, 1997). The natural aggregate is part of a greater geological rock cycle where sand erodes from mountains and is transported by rivers towards the sea as sedimentary rock. There it deposits and gets transformed by high pressure into metamorphic rock in the Earth's crust. Eventually, metamorphic rock is transformed into igneous rock, which closes the loop on a geological timescale (Copuroglu, 2017). Sand and gravel are composted out of the silicate mineral (silicon dioxide, SiO2) and differ from each other by grain size, with the grain size of sand between 0,063 and 2 mm and gravel between 2 and 63 mm (Zimmermann, 2011). The grain size also defines the application of the mineral, sand for coastal defence and land reclamation and the mix of sand gravel for concrete ('t Hoen, 2017; Zimmermann, 2011).

The natural system of sediment transport still impacts urban ecosystems. Especially in the Dutch delta, rivers flow through urbanised and industrialised areas. Human actions alter these rivers and sediment deposition for maintenance of its ecosystem services, i.e. the transportation of ships (van Veelen et al., 2018).

3.3.1 Application

As described in the previous paragraphs, sand and gravel is applied in several products and constructions. The research focuses on the urban construction where sand and gravel is applied.

Concrete, asphalt, structures and buildings

Sand and gravel are the key ingredients for concrete which is massively applied in modern (building) structures because of its strength and durability (Beiser, 2018; Copuroglu, 2017). Buildings are the biggest consumers of sand and gravel for concrete globally (UNEP, 2016). Asphalt is also a sand and gravel product which is applied on the Dutch roads. The difference between asphalt and concrete is that asphalt is binding material. Bitumen in asphalt and cement in concrete (Beiser, 2018; Copuroglu, 2017).

Building site preparation & land reclamation

In the Netherlands, building site preparation is necessary in order to construct buildings and infrastructure (Hooimeijer, 2014). In several areas, the top layer of soil is clay or peat making it unstable for civil structures. Next to unstable soil is the high water table. By adding sand, buildings and infrastructure can be placed on a strong, stable and permeable surface without (or minimised) seepage. Sand is applied through several methods which differ from integral filling under the entire constructed district to only the infrastructure (Hooimeijer et al., 2016).

Beach nourishment

In order to remain safe from flooding, protection is necessary in the Netherlands. This is done by beach nourishment where sand is mined from the North Sea and applied on the Dutch coastal area or dikes (Prins & Hulsman, 2009).

3.3.2 Durability

A building is developed for a certain period, which is its lifetime or lifespan. The lifespan of a construction is important because it gives information about the flux of the stock. In other words, the lifetime of a construction gives an estimation of when a construction might be demolished and thus a material flow occurs. Its lifetime can also be described as the durability of a building. According to the Standard ISO 15686-1:2011 durability can be defined as: "Durability is the capability of a building or its part to perform its required function over a specified period of time under the influence of the agents anticipated in service" (ISO, 2011). Liu et al. (2014) describes the internal and external key factors (or agents) which influence the buildings lifespan. Internal factors includes physical conditions such as construction/material quality but external factors are location conditions such as distance to CBD (central business district) or political variables as urban planning. The internal and external factors show a distinction between the field of civil engineering, the internal factors and the field of urban planning, external factors.

The internal factors are based on the degradation and performance of the structure, which are designed to remain intact during its lifespan (Bijen, 2003). The degradation (or aging) is influenced by factors such as climate which happen during the lifetime of the construction. Without interventions such as maintenance, rapid loss of value will occur which causes failures or conditions which do not meet the threshold of the utility (e.g. usability, safety) (König, Kohler, Kreissig, & Lützkendorf, 2010).When talking about durability of a engineered structure, components should be taken into account because each component has its own lifespan (Bijen, 2003). Brand (1994) described the lifespan of each component in a building. Components such as its service (function) or space plan have a shorter life span then its structure. The site (foundation) where the construction stands on has an unknown or even infinite lifespan. Good to mention is that sand and gravel is applied in the latter two components, for concrete or site raising.

The external factor in durability is harder to estimate (in the design phase in particular) because it is influenced by unforeseen events. According to Heeling et al. (2002) a good urban design and fabric needs to be durable, thus flexible, in order to adapt to future changes. In this period, changes such as lifestyle or population changes and even hazards affect the durability of a construction.

The durability can be measured and estimated by its internal conditions (construction year, material characteristics) but also needs to take external factors into accounts. The latter are more based on events or prognoses (change in lifestyle or increase of population) which are more difficult to validate. However, the real lifespan of a product is based on the status of the product, not the technical estimated lifespan (Allwood et al., 2011).

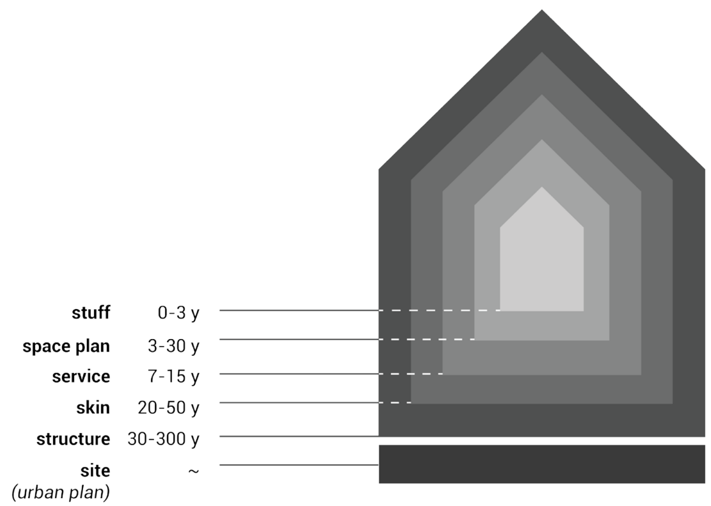


Image 15:
Lifespan of building components (Brand, 1994)

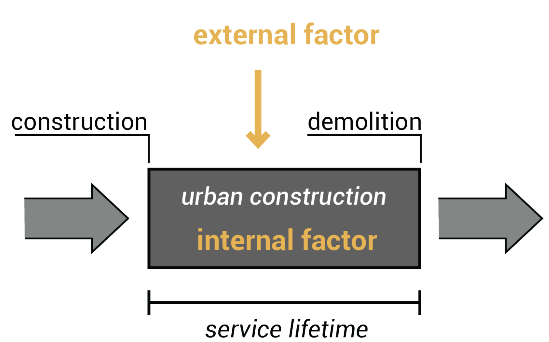


Image 16:
Factors influencing the service lifetime of urban construction

3.4 Process: Urban design

The discipline and concerns of/in urbanism can be describes in the 'layers' of urban design; usage, buildings, public space, urban composition and territory (Heeling et al., 2002). Furthermore, urban design does not have clear boundaries between spatial planning, (landscape) architecture or civil engineering, resulting in an interdisciplinary domain.

3.4.1 Material choice

The material choice in area development is the core choice in materialising the new district. These choices distinguish neighbourhoods from one place to another and manages to stand for quite a time. These two aspects can be describes as characteristic/legibility and durability.

In urban design, durability of the urban design is not done by materialisation but composition of the urban plan (Heeling et al., 2002). Characteristic is done in urban design by materialisation. It determines the function of a certain element (asphalt for road), legibility for orientation or quality/exclusiveness (Meyer et al., 2006).The materialisation is related to the (architectural) image the urban designer wants to create in the design. The material choice becomes more critical in the design on a smaller, more specific level of detail, such as constructions in architecture or civil engineering. These disciplines determine which materials are necessary for the intended function.

Within the urban planning profession, there is an acknowledgement which integrate the site selection into design, 'situation-conscious' site selection. Urban designers with this tendency integrate an accurate analysis of the soil conditions and water situation, which is linked with the building site preparation, in their planning (Jong, 2008).

3.4.2 Development process

The concept of urban metabolism makes the analogy of the city as an organism. This means that cities have certain activities which causes in- and outflow of materials. In the construction sand and gravel metabolism, these urban activities are related to the construction of buildings and infrastructure, also urban development. These urban development are caused, as described before, by different factors such as policy change or population growth. The population growth is related to urbanisation of cities. Urbanisation is the trend when people move towards urban areas so the urban population increases (Daniels & Sidaway, 2012). This urbanisation causes urban development for housing construction, thus materialisation. Ferrão & Fernandez (2013) described the process of urbanisation according to how material is mobilised, processed and placed for the populations need. At the origin of a city, materialisation occurs for the construction of buildings and infrastructure. At a certain level the materialisation decrease but this does not means that the materialisation (thus inflow) stops because the stock requires input for maintenance. Also densification within the urban boundaries can occur. Eventually, a city will reach a satisfied level where only maintenance of the current stock is required. In their description, Ferrão & Fernandez also suggest the stage and transition towards 'sociometabolism' where a solar economy is realised and material loops are closed.

3.4.3 Rhythm of the city

Durability can also be distinguished on a greater spatial scale, such as the city. Within the field of urbanism, the concept of durability can be found within the Dutch layer approach, constructed by De Hoog, Sijmons and Verschuuren (van Schaick & Klaasen, 2011). This approach divides the (Dutch) landscape in three layers of spatial organisation based on their different 'time' aspect within the urban dynamics. These layers are, from bottom to top; substratum, networks and occupation pattern with respectively the durability of 100 to 500 years, 50 to 100 years and 25 to 50 years (Hagens, 2006). This concept is quite abstract but it gives an idea of the distinction and different dynamics within the urban environment and how they influence each other.

The layer approach has been an inspiration within the (Dutch) urbanism discipline. Heeling et al. (2002) described the discipline of urban design with a five layer scheme consisting of, from bottom to top; territory, urban composition, public space, buildings and usage. This division does not states autonomous categories, but stimulates the relation between elements and disciplines. The layers also sets the requirements or conditions for the other, for example the territory influences the building and occupation possibilities. The urban composition layer is an important one in both urban design profession as practical transformation process. Heeling et al. (2002) describes the urban composition as "the map of the territorial organisation of a territory for the purpose of housing, majorly humans, and other human activity". The essence of the urban plan can be translated in the relation between the lower and upper layer; the transformation of the territory towards the usage of housing and other human activities. This transformation is the materialisation of the urban composition into physical public space and buildings which is related to other disciplines such as architecture or civil engineering (to make the territory buildable through building site preparation).

A durable urban composition is a flexible design that is capable of transformation and alteration in the upper layers, for example change in buildings through demolition and construction. This strength of the urban composition can be seen in the grid design of Manhattan, New York. The urban composition is also hard to change

because the boundaries of ownership are established by law. This flexibility and durability of a urban composition or urbanism is recently translated into several design philosophy such as the flexible city (Bergevoet & Tuijl, 2016) and the spontaneous city (Broekmans, Urhahn, & Urhahn Urban Design, 2011). This later philosophy integrates the different rhythm of the city, as visualised on image 17. This rhythm relates to the lifespan of building components by Brandt (1994).

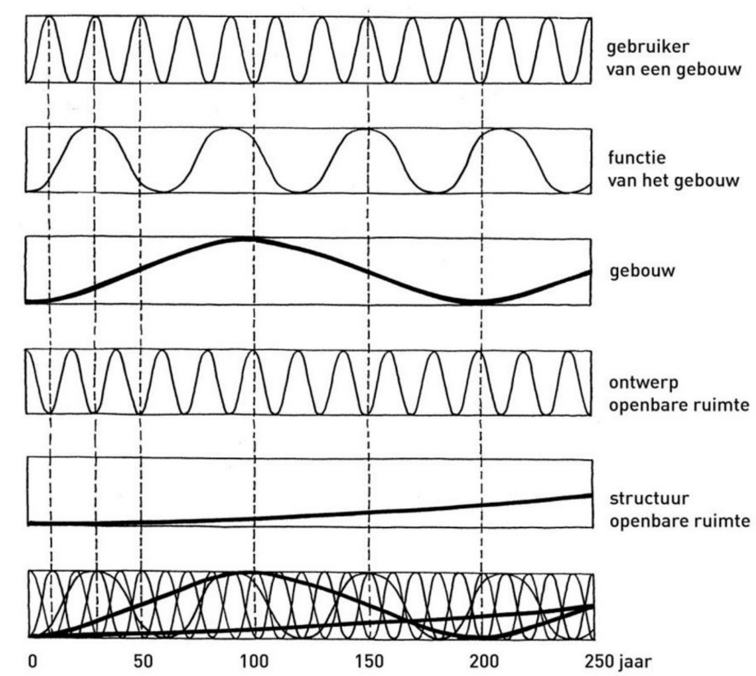


Image 17:
Rhythm of a city (Urhahn, n.d.)

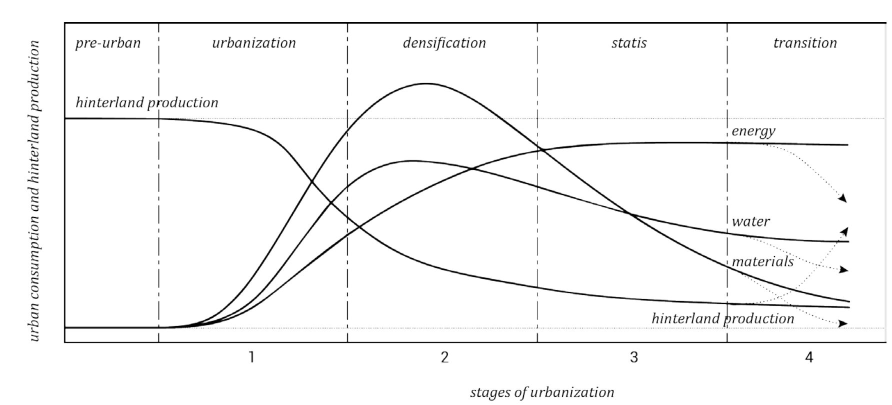


Image 18:
Materialisation and urbanisation
(Ferrão & Fernandez, 2013)

3.5 Conclusion: The unconscious relation

The theoretical framework defines the key concepts and theory of the research project. This framework is integrated in the entire project, as explained in the methodological framework later on. The sub questions related to the theoretical framework are: ***'what is the material flow of construction sand and gravel?'*** and ***'how are sand and gravel integrated in the urban ecosystem?'***

The material flow of construction sand and gravel can be explained according the concept of urban metabolism, which explains how materials flow and are consumed in urban environments. Construction sand and gravel are part of the construction metabolism because they are integrated within urban constructions such as concrete building structures or site raising. The material flow (in the Dutch context) is summarised in the metabolic framework for sand and gravel and illustrated in image 12. Overall, sand and gravel are applied in a linear and end-of-life way, which sustains its high demand as a new construction material in the current construction ecosystem. On the one hand, construction sand and gravel are completely extracted from their natural ecosystems because the absence of return flows to the natural system due to relocation of deposits for building site preparation, and the manufacturing and downcycling of concrete. On the other hand, construction sand is still part of its natural system in beach nourishment where it is applied in order to maintain the natural coastal defence.

The integration of sand and gravel in the urban ecosystem is also illustrated in the metabolic framework. It is the key ingredient for urban constructions where it contributes to the durability, accessibility and safety of the urban environment. The consumption of the material within the urban ecosystem can be clarified by the notion of durability. The durability relates to internal and external factors which influences the flux of the stock. In other words, these factors drive the metabolism and consumption of sand and gravel. Urbanisation is an important driver which results in material consumption of sand and gravel. Urbanisation results in urban designs which is the transformation of a territory for the purpose of housing and other human activities. Continuing on the field of civil engineering, the durability of urban design is primary determined by external factors. On the first place because a urban plan is just a composition without physical features (the features are the products based on the urban design; buildings (sites), streets, parks etc.). Secondly, the development dynamics are unforeseen events such as policy or climate change, which affect the products and condition of the urban design.

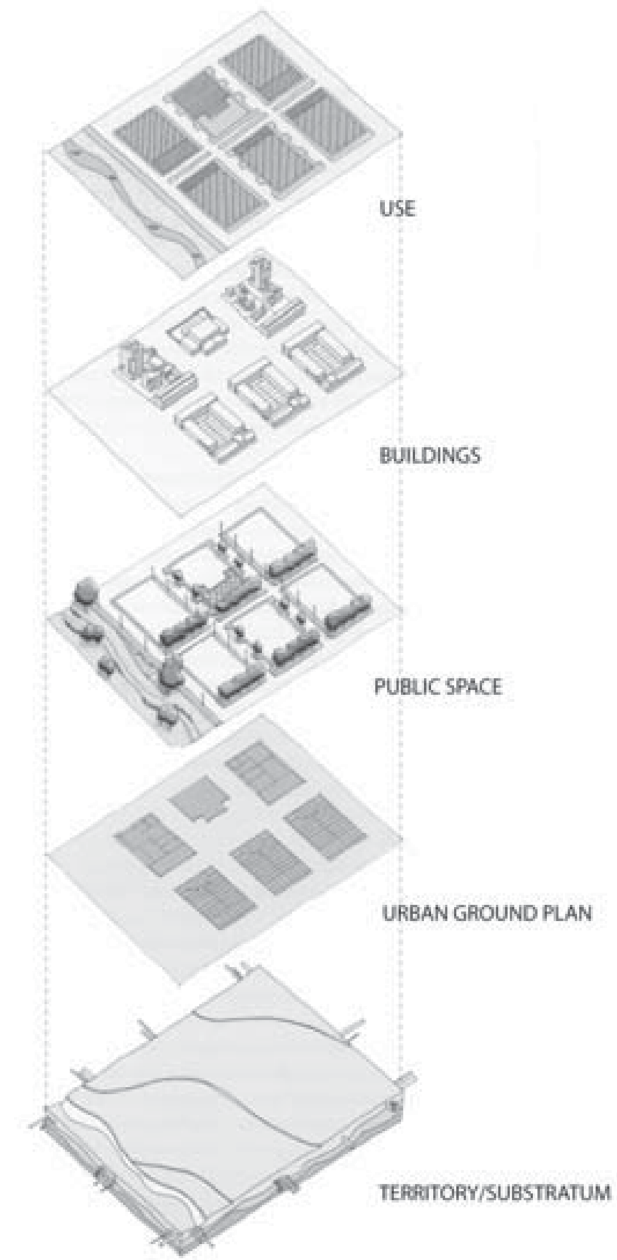


Image 19:
The layers of urban design
(Heeling et al., 2002)

What can design do?

4. Research question and objectives

How can urban design reduce the consumption of primary construction sand and gravel in the construction ecosystem of the RIjnmond-Drechsteden region?

Source: Rijkswaterstaat, 2009

The project tackles the problems related to the construction metabolism, material choice and impact, and urban design. It is stated that construction activities are still relying on its crucial, but also finite resource sand with significant environmental impacts, which is deeply integrated in the construction of the urban landscape. Next to this reliance on finite resources is the linear construction process where sand is related to. Furthermore, there is also the absence of material choice and accompanied impact in the profession of urban design. The profession of urban design is criticized from an urban metabolic and environmental impact perspective in order to design circular constructed and low-impact urban environments. This perspective goes in the same direction as the ambition of European cities, such as the Resource Agreement of the Dutch Government.

The construction and demolition systems of the urban metabolic framework will be analysed and a new system with accompanied spatial and environmental consequences will be proposed in order to answer the following research question:

"How can **urban design** reduce the **consumption of primary construction sand and gravel** in the **construction ecosystem** of the Rijnmond-Drechtsteden region?"

4.1 Research aim

The research aims to find ways to reduce the demand of new sand in urban design. This aim is an approach towards a sand-sensitive urban design. The reduced use of sand and gravel is part of a construction metabolism which is less dependent on finite natural resources and more on circular, recycled methods or renewable materials. For the location of the RMDS region, the project aims to understand the integral sand flow and balance through sedimentation and 'status quos' of dredging, sand mining and construction metabolism.

4.2 Scientific relevance

Urban consumption is part of urban design in sense of processes it drives. However, the notion of consumption and the skills to reduce the consumption is missing in the current discipline. And also is the lack of construction metabolism is currently underexposed in urban metabolism studies. This is notable because the construction sector is the largest consumer.

The area consists of the following municipalities, based on the conurbation of the CBS in the Rhine-Meuse estuary:

Rijnmond region

- *Albrandswaard*
- *Barendrecht*
- *Brielle*
- *Capelle aan den IJssel*
- *Hellevoetsluis*
- *Krimpen aan den IJssel*
- *Maassluis*
- *Nissewaard*
- *Ridderkerk*
- *Rotterdam*
- *Schiedam*
- *Vlaardingen*
- *Westvoorne*

Drechtsteden region

- *Alblasserdam*
- *Dordrecht*
- *Hardinxveld-Giessendam*
- *Hendrik-Ido-Ambacht*
- *Papendrecht*
- *Sliedrecht*
- *Zwijndrecht*

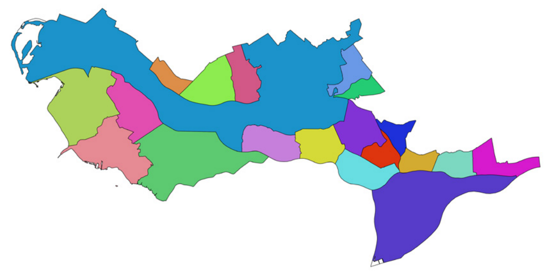


Image 20 (left):

Municipalities in the RMDS region

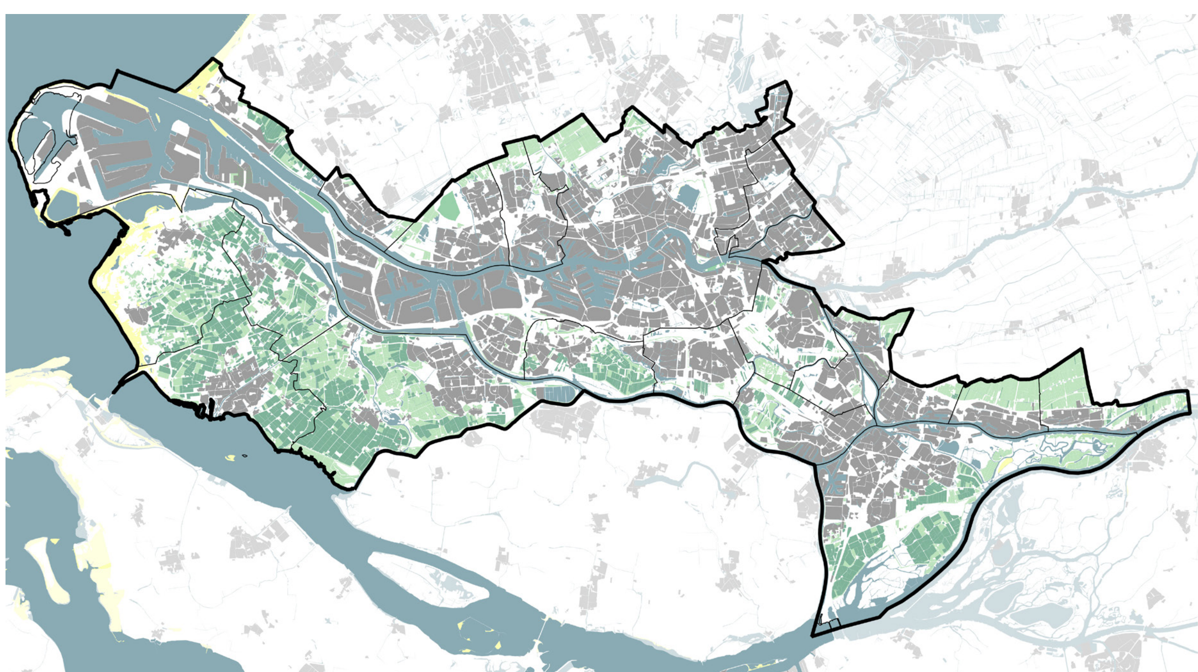


Image 21 (left):

Map of the RMDS region

4.3 Social relevance

As mentioned in the introduction, resource reduction is part of a global challenge to become more circular and less dependent on primary resources. The Netherlands is currently aiming for a 100% circular economy in 2050. The construction sector is taking a large share in the consumption but the sector is also extremely conservative (Kibert et al., 2000), which, related to other sectors, means that innovation does not develop quickly due to regulation and liability. In order to meet the circular ambitions, insights in the consumption of sand and gravel and new design solutions will help the society in the achievement of the challenge.

4.4 Ethical considerations

In1987 the Brundtland report 'Our Common Future' was published focussing on our current and prospected direction in consumption and development (World Commission on Environment and Development, 1987). They thrive for a sustainable development where sustainability is defined as: *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"*. The current resource depletion of finite resource, oil, gas but also minerals such as sand and gravel, is disabling the future generations to meet their needs with the same changes and opportunity as we currently do, creating inequality. Although sand and gravel is transformed into durable construction, the ability of reusing the minerals is, given current technology, lacking or difficult after its life-span.

As stated in the problem description, our urban construction is linked with resource depletion. This resource depletion is causing environmental impact such as harming the natural ecosystem and damaging natural flood protection (UNEP, 2014). Our method of design and construction is neglecting this impact and integrating this knowledge could result in less impact on the environment and its effected population.

A Sand-Sensitive experiment

5. Methodological Framework

This chapter explains which methods are chosen and why. The choice of method is linked to the problem statement, aim and objective This link is translated in the multiple research (sub)questions. An explanation will be given why this method is suitable and which limitations the research considers. These explanations and consideration are summarized and visually explained in the conceptual framework graph.

Source: Wikipedia, 2005

The aim of the research is to reduce the consumption of construction sand and gravel through urban design in the construction ecosystem in the RMDS region. This aim can be specified into the following objectives:

(1) Improve the sand and gravel metabolic balance in the RMDS region by minimising the consumption

(2) Clarify the drivers behind the construction sand and gravel in order to understand its ecosystem

(3) Improve the metabolic balance by applying solutions in spatial and urban planning which requires less primary sand and gravel.

(4) Develop an approach in urban design where material impact and application is better exposed in the design process.

The objectives are related to each other as each objective underpins or elaborates on the previous one. Objective four needs to be achieved in order to reach objective three, three for two and so on. This objective narrative already gives an insight in the research process and method. In order to clarify this, the research questions are restated and linked with a method.

5.1 Research questions

The related research question is:

"How can **urban design** reduce the **consumption of primary construction sand and gravel** in the **construction ecosystem** of the Rijnmond-Drechtsteden region?"

The research question relates to three main topics in the project; ***urban design, consumption of primary construction sand and gravel*** and ***construction ecosystem***. Each topic is related to sub-questions and methods in order to reach the objectives.

1. What is the construction sand and gravel metabolism of RMDS region until 2040?

This sub-question focuses on both the ***consumption of primary construction sand and gravel*** and the ***construction ecosystem***. These topics are the core in the theory of the research, which is explained in the theoretical framework. The consumption of primary construction sand and gravel in the construction ecosystem impacts the environment negatively due to resource depletion and damaging the natural ecosystems (UNEP, 2014). By clarifying the construction sand and gravel metabolism of the RMDS region, the consumption patterns and drivers will be visible. The urban metabolism of a certain region and/or material can be made visible with the material flow analysis (MFA). The MFA is a key instrument in order to understand the urban metabolism (Decker, Elliott, Smith, Blake, & Rowland, 2000; C. A. Kennedy et al., 2015; Newell & Cousins, 2015; Niza, Rosado, & Ferrão, 2009). The MFA both includes systematic as geographical representation of the RMDS region.

The patterns and drivers of the urban construction consumption include the future urban construction and demolition activities for the region but also the life-cycle of the integrated construction sand and gravel. This is partly explained in the theoretical framework where a metabolic framework was constructed for urban construction sand and gravel in the Netherlands (see image 12).

The construction sand and gravel metabolism is constructed for C&D activities in the RMDS region from now until 2040. This mean that this metabolism will be based on assumptions and projected trends in the region which will result in a scenario.
In order to answer this sub question, the following questions need to be tackled which will result in the construction sand and gravel metabolism for the case study area:

a. *What is the material flow of sand and gravel in the RMDS region?*
b. *How is sand and gravel integrated in the urban construction of the urban landscape of the RMDS region?*
c. *What is the construction and demolition ecosystem of the RMDS region?*
d. *Where will sand be available and required in the near future of the RMDS region?*
e. *What are drivers and trends in the C&D ecosystem of the RMDS region?*

2. What is the impact of the construction sand metabolism of RMDS region until 2040?

The construction sand and gravel metabolism has a certain impact on the environment. This is also one of the motivations of this research. However, the analysis of the characteristics of the construction sand and gravel metabolism is not providing the information about this environmental impact. By linking the MFA of the researched metabolism with environmental impact, a Life-Cycle Assessment (LCA) will be achieved. This will eventually be concluded in an environmentally understanding of the envisioned perspective of the construction ecosystem of the region.

3. How can urban design improve the materialization consumption and impact of construction sand and gravel?

Currently, urban design does not integrate the choice of material and its related quality in its process. However, the product of urban design, i.e. urban development of new neighbourhoods, are the main drivers of the C&D activities and the related ecosystem/metabolism. In order to design cities which consume less sand and gravel, an approach should be embraced which integrates the material choice in urban design. This approach will result in new solutions for so-called 'sand-sensitive methods' for urban design practice. These are collected in the Catalogue of Solutions, which will be used in the continuation of the research. Related questions in this section are:

a. *How can materialisation and impact be integrated in the urban design process?*
b. *What are the alternatives for sand in the construction of the urban landscape?*
c. *How can sand sensitive methods be translated into spatial solutions?*

4. How can the sand and gravel metabolism of RMDS region be improved?

This sub-question is the crux of the research where the three topics will be combined. The developed Catalogue of Solutions will be applied to the construction sand and gravel metabolism of the RMDS region in order to reduce the consumption of primary material. The LCA will be applied here as well in order to evaluate the impact of new scenarios and designs.

a. *How can the sand sensitive solutions be implemented in urban development projects of the RMDS region?*
b. *What is the impact of the new urban designs for the RMDS region?*

5.2 Expected outcomes

The research aims to reduce sand and gravel consumption in the RMDS region through urban design. This means that the final outcome is a scenario and an urban design with related system change. In order to develop these products, the system of construction sand and gravel ecosystem of the case study needs be understood. This system is visualised through the MFA which results in a flow diagram as displayed in image 12. The system is based on an analysis and scenario of the current construction metabolism and its C&D activities of the RMDS region until 2040. The MFA is input for the LCA which results in a conclusion of the environmental impact in graphs and data. The flow diagram of the MFA, which represents the system, can eventually be improved in order to meet the objective and research aim. The improvement is done with input from a developed Catalogue of Solutions which is a documentation of the sand-sensitive spatial methods. The improvement is the same scenario format as resulted from the analysis but different improvement methods will alter the possibilities into several scenarios which are the result of alteration in the sand system. As an (hypothetical) example: in order to eliminate input for fill sand for land raising and building site preparation, all new constructions will happen exclusively in the already built areas by densification. These alterations relate to urban design results and project. This product will eventually prove how (or if) urban design can reduce the consumption of primary urban construction sand and gravel in the RMDS region.

The conceptual framework will elaborate on the product per sub-question and method.

5.3 Conceptual framework

TThe thesis is a quantitative research with a qualitative outcomes in terms of urban design. The quantitative aspect is typical for studies on urban metabolism. The research follows a systematic approach where first the current situation (scenario) and perspective will be evaluated with a LCA, improvement will be sought on deductive and inductive level which eventually will be applied on the situation (scenario) in concrete solutions (urban design) in order to improve the future perspective environmentally. This approach seems to be a typical engineering method of optimising current systems. However, the measure which need to be taken in order to improve the system are unknown and the objective is not indisputably making it an experiment, which is the core of the design discipline (van de Ven, 2016). This makes the research an interdisciplinary project where systematic thinking from civil engineering or industrial ecology (the LCA and MFA) is combined with urban design problems and processes.

The conceptual framework (see image 22) can be divided in two parts, which are both assessed with the LCA; the analysis of the current situation and research by design. In the conceptual framework the process for gathering, analysing and interpreting data and approaching of the research question will be explained. This explanation is divided according to the division of the conceptual framework.

Analysing the current situation

The first part focuses primarily on the research questions; ***'What is the construction sand and gravel metabolism of the RMDS region until 2040?'*** and ***'What is the impact of the construction sand and gravel metabolism of the RMDS region until 2040?'*** The part also introduces the question of ***'How can urban design improve the materialization consumption and impact of construction sand and gravel?'*** but this is one which stretch over the two parts. The main objective in the first part is: ***(2)*** Clarify the drivers behind the construction sand and gravel in order to understand its ecosystem.

The current situation is the status quo of the construction ecosystem in the RMDS region. This ecosystem consist of construction and demolition activities which drive the urban construction sand and gravel metabolism. These drivers are the process (system) and stocks which needs to be analysed. This analysis will underpin the scenario of the sand and gravel consumption in the region until 2040. This scenario can be assessed to a LCA. In order to fully execute the LCA, several actions need to be undertaken, which are;

1. *An analysis of the current material flow of construction sand and gravel (system flows)*
2. *An analysis of the processes driving the construction and demolition activities and its demands*
3. *An analysis of the current stocks of sand and gravel in the region*

These three actions will support the understanding of the sand and gravel metabolism because it is based on the MFA method, which eventually supports the LCA. Each action is explained separately with the related method and why it is chosen.

Action 1: An analysis of the current material flow of construction sand and gravel

In order to understand the processes related to urban metabolism, a material flow analysis (MFA) is a key method for the analysis (Decker et al., 2000; C. A. Kennedy et al., 2015; Newell & Cousins, 2015; Niza et al., 2009). Urban metabolism is also defined by Kennedy et al. (2007)as ***"the sum total of technical and socioeconomic processes that occur in cities, resulting in growth, production of energy and elimination of waste"*** what refers to understanding and visualising the processes in

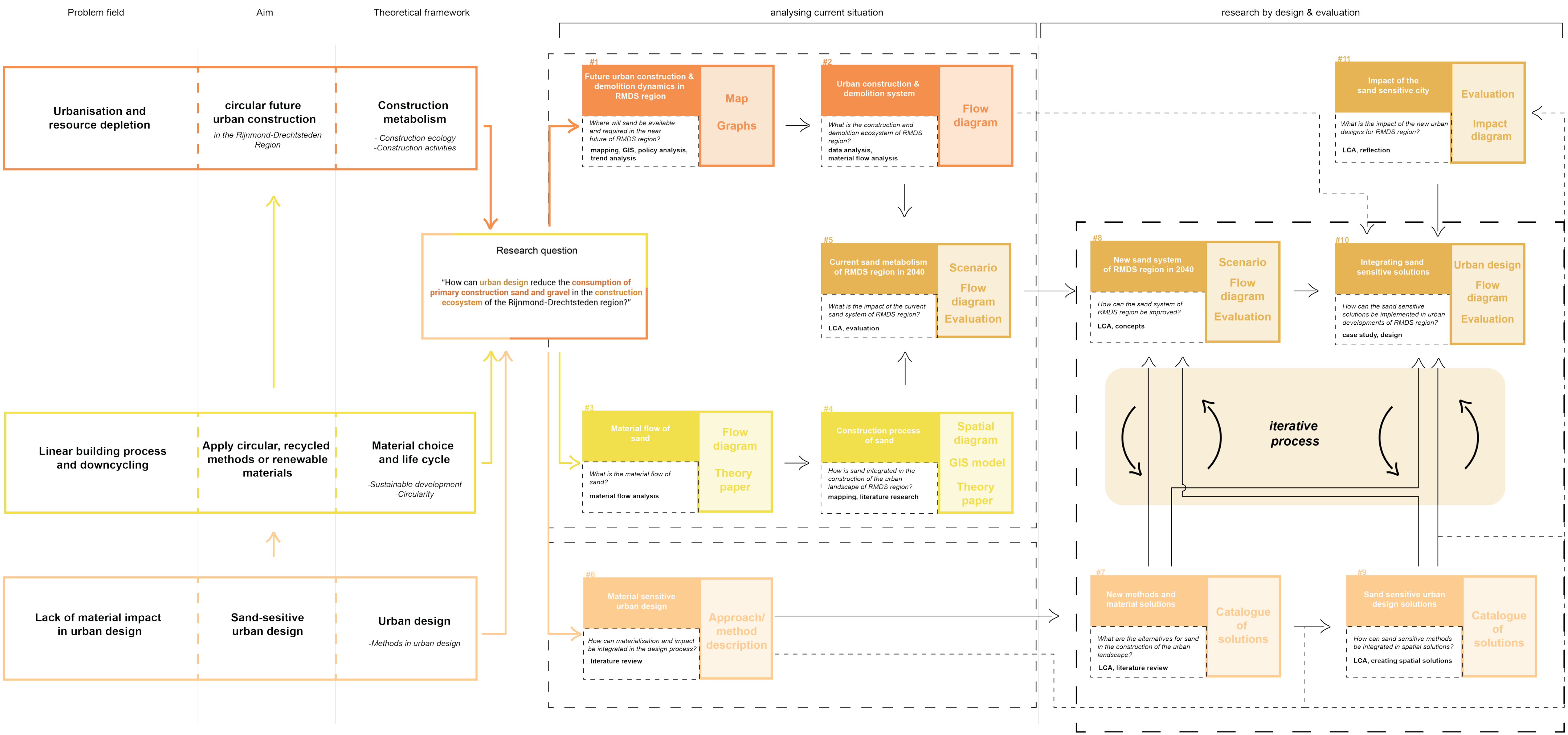


Image 22:

Conceptual Framework

cities. The MFA is ***"a systematic assessment of the flows and stocks of materials within a system defined in space and time"*** (Brunner & Rechberger, 2017). The MFA can be seen as an input-output model which, in this case, shows which materials flows into the regions system and what it materialises but also which material flows out of the system as waste or be recycled. The core of urban metabolism studies is to eventually minimise the metabolic footprint by reducing the in- and outflow, which needs a clear understanding of the material flow.

A MFA needs certain defined limits in order to execute the analysis, a topic (material), a certain space (region) and time. The material which is analysed in this research is the construction material sand and gravel for urban construction. The space is the Rijnmond-Drechtsteden (RMDS) region. This specific location is chosen because of its prospected construction activities, circular ambitions and sedimentation situation in the delta. The RMDS region is the most urban area in the estuary. The region is spatially bordered by rivers and political boundaries. The time is from 2018 until 2040, which means it is a forecast of the future urban constructions in the RMDS region. 2040 is the timeframe for the housing demand.

The MFA in the research consist of two levels, the theoretical part and location-specific part. The theoretical part focus on what the general the flow is of sand and gravel and which 'stocks' it relates to. This is done in the theoretical framework by a literature review and documented in the theory paper and answers the questions ***'what is the material flow of construction sand and gravel?'*** and '***how is sand and gravel integrated in the urban ecosystem?'***. The theoretical part visualises the quality part of the material flow. After reviewing the theoretical part of the material flow, the metabolism framework of sand and gravel is applied on the location by the quantity of construction sand and gravel in the system. However, the location-specific MFA needs input from the other two actions.

Action 2: An analysis of the processes driving the construction and demolition activities and its demands

The thesis researches the construction and demolition activities which will happen until 2040, which means that it is a forecast of 'possible' development; stock dynamic model and policy review. The stock dynamic model (Müller, 2006) is an extension of the MFA but it includes trends, such as population or lifestyle change which alter the stock in the model (see fig.) It actually describes the lifespan and durability of the stock and when it will be grow, renovated or demolished. The stock dynamic model is very general and theoretical which would create a distorted and unrealistic view of the region when it is applied theoretically. This is why the policy review is integrated in the stock dynamic model. Policies of the government give information about why stock changes will be made, for example energy model, which stock will not be demolished, heritage policy, or which areas are indicated as development areas. This will enrich the model but also maps the activities in the region. The entire stock dynamic model will visualise the demand and supply of the construction sand and gravel in the region.

Forecasting future development is always based on assumptions which makes this part disputable. By making use of a transparent model which is linked with the MFA study, alterations in the detail of numbers or changes in policy can be integrated when updating the model. The research will clarify the level of certainty of the variables used in the model

Action 3: An analysis of the current stocks of sand and gravel in the region

The analysis of the construction and demolition activities does not immediately supports the MFA and scenario of the construction metabolism in the RMDS region. The drivers and activities need to be translated into numbers (quantified) of how much sand is needed for construction and how much will become available from demolition. This method is based on the quantification of material intensity in the built environment by Stephen & Athanassiadis (2017) and the PUMA (Prospecting the Urban Mines of Amsterdam) by the AMS (2017) as explained in image 24. This is an advanced mapping method with Geographical Information System (GIS) where the stock of sand and gravel will be geographically visualised. The method focus on the sand and gravel in urban construction which are related to different scales. Sand in beach nourishment and sedimentation on regional level, sand and gravel for roads and building site preparation on district level and sand and gravel in building construction on building level. The model will integrate trends (from the stock dynamic model) and data from GIS (e.g. construction year) which will result in a geographically representation of the construction activities. The material intensity is based on a database from the TU Delft of material per square meter determined per archetype. This archetype can be assumed from GIS data such as function, construction year and height. By combining this data, the material of sand and gravel can be estimated per building. For district level, material intensity can be based on building site method, road construction and subsidence pace, which is related to maintenance regimes for site raising and sand input. This information is direct input for the MFA model of construction sand and gravel of action 1. By integrating this model with the stock dynamic model, a scenario can be developed for the construction metabolism in the RMDS region until 2040.

Life Cycle Assessment

The MFA itself only describes the system, not the impact on the environment which is essential in order to understand the consumption of the sand and gravel. That is why the Life-Cycle Assessment (LCA) is applied which will review the MFA from cradle-to-grave. The LCA assess the entire life cycle of a product or material and its impact on the environment. The LCA consist of four steps: 1. goal and scope/ definition, 2. inventory analysis, 3. impact assessment and 4. interpretation (NEN, 2013). The LCA is not completely qualitatively assessed but used as a tool to identify changes within the lifecycle of the ecosystem and its related stock. This evaluation is done by interpreting the scheme of the lifecycle stages and modules for the building assessment according to the NEN-EN 15804:2012+A1, see image 23. By using this tool, a notion to the environmental impact can be done and the study is transparent for the quantitative assessment.

Material sensitive design approach

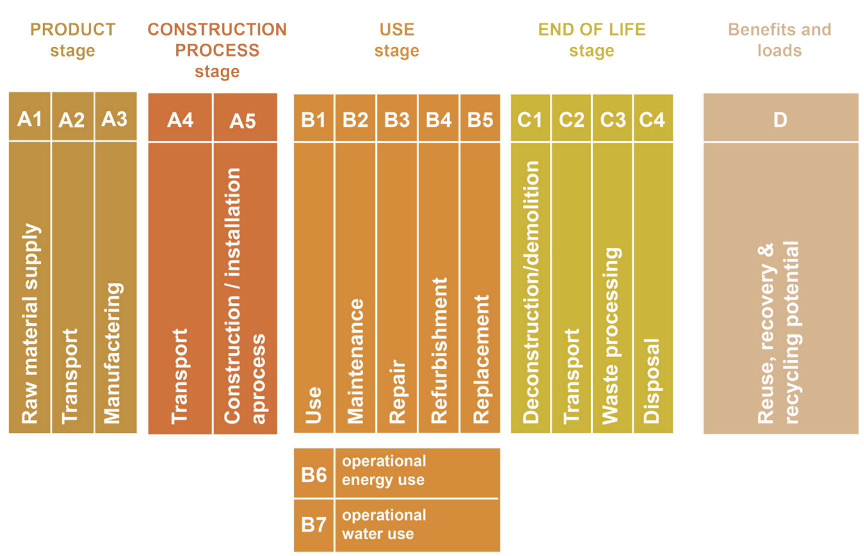
The hypothesis of the research is that urban design can reduce the material consumption of primary sand and gravel but that material choice is not integrated in the design process. The objective is ***(3)*** Improve the metabolic balance by applying solutions in spatial and urban planning which requires less primary sand and gravel and ***(4)*** Develop an approach in urban design where material impact and application

Image 23

NEN-EN 15804:2012+A1

LCA scheme

(based on NEN, 2013)



Mapping the current sand stock

based on Stephen & Athanassiadis 2017, AMS-PUMA 2017

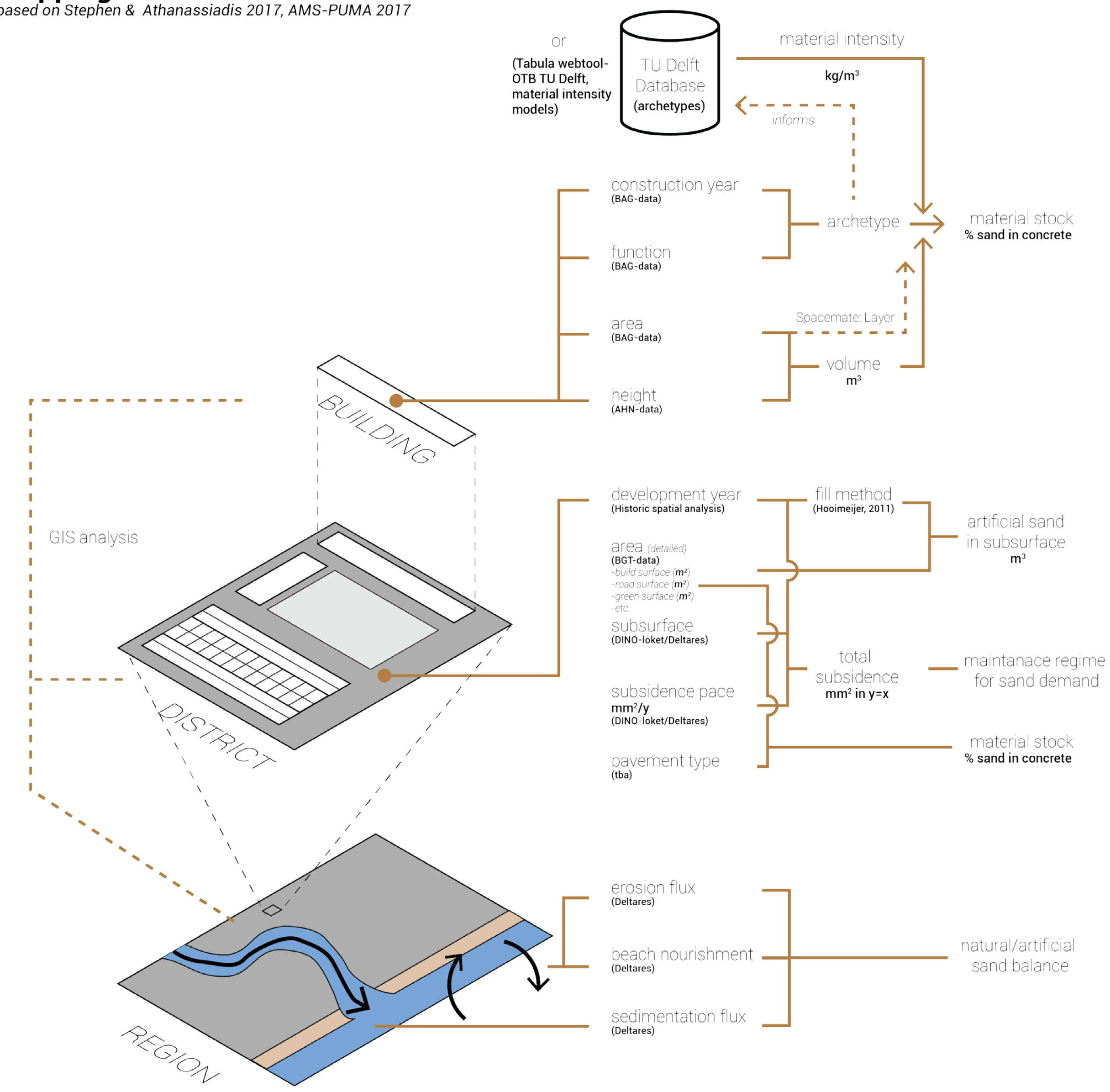


Image 24

Material intensity method

is better exposed in the design process. It is structured by the research question ***'How can urban design improve the material consumption and impact of construction sand and gravel?'***. The problem is tackled by two approaches; a literature review on material choice in design process and the development of material sensitive design solutions. The literature review will evaluate and criticise the current design process in urban design but will also clarify the quality part of the design discipline. Optimisation might ignore quality and focus on quantity but in design, quantity and quality is combined which is necessary for the research to prevent technocratic futures only based on resource reduction. For this reason, material choice from reviewed literature or best practice will be applied in order to develop an approach for material sensitive design.

The material sensitive approach will be joined with a catalogue of solutions where designs which reduce sand and gravel demands are collected. The development of the catalogue of solutions is based on several factors which can be linked with the scenario and MFA, such as application or material source. The solutions also are applicable for the LCA in order to review the improvement.

Research by design

The first part clarifies the current situation and forecast of the construction metabolism in the RMDS region until 2040. The LCA result in a certain environmental impact which needs to be improved. The second part will improve the construction metabolism via research by design. This research by design is closely linked with the LCA of the material flow which will function as an assessment for improvement. The research by design is executed on two scales; regional and district. The regional scale is linked with the scenario and MFA conducted in the first part. This situation will be improved with solutions from the material sensitive design approach or other conclusions derived from the analysis. The improvements are applied on system level and spatial level resulting in a new scenario(s). The new scenario is assessed with a LCA in order to evaluate the improvement. Simultaneously, research by design is applied on district scale where the material sensitive design solution is applied on specific cases. The different scale can feed each other with new insight or solution which eventually will reduce the resource consumption whereas the design aspect will guard the quality aspect in the projects and eventually answers the main research question: ***"how can urban design reduce the consumption of primary construction sand and gravel in the construction ecosystem of the Rijnmond-Drechtsteden region?"***.

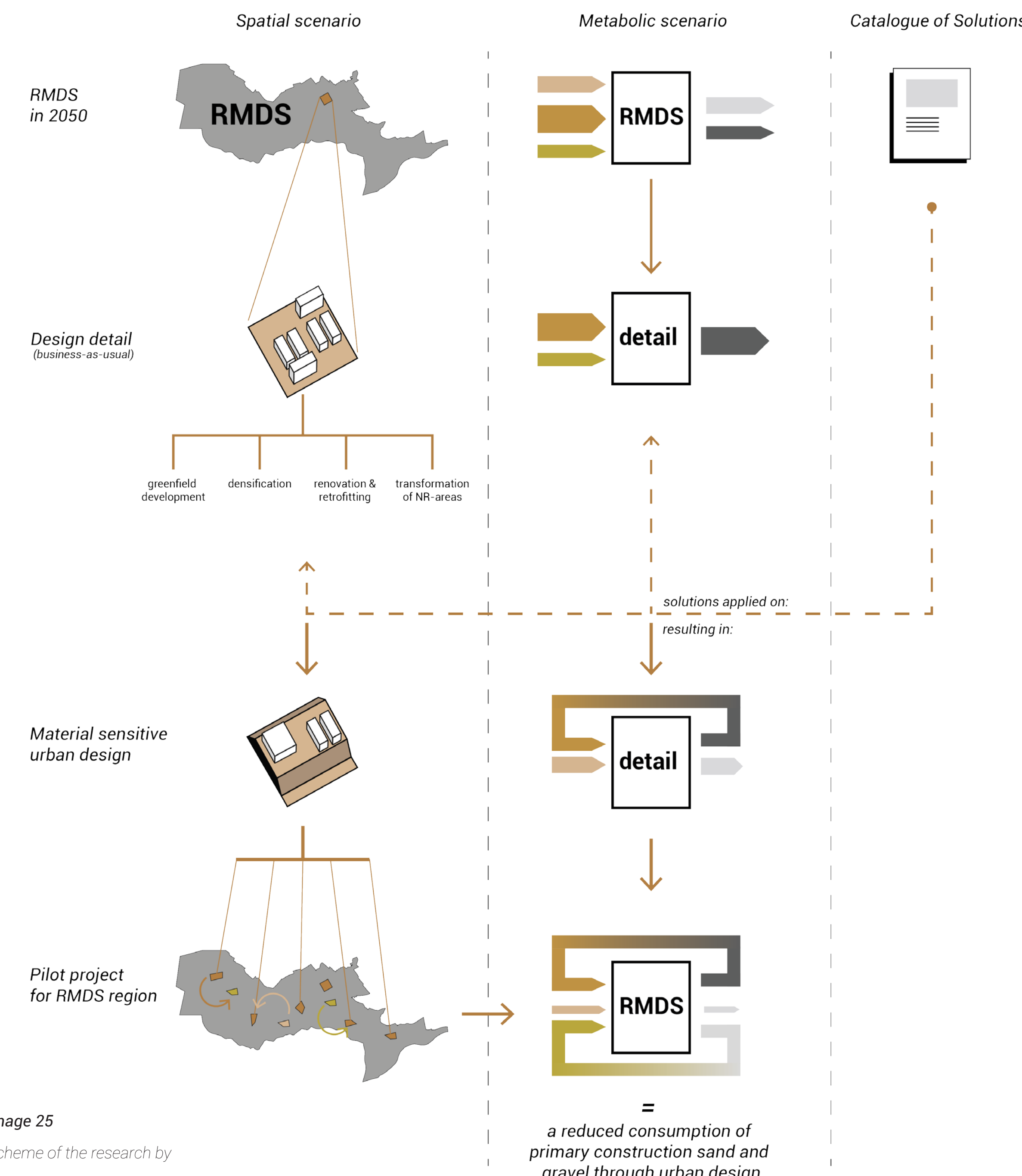


Image 25

Scheme of the research by design method & extrapolation

5.4 Conclusion

The research is a systematic experiment where construction possibilities will be assessed and improved according to their impact on the consumption of primary construction sand and gravel metabolism. The methodology is linked with the current domain of urban metabolism and industrial ecology but also linked with methods from civil engineering (LCA). The research consists of a broad and detailed analysis which will visualise the current and prospected system and scenario. In order to prevent resource depletion according to the status quo, improvement need to be done which are part of the design discipline but closely linked with the optimisation approach of engineering. In order to meet future requirements of urban construction, quality is integrated via the design discipline.

The method is transparent for improvement and critics because it is a forecast but also based on assumption for input. These limitation are further explained in the next part. However, in order to meet future requirements of urban construction, quality is integrated via the design discipline. Nevertheless to prevent resource depletion according to the status quo, improvement need to be done which are part of the design discipline but closely linked with the optimisation approach of engineering.

5.5 Limitations

A life-cycle assessment always relates to limitations and boundaries in order to execute the assessment. These are set in the method description but it should me mentioned that some aspects are neglected. Some of them are described below.

Sand and gravel are applied in several products, stretching from glass and concrete to toothpaste and silicon for microchips (Beiser, 2018). The research focuses on sand and gravel applied in the urban construction according to Huang et al. (2003). The urban construction includes; road, bridge, mass railway transit, dike and levee for flood prevention, and storm drainage and sewerage pipes, and buildings but also building site preparation and beach nourishment. These are components in urban design and specific on the case study but also products which consume the most sand and gravel ('t Hoen, 2017).

The method about stock dynamics originates from the field of energy efficiency in buildings which includes the term emergy, embodied energy. This variable is the sum of energy used in the entire service life of a product. This includes production but is also related to energy use during its service life. The research will not integrate the energy aspects of building because of time limit and its missing relation with the overall research aim.

The data used in the research will be based on several estimations. These estimations need to be done because of lacking or unknown information or time limit. The estimations will be clarified in the research so improvements can easily be applied when future scholars use or update the model for the region.

The sand metabolism of the Rijnmond-Drechtsteden Region

6. Research Results

The research focus on future primary sand and gravel consumption in the Rijnmond-Drechtsteden Region until 2040 with the aim to reduce its consumption. In order to understand and predict the future demand and supply in the region, the urbanisation and construction production is investigated in this chapter in order to answer the research question 'What is the construction sand and gravel metabolism of RMDS region until 2040?'. The construction sand and gravel metabolism is already partly investigated in the theoretical framework. The metabolic framework will be applied to the RMDS region.

Source: Anteagroup, n.d.

6.1 RMDS construction until 2050 *demand and supply*

In order to know understand the metabolism, the system needs to be investigated. The construction and demolition ecosystem in the RMDS region will be analysed according to the following two research questions: ***'Where will sand be available and required in the near future of the RMDS region?'*** & ***'What are drivers and trends in the C&D ecosystem of the RMDS region?'***, which will answer the research question ***'What is the construction and demolition ecosystem of the RMDS region?'***. As explained in the methodological framework, the investigation of the ecosystem is related to action 2 & 3; An analysis of the processes driving the construction and demolition activities and its demands & An analysis of the current stocks of sand and gravel in the region, which uses the stock dynamic model with a policy review and quantification of the material intensity respectively. First, the stock dynamic model with a policy review will be explained.

6.1.1 RMDS stock dynamics

This part investigates where construction and demolition will happen according to two methods: the stock dynamic model (Müller, 2006) and a policy review. These two combined will underpin the scenario of the construction and demolition ecosystem.

As mentioned in the introduction, Rijnmond-Drechtsteden is in demand for the construction of housing. According to the latest documentation of the province, 230.000 dwellings need to be constructed between 2010 and 2030 with 60.000 additionally between 2030 and 2040 (De Zwarte Hond, 2017) Several studies and explorations researched the urbanisation in the region, resulting in scenarios with

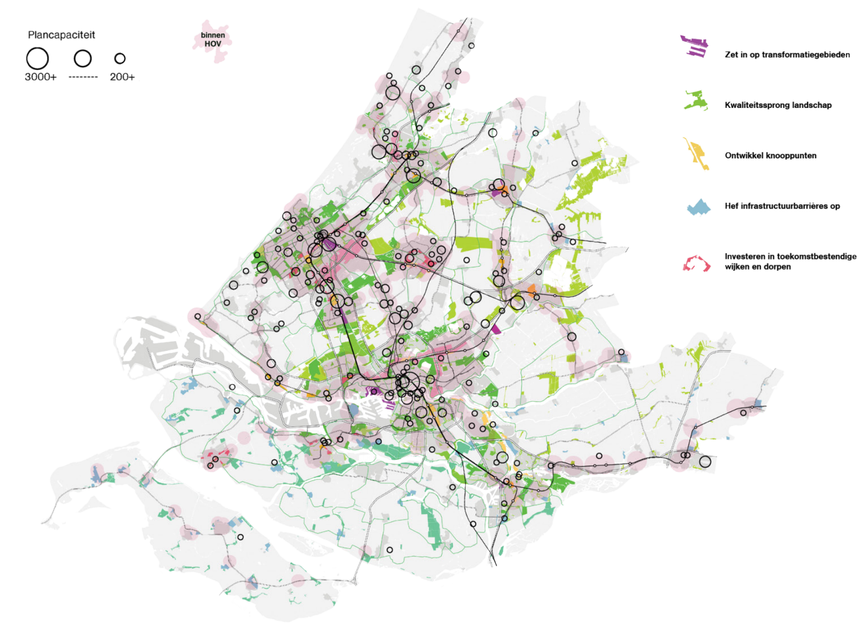


Image 26:

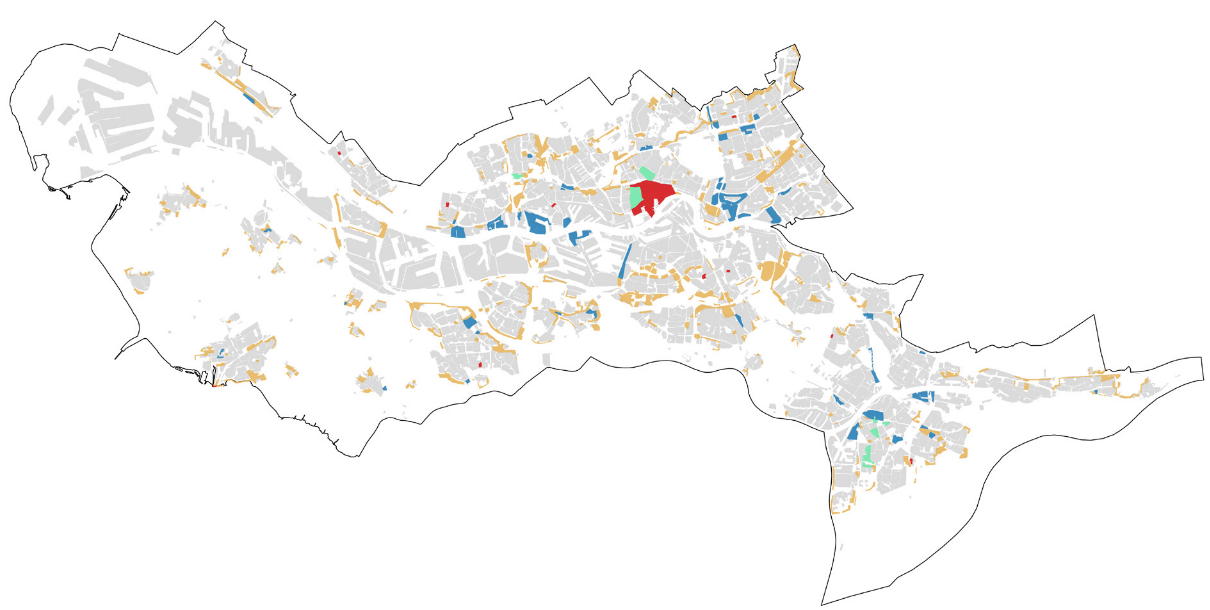
Urban plans and possibilities in South Holland (De Zwarte Hond, 2017) development areas mainly in the built environment, as visualised on image 27 (De Zwarte Hond, 2017; Vereniging Deltametropool & College van Rijksadviseurs, 2014). The urbanisation is not only characterised by the migration of people to cities but also the transition in household size, which is becoming smaller (De Zwarte Hond, 2017). The challenge to facilitate the urbanisation comes together with the transition in energy, mobility and climate adaptation. The province has set six guiding ambitions for the future development, which includes; a diversity in stock typologies, accessibility by building nearby public transport nodes, contribution to the energy transition, employ the potentiality of green and water, develop areas for new economy and development within the current built environment

The province already published the (potential) development sites with the majority within the built environment (College van Rijksadviseurs, Provincie Zuid-Holland, & RIGO research & advies, n.d.). Within the construction ecosystem, four types of urban development can be distinguished. These types, according to the Nieuwe Kaart (College van Rijksadviseurs et al., n.d.), are greenfield development, retrofitting, densification and transformation (of non-residential areas). A closer look at the construction activities of each type reveals their impact on the construction ecosystem:

Image 27

Plan capacity RMDS without existing plans (based on Vereniging Deltametropool, 2014)

- *Densification*
- *Greenfield development*
- *Retrofitting*
- *Transformation of non-residential areas*



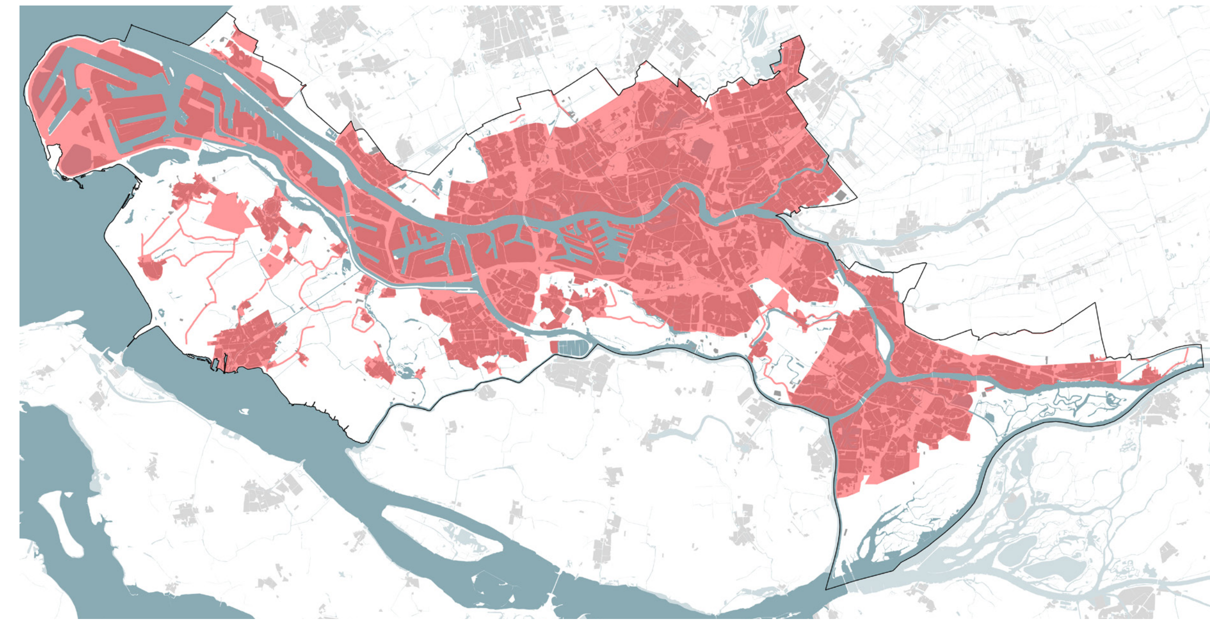


Image 28

Built environment RMDS

0 3 6 9 12km

- *open built environment*
- *closed built environment*

Image 29

Published development sites (Provincie Zuid-Holland)

- *Retrofitting*
- *Transformation*
- *Densification*
- *Greenfield*

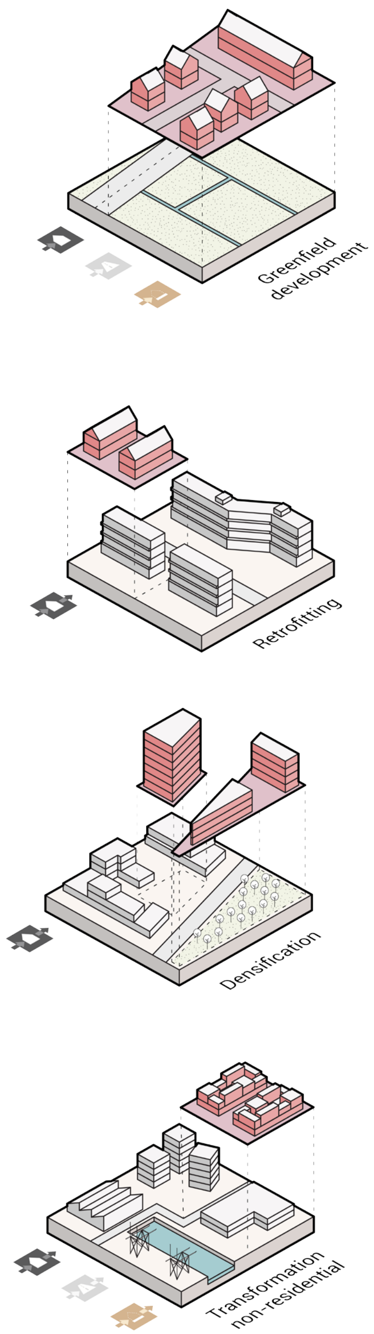


Image 30

Four urban development conditions

Greenfield development

This type of development is the transformation of a non-urban/non-built area (natural or agricultural sites) towards a built environment. This transformation causes an inflow of all major sand product, fill sand, asphalt and concrete. Greenfield development is currently not favorable due to a zero net-take policy or ambition on non-build land. However, within the current built environment some farmlands could still be developed.

Retrofitting

Retrofitting is a planning strategy where current, sometimes mono-functional, built environment is upgraded and updated in terms of diversity in housing stock and target groups. This activity occasionally occurs within the urban fabric which causes only an in- and outflow of concrete, when a building is demolished in the process.

Densification

Residential areas with a low density are candidates for densification of dwelling units. This type is comparable with the retrofitting development because it also occasionally occurs within the current urban fabric (due to land property).

Transformation of non-residential areas

Areas with a non-residential function, such as industry or office, can be transformed into residential area because these areas become interesting for housing development or/and are vacant. This type of development causes an outflow (and inflow) of concrete and sometimes asphalt when the urban fabric is changed and/or fill sand when the site is contaminated.

The different types clarify the relation between urban development and material consumption. This is useful in the analysis and understanding of C&D activities in the region and their metabolic processes. These development can be seen as conditions within the construction ecosystem which causes material consumption. Next to these four urban development type, another category of conditions can be made. Material consumption of sand and gravel can also be found during the lifespan of a construction, due to maintenance. This maintenance can be found in four conditions which are:

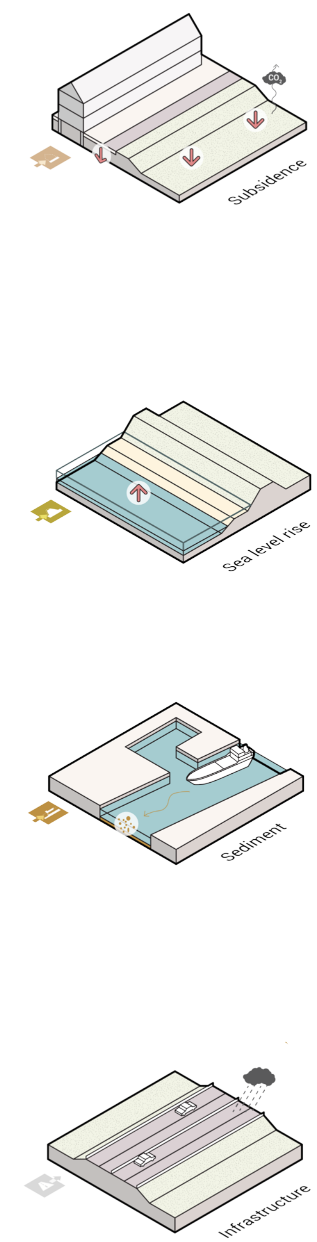


Image 31

Four maintenance conditions

Subsidence

Large areas in the RMDS region are constructed on weak soils. In order to make the soil buildable and accessible, sand is deposited through building site preparation. However, this layer of sand causes weight compression which makes the land subside. This subsidence results in a height difference between dwelling and public space which results in maintenance where the streets are raised with a new layer of sand. Subsidence also occurs in peat land where it causes CO2 emission. However, this type of subsidence relates to other factors.

Sea level rise

Due to climate change, sea level rise is occurring. In order to secure the lowland and coastal areas of the Netherlands, maintenance is required of the coast through beach nourishment. During this activity, sand is deposit on the beaches where it contribute to the natural coastal defence system. Climate change also affects other water related issues such as river management, which result in maintenance of our dikes.

Dredging

In order to keep the harbour and waterways in the RMDS accessible for economic activity, dredging of sediment is required. This sediment enters these areas via a natural flow.

Infrastructure

Maintenance is also required for the asphalt in the infrastructure. Due to car intensity and climate effects, maintenance occurs according to a specific regime.

The data from the policy review and stock dynamics model are combined to create an scenario of where construction will happen. The next step is to quantify this data for the input in the MFA. However, the policy review and stock dynamics model only includes housing and partly infrastructure but fill sand for foundation and is still absent. This is integrated according to the material intensity model. Data from Deltares e.d. gives insight on sand required for beach nourishment and flood protection and sand for building site preparation and maintenance regime related to subsidence.

6.2 The material stock and dynamics in the RMDS region
the quantification

Each urban construction is exposed to an internal or/and external factor which influences the demand for construction activities in e.g. maintenance rhythm or service lifespan. The internal factors are continuous changes or effects on the urban construction, thus designed or known from design and construction stage. External factors are dynamic changes or effects which (almost) cannot be determined at the design and construction changes. The table below states the internal and external factors which affect each urban construction which are applied on the metabolic framework of sand and gravel, resulting in the dynamic stock model.

The detailed information and data behind the quantification is integrated in appendix B.

Table 2

Internal and external factors of the urban constructions

Urban construction	Internal factor	External factor
Buildings (concrete)	*Material degradation (aging buildings), Building structure*	*Population growth, migration, policy/land use/lifestyle/ economic change*
Roads (asphalt)	*Material degradation*	*Traffic intensity, policy change*
Site preparation and raising	*Soil conditions*	*Climate change (drought, water level change), new construction*
Artificial flood defences (dike)	*-*	*Climate change (water level rise, drought)*
Natural flood defences (coast)	*Sediment erosion and deposit*	*Sea level rise*
Natural sediment management	*Sediment flux*	*Policy (-change)*

6.2.1 Buildings

Müller (2006) developed the stock dynamics model which comprises the processes of construction and demolition. The model includes, related to described above, population and lifestyle changes, but also service lifetime of the buildings. As describes in the theoretical framework, buildings have a certain service lifetime after which they need to be demolished or renovated. This model can be applied to the GIS data of construction year in the region in order to conclude which buildings are at the end of their service life and where construction or demolition can be expected.

Residential buildings

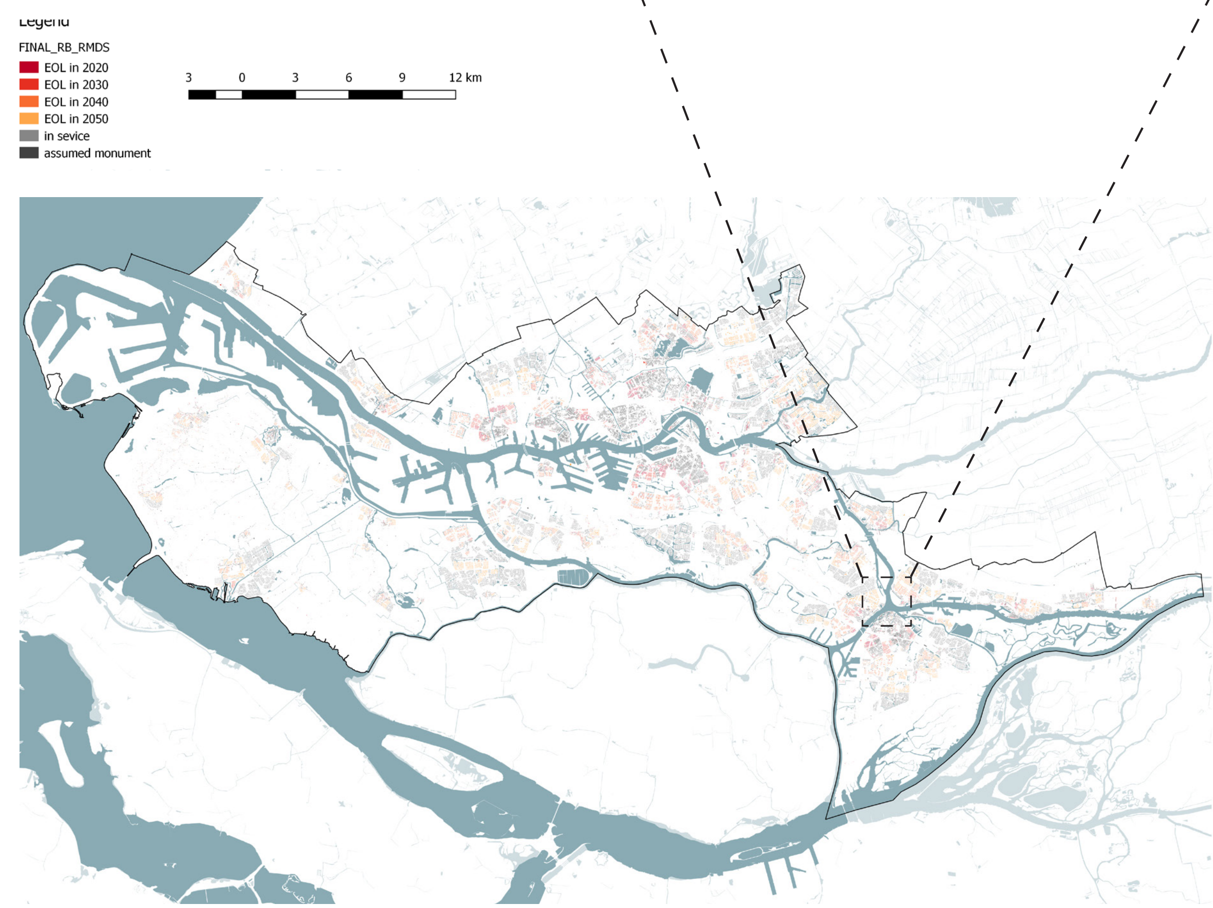
The durability is determined by the service lifetime of a building which will result in an end-of-life scenario (demolition) of the structure. Demolition causes outflow of material from the current housing stock to another one. The service lifetime is not a certain fact but is based on estimated lifespan, which differs per designated function of a building. Müller (2006) determines three scenarios of a residential building's lifespan; 75 year, 100 year and 125 year. In this study, the variable of 75 year is used. The total houses that will be demolished is 119.807. which have an output of

Image 32

EoL residential buildings RMDS region

Residential Buildings reaching EOL v=75 year

EOL residential stock	in 2020	in 2030	in 2040	in 2050
amount	*13.494*	*14..912*	*36.472*	*46.020*
cumulative	*13.494*	*28.406*	*64.878*	*110.898*
				= total deomolished



Stock database

How to calculate the material stock in the current building stock

In order to quantify the materials in the MFA, a database is needed from which the numbers are based on. Some are facts based on CBS data monitoring and others are estimations from case studies or related literature. The scheme in the methodology chapter explains how databases and facts are linked in order to generate a material stock intensity analysis. An example of how this works is explained below:

Example

Building A

Function = residential (RB)
Year =1960
Height = 9m
Footprint = 90m2

Database validation

RB < 12 so Single-Family
Year = 1960
so $MI_{concrete}$
(material intensity) = 0,85 metric tonnes /m²

Calculation

Total floorspace (GFA) is needed
GFA = (9/3)*90 = 270 m²
Total material intensity in building is
GFA*MI = 270*0,85 = 229,5 metric tonnes of concrete.

(if concrete is composed of 32% sand and 45% gravel then)

Sand = 73.44 metric tonnes in Building A's concrete
Gravel =103.28 metric tonnes in Building A's concrete

These calculations and formulas will be applied on the RMDS building stock by the following steps:

1. Determine Residential (RB) or Non-Residential (NRB) (based on BAG

If RB:

2. Validate typology (SI/MF/HR) based on height, which corresponds with the Material Intensity database for concrete ($MI_{concrete}$)
3. Calculate total floor space (GFA) of building (levels (height/3*)*Footprint)
4. Multiply GFA with $MI_{concrete}$ in order to gain the material stock of the building

If NRB

2. Specify function further (commercial/factory etc.) , which corresponds with the Material Intensity database for concrete ($MI_{concrete}$)
3. Calculate volume of building (height*footprint)
4. Multiply volume with $MI_{concrete}$ in order to gain the material stock of the building

*The levels of a building is a completed whole number

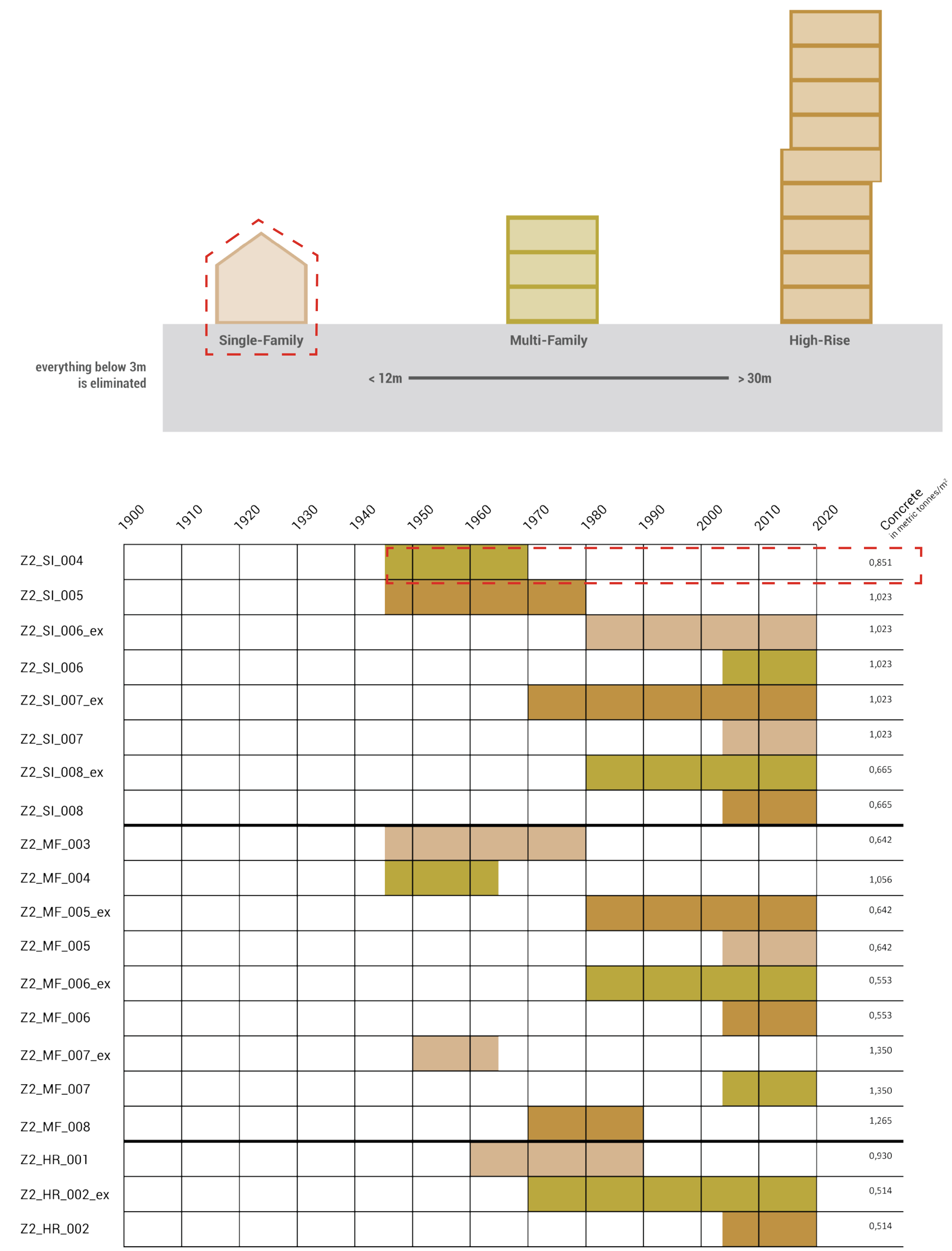


Image 33:

Material intesity database for residential buildings.

Based on Wiedenhofer et al. 2015

22.180.508 tonnes of concrete. As mentioned in the theoretical framework, demolition waste will be used as foundation in infrastructure projects.

The demolished buildings need to be replaced which means that 119.807 dwellings needs to be build, which requires a material input of 14 mln tonnes concrete. Next to the replacement is the construction of new buildings in the region due to the expected growth. The 88.300 dwellings requires 11,7 mln tonnes of concrete.

Non-residential buildings

Non-residential buildings have a different service lifetime and material intensity database then residential buildings. Currently, the material dynamics of non-residential are not integrated in the MFA study.

6.2.2 Infrastructure

Roads need to be maintained which requires new asphalt. This flux is based on the 20 years maintenance regime. The total roads of 482 km in the region will thus all be renovated the next 20 years. Based on the national consumption of all the asphalt infrastructure roads, an assumption is made for the RMDS region, see table 3. According to this assumption, 6,2 mln tonnes asphalt will be needed for the infrastructure maintenance.

The construction of the new A16 will require 614 tonnes asphalt.

6.2.3 Site peraration

Fill sand for building site preparation of new buildings will requires 7,4 mln tonnes of sand. The conditions greenfield development and transformation of non-residential area contribute add a total of 67,7 mln tonnes for building site preparation.

Fill sand is also needed for the maintenance of neighbourhoods were subsidence occur. Image 35 visualise the subsidence in the region. This data is combined with the amount of paved areas in the neighbourhoods. These areas are the places and total area which will subside. The maintenance regime is assumed to restore the current status quo which means that area where 40 cm subsidence occur, 40 cm of fill sand demands. This assumption results in a total of 19,5 mln tonnes of fill sand which the region demands.

Table 3

Dutch roads and asphalt consumption (based on CBS, 2018 & cobouw.nl, 2019)

Roads	provincial roads (km)	highway (km)	total (km)	asphalt consumption (mln tonnes/y)
NL	5.000	8.000	13.000	7,5-8
RMDS	78	404	482	0,28

CBS, 2018; cobouw.nl, 2019

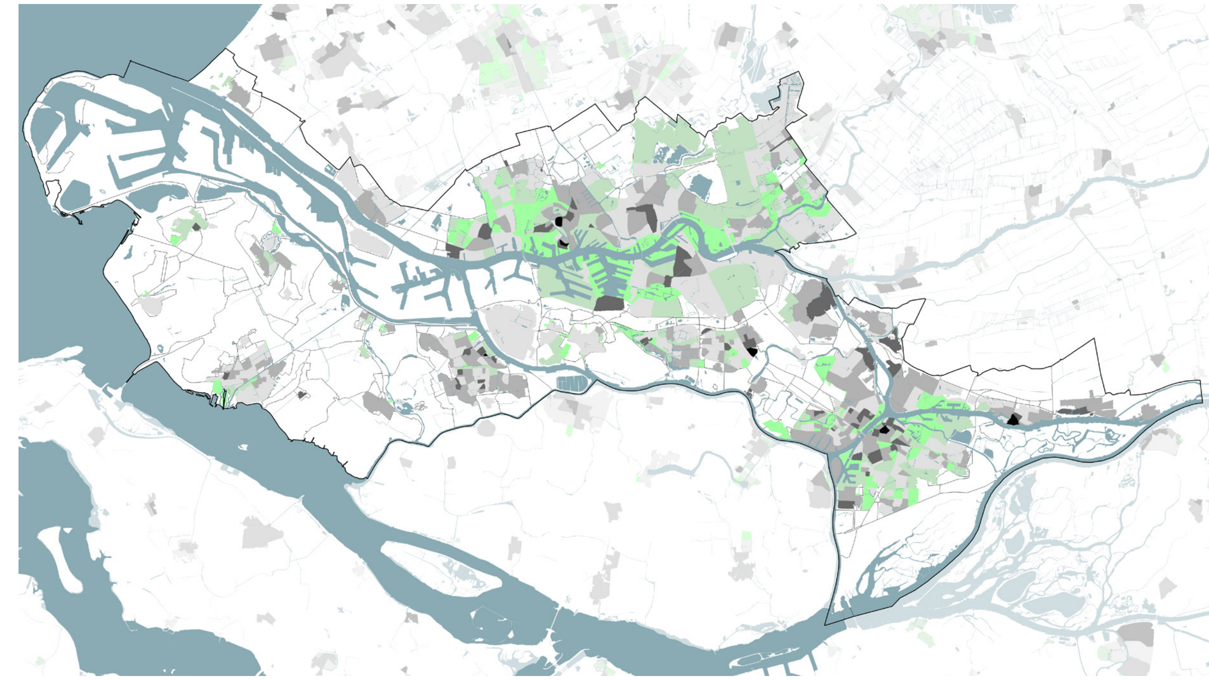


Image 34

Paved areas per neighbourhoods

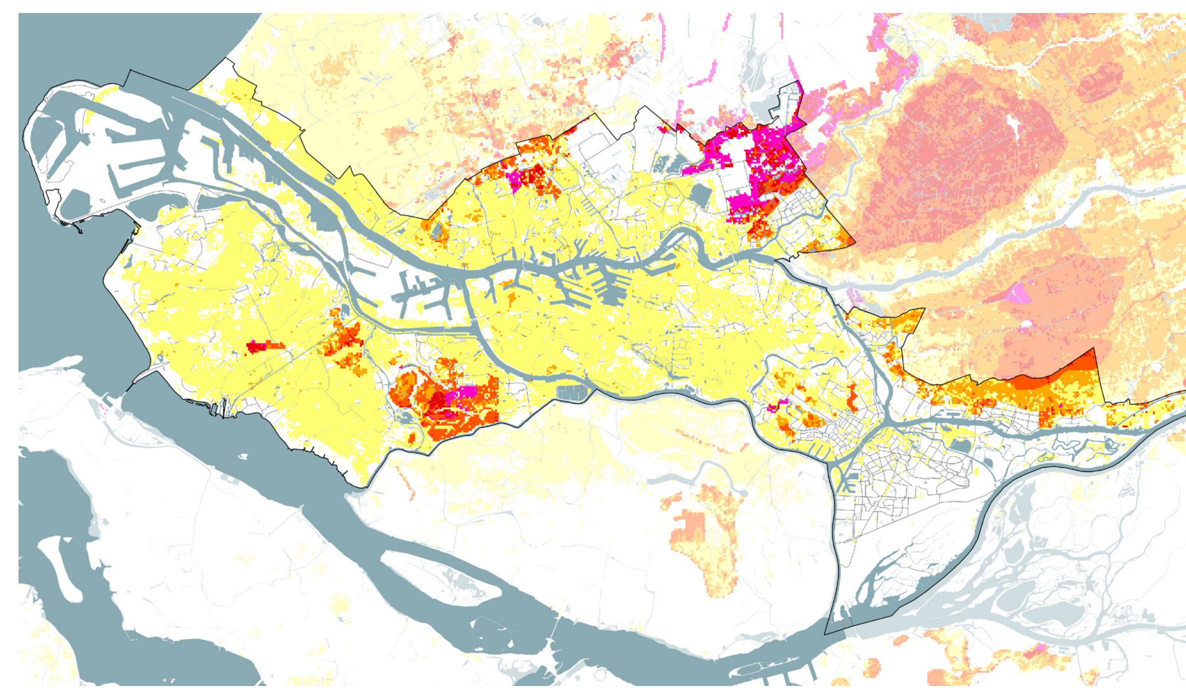


Image 35

Subsidence until 2050

6.2.4 Artificial flood protection

Due to new policy, dikes in the region needs to be adapted and heighten. Image 36 displays dike structures where maintenance is required. This maintenance will result in a total of 28 mln tonnes of fill sand

6.2.5 Natural flood protection management

Beach nourishment is the application of North Sea sand on the Dutch coast. This activity is annually not equally distributed along the coast but by several projects. The annual consumption of coastal protection sand is divided along length of Dutch coast, 30,2 mln tonnes a year for 278 km coast. The coastal protection of the RMDS region can be divided in adjacent coast (Voorne, 9 km with 0,91 mln tonnes a year) or the entire coast which protects the water safety region in which the RMDS region is located in (incl. Voorne, Delftland & Rijnland) which is 71 km and shares 7,71 mln tonnes a year. In the projected period with no increased demand, this would result in a total of 169,68 mln tonnes.

6.2.6 Natural sediment and management

Van Veelen et al. (2018) made a material flow diagram of the sediment balance in the Rhine-Meuse estuary. This study focus on the relation between artificial and natural sedimentation flows in the region where the sand plays a big role. The construction sector is integrated as how it is related to the other flows. 't Hoen (2017) researched the mining and consumption activities of resources in the Netherlands (see Sankey diagram), which argues the vast extraction and consumption of the resources. This research clearly shows that the volume of coastal defence sand and fill sand is higher than sand for concrete. The circularity of these resources is never discussed, only the possibility of increase in consumption (Deltares, 2018; van Veelen et al., 2018).

Natural flow and the related management has a flow quantity of 21,69 mln tonnes of natural river inflow, 261,8 mln tonnes of dredged material to the North Sea and 37.4 mln tonnes of the natural sea influx.

On the next page, the intensity of concrete in- and ouflow and fill sand for subsidence are mapped which contribute to the choice for a focus location in the research by design part.

Image 36

Dike reinforcement requirements RMDS region

Image 37

Total beach nourishment in the in the Netherlands. Voorne, Delftland & Rijnland relate to the flood defence of the RMDS region (RWS, 2018).

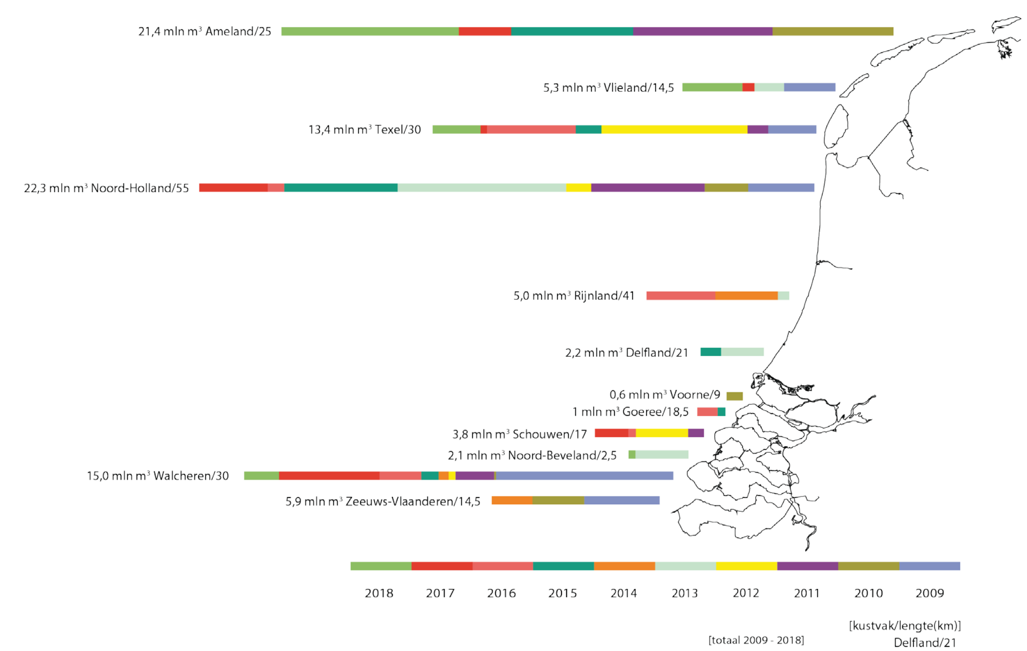


Image 38

input of concrete per neighourhood

High

Low

none

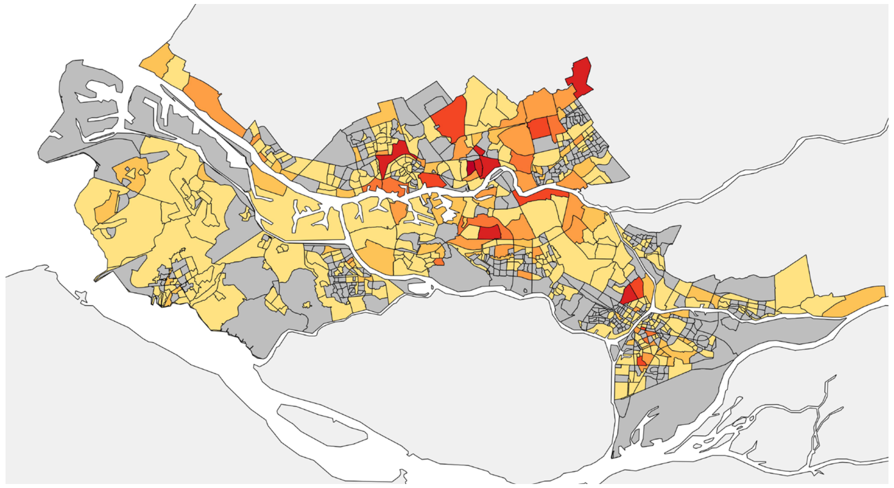


Image 39

output of concrete per neighourhood

High

Low

none

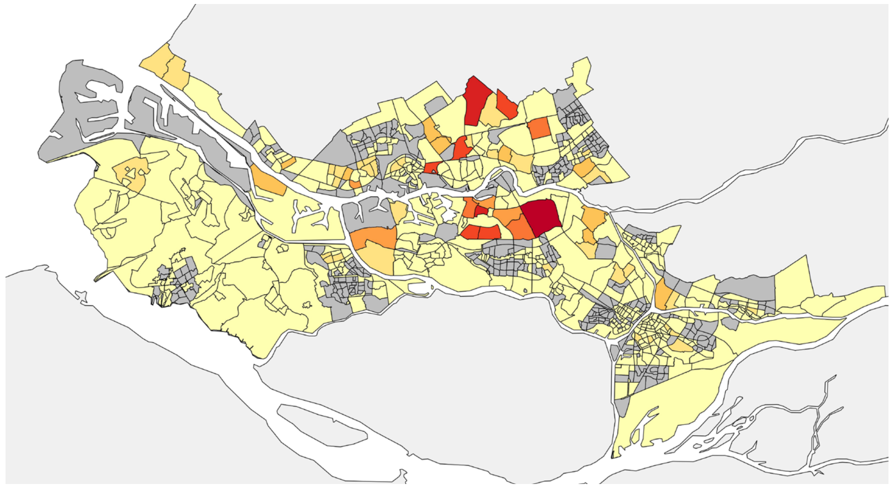


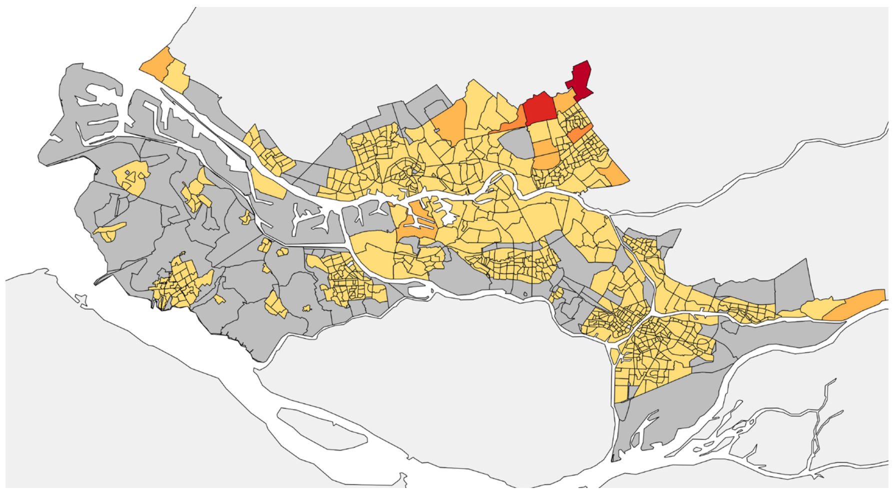
Image 40

input of fill sand for subsidence per neighourhood

High

Low

none



6.3 The construction sand and gravel metabolism of RMDS *the MFA*

The quantification of each component results in the required data for a Material Flow Analysis of construction sand and gravel in the RMDS region. This MFA will expose the metabolic framework of the material. The MFA is visualised in an isometric sankey diagram on the next page (in a sankey diagram, the weight of the arrows represent the quantity) . The diagram clarifies the large quantity of flows and demand of the region. Fill sand is the largest consumer and large transporation flows occur due to dredging and beach nourishment activities.

A standard MFA clearly has inflows from a different ecosystem which is used in the researched ecosystem and outflows which leaves the researched ecosystem. The MFA of sand and gravel in the RMDS does almost not have outflows of consumed materials. Sand is used in other reservoirs (demolished debris as foundation material) and remains in the anthropocentric stock. This recycling destination has a chance to become saturated, which is assumable with the given quantity of demolition concrete waste.The only outflow of material is the dredged sediment in the harbour area which is returned to the mining reservoir of other stocks, the North Sea.

Another aspect of the construction sand and gravel metabolism in the RMDS region is the continuous demand for material of some conditions. An example can be found in fill sand which, due to subsidence, continuous requires primary material. The application of fill sand can be compared to a 'grave' destination in the material flow because it does not leave this stock.

Construction sand and gravel metabolism

2018-2040

Rijnmond-Drechsteden

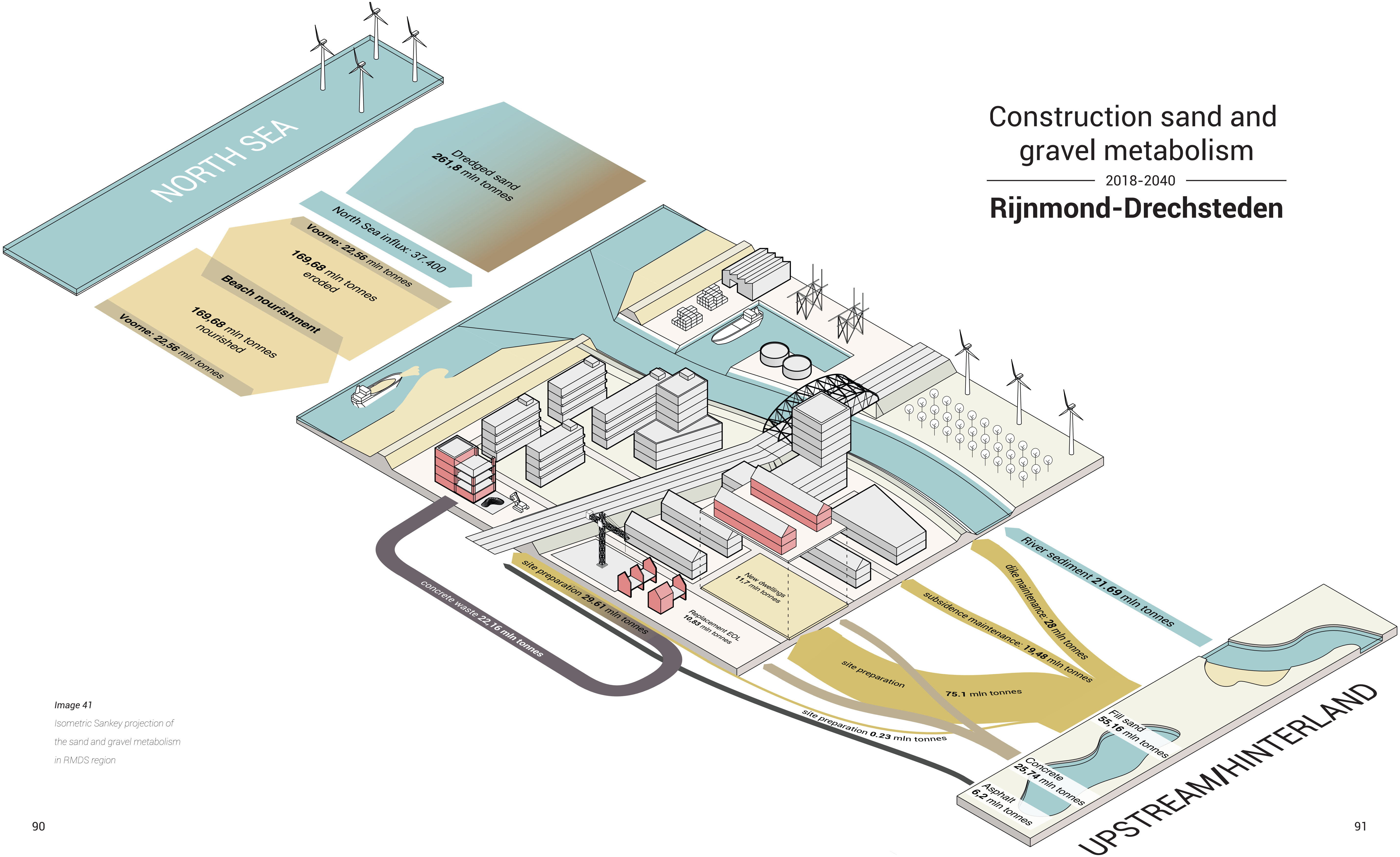


Image 41

Isometric Sankey projection of the sand and gravel metabolism in RMDS region

6.4 The construction sand and gravel metabolism of RMDS
the LCA

Image 42
LC stages per urban construction within the sand and gravel metabolism

The MFA scheme can be used for the LCA of the researched material. In order to increase the link with spatial implications and urban design, a new graphic style of the MFA scheme is developed which combines the spatial elements with the LCA components, as visualised on the next page. This combination of spatial elements with LCA components also embraces the link with the NEN scheme of LCA. Metabolic and spatial interventions become transparent for the execution of a LCA. This transparency will be highly applicable in the next step of the research where solutions can be integrated and evaluated in the new LCA scheme.

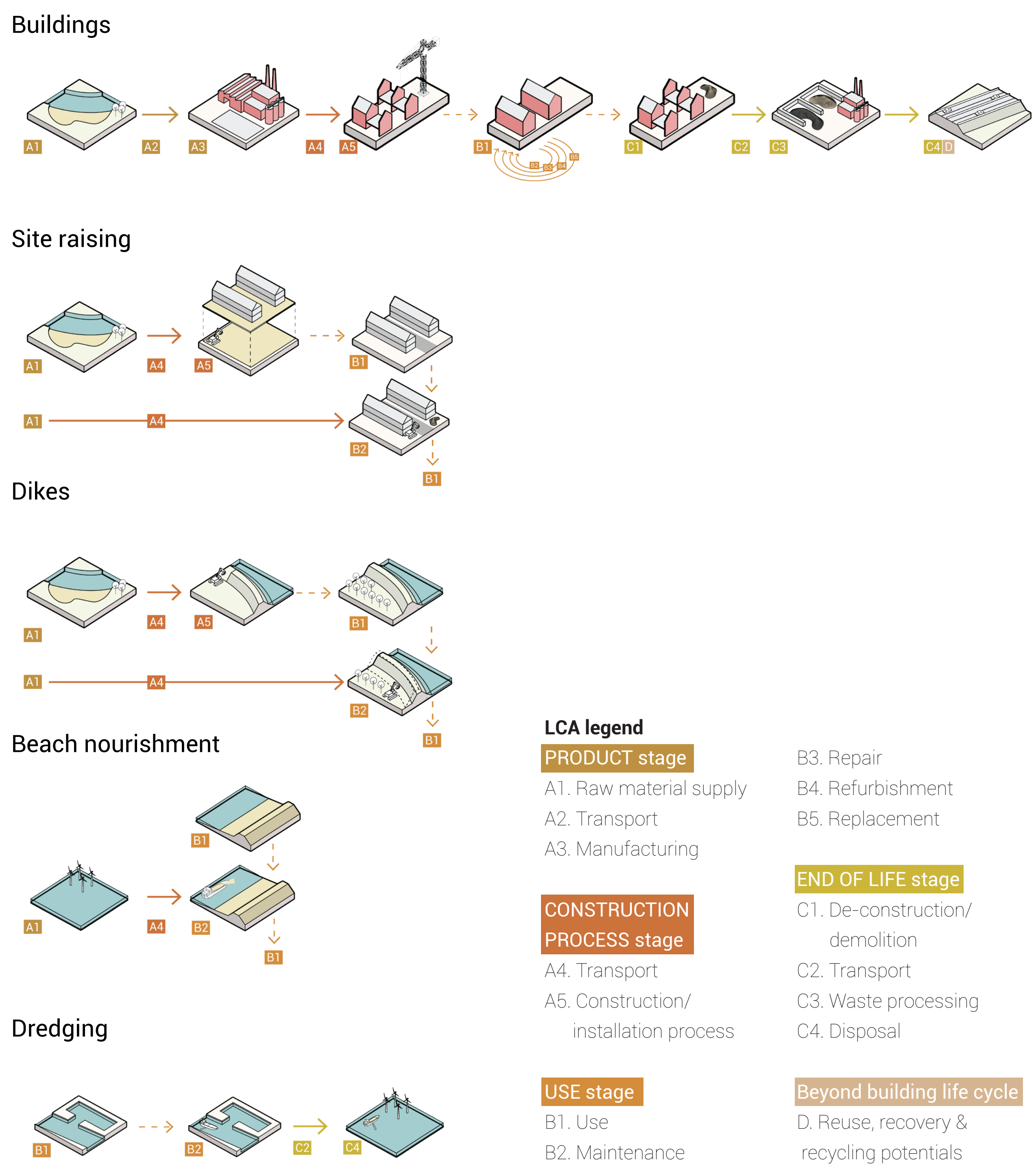
The main aspects of the LCA are summarised in table 4. The majority of inflow relates to fill sand, which match with the national sand and gravel consumption as visualised in chapter 2. The inflow relate to resource depletion but also to indirect emission due to cement production, which is assumed to be around 25,7 mln tonnes of CO2. Within the ecosystem, flows occur between the demolition of buildings and foundation of roads. Another flow occur between soil deposition and building site preparation. The condition 'transformation of non-residential areas' drives an outflow of fill sand because this might be contaminated. The return flow from the soil deposition is unknown. The outflow of material is only caused by artificial dredging but also naturally through the erosion of the beach.

A visualisation of the lifecycle per urban construction clarifies the consumption patterns, as visualised on the left. This contributes to the understanding of the link between environmental impact, urban processes and material consumption.

In order to conclude a stronger environmental impact, a more detailed study on the LCA needs to be made.

Table 4
Main flows in the business as usual scenario of the construction sand and gravel metabolism in the RMDS region

Flow	Business as usual scenario
Total inflow	146,52 mln tonnes
Transport within ecosystem	94,49 mln tonnes
Total outflow	261,8 mln tonnes



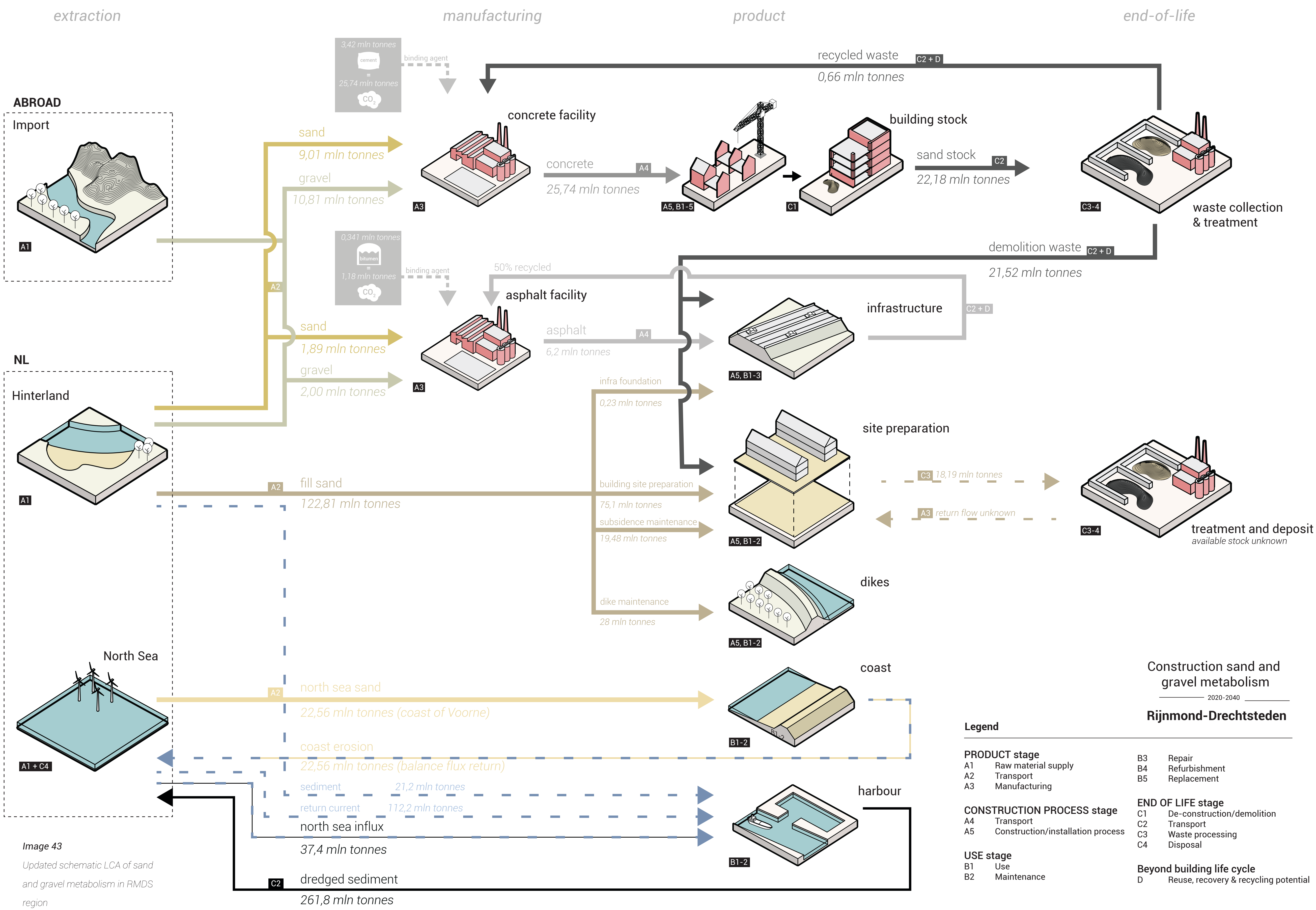


Image 43

Updated schematic LCA of sand and gravel metabolism in RMDS region

6.5 Conclusion: The material consumption of RMDS

This chapter answers the research question: '***What is the construction sand and gravel metabolism of the RMDS region until 2040?'*** and ***'What is the impact of the construction sand and gravel metabolism of the RMDS region until 2040?***'. These two questions are answered with the material flow analysis and lifecycle analysis. The results of the analysis reach the objective ***'clarify the drivers behind the construction sand and gravel in order to understand its ecosystem***'.

Drivers behind material consumption within the context and processes in the urban environment are called conditions. Within the metabolic framework of construction sand and gravel, eight different conditions can be distinguished, which are divided in two categories: urban development activities (densification, retrofitting, transformation of non-residential areas and greenfield development) and maintenance activities (due to subsidence, sea level rise, dredging or infrastructure status). Each of these conditions have a certain relation with how it consumes sand and gravel, and which urban construction it contains. The conditions are used in the spatial analysis to identify the total material flow and consumption in the RMDS region. The conditions are transferable to other urban ecosystems as well.

The conditions were used in the material flow analysis, extended with a dynamic stock model and stock intensity model. In the dynamic stock model, internal and external factors are made explicit within the (theoretical) metabolic framework of sand and gravel. These factors have an impact on the consumption and differ per condition. Overall, the external factors are based on top-down scenarios and policy concerning the urban construction while the internal factors are based on the material intensity study.

The results of the analysis visualise the assumed material consumption in the RMDS region until 2040.This consumption is characterised by the large quantities it requires but also the high amount of waste material which is generated. The majority of consumption is related to fill sand, 69% of the total consumed primary material (this percentage corresponds to a certain extend with the national consumed as shown in image 4). The waste generated by demolition is assumed to be 22,18 mln tonnes which all would be recycled as foundation material according to the business as usual scenario. These processes are an example of the continues consumption of sand and gravel within the urban ecosystem. In other words, construction sand and gravel flows and remains within the urban ecosystem from cradle to grave. Exceptions to this rule are the water related conditions such as maintenance via beach nourishment and dredging. Dredging of sediment to the North Sea has by far the largest flow within the sand and gravel metabolism of the RMDS region, 261,8 mln. Meanwhile, sand from the North Sea is used in coastal protection via beach nourishment, which, after deposit, is influenced by the natural erosion process of the sea.

The results of the material flow analysis are the basis of the lifecycle analysis which is summarised in the scheme. This scheme clearly shows the flows and related LCA module of the material consumption within the urban ecosystem of the RMDS region. The biggest impact can be found in the quantities and transportation of the material within the system. A note can be made at concrete which has a significant but indirect impact due to the production of cement. The LCA is a transparent interpretation of the material consumption which can be used for further research on the overall environmental impact.

In this research, the conditions most related to urban design are chosen to be improved within the research by design. These conditions are all four urban development activities and maintenance due to subsidence. Within these conditions, the potentials of fill sand reduction and recycling opportunities of waste flows will be explored and improved. The improvement opportunities will be explored in the next chapter by the development of the Catalogue of Solution and the material conscious approach.

Post-sand cities

7. Solutions for Sand-Sensitive Urban Design

This chapter explores the alternatives of urban design aspects which can reduce the sand and gravel demand through the use of material: recycling, renewable elements, or the type of spatial intervention; reduce land consuming elements, zero net-take. This exploration to alternatives results in a new approach for the design phase and a catalogue of solution.

Source: Van Mierlo Bouw, 2008

7.1 From material choice to material consciousness

The MFA and LCA resulted in the assumption that the RMDS region requires an enormous amount of sand and gravel for its future developments. The research started with the hypothesis that another material choice would be necessary to reduce the material consumption. However, another material choice would just shift the problem to another material which needs to be reach this amount and services. This is why the material conscious approach is constructed within this research. The material conscious approach consists of three main components; awareness, material efficiency and lifecycle perspective. The approach is summarised in the framework and has an important tool for execution and evaluation, the territorial metabolic lifecycle analysis (TM-LCA) scheme.

7.1.1 Awareness

In order to reduce consumption, choice is not important but the consciousness of consumption within urban processes. This awareness is more abstract and can be better integrated within the urban design profession. This concept of consciousness is based on the situation-conscious approach by Bijhouwer.

Bijhouwer integrated the notion of suitability for urban development on the site in his design for the neighbourhood Kethel in Schiedam. He knew that weaker soil would require building site preparation and might suffer from subsidence during its lifespan. He applied a design/strategy of positioning construction on the strongest ground. This is also the first decision strategy in the construction on weak soil (Tromp, 2008).

The material flow analysis of the RMDS region gives an insight in the potential drivers behind sand and gravel consumption within this construction ecosystem.

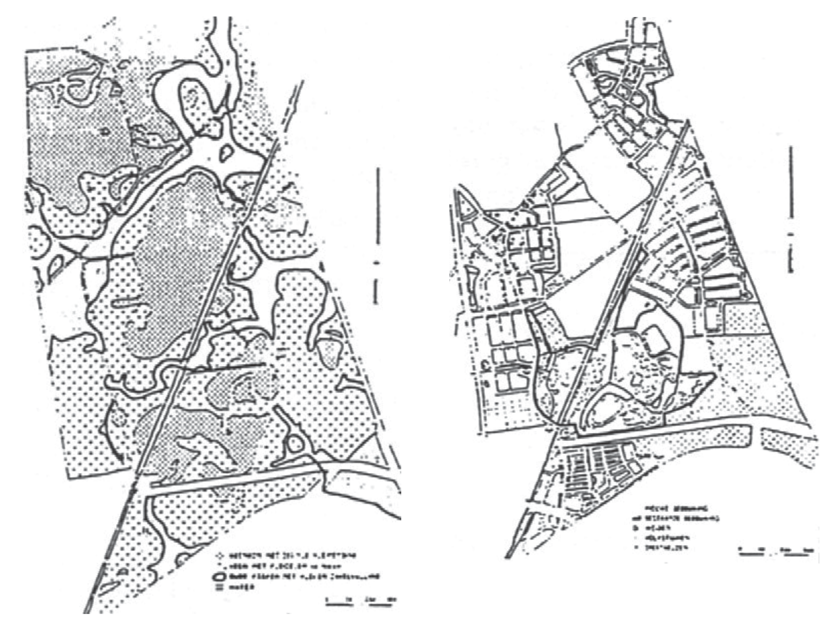


Image 44

Bijhouwer's soil analysis and urban plan for Kethel, Schiedam (De Jong, 2008)

These drivers are called conditions which are categories in two main types; (1) urban development causing construction and demolition flows and (2) maintenance due to i.a. climate effects. The first category includes retrofitting, densification, greenfield development and transformation of non-residential areas, and the second category includes subsidence, flood defence, infrastructure and dredging. The eight conditions and their related material in- and outflow are the events where an urban designer should be conscious about. Other type of (construction) material will require a new analysis of the drivers and condition behind the consumption.

7.1.2 Material efficiency

Bijhouwer's decision for the Kethel is a good example of a material efficiency strategy, that is reduction. These strategies are part of the next component within the material conscious approach. The material efficiency strategy are set up by Allwood et al. (2011) which describes how the demand for material can be reduced. There are four strategies which are; longer-lasting products; modularisation and remanufacturing; component re-use; designing products with less material. Cordella et al. (2019) extended the material efficiency of Allwood et al. into a clear hierarchy of priority between the different strategies. They also linked the material efficiency strategies with the waste hierarchy, which is similar to the Ladder of Lansink for waste management (although, in this hierarchy, energy and incineration are also

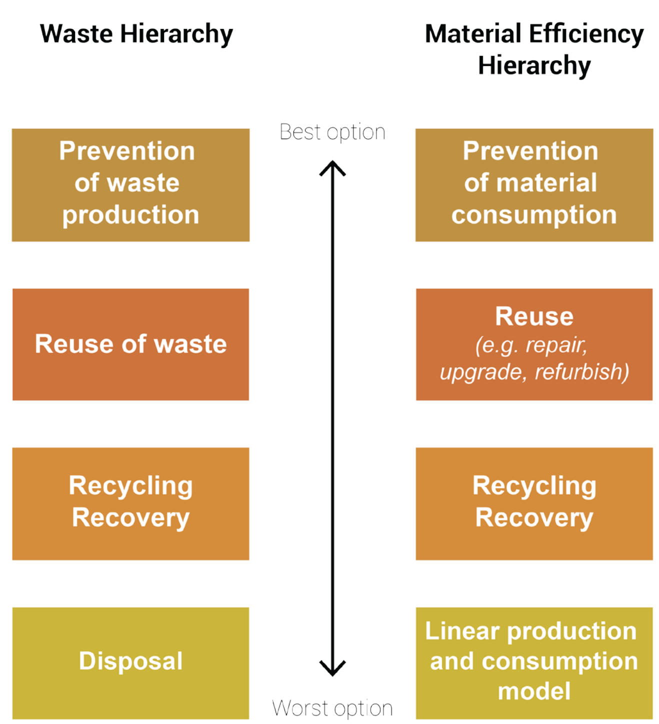


Image 45
Waste and material efficiency hierarchy
(adapted from Cordella et al., 2019)

integrated) (Lansink & de Vries, 2010). The waste hierarchy and material efficiency hierarchy show many similarity which also clarifies the link between waste and resources, which is an important action for a circular economy (de Wit, Hoogzaad, Ramkumar, Friedl, & Douma, 2018). Both waste and material efficiency has prevention as the highest priority, followed up by reuse as second, recycle as third and disposal or linear consumption model as lowest priority. In the material conscious approach for urban design, it is assumed that traditional design follows the linear consumption model. The approach aims to apply the three strategies of prevention/reduction, reuse and recycle in the urban design process. Cordella et al. (2019) defines the different strategies as following:

(1) Reduction: Direct reduction of the quantity of materials used for products and services, which can be promoted through design and manufacturing process. Important difference with (3) recycling is that recycling does not necessary reduces the mass of material in the product.

(2) Reuse: Prolong the use of products or parts of products, which prevents the demand for new products. This can be done by making products or its part more durable and by facilitating repair, reuse and upgrade operations. The reuse of parts of a product are recovered through a non-destructive process (disassembly).

(3) Recycling: Recovering the material at the end-of-life of a product through a destructive process (dismantling).

7.1.3 Lifecycle perspective

The metabolic activities within the construction ecosystem occur not only at the construction of a building. Material flows during construction, maintenance and demolition, in other words, from cradle to grave. A fourth process should be added which is the situation before the construction. In some cases, for example in the condition 'transformation of non-residential buildings', existing structures need to be removed, which also causes material flows. By examining these four processes within the construction ecosystem, a lifecycle perspective is created for the material conscious approach. This perspective is necessary to examine the environmental impact according the LCA module NEN-EN 15804:2012 and to prevent the possibility of impact elsewhere within the lifecycle of the construction. In the case of Bijhouwer's design, its consciousness also resulted in the fact that the neighbourhoods did not needed (or needed lesser) fill sand for subsidence maintenance, which would be the case when it was situated on weak soil.

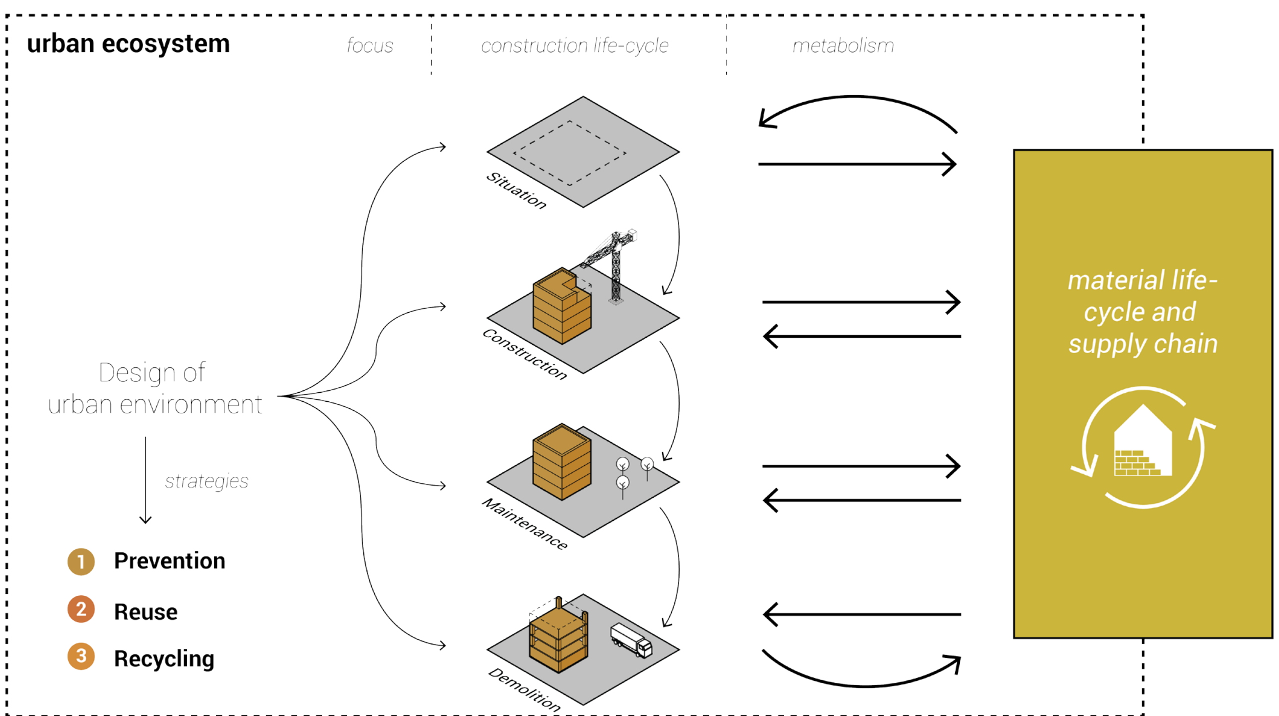
7.1.4 Material conscious approach framework

The approach is meant for urban designers who can use it within their design process. The application of the approach within a design case for the urban environment is explained in image 46. The core of the approach is to examine the entire lifecycle within the urban construction processes (situation, construction, maintenance and end-of-life). Each process has a certain material consumption pattern within the construction metabolism which can be evaluated. For example, the consumption of concrete and fill sand for the construction of a neighbourhood. Eventually, the three material efficiency strategies can be applied in order to reduce the consumption and the environmental impact.

Within the design process, the approach can be applied after a first design is made. This evaluative method is used within the 'research by design' part in this graduation project, as explained in chapter 8. The first design is a 'business as usual' scenario where the material efficiency strategies are not integrated. By applying the material conscious approach on this scenario, a reduction of material consumption can be designed and achieved. The Territorial Metabolic Lifecycle Analysis (TM-LCA) scheme is an essential tool in this process.

Image 46

Material conscious approach scheme



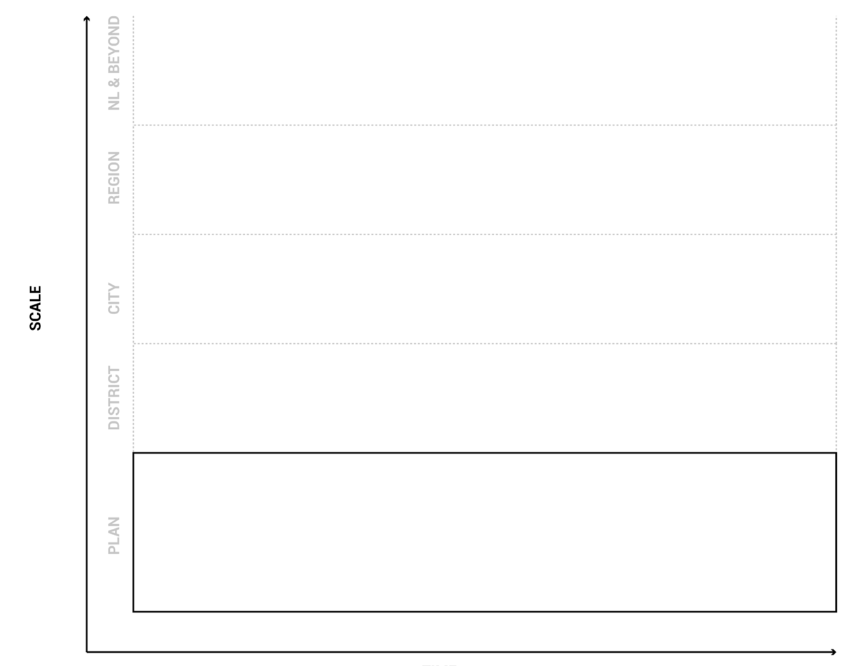
7.1.5 Territorial Metabolic Lifecycle Analysis scheme

The material conscious approach links material consumption (the flows) with the impact over the lifespan of the construction or design. This link between material flow and their impact is also explored by Sohn et al. (2018) in their method for Territorial Metabolic Lifecycle Assessment (TM-LCA). Territorial metabolism differs from urban metabolism because in this concept the boundaries of the ecosystem disappear and becomes an 'aggregation of non-contiguous areas, which are defined as a 'territory'. Here, territory is defined as 'the aggregated individual producers and the land within their geographic delineations contained in a defined region' (Sohn et al., 2018). The concept of territorial metabolism provides the opportunity to extend the environmental impact beyond the boundaries of the design site. This is essential for the Lifecycle Analysis which relates to material consumption and its impact within the approach. This transparency of environmental impact was also the purpose for the TM-LCA.

In the material conscious approach, the LCA is not integrated as an assessment, but as an analysis. Within this research, a difference is defined where the analysis clarifies the system from a lifecycle perspective (inventory) and where an assessment

Image 47

TM-LCA tool scheme



quantifies the impact from this system. The analysis is the base of the assessment and can be seen as a transparent system description which can be used for civil engineers in further study.

The TM-LCA scheme (see image 47) is an essential tool in the material conscious approach. It is a matrix with the scale on the vertical axis and time on the horizontal axis. The vertical axis is divided in five categories which represent the different scales of the project's territorial metabolism; plan, district, city, region and NL & beyond. The lifespan of an urban construction (the plan) can be lay down on the horizontal time axis. This lifespan consist of the four urban construction processes; situation, construction, maintenance and end-of-life. The outcomes of an urban design are the input for the scheme. A design is a change from a current (1) situation to a new 'product' through (2) construction. The new 'product' needs (3) maintenance during its lifespan until it reaches its (4) end-of-life which results in deconstruction. Each change from one process to another consumes material, which originates from a certain source. These sources are located somewhere. For example, the construction of a building from concrete requires sand and gravel from a sources somewhere in the Netherlands, which is then transported for manufacturing in a concrete facility in the region and eventually transported to the plan location. This flow is mapped within the scheme where each phase of the material flow is documented according the NEN-EN 15804:2012.

The scheme will be broadly tested in the research by design in the next chapter.

7.2 Catalogue of solutions: exploration of alternatives

In order to improve the current construction sand metabolism, new solution needs to be found which can be integrated in the urban development strategy and have a significant impact on the consumption system. The exploration of solutions is based on literature review of innovative projects on circular construction on different scales and is shown in the external appendix (A) of this thesis, Catalogue of Solutions. An overview of the solutions can be found on page 106.

Name of solution (template)

Solution #

Description
Description of the solution

Related stock
Building/site/infra
Stock which the solution affects or relates to.

Related LCA module
A-B-C-D
Module/stage which the solution affects or relates to. Corresponding codes are explained in the LCA module legend on the next page.

Applicable on the current stock?
Yes/No
Clarifies if the solution can be applied on current building stock or if it is only applicable in new construction.

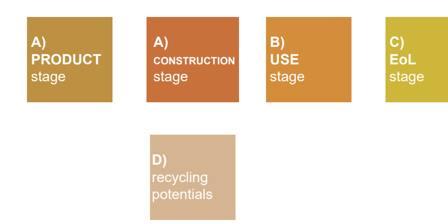
Link with other solutions
Relation to other solutions for essembles

Spatial impact
+ Positive *(e.g. contribution to green)*
- Negative *(e.g. change in accessibility)*
! Requirement *(e.g. stable soil)*
Impact on the spatial environment, both positive and negative quality. The requirements can include elements which are needed for success.

System impact
+ Positive *(e.g. based on waste flow)*
- Negative *(e.g. more transport)*
! Requirement *(e.g. requires biobased facility)*
Reduction or improvement changes the metabolic system of the material or related stock. Sometimes, a specific requirement is needed for success.

Governance impact
Descriptive
Some solutions requires change in policy and strategies in order to succeed,

Environmental impact
A-B-C-D
Based on the related LCA module, a desciption will be given about the impact in the life cycle information. The structured description in the LCA format embraces the transparency for an environmental impact assesment and supported with the diagram below



Source
Related source of solution

Image 48

Template for each solution

Overview of solutions

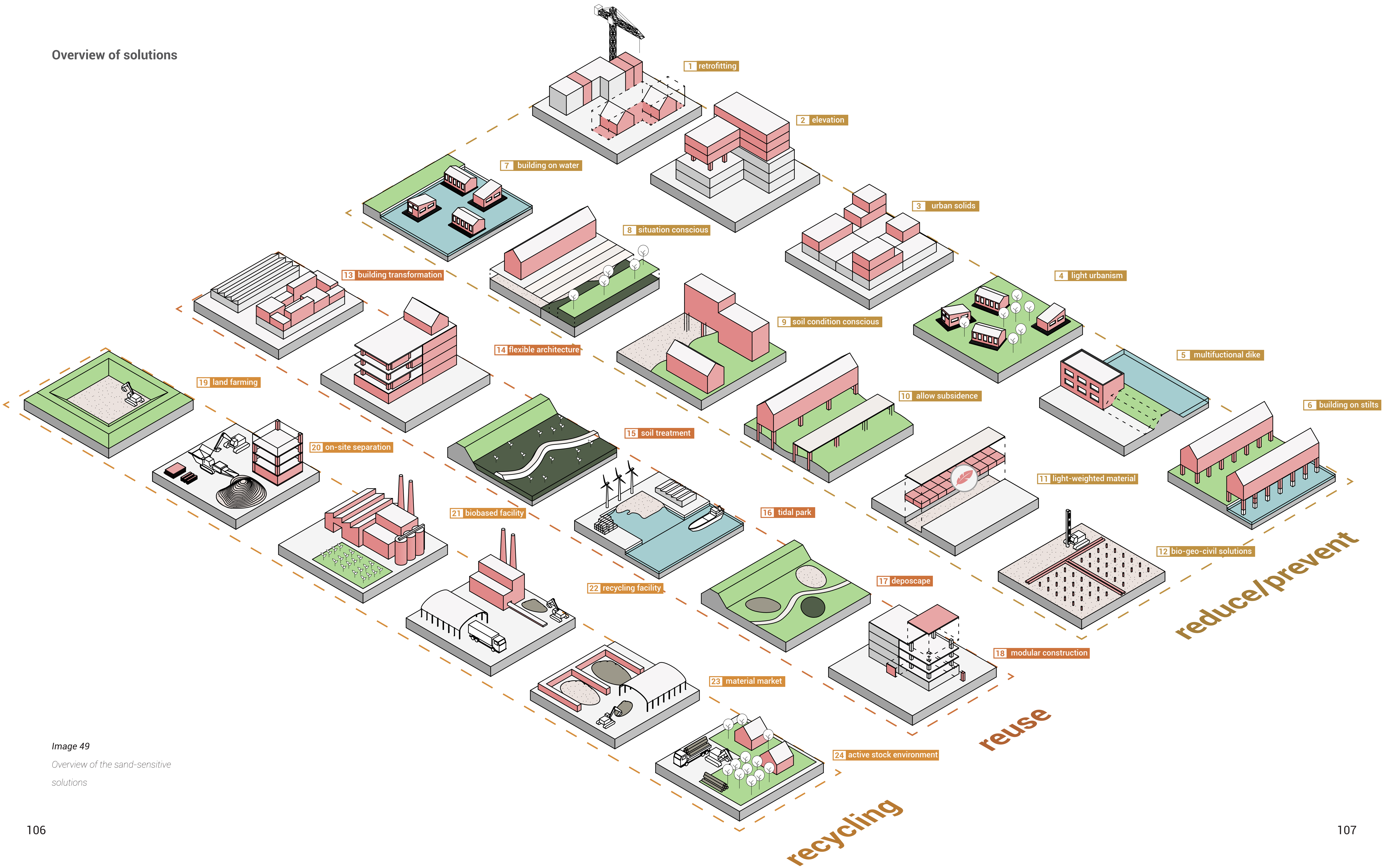


Image 49

Overview of the sand-sensitive solutions

The solutions can be divided in three sections, based on the material efficiency approach, which are:

Reduction of material

This includes solutions which integrate changes in the design that reduces the material demand.

For example solution 7: Building on water. This intervention prevents the demand for fill sand in urban development, due to its location on water and floating structures or buildings on piles.

Reuse of products or components

This include solutions which reuse structures or parts of structures (modular).

For example solution 13: Building transformation. Current buildings can be reused and transformed for new functions, which reduces both construction and demolition flows. This solution can be found in projects where former industrial buildings are transformed into residential buildings.

Recycling of material

Waste material flows can be recycled and reused in new construction which replaces the demand for primary material. This requires the link between demolition activities, secondary resources or urban mining, with construction activities. This connection requires supportive facilities for its development.

For example solution 22: Recycling facility/materials. In this solution, the potential of the plastic EPS is explained which could be a substitute of fill sand and can be 'mined' from demolished buildings where EPS is used as insulation material

All the discussed solutions in the catalogue are assessed according the same format. This format is displayed on page 105. Most important is the impact the solution has which are categorized in spatial, system, environmental and governance. The first two are evaluated according the positive or negative impact and the requirement for its succession. The environmental impact describes its changes according the life-cycle assessment tool and terminology which is supported with a scheme. The governance impact is a descriptive explanation.

Eventually, the solution can be applied on different condition, as described in table 5. The solutions are also linked with related geographical information, for example soil condition data for the application of light urbanism. These data is necessary for the implementation of the solution in urban design projects. The image on the next page visualises how the solution might be integrated in certain conditions.

Reduce/prevention	Condition	Related geographical data
1. Retrofitting	R	Building age (*monofunctional; 1950 until 1980*)
2. Densification by elevation	D	Flat roofs (*for topping*)
3. Urban solids	D, R, T	New construction site (*urban typology*)
4. Light Urbanism	G	Soil condition (*soil strenght*)
5. Multifunctional dike	G, M	Dike improvement (*available*)
6. Building on stilts	T, G	Development areas (*for new construction*)
7. Building on water	T, G	Water areas (*available*)
8. Situation-conscious	G	Soil condition (*soil strenght*)
9. Soil condition-conscious	R, T, G	Soil condition (*contamination level*)
10. Allow subsidence	D, R, T, G, M	Soil condition (*subsidence*)
11. Light-weighted material	D, R, T, G, M	Soil condition (*subsidence, infrastructure*)
12. BioGeoCivil solutions	D, R, T, G, M	VARIOUS (*e.g. soil condition*)
Reuse		
13. Building transformation	D, R, T	Building typology (*vacant, non-residential*)
14. Flexible architecture	D, R, T, G	New construction sites (*urban typology*)
15. In-situ soil treatment	R, T	Soil condition (*contamination level*)
16. Tidal park	M	Harbour sites (*vacant*)
17. Deposition landscape	T, M	Waste landscapes (*available locations*)
18. Modular construction elements	D, R, T, G, M	[NON] (*requirement in architecture*)
Recycling		
19. Land farming	T, G, M	Waste landscapes (*available locations near water*)
20. On-site deconstruction & separation	D, R, T	Demolition sites (*source location*)
21. Biobased material/facilities	D, R, T, G, M	Strategic/logistic location (*for implementation*)
22. Recycled material/facilities	D, R, T, G, M	Strategic/logistic location (*for implementation*)
23. Material deposition/market	M	Strategic/logistic location (*for implementation*)
24. Active building stock environment	D, R, T, G, M	All urban environment (*transformation option*)

Table 5

Related conditions and geographical data for the application of the solutiosn

D= Densification
R= Retrofitting
T= Transformation
G= Greenfield
M= Maintenance

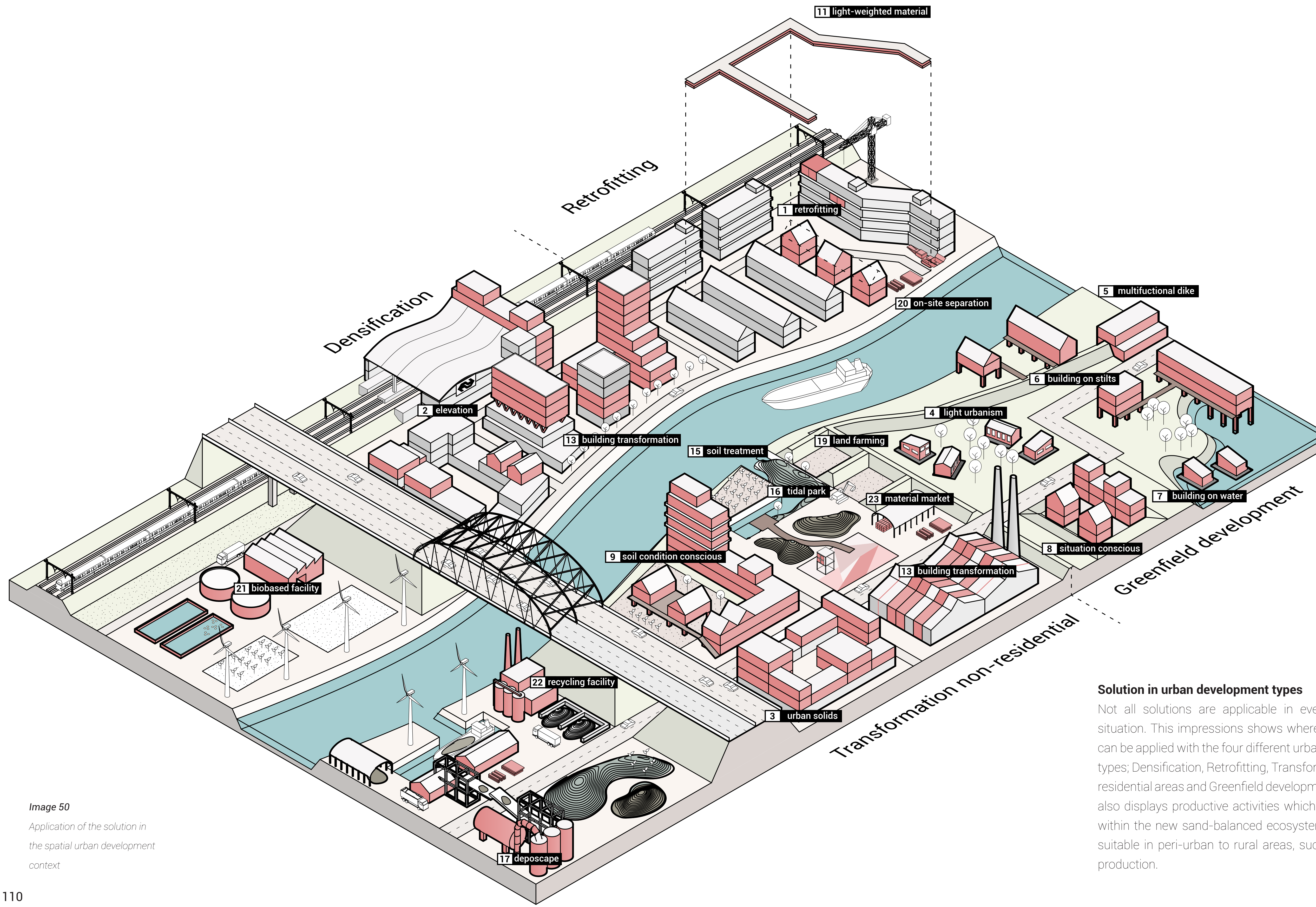


Image 50

Application of the solution in the spatial urban development context

Solution in urban development types

Not all solutions are applicable in every location or situation. This impressions shows where each solution can be applied with the four different urban development types; Densification, Retrofitting, Transformation of non-residential areas and Greenfield development. The image also displays productive activities which are necessary within the new sand-balanced ecosystem but are best suitable in peri-urban to rural areas, such as biobased production.

7.3 Conclusion: solutions for a post-sand city

This chapter answers the research question ***'How can urban design improve the material consumption and impact of construction sand and gravel?'***. Therefore, it reaches the objective ***'Develop an approach in urban design where material impact and application is better exposed in the design process'***. On the other hand, it sets the foundation for the objectives ***'Improve the metabolic balance by applying solutions in spatial and urban planning which requires less primary sand and gravel'***.

The Catalogue of Solution and material consciousness approach emphasise that improvement and reduction can be done on different level within the urban ecosystem. The improvement towards a sand-balanced ecosystem needs a be multiscalar and the interrelation between scales needs to be designed or highlighted.

The material consciousness approach integrates the four stages of a construction process from the lifecycle perspective (situation, construction, maintenance and end-of-life). The approach is expanded by its relation with material consumption and the possibilities to integrate the material efficiency strategies (prevention, reuse, recycle) within the design. This helps the designer to make well-founded decision in planning and to point out critical nodes within the system which need to be changed. These changes might be beyond the profession of an urban designer, such as technical innovation within recycling options or biobased solutions, but can be used as input and feedback for researchers within this field.

The solutions, which are integrated in the Catalogue of Solutions, contribute to the material efficiency strategies. This gives the designer insight in the possibilities which can be applied in urban design projects. The solutions are also translated into the spatial context and the four development types. This spatial translation is visualised in image 50 where each solution is located in the most suitable situation and condition. The visualisation also includes the productive landscapes which are necessary for the facilitation of a circular construction ecosystem.

In the next chapter, the material conscious approach and the related solutions will be applied on five urban design related conditions through research by design.

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A sand-sensitive Rijnmond-Drechsteden region

8. Design Research

The sand-sensitive solutions and evaluation of the construction sand and gravel metabolism scenario are the foundation for the design research where the aim is to reduce the sand demand in the region. This reduction by design is done on two scales in an iterative process. The two scales are RMDS region scale and urban design scale. The two scales are influencing each other because small scale implementation sometimes requires larger scale policies or influences development elsewhere. For example, the application of recycled concrete in a development with net growth (e.g. urban expansion) requires input from demolition activities or material deposits from somewhere else in the region. The urban design scales includes several cases of urban development. These are; urban densification, urban transformation and urban expansion.

Source: AIR, 2018

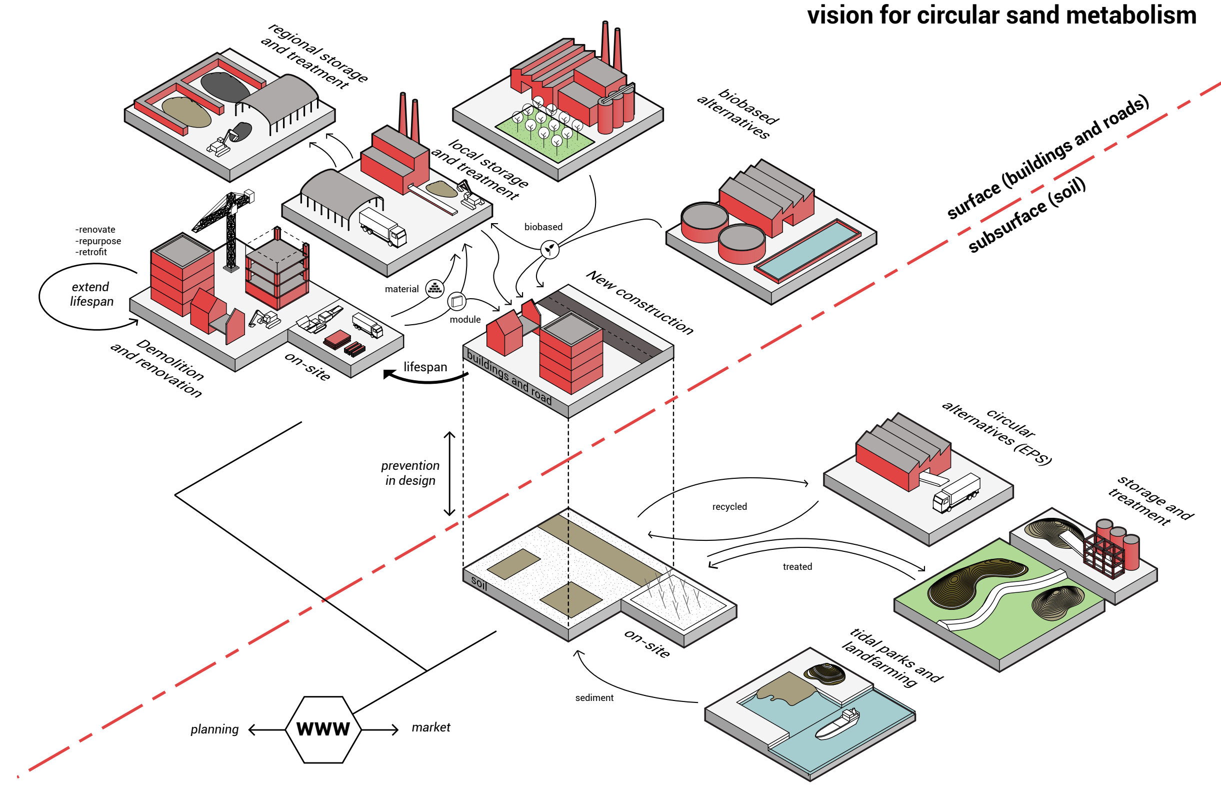
8.1 Towards a sand-balanced RMDS region

The aim of the research is to reduce primary construction sand and gravel consumption in the context of the RMDS region. This can be done by becoming more efficient with our material, as explained in the previous chapter. The design research focuses on the urban design scale but before this part is elaborated, it is important to set up the regional improved metabolic context where each project will react to or linked with. The new regional metabolism is based on the material efficiency strategies and focus on two major flows, sand and gravel in concrete and fill sand for building site preparation. These two flows are the most related to urban design and the conditions which will be explored in the research by design study.

In the circular sand and gravel metabolsim, a first approach is to reduce or prevent demolition waste by extending the lifespan of a building by repurposing or renovating (accoding to both Ladder of Landsink and material efficiency stratgy). If the construction will be demolished, materials or building components will be reused in new construction via reusing material in new components or as a new modular element in new construction. The material will be stored temporarily on a local or regional storage facility based on the supply and demand in the region. This supply and demand will be monitored for application in the market or planning. New construction will use secondary material or components or biobased material from regional production sites which can be linked with other urban waste flows

Image 51
vision for a circular sand metabolism

vision for circular sand metabolism

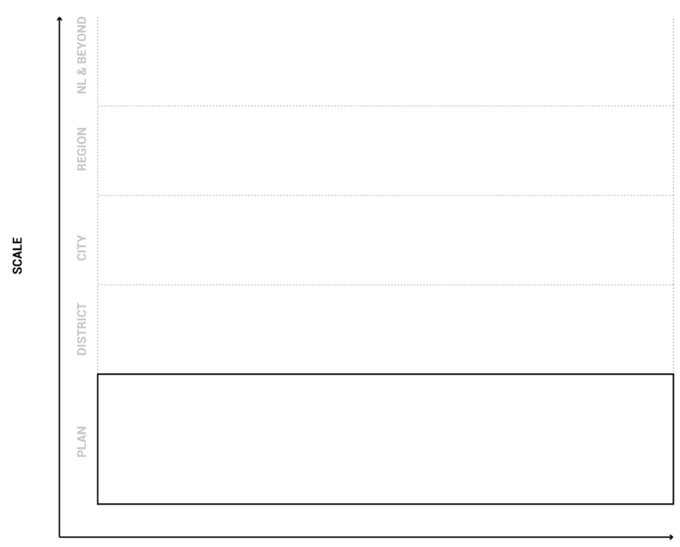


and innovation. Each new construction will function as a long-lasting material storage which will be a source for new material after its lifespan. The material needed in building site preparation will also use secondary or biobased materials. The contaminated soils will be actively cleaned on deposition and treatment sites. Dredged sediment will, instead of relocation, be used, stored and, if necessary, treated in tidal parks where it eventually can be used as foundation material. Substitutes can be found in secondary sources or biobased options (such as EPS). Each construction needs to become material efficient by reducing the demand of material by smart design decisions.

The new regional metabolism is a vision which needs to be research further for (technical and quantitative) feasibility and environmental impact. The design research will elaborate on the impact and possibilities on the smaller scale based on the four urban development types.

8.2 Approach and method

The research on the sand and gravel metabolism in the RMDS region visualised a scenario of the consumption of future urban development and construction. The design research continues on this scenario by firstly focusing on notable locations and situation within the region and secondly by improving and exploring possible sand-reducing alterations by urban design. The regional scenario is a business as usual situation which is based on generic assumptions and principles. In order to evaluate and improve urban design situation, a similar approach is executed on the small scale. This approach, partly explained in the methodology chapter, sets up a business as usual design* (BaU) in each situation where improvements (for City



* The BaU design is based on reference study and spatial ensembles from projects with a similar diversity and density.

Image 52
Territorial-Metabolism Life-Cycle scheme

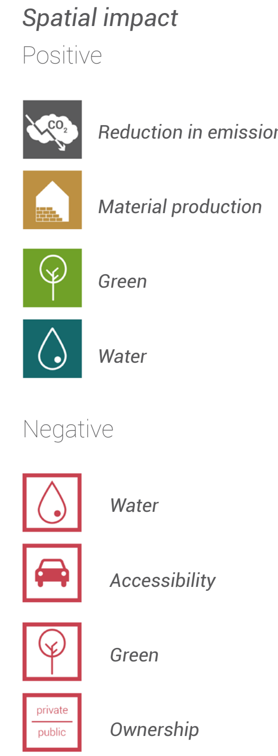


Image 53
Spatial impact icons

without Sand design; CwS) can both react and evaluate on, and analyses the material consumption and environmental impact on urban design scale. Both BaU and CwS uses the same products for transparency and evaluation, which are; (1) design in isometric projection, (2) territorial metabolic life-cycle assessment (TM-LCA) scheme based on the urban design and (3) a design impression.

The isometric projection visualises the spatial implication within the urban context which causes a metabolic impact on the material consumption. This material consumption is visualised in the territorial metabolic life-cycle assessment scheme where the generally four steps in the life-cycle of the design are highlighted; situation/demolition stage, design/construction stage, maintenance scenario and end-of-life scenario. These chronological steps are positioned at the horizontal axis of the scheme and corresponds with the NEN-EN 15804:2012+A1 LCA model for building construction. On the vertical axis, a spatial division is made in five scales; design, district, city, region and NL (Netherlands) & beyond. In this graph, the material flows caused by the design can be visualised and linked with environmental impact and stages based on the above mentioned LCA-model standard. The material flows are drawn in the scheme as a sankey diagram where the weight of the arrow represents the quantity. Next to the environmental impact, spatial impact and requirements are also visualised within the design impression. The spatial impact is highlighted with icons representing negative (for example a decline in accessibility) or positive impacts (for example an increase in green or biodiversity).

The results from each location will function as an example to evaluate the impact of the different improvements which will be used in an extrapolation to regional level where an assumption of the feasibility of a sand-balanced RMDS region can be visualised and discussed. Appendix D consist of early design studies which contributed to the development of the design approach and extrapolation method.

Situation — *-Situation plan*, *-Material stock*, *-Situation impression*

↓

Design (Business as usual) — *-Design (isometric)*, *-TM-LCA*, *-Design impression*

↓

CwS ReDesign A, B, etc. — *-Design (isometric)*, *-TM-LCA*, *-Design impression*

Image 54
Design method for the material consciousness approach

8.3 Focus locations

Based on the spatial outcomes of the research on the sand metabolism within the RMDS region, three focus locations are chosen for further design research. These locations represent the four urban development typologies; greenfield development, densification, renovation and transformation of non-residential areas. All of the location have a significant impact on both construction and demolition dynamics as urban metabolic activities related to subsidence and fill sand. The locations are:

ROTTERDAM - OMMOORD (Transformation of NRB)

In the neighbourhood of Rotterdam Ommoord is the potential to transform a current industrial/commercial site into a residential neighbourhood, the Vlambloem. However, this area is prone to subsidence which makes it both new development (Vlambloem) and maintenance (Roosbuurt) in this area an interesting design topic for the research.

This design study explores the possibilities of 'material reduction (circularity, urban metabolism)' in the urban design and maintenance of transformation of areas in subsidence-prone urban areas.

DORDRECHT - SPOORZONE/KRISPIJN (Densification & retrofitting)

The Spoorzone in Dordrecht is designated as potential area for densification. This area includes former industrial sites (comparable to Ommoord) but also inner-urban mixed areas where low-density should be increased or gaps in the urban morphology should filled. Located next to the Spoorzone is the post-war neighbourhood Krispijn where planned but also potential retrofitting is designated. These activities cause several similar flows and construction and are therefore interesting for this design research.

This design study explores the possibilities of 'material reduction (circularity, urban metabolism)' in the urban design of densification and retrofitting challenges in urban areas.

SPIJKENISSE - VRIESLAND (Greenfield development)

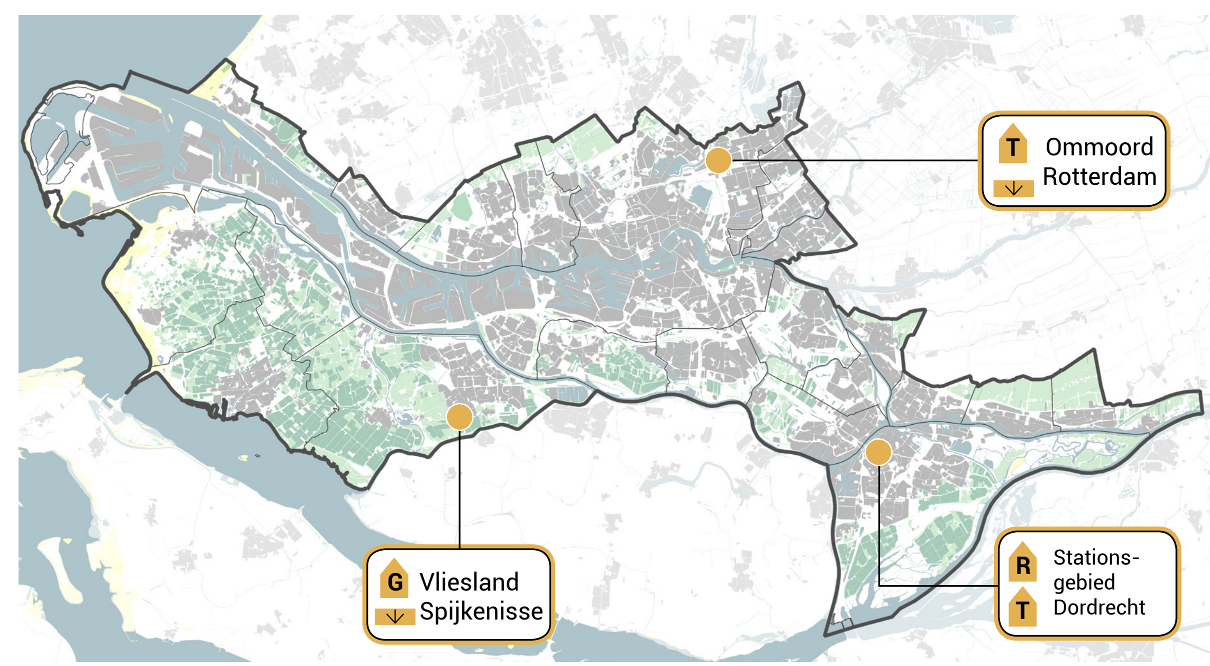
Greenfield development is the least politically favourable type of urban development. Currently discussion is going on whether or not the housing demand should be realised on greenfield outside current urban areas (source +EU net take). However, built environments drawn by the province enclose greenfield which are thus, according to the Deltametropool study, potential for urban development. However, these areas are most of the time located on weak soil and therefor requires material input for building site preparation.

One of the potential location is a possible expansion of the neighbourhood Vriesland in Spijkenisse. This area is located on a weak peat soil which is prone to subsidence. Water- and building site management are required for the development of this area.

This design study explores the possibilities of 'material reduction (circularity, urban metabolism)' in the urban design of expansion areas on weak soil.

Image 55

Overview of the focus locations in the RMDS region



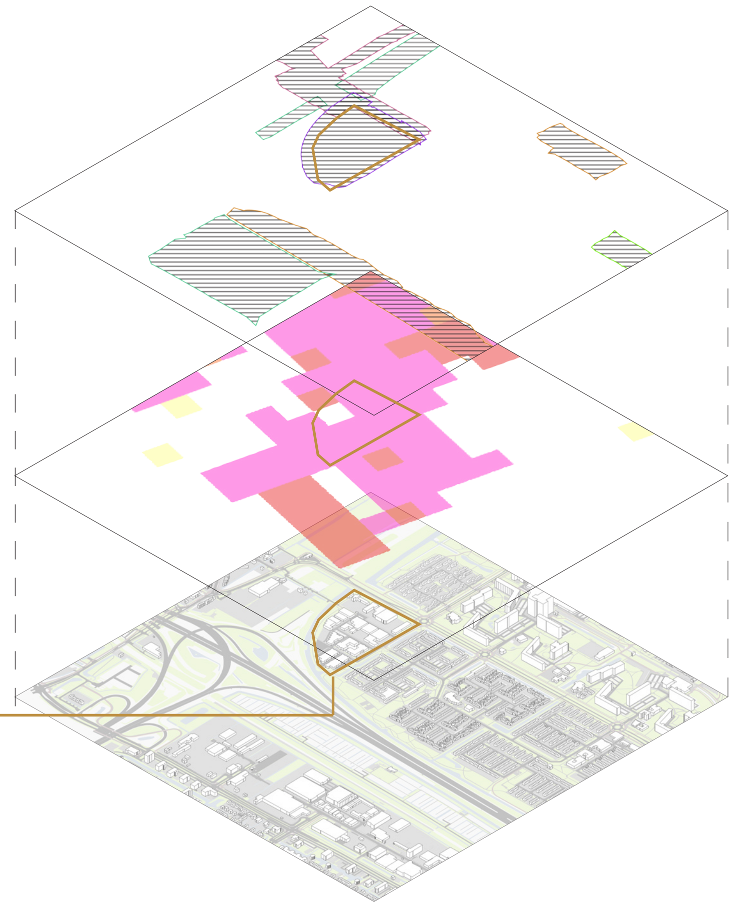


Image 56
Spatial analysis of Ommoord - Vlambloem

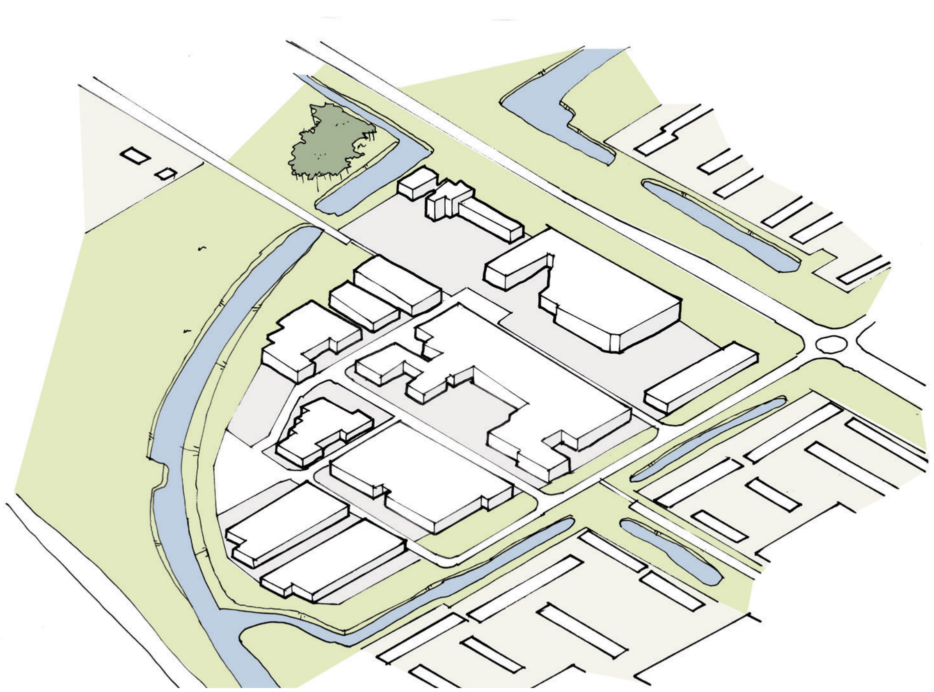


Image 57
Isometric situation of Ommoord - Vlambloem

8.4 Focus: Ommoord - Vlambloem
Situation

The Vlambloem area is located southwest in the neighbourhood Ommoord of Rotterdam. Currently, it is an industrial site with commercial building boxes with monofunctional space. Due to its surface function, the top soil could be contaminated and the area is prone to subsidence to next 20-30 years with an expectation of 60cm (2cm/y). Stock is calculated based on material intensity estimation of non-residential building and building site preparation method based on the most generic method in 70s neighbourhoods (partial filling)

Image 58
Material stock of Ommoord - Vlambloem

Concrete (Building)
34.639 tonnes

Asphalt (Road)
52 tonnes

***Fill sand** (Building site preparation)*
93.409 tonnes

Image 59
Situation impression of Ommoord - Vlambloem

8.4.1 Busines as usual

According to the study of Deltametropool, the location is potential for a residential area with a density of 30 dwellings/ha with a mixed housing stock. Based on a simple spatial concept and the reference designs and spatial ensembles of Park Zestienhoven (Rotterdam) and Lagewei (Barendrecht), a business as usual design is constructed (see map and image). The construction and maintenance causes outflow of contaminated soil, concrete from the buildings and asphalt (because a new urban fabric is constructed). Inflow will be sand for building site preparation, concrete for buildings and asphalt. Sand inflow is necessary for subsidence maintenance.

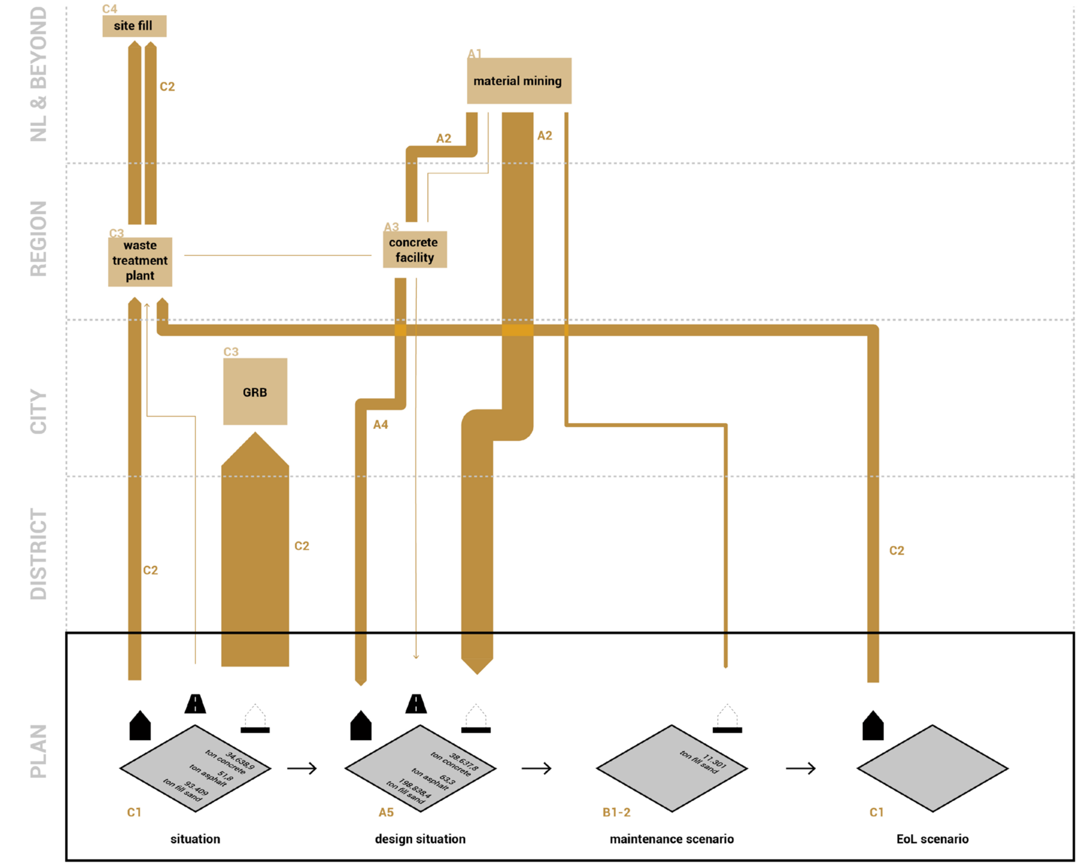


Image 60

Isometric map of the business as usual design of Ommoord - Vlambloem

Image 61 (right-top)

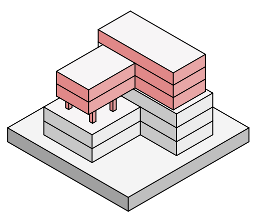
TM-LCA of the business as usual design of Ommoord - Vlambloem

Image 62 (right-bottom)

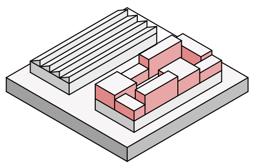
Impression of the business as usual design of Ommoord - Vlambloem

8.4.2 CwS01: Transformation of industrial buildings

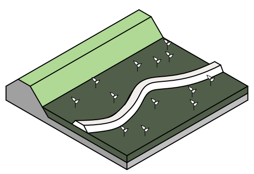
The first design improvement is done by preventing the outflow and replacement of material to happen. This is done by treating the soil locally through phytoremediation and removing the asphalt and road structure from the area. Current building remains and new structures are built on top of the old industrial boxes. The accessibility of the area is decreased because platform are now the only way of transport through the area. The area also remains an industrial atmosphere but can also introduce local manufacturing industry in the old industry boxes. The transformation of the road and public space towards phytoremediation field increases the biodiversity and water storage capacity in the area. Because of the absence of road structure, infrastructure for electricity e.g. also need to be integrated differently through for example an autarkic building systems. The only inflow of sand-based material is concrete for construction which can be introduced as modular components which originate from the modular stock or recycled elements from urban mining.



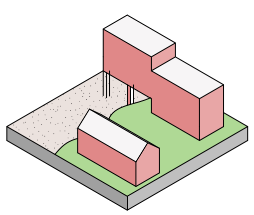
#2: densification by elevation



#13: building transformation



#15: soil treatment



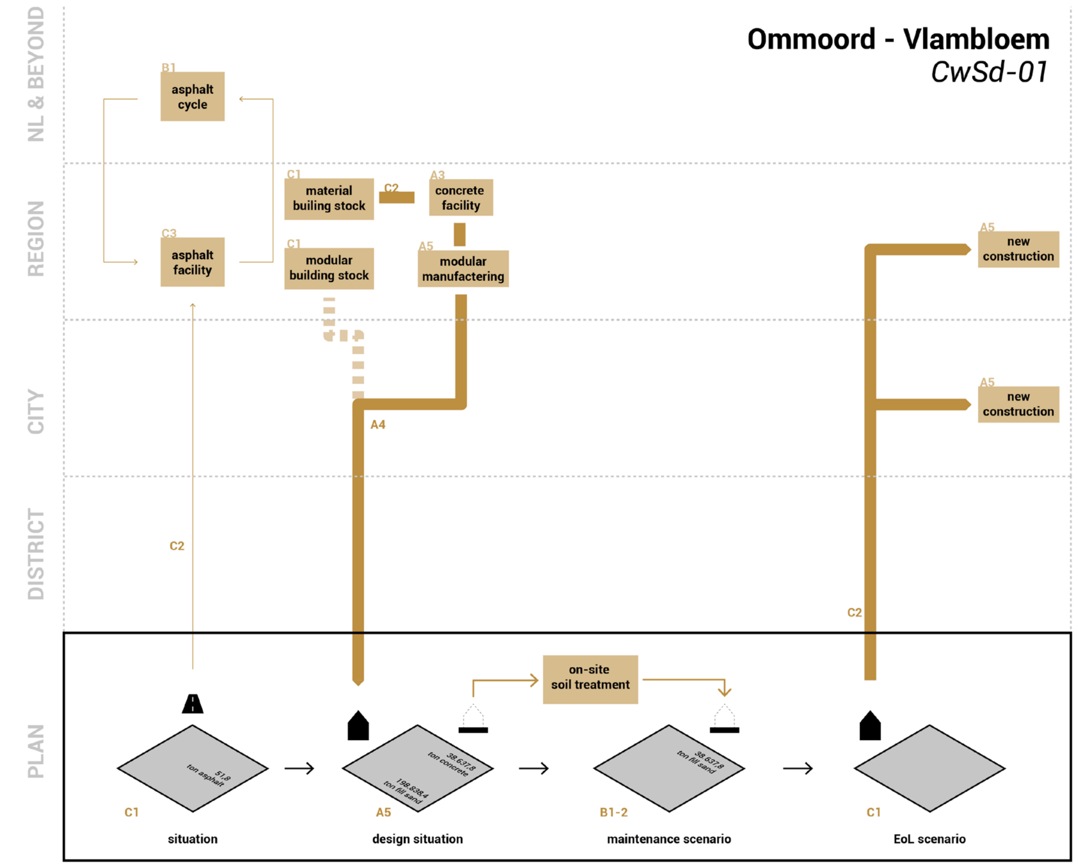
#19: soil condition conscious

Image 63
Applied solutions in CwS01 design

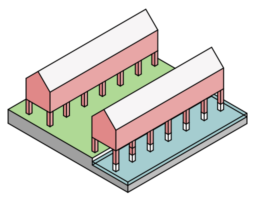
Image 64
Isometric map of the CwS01 design of Ommoord - Vlambloem

Image 65 (right-top)
TM-LCA of the CwS01 design of Ommoord - Vlambloem

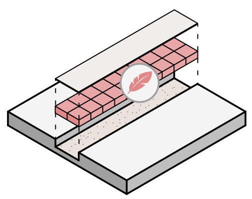
Image 66 (right-bottom)
Impression of the CwS01 of Ommoord - Vlambloem



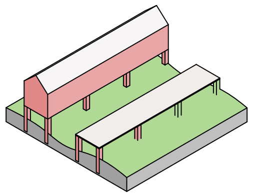
8.4.3 CwS02: Living platforms



#6: building on stilts



#11: light-weighted material



#10: allow subsidence

The current urban structure is used in the second design but all other material are removed from the area. The contaminated fill sand is transported to deposcapes where it can be treated for secondary use. On-site, fill sand is not introduced because the new construction area built on piles and are connected to the road, as a dike, via platforms. The road is the only pressure structure in the area but the foundation is updated with EPS (Expanded Polystyrene) which is a light-weighted material and can become available via urban mining. This design creates a more greener environment where the areas within the urban fabric can become wetlands. The introduction of new building material can be done with modular elements recycled from the demolition of the former industrial buildings. These elements can be changed during the buildings lifespan and removed and reused at the end-of-life. This also applies for the EPS used in the road construction.

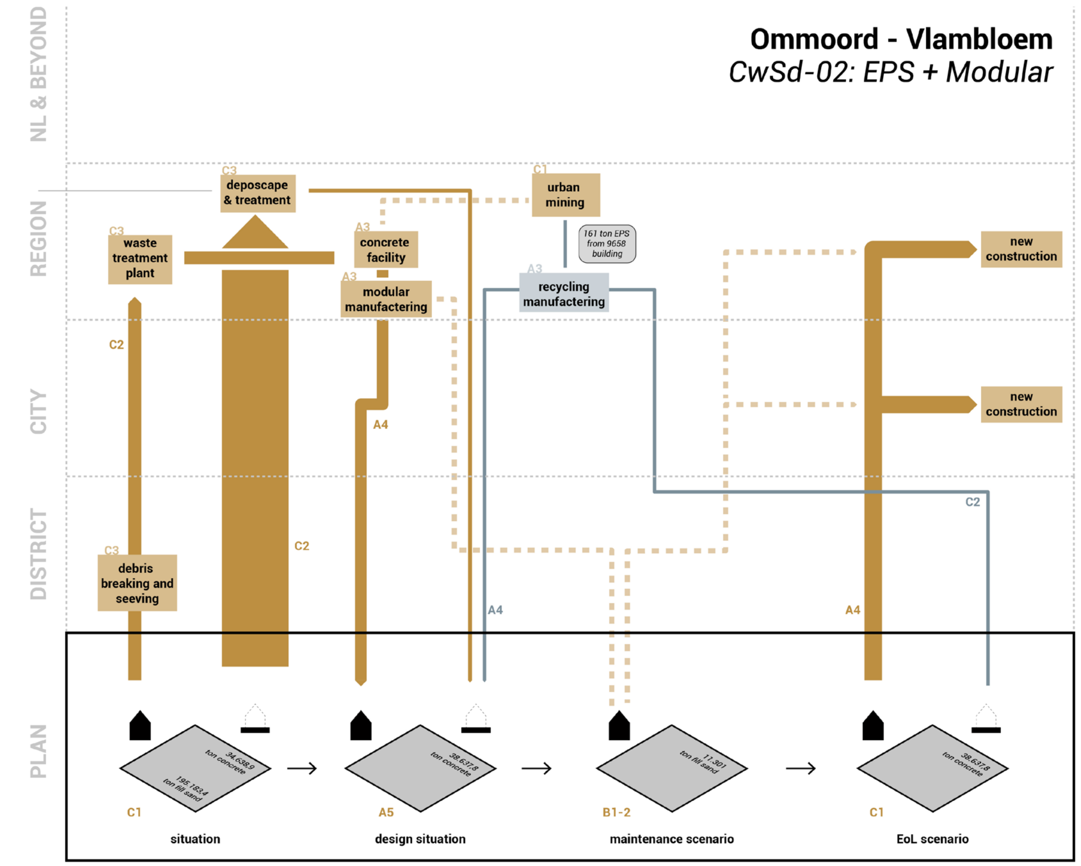


Image 67

Applied solutions in CwS02 design

Image 68

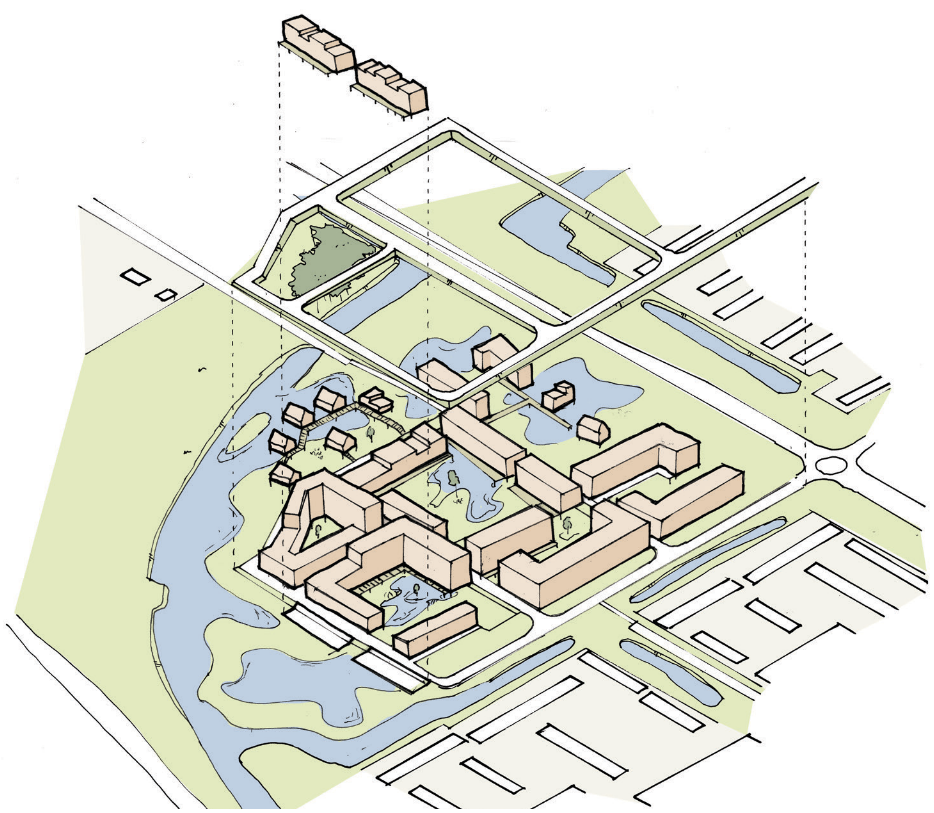
Isometric map of the CwS02 design of Ommoord - Vlambloem

Image 69 (right-top)

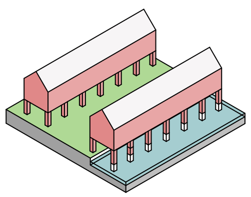
TM-LCA of the CwS02 design of Ommoord - Vlambloem

Image 70 (right-bottom)

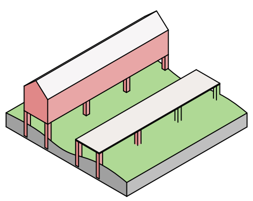
Impression of the CwS02 of Ommoord - Vlambloem



8.4.4 CwS03: Living platforms



#6: building on stilts



#15: allow subsidence

The last version continues on the second design but removes all the elements from the surface level. The current road structure is removed and replaced with a wooden platform connection. The entire surface level is transformed into a wetland where the houses are located on piles. As the previous design, a more greener environment is created but accessibility has become less due to the absence of the traditional infrastructure. Sand available from the deconstruction can be treated on deposcapes for later use elsewhere and concrete can be reused in the manufacturing of modular components for the new buildings.

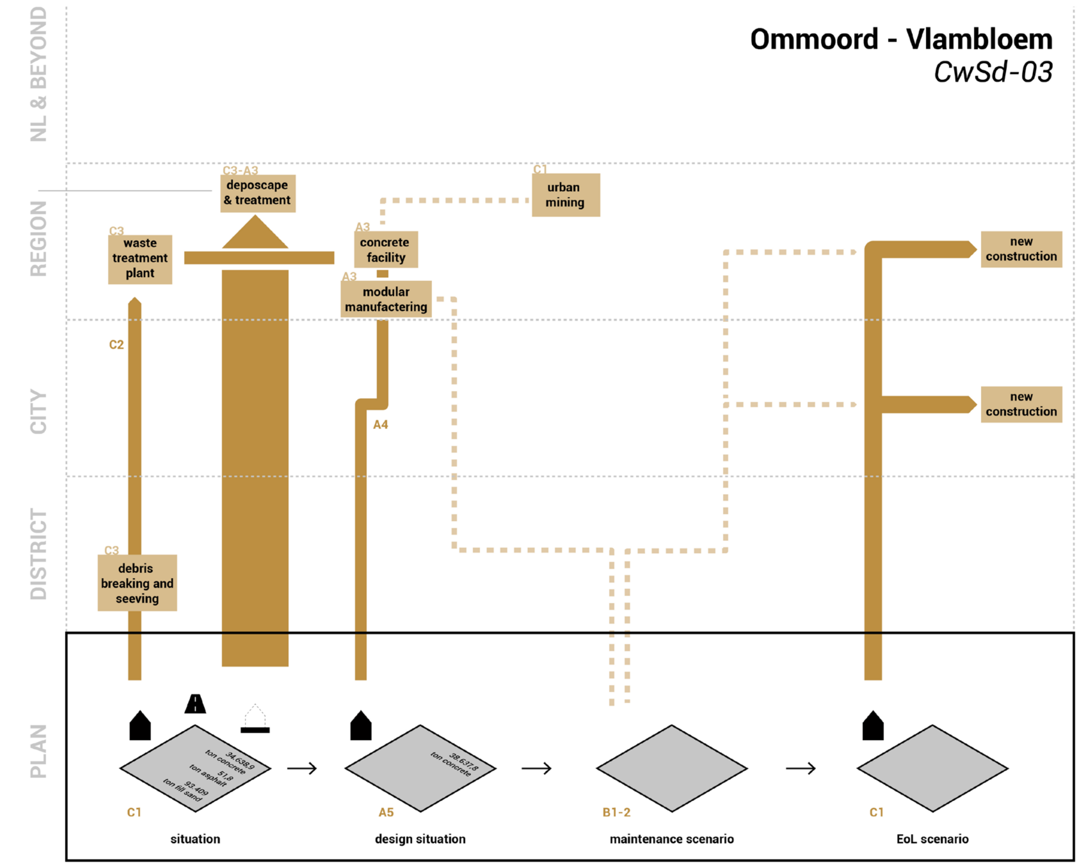
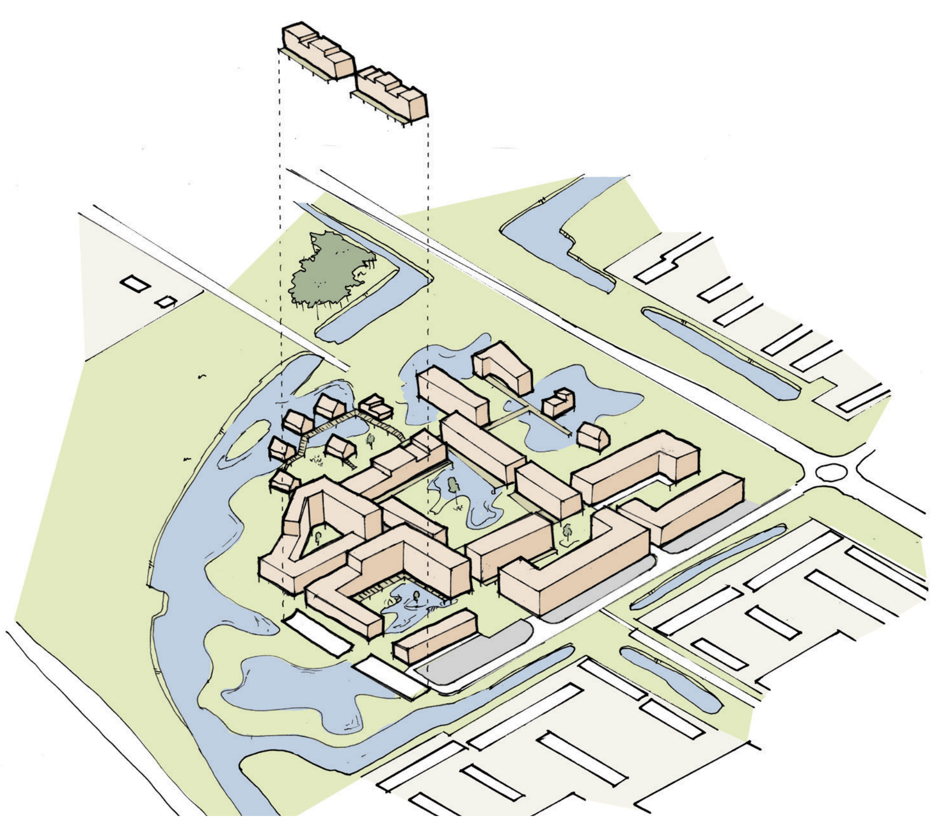


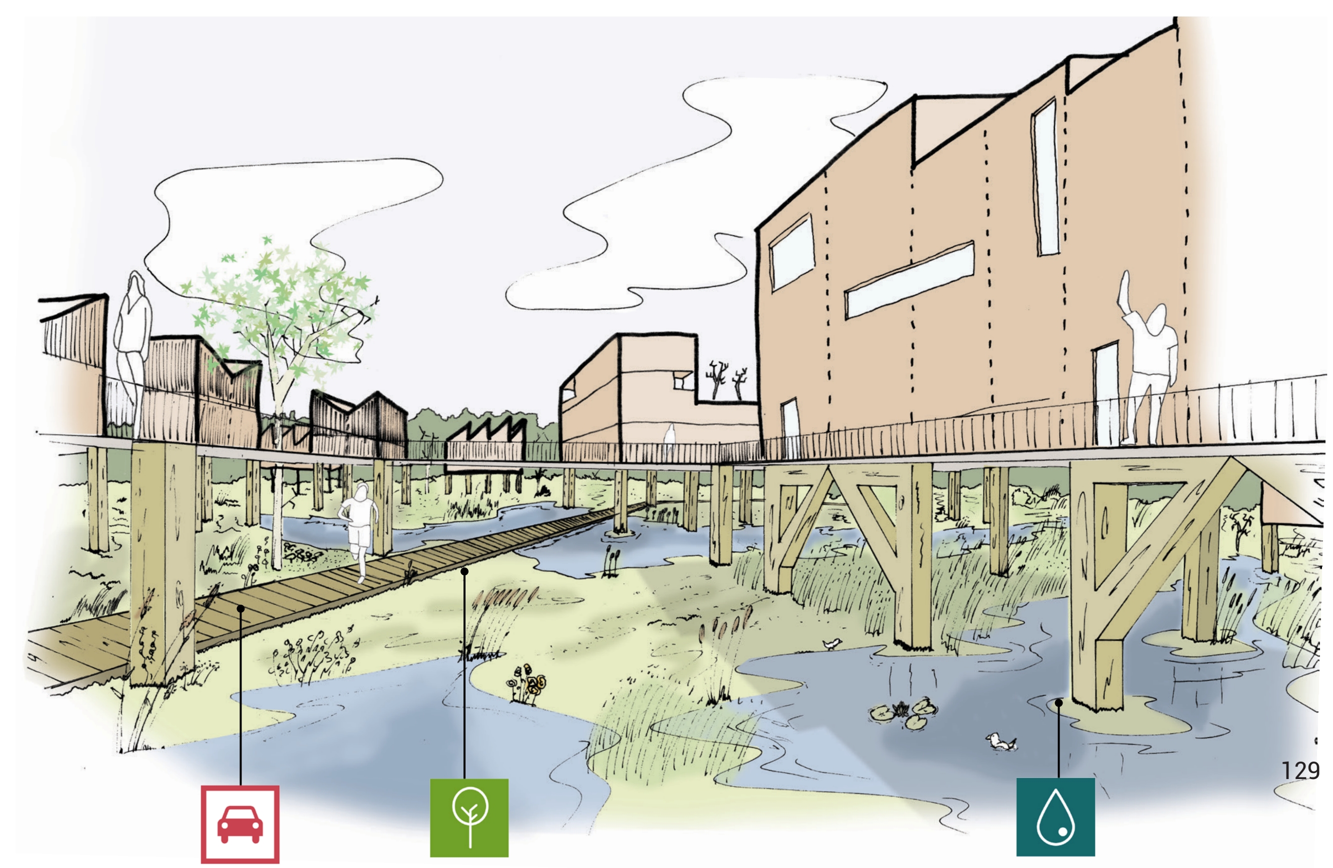
Image 71
Applied solutions in CwS03 design

Image 72
Isometric map of the CwS03 design of Ommoord - Vlambloem

Image 73 (right-top)
TM-LCA of the CwS03 design of Ommoord - Vlambloem

Image 74 (right-bottom)
Impression of the CwS03 of Ommoord - Vlambloem





8.4.5 Ommoord Vlambloem: conclusion and evaluation

The design study for Ommoord Vlambloem is an example of the condition 'transformation of non-residential areas'. Each improved design option succeeds to reduce the inflow of fill sand for building site preparation but this has a significant spatial impact resulting in new urban environments. This spatial impact might conflict with the current standard of Dutch neighbourhood. Another remark on the spatial impact is the suitability of this type of environment in this location. On the one hand, transformation of industrial buildings to residential ones (CwSd01) is generally applied in situations where the industrial buildings have a certain contribution to identity or heritage (for example the Fenixloods in Rotterdam which can be seen in Solution 2 of the appendix Catalogue of Solutions). The industrial buildings in the case of Vlambloem are functional and generic garage boxes which might not have a identity potential for the transformation. On the other hand, the two improvements with building on stilts (CwSd02&03) would be more suitable in rural environments, due to its large landscape underneath. Nevertheless, the solutions reduce the application of fill sand and subsidence maintenance. Through these designs, the average reduction of fill sand is around 95% but the reduction of primary concrete is unaltered. The improvement of this flow requires regional changes such as urban mining options and recycling facilities (as seen in the schemes on the right where improvements are done on the 'region' scale).

Due to the reduction of fill sand, the location becomes, after treatment, a source for other locations which requires fill sand. However, the treatment takes a certain period before it is applicable in other locations. The introduction of recycled material from secondary sources such as concrete and EPS also reduces the demand for primary resources but the feasibility in terms of quantity and environmental impact from transportation and treatment should be research more closely.

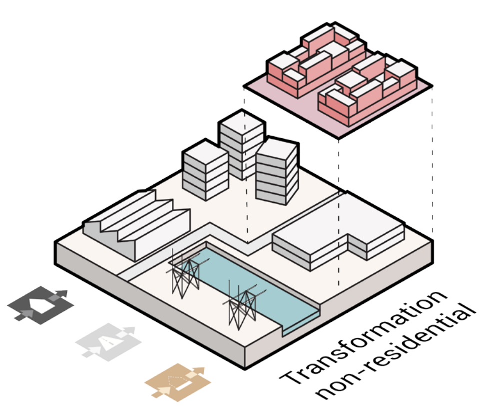


Image 75

Related condition of Ommoord - Vlambloem

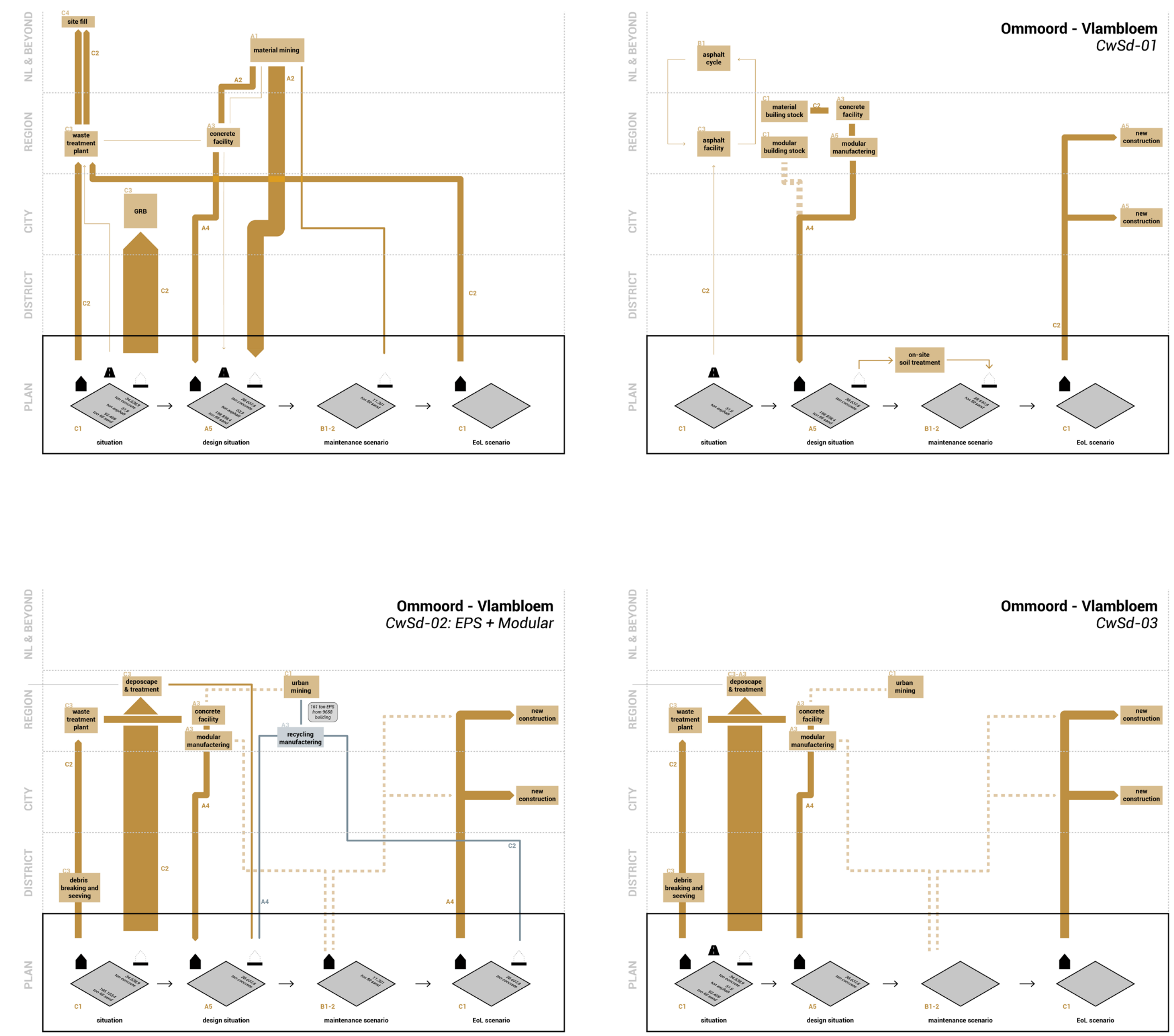


Image 76

Overview of the TM-LCA of the design research for Ommoord - Vlambloem

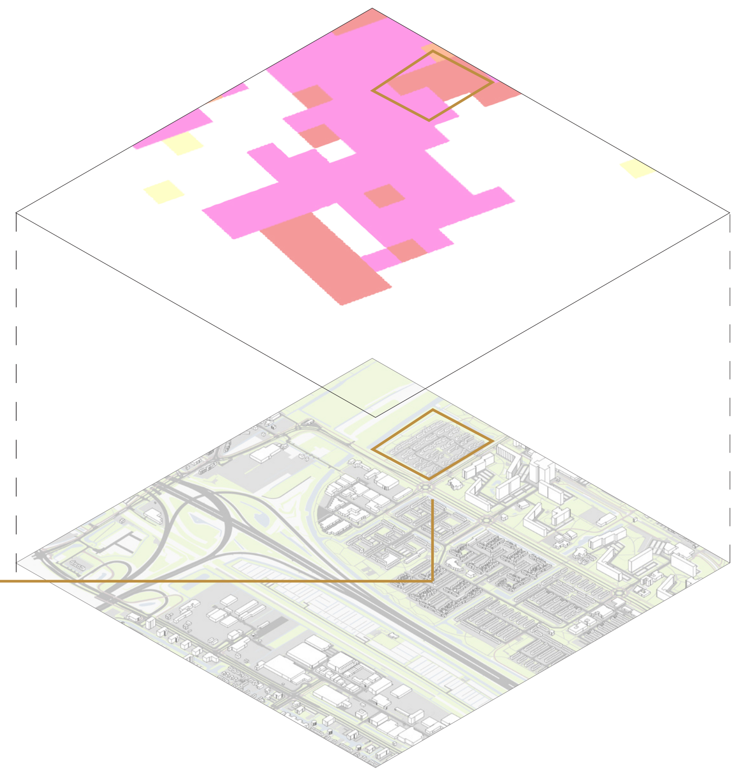


Image 77
Spatial analysis of Ommoord - Roosbuurt

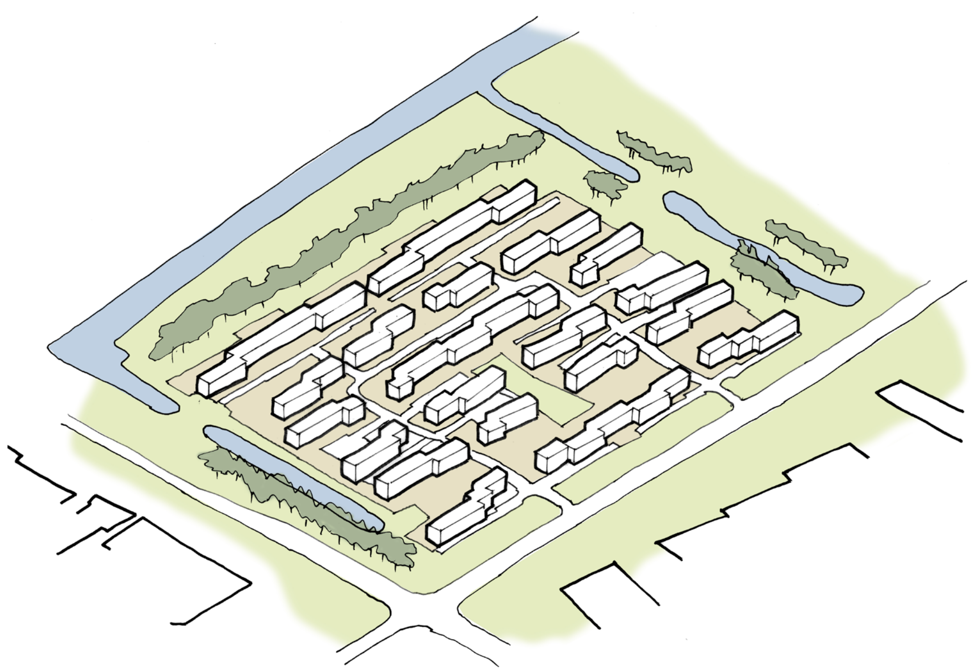


Image 78
Isometric situation of Ommoord - Roosbuurt

8.5 Focus: Ommoord - Roosbuurt
Situation

The Roosbuurt is a residential area location next to the Vlambloem area where subsidence is occurring. This event is expected to cause a subsidence of 60cm until 2050 (1-2 cm/year). This may cause water nuisance or inaccessibility because of height difference between surface level of the public space and the doorstep of buildings. The subsidence is expected to occur in both private garden and public roads and parking space. The public-private division is 40-60% (11.375m^2 and 22.750m^2) where in the public space 1/3 functions as access road and the private space has a layer of black soil.

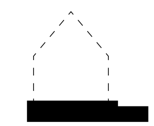
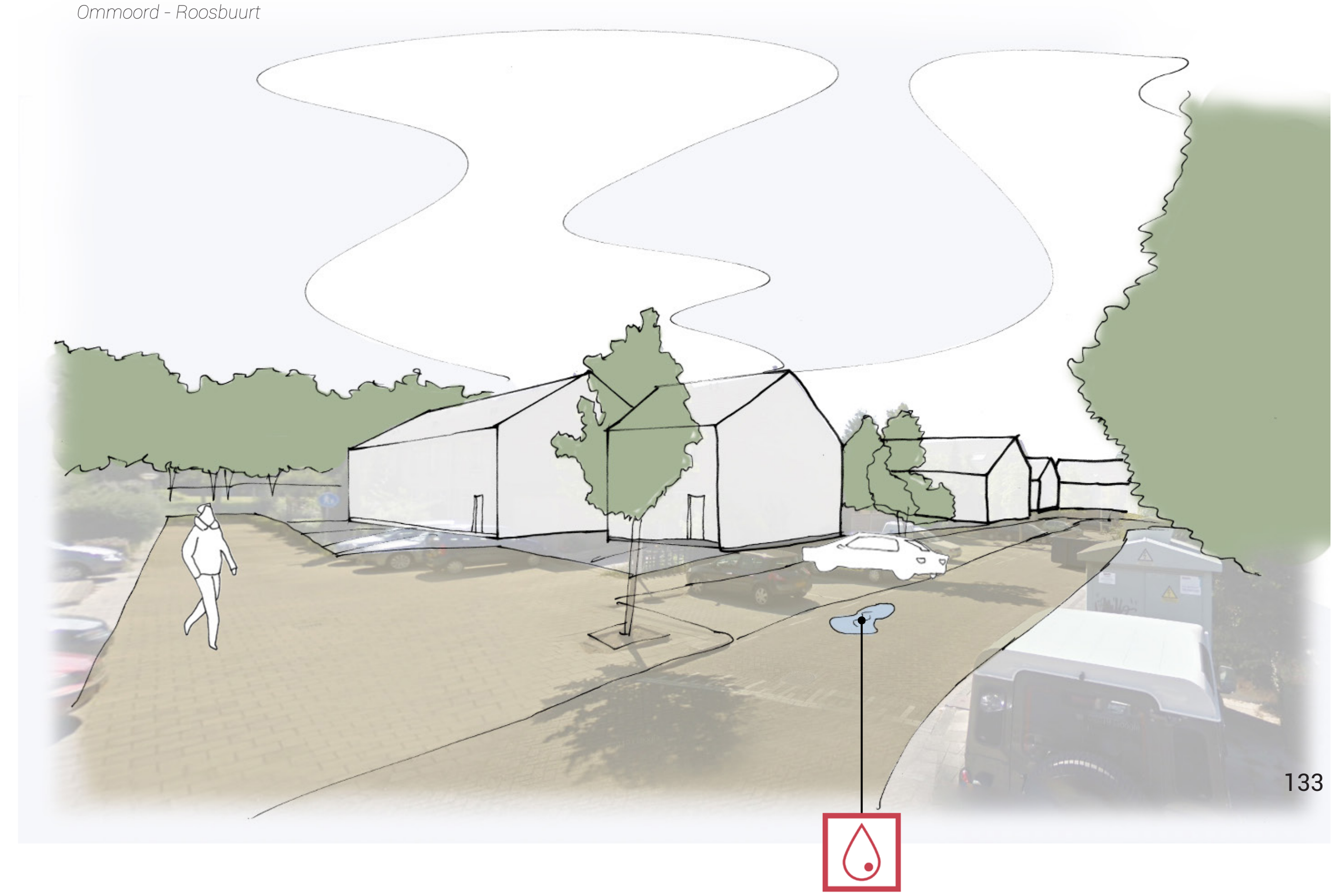


Image 79
Material stock of Ommoord - Roosbuurt

Fill sand (Building site preparation)

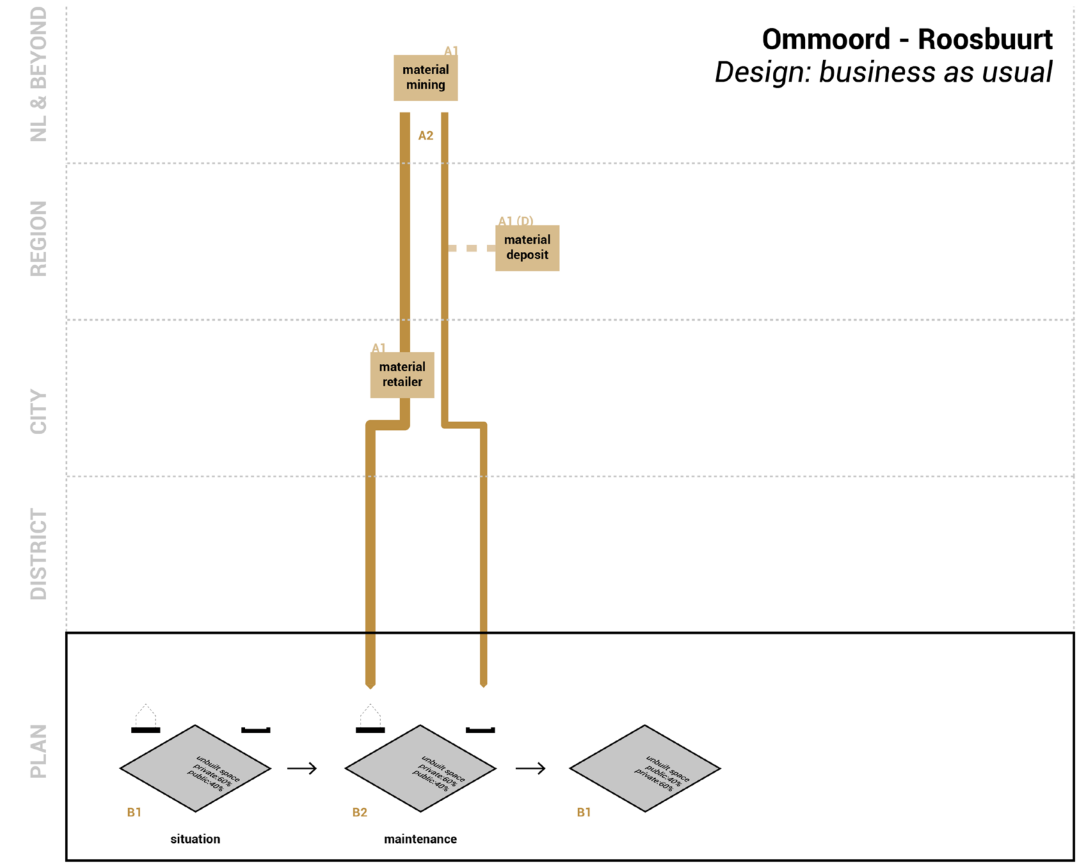
Public: 40 %	Private: 60%
21.863 tonnes	assumed 22.750m^3 of
33% under access road	black soil

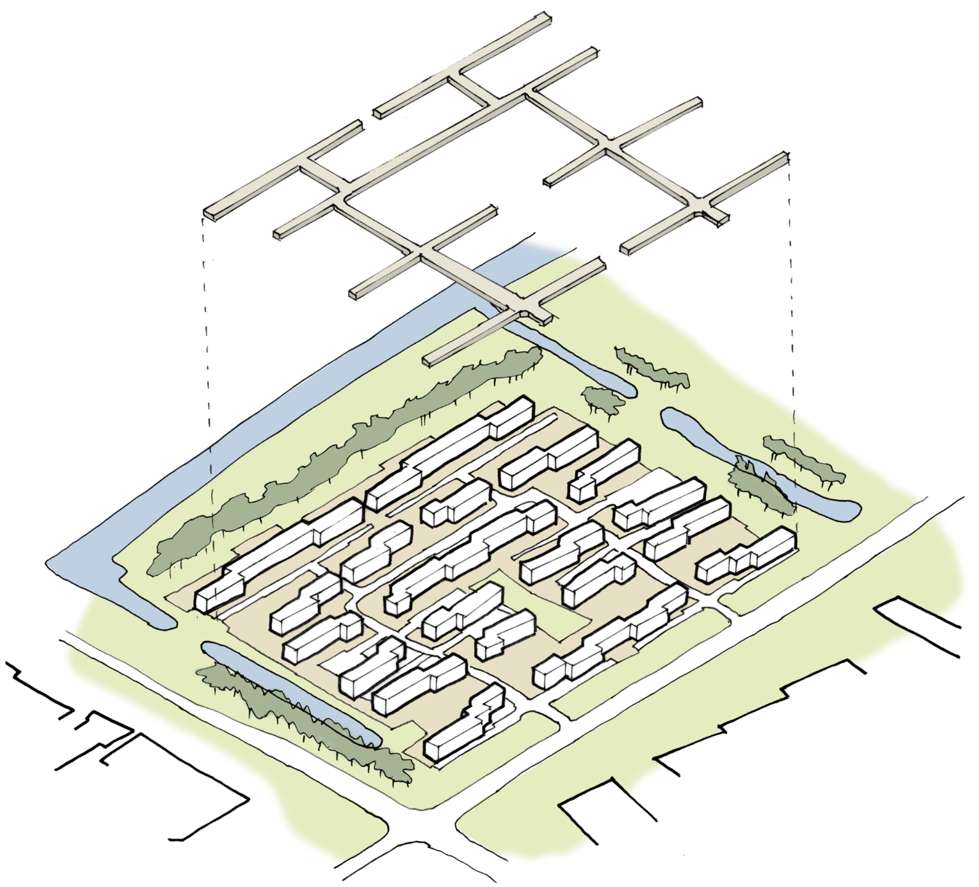
Image 80
Situation impression of Ommoord - Roosbuurt



8.5.1 Business as usual

The effect of subsidence on the surface level of the area is expected to be solved by adding sand to heighten the level. This addition can be done both for the private and public affected ground. Both requires sand from primary resources where the public ground can partly be filled with soil originated from the city's material depot where private parties need to get their sand from the retailer. This maintenance preserves the current spatial quality but some trees can be removed and replaced during the construction process.





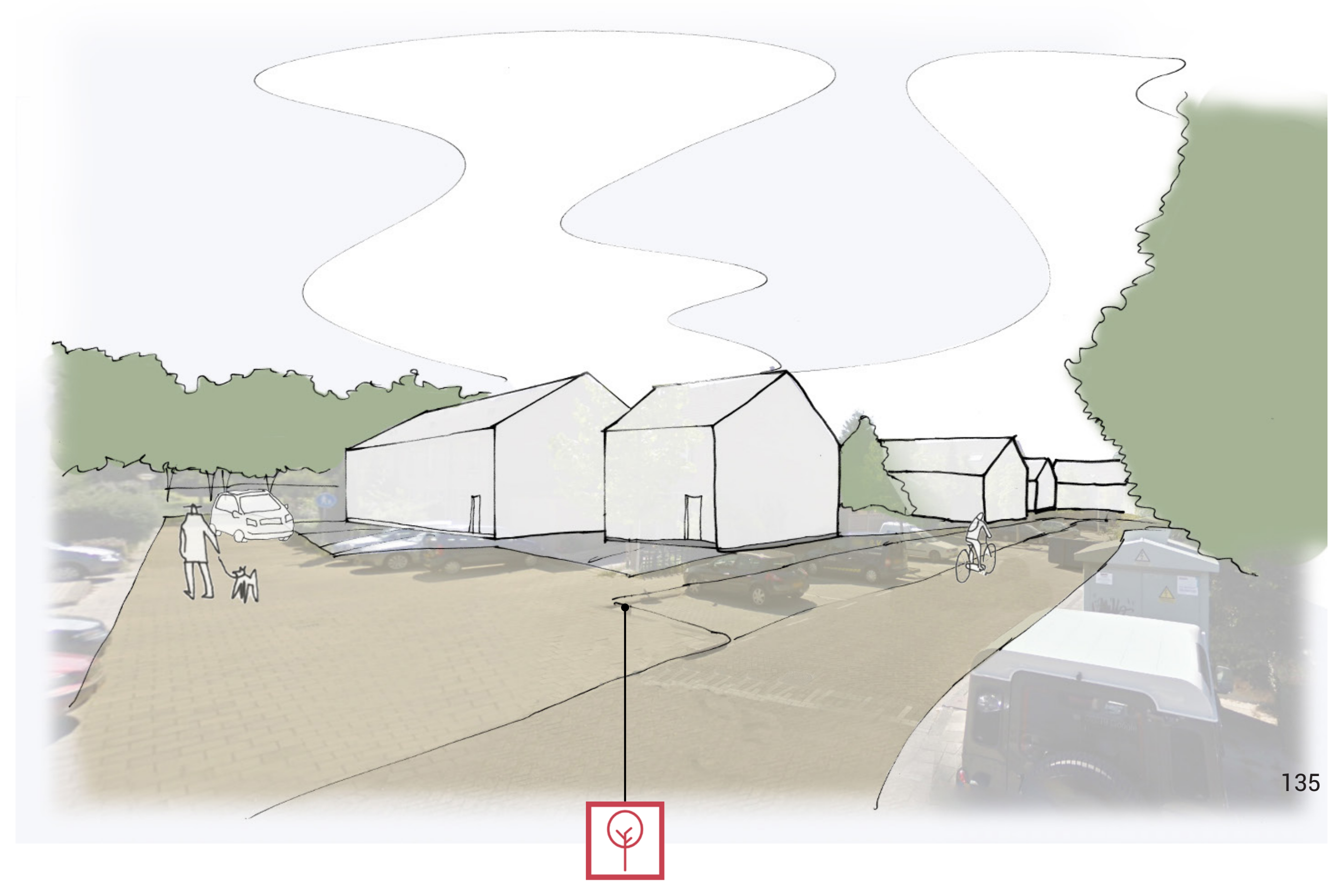


Image 81

Isometric map of the business as usual design of Ommoord - Roosbuurt

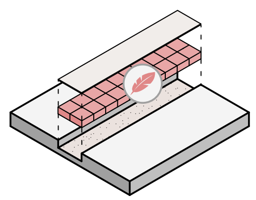
Image 82 (right-top)

TM-LCA of the business as usual design of Ommoord - Roosbuurt

Image 83 (right-bottom)

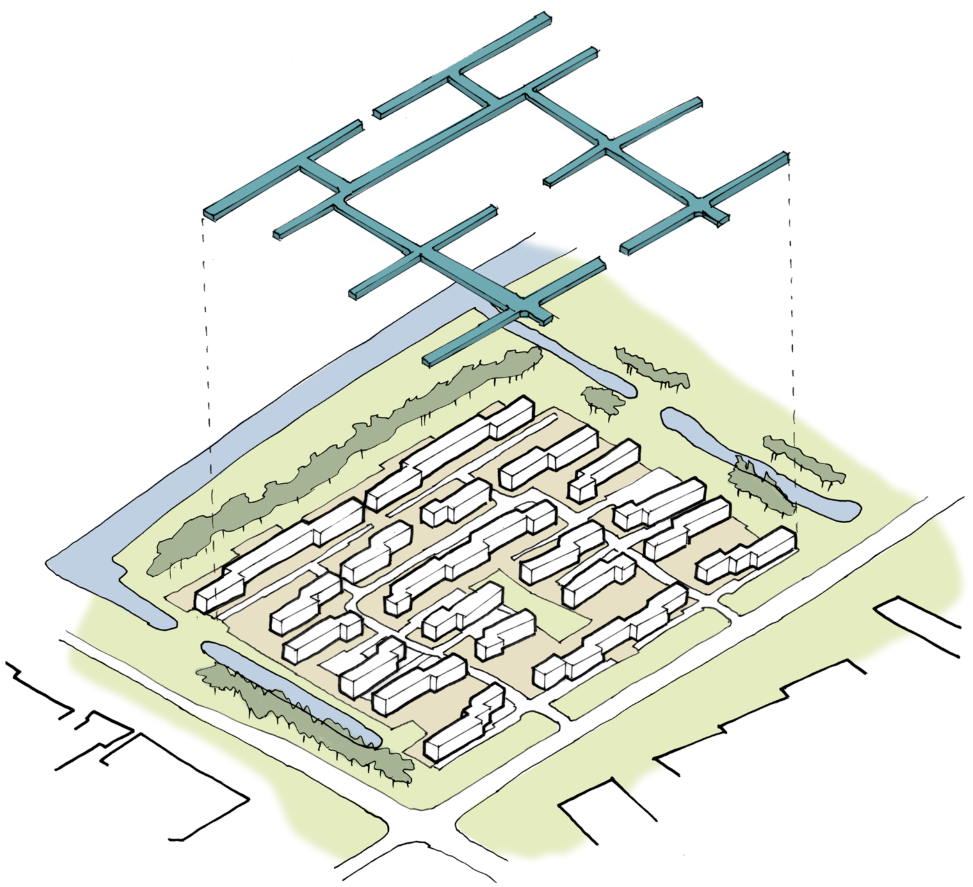
Impression of the business as usual of Ommoord - Roosbuurt

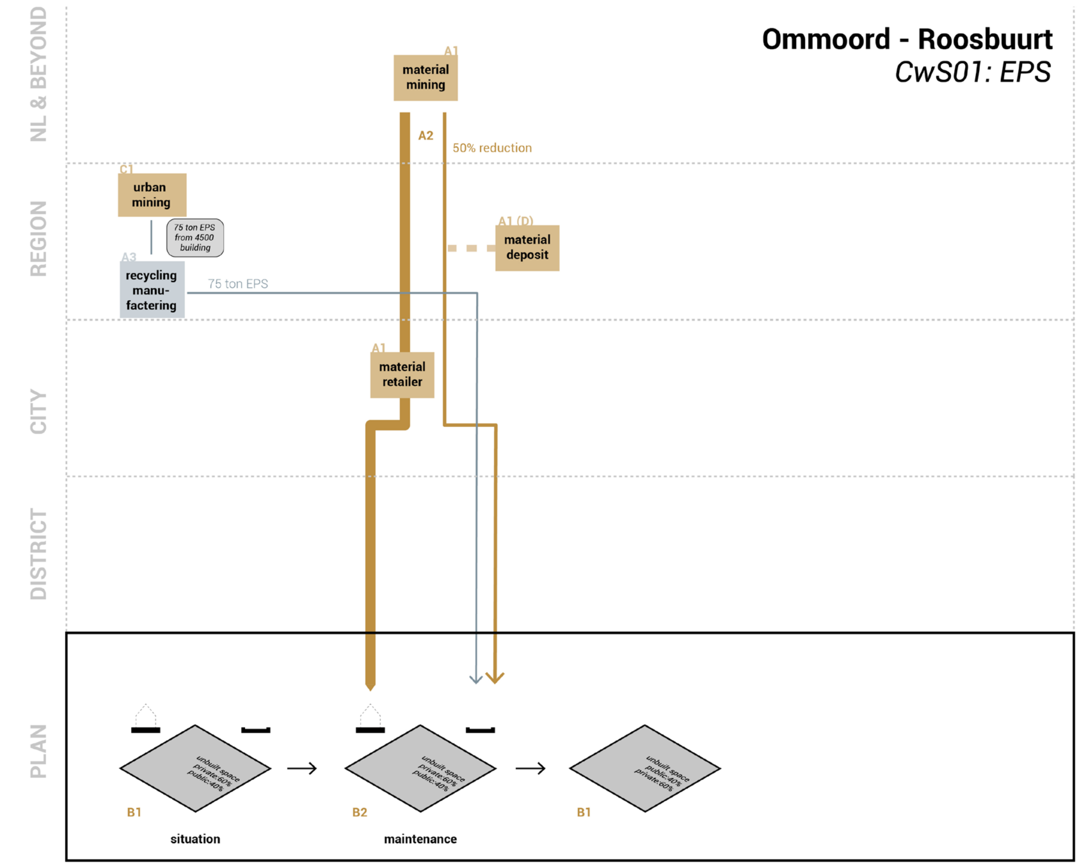
8.5.2 CwS01: Subsidence maintenance with EPS



#11: light-weighted material

The fill sand can be replaced with light-weighted material such as EPS. This material is only environmentally interesting when it is recycled from secondary sources. When it is extracted from demolished buildings, assumedly 4500 buildings are needed where EPS can be mined from. This option has the same environmental impact as the business as usual scenario.





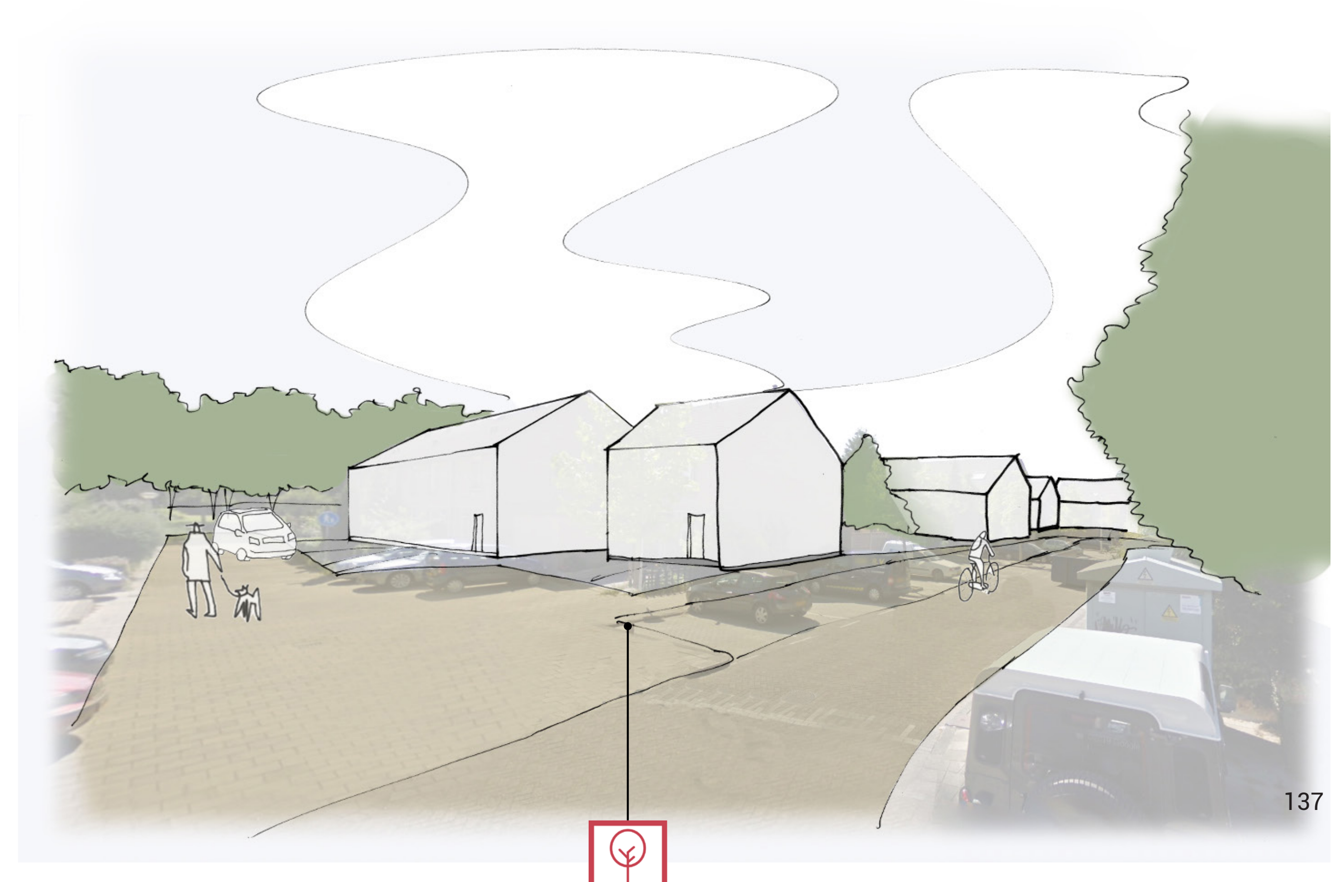


Image 84

Applied solution in CwS01 design

Image 85

Isometric map of the CwS01 design of Ommoord - Roosbuurt

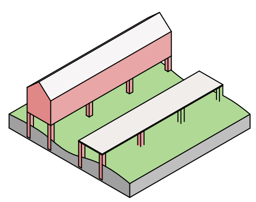
Image 86 (right-top)

TM-LCA of the CwS01 design of Ommoord - Roosbuurt

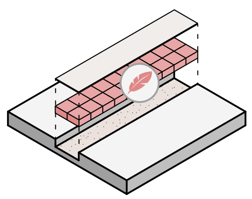
Image 87 (right-bottom)

Impression of the CwS01 of Ommoord - Roosbuurt

8.5.3 CwS02: Allow subsidence



#10: Allow subsidence



#11: light-weighted material

Another option is to reduce the areas which requires fill sand for subsidence maintenance. In this option, gardens are removed and replaced with wooden platform as terrace and connection path while the surface level can subside. The access roads are still built out of EPS but less material is needed for this construction. This option has a significant impact on the spatial environment because former private gardens become public natural spaces and accessibility becomes less because parking needs to be relocated as well. The greener environment however contribute to the water storage capacity and heat reduction in the area.

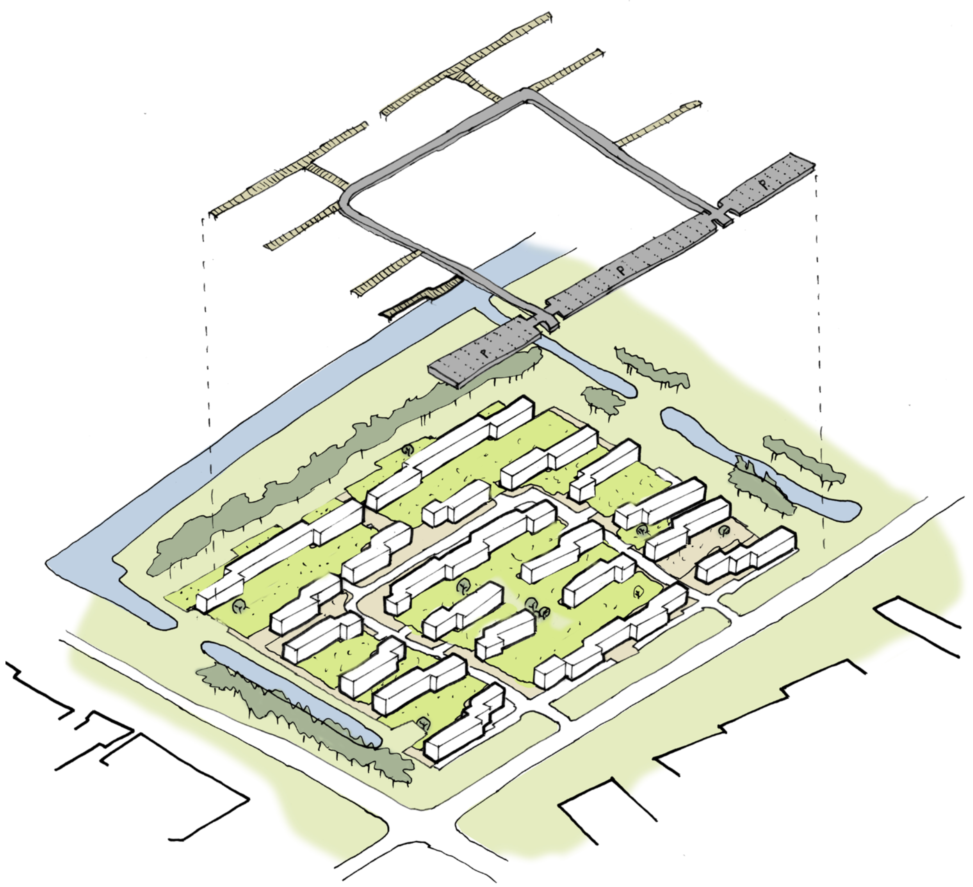


Image 88

Applied solutions in CwS02 design

Image 89

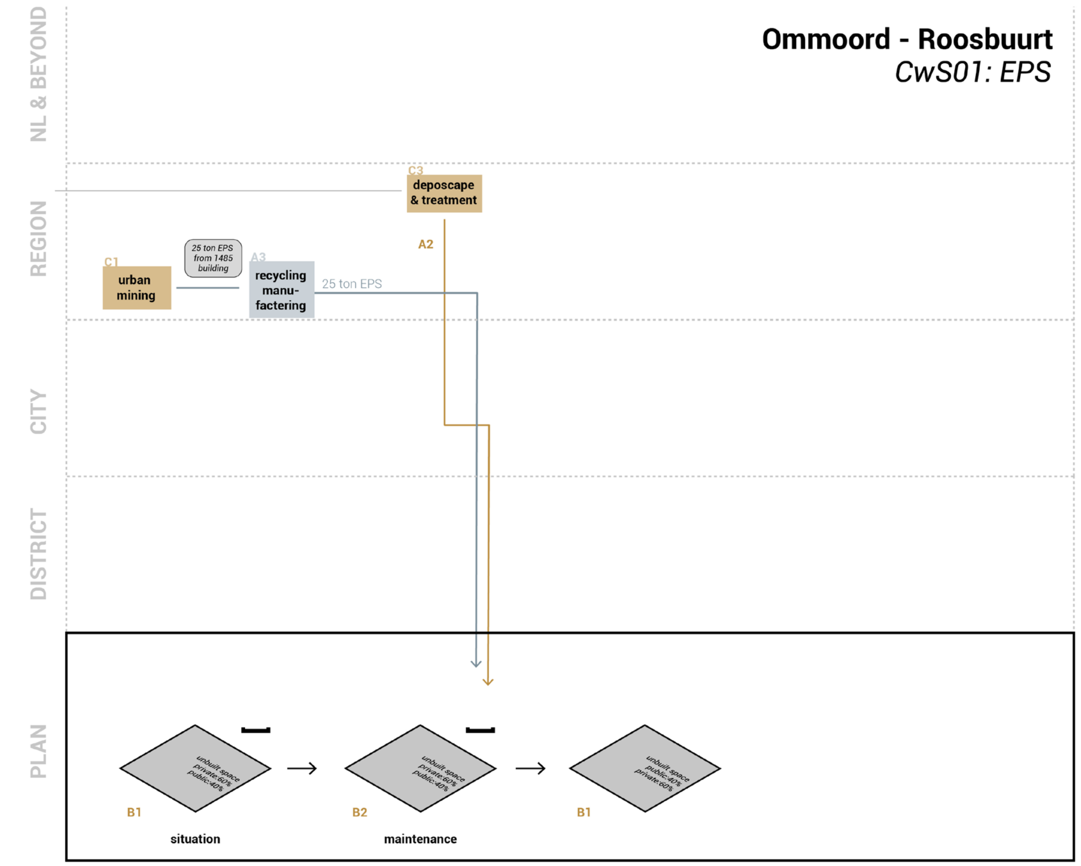
Isometric map of the CwS02 design of Ommoord - Roosbuurt

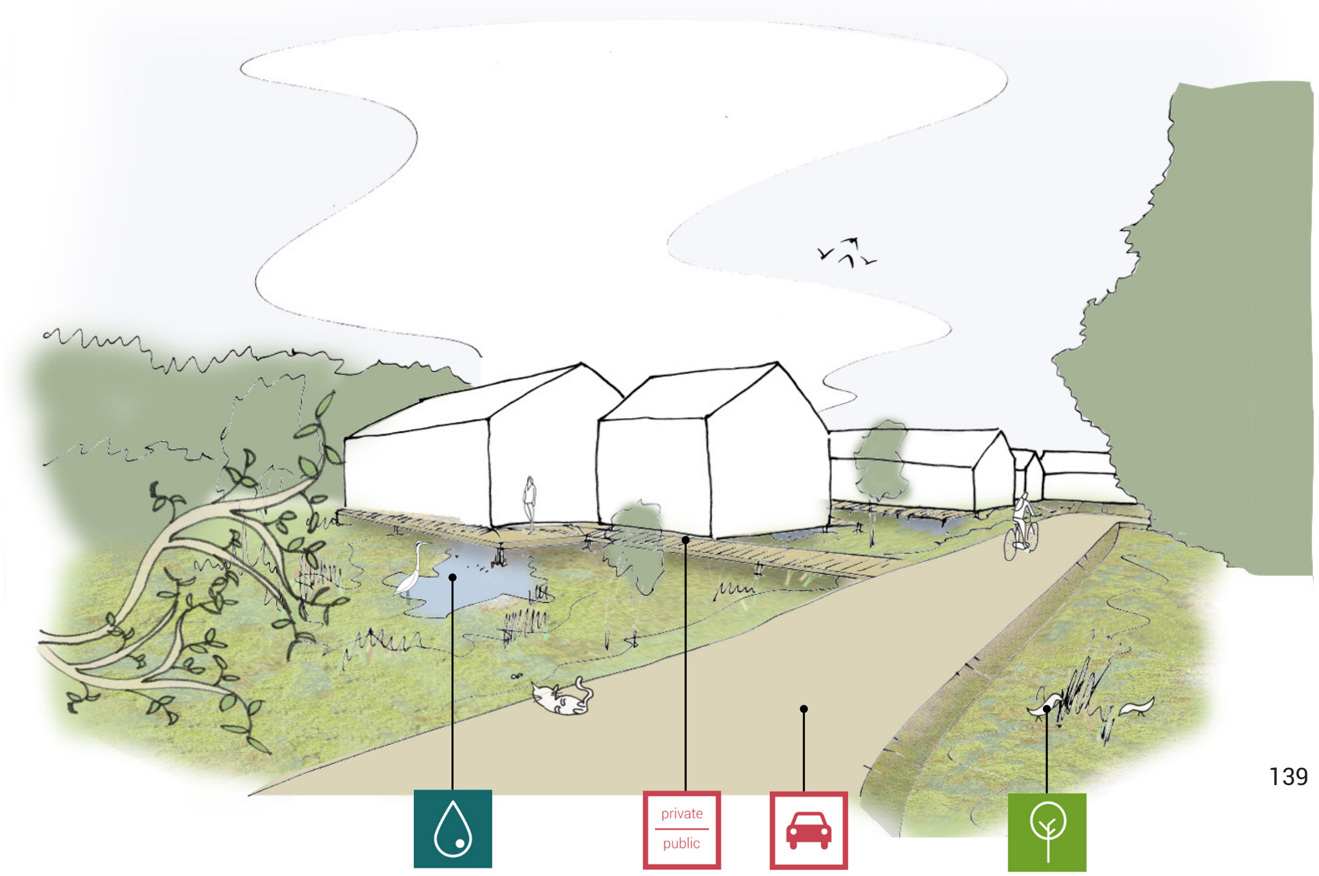
Image 90 (right-top)

TM-LCA of the CwS02 design of Ommoord - Roosbuurt

Image 91 (right-bottom)

Impression of the CwS02 of Ommoord - Roosbuurt





8.5.4 Ommoord Roosbuurt: conclusion and evaluation

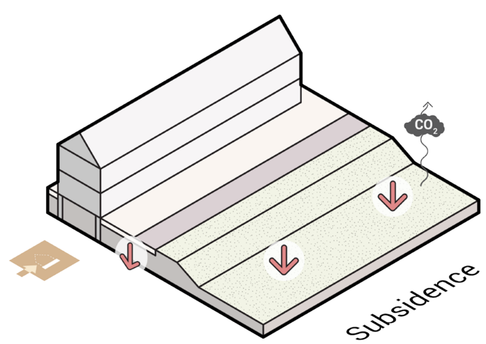
The design study for Ommoord Roosbuurt is an example of the condition 'maintenance due to subsidence'. The application of EPS is potential via secondary resources but it is questionable if the supply from secondary sources can fulfil the demand. The first option requires 75 ton EPS from secondary resources which is the equivalent of 4500 demolished buildings. This demand for demolished buildings is very high compared to the area it would supply. Furthermore, the application of EPS only impacts the public spaces which means that the assumed private inflow of fill sand for the gardens is not reduced.

The second option reduces the demand of both EPS and fill sand for private purpose (up to 66% and 100% respectively). However, this option has a big impact on both the spatial quality and private property. Gardens are removed and transformed which diverges from the generic spatial standard for Dutch neighbourhoods. This removal would also requires the expropriation of private gardens, which might hinder the feasibility of this option. These outcomes from both options are important but also difficult in the situation of this condition on how to deal with subsided areas.

Interesting is an option where more green (from CwSd02) is combined with secondary sand sources from e.g. dredged sediment. Technical feasibility and impact on subsidence should be research in this design option.

Image 92

Related condition of Ommoord - Roosbuurt



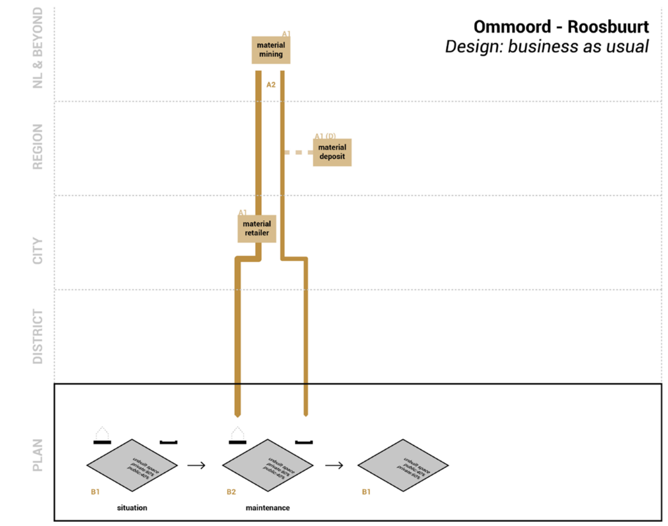
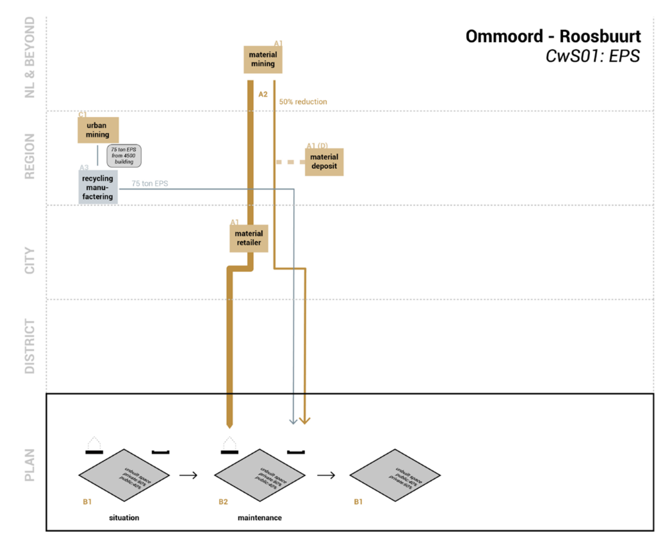
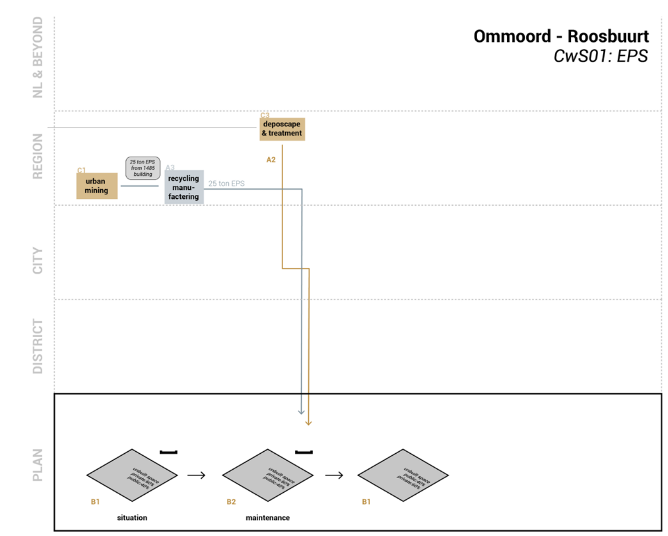
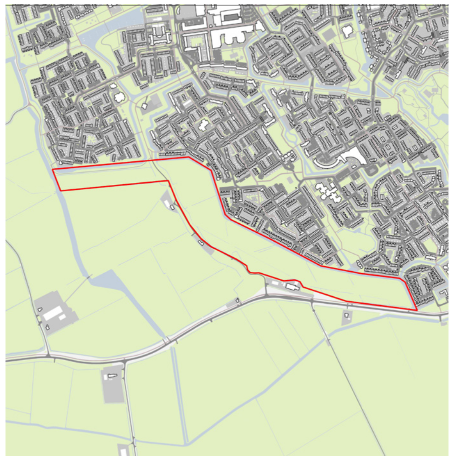


Image 93

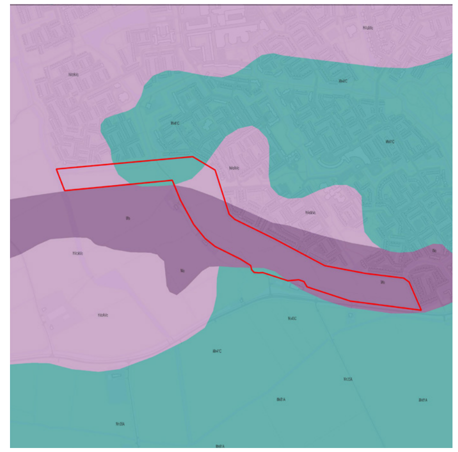
Overview of the TM-LCA of the design research for Ommoord - Roosbuurt







Soil type
- Peat
- Clay
- Built



Subsidence
- 3-10cm
- 10-20cm
- 20-40cm
- 40-60cm
- >60cm

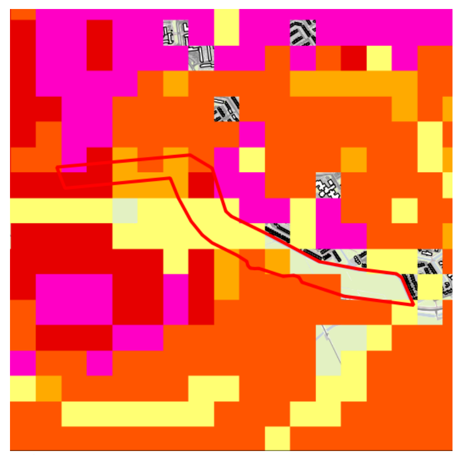


Image 94 (maps)

Map overview of location, soil type and subsidence

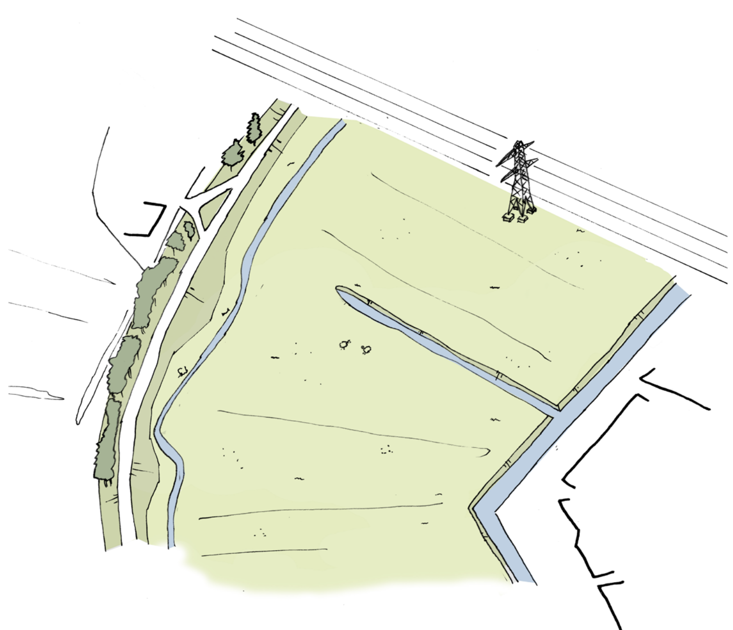


Image 95

Isometric situation of Spijkenisse - Vliesland

8.6 Focus: Spijkenisse - Vliesland
Situation

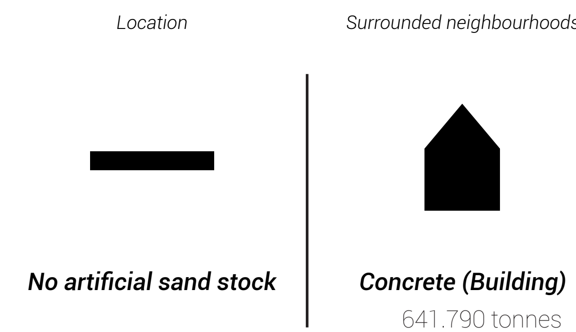
One of the potential location for greenfield development in the RMDS region is an expansion of the city of Spijkenisse on the southwest. This area consist of weak soil where subsidence is currently occurring due to peat oxidation. The bordered neighbourhood is a typical 70s urban area with the 'woonerf' structure.

Image 96

Material stock of Spijkenisse - Vliesland

Image 97

Situation impression of Spijkenisse - Vliesland



8.6.1 Business as usual

A business as usual scenario is based on the concept where residential units will be placed along a backbone access road on the eastside of the area so optimal perspective and relation is created with the rural landscape. Each residential unit is divided from each other by a green strip which creates a connection between the 70s neighbourhood and the rural landscape. 327 dwellings are constructed on the area with a diversity of detached, semidetached, terraced houses and a small apartment block. The construction requires input for every urban construction; concrete, asphalt and fill sand. The building site preparation is assumed to be partial filling which means that the infrastructure is prone to subsidence which requires fill sand input during its lifespan.

Image 98

Isometric map of the business as usual design of Spijkenisse - Vliesland

Image 99 (right-top)

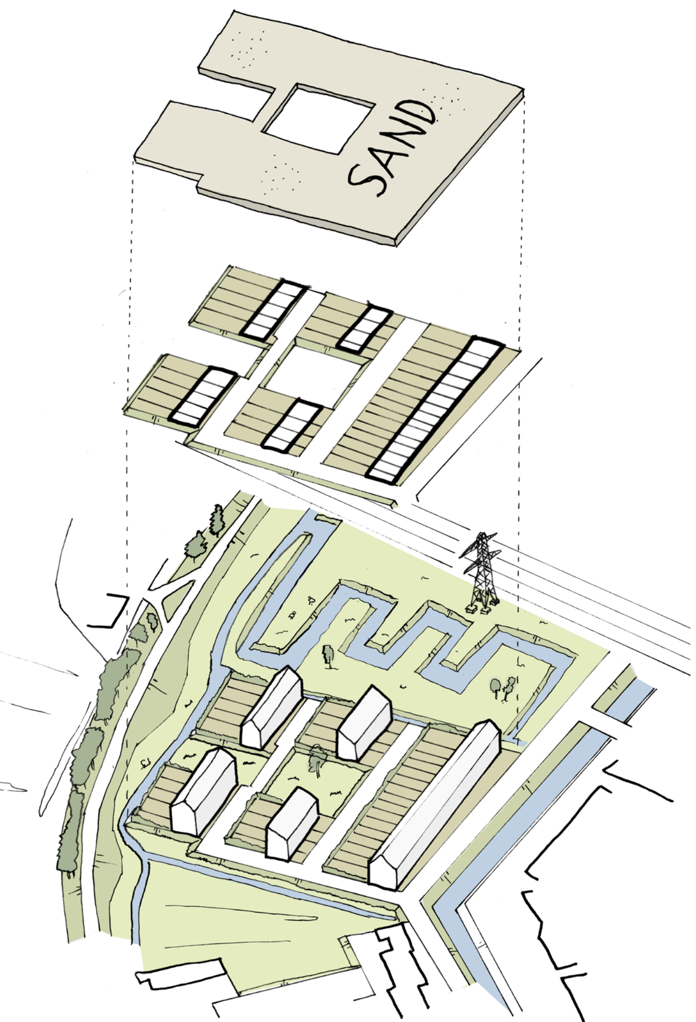
TM-LCA of the business as usual design of Spijkenisse - Vliesland

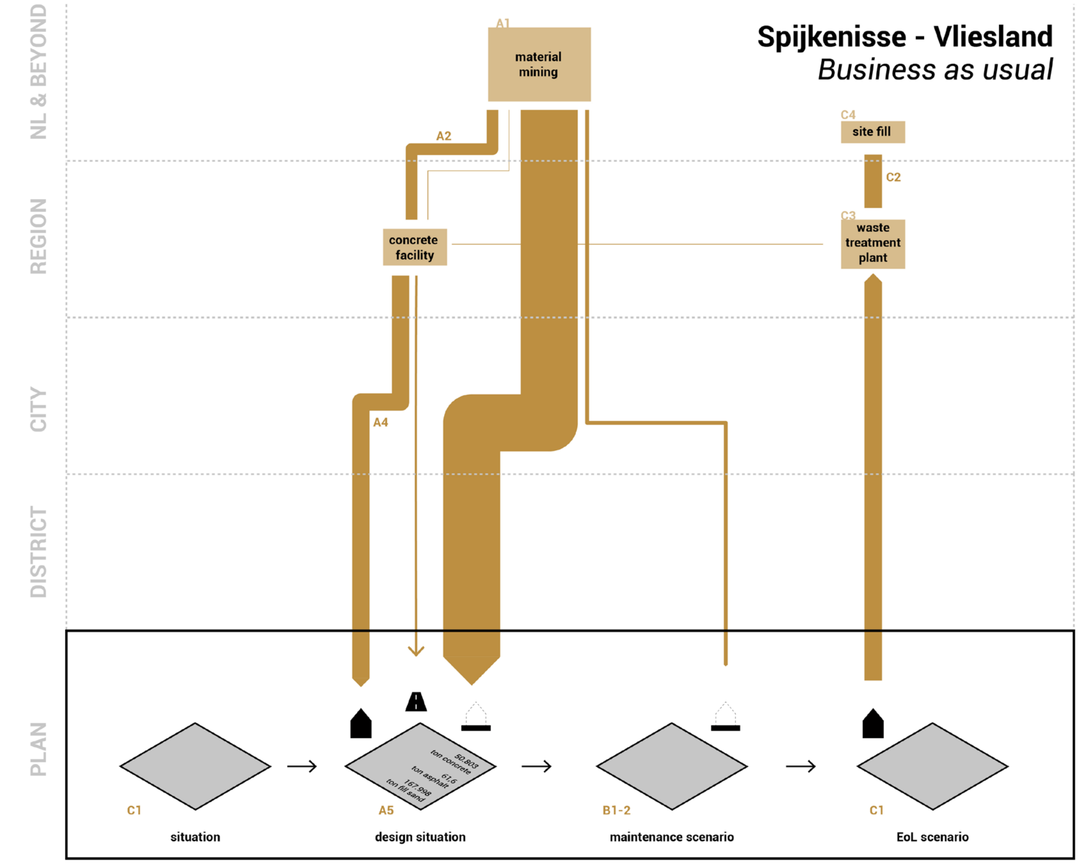
Image 100 (right-bottom)

Impression of the business as usual design of Spijkenisse - Vliesland

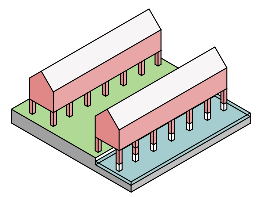
Image 101

Map of the business as usual development concept.

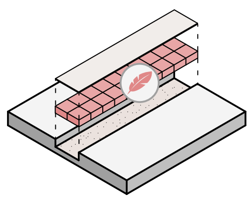




8.6.2 CwS01: building on stilts



#6: building on stilts



#11: light-weighted material

The first option proposes a reduction of the areas which requires fill sand. This is done by leaving the road structure on a heightened dike level, with recycled EPS, where the buildings are situated at while constructed on piles. This means that the buildings are partly above the surface level. This level difference creates an option for the original landscape to be unaltered. The gardens of the buildings are wooden platforms which are elevated from the surface level. The urban morphology of this option is similar to the business as usual design but more public green is proposed which contributes to the water storage and biodiversity and reduces subsidence due to pressure. To prevent peat oxidation, the water level can be controlled less artificially which results in a wetland. This wetland can be used as a production landscape for cattail plant.

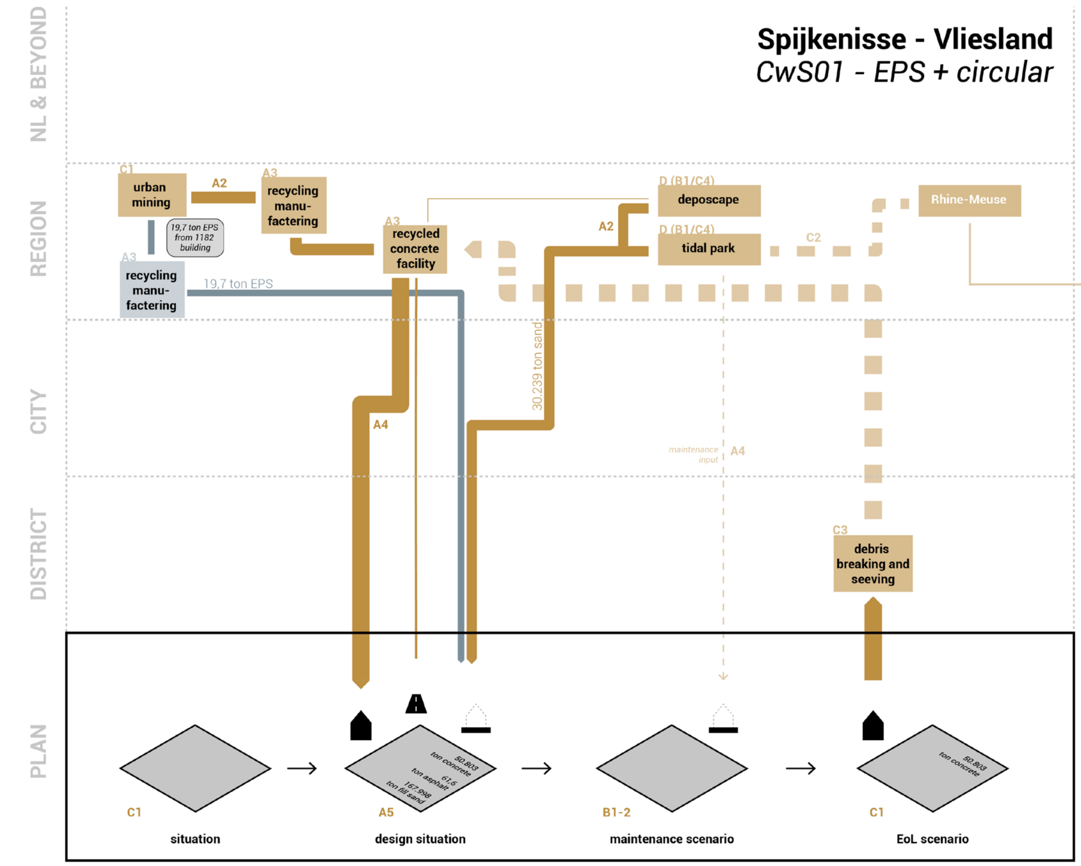


Image 102

Applied solutions in CwS01 design

Image 103

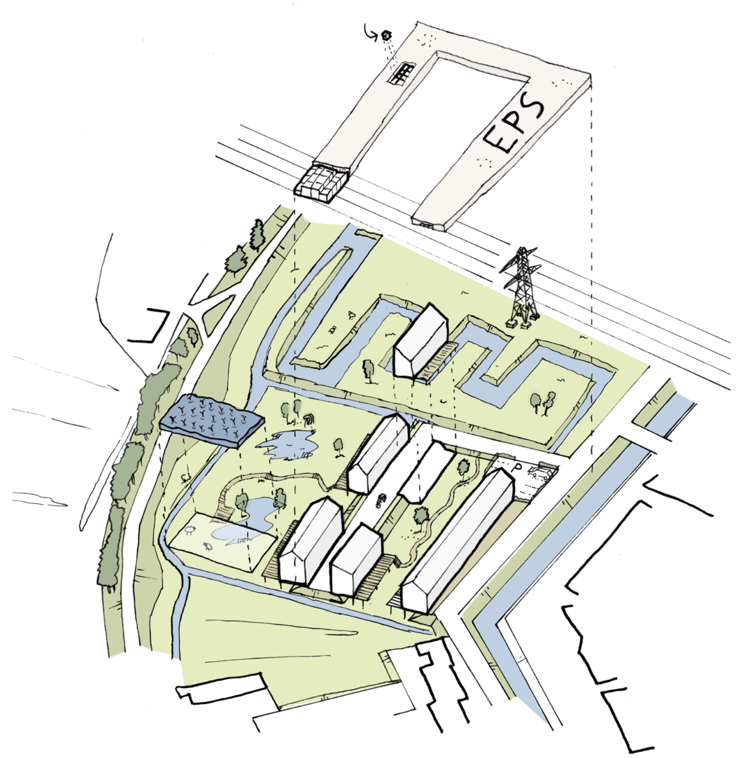
Isometric map of the CwS01 design of Spijkenisse - Vliesland

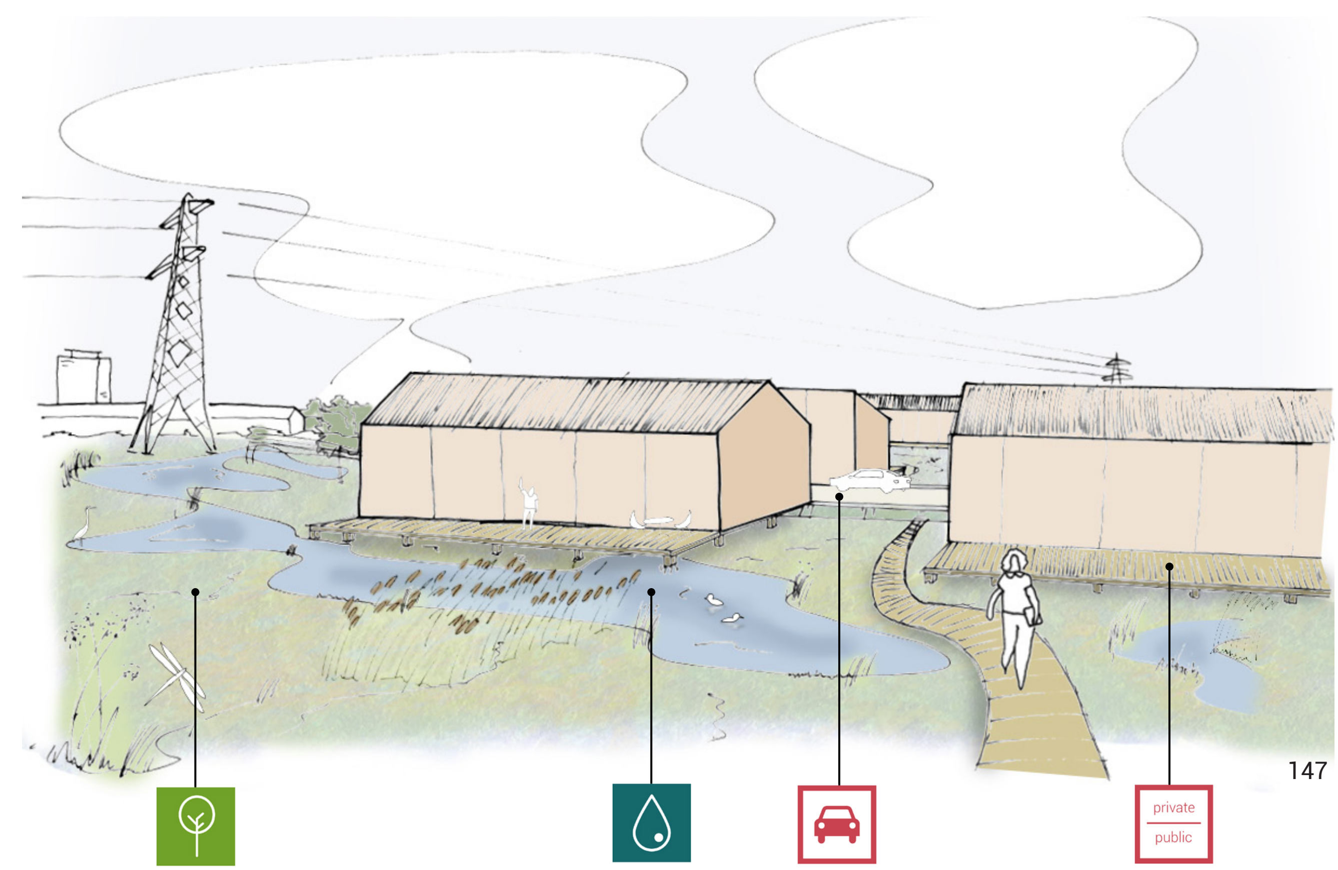
Image 104 (right-top)

TM-LCA of the CwS01 design of Spijkenisse - Vliesland

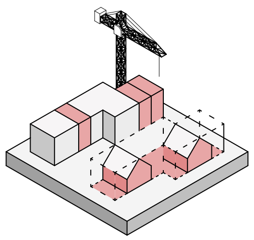
Image 105 (right-bottom)

Impression of the CwS01 design of Spijkenisse - Vliesland





8.6.3 CwS02: Retrofitting and densification of existing neighbourhood



#1: retrofitting

The second option prevents construction at this area by densifying the bordered 70s neighbourhood. This transformation requires a construction of 327 dwellings in the current fabric which results in an increase of the density from around 35 dwellings/ha to 40 dwellings/ha. This transformation preserves the current rural landscape but more dense building structures will be constructed in the neighbourhood. This result in demolishing of current buildings for replacement of bigger but material efficient new ones with recycled material. The transformation can also result in a reduction of green space in the area but contributes to the diversity of current building stock.

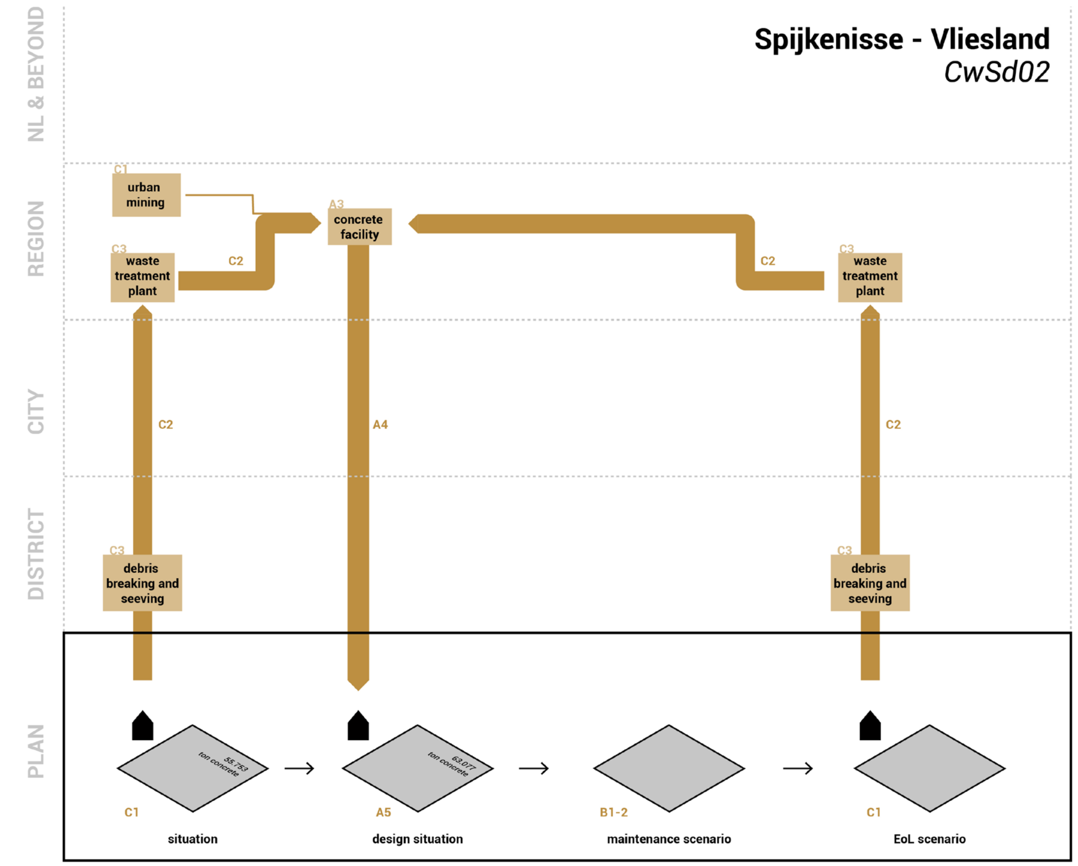
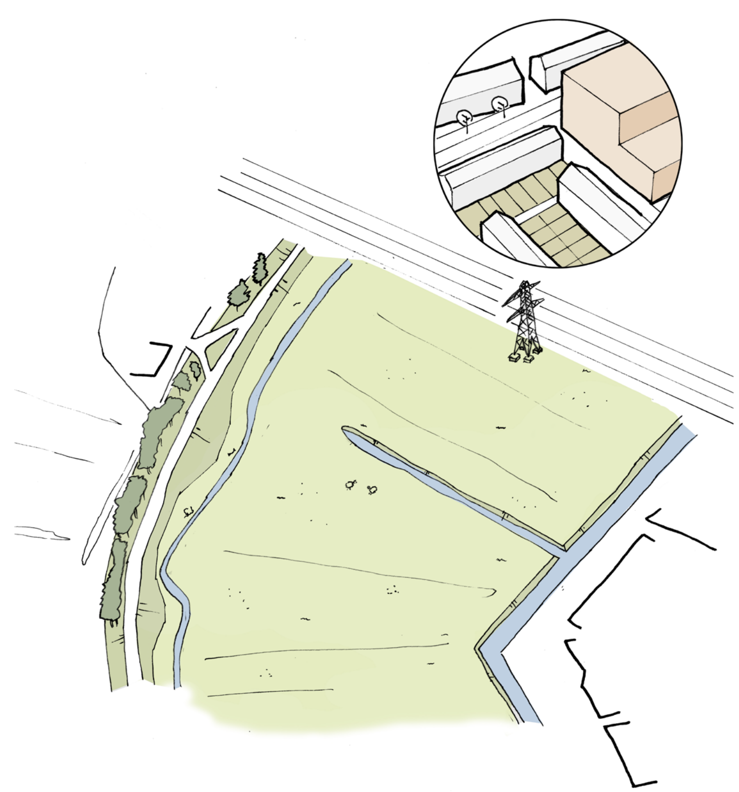


Image 106
Applied solution in CwS02 design

Image 107
Isometric map of the CwS02 design of Spijkenisse - Vliesland

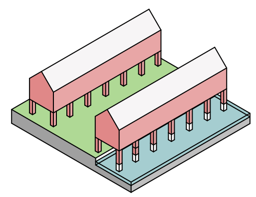
Image 108 (right-top)
TM-LCA of the CwS02 design of Spijkenisse - Vliesland

Image 109 (right-bottom)
Impression of the CwS02 design of Spijkenisse - Vliesland

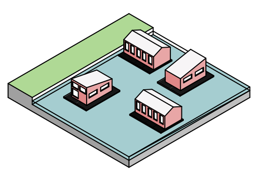


8.6.4 CwS03: Living platform above peat landscape

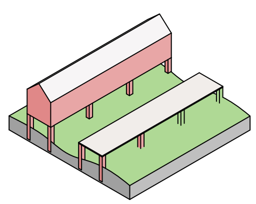
The last option is similar to the first one but it proposes a complete elevated urban design with a transformed peat wetland. The transformation towards a wetland creates an opportunity to develop floating buildings on water and contribute to the CO2 reduction of peat oxidation and subsidence. The infrastructure and buildings are all constructed on piles while the main access backbone road is still a dyke, built out of EPS (or, as a normal dike, out of clay which can be extracted from the location while wetland is created). The buildings can be constructed out of recycled material from urban mining elsewhere.



#6: building on stilts



#7: building on water



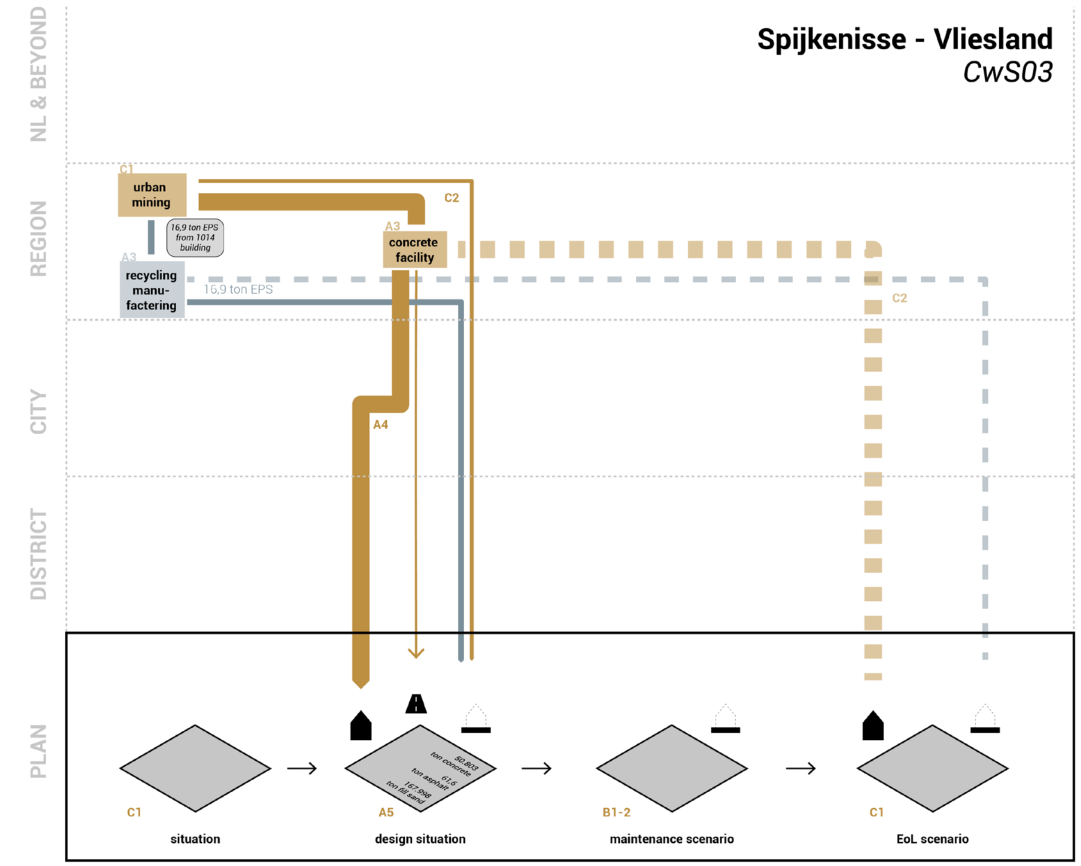
#11: allow subsidence

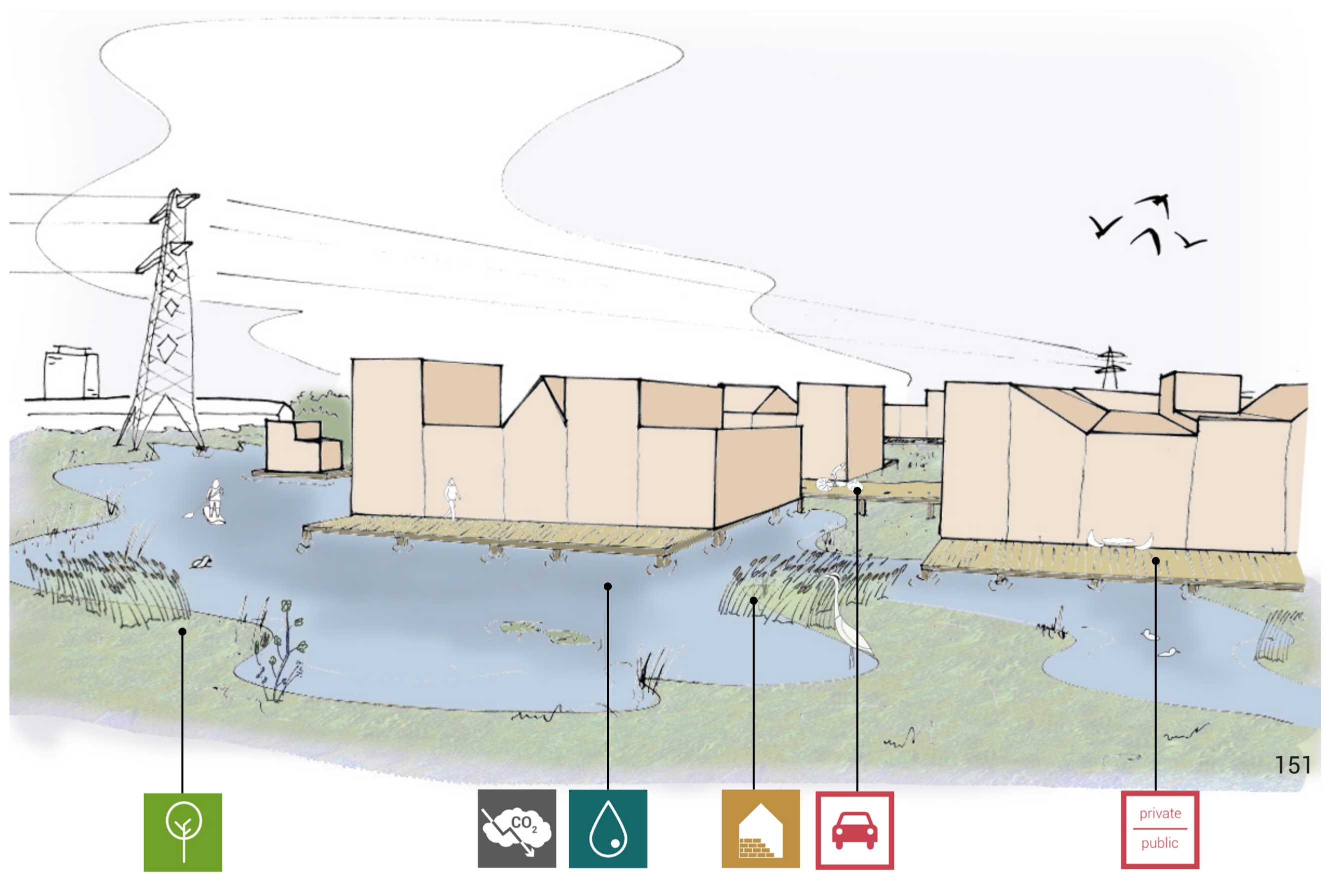
Image 110
Applied solutions in CwS03 design

Image 111
Isometric map of the CwS03 design of Spijkenisse - Vliesland

Image 112 (right-top)
TM-LCA of the CwS03 design of Spijkenisse - Vliesland

Image 113 (right-bottom)
Impression of the CwS03 design of Spijkenisse - Vliesland





8.6.5 Spijkenisse Vliesland: conclusion and evaluation

The design study for Spijkenisse Vliesland is an example of the condition 'greenfield development'. In all improvements, fill sand is reduced compared to the BaU design. This reduction also reduces the inflow of fill sand due to subsidence during the lifespan of the neighbourhood. However, the inflow of construction material for building is still based on resources elsewhere. Except in option 2 where recycling of concrete is possible from the urban mine and demolition. This reduces the primary demand but, similar to the other improved options, increases the flows (and thus transportation) between different stock and manufacturing sites. Furthermore, quantitative feasibility study is necessary for the input from urban mining. Otherwise, alternative resources such as biobased material needs to be introduced which has another environmental impact.

The designs with EPS and piles environment are similar to Vlambloem example but the natural character fits here better in terms of environmental 'image' which in the rural environment context. This natural character and construction on piles also has benefits from land transformation of wetland (water storage, heat reduction, CO2 reduction, production landscape). Overall, a lot of reduction options are possible here through urban design with even some other environmental benefits.

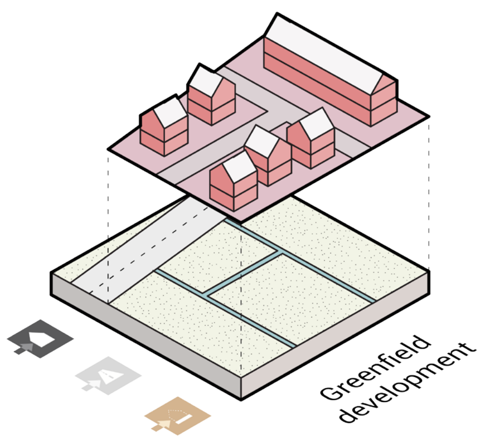


Image 114

Related condition of Spijkenisse - Vliesland

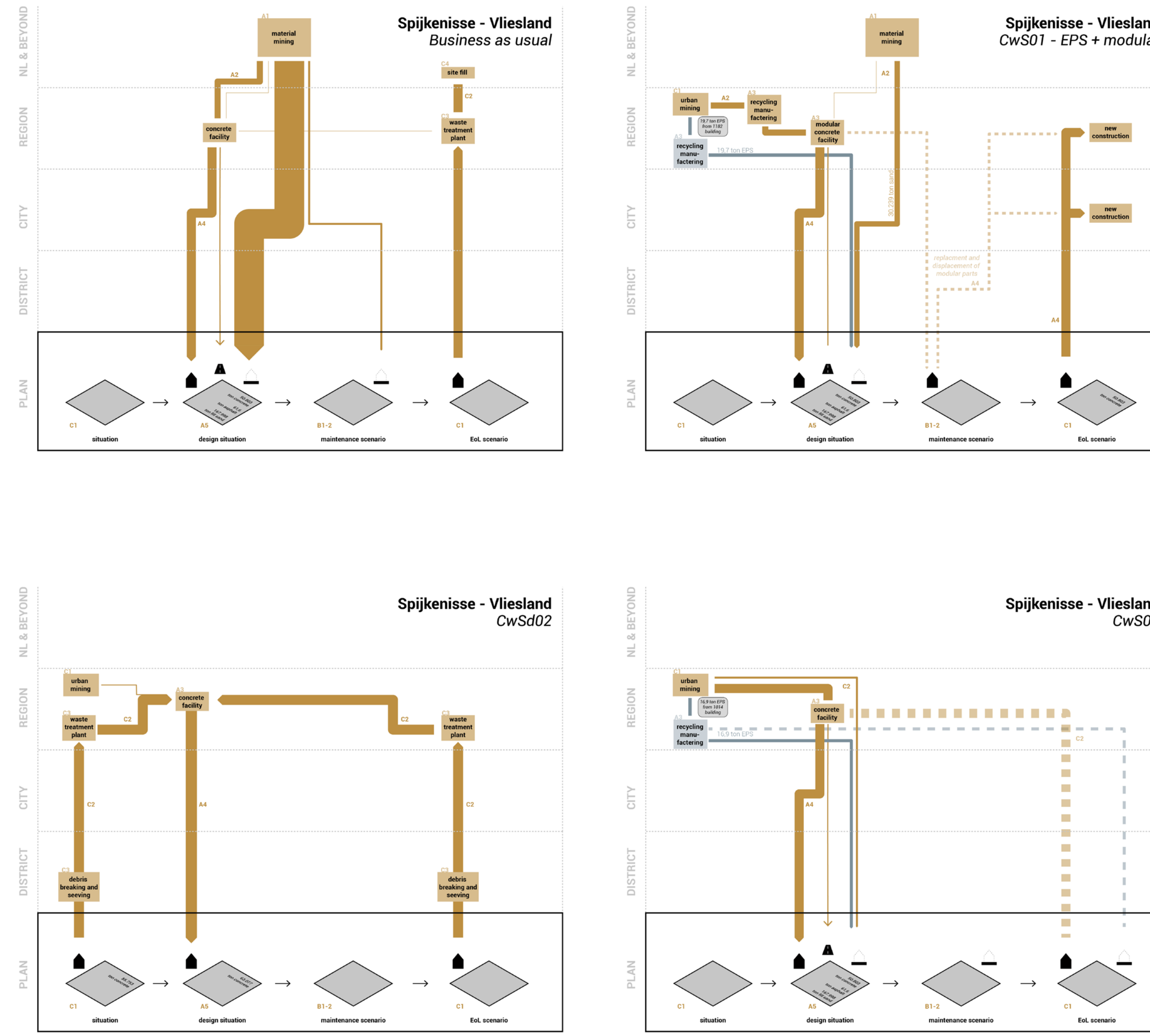


Image 115

Overview of the TM-LCA of the design research for Spijkenisse - Vliesland

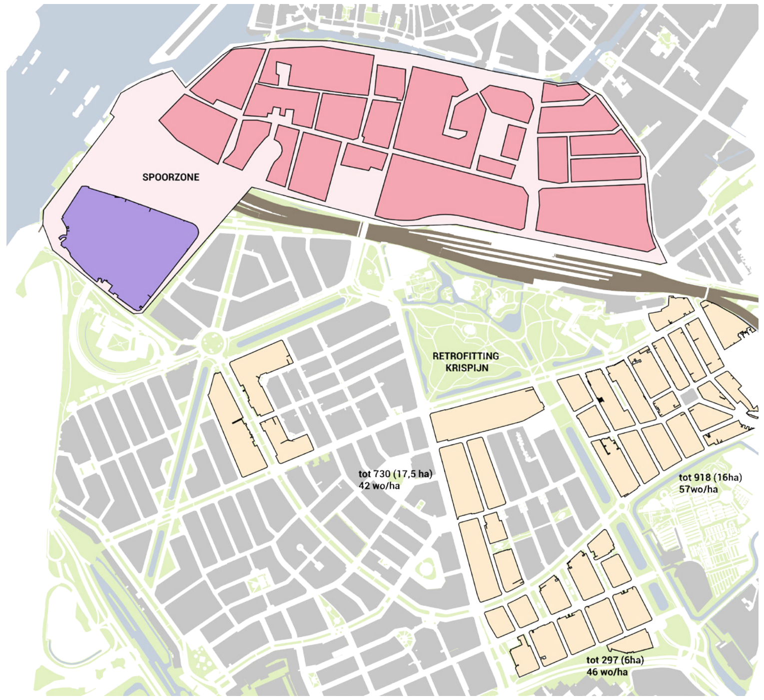


Image 116
Potential development in Dordrecht - Spoorzone
- *Densification*
- *Transformation*
- *Retrofitting*

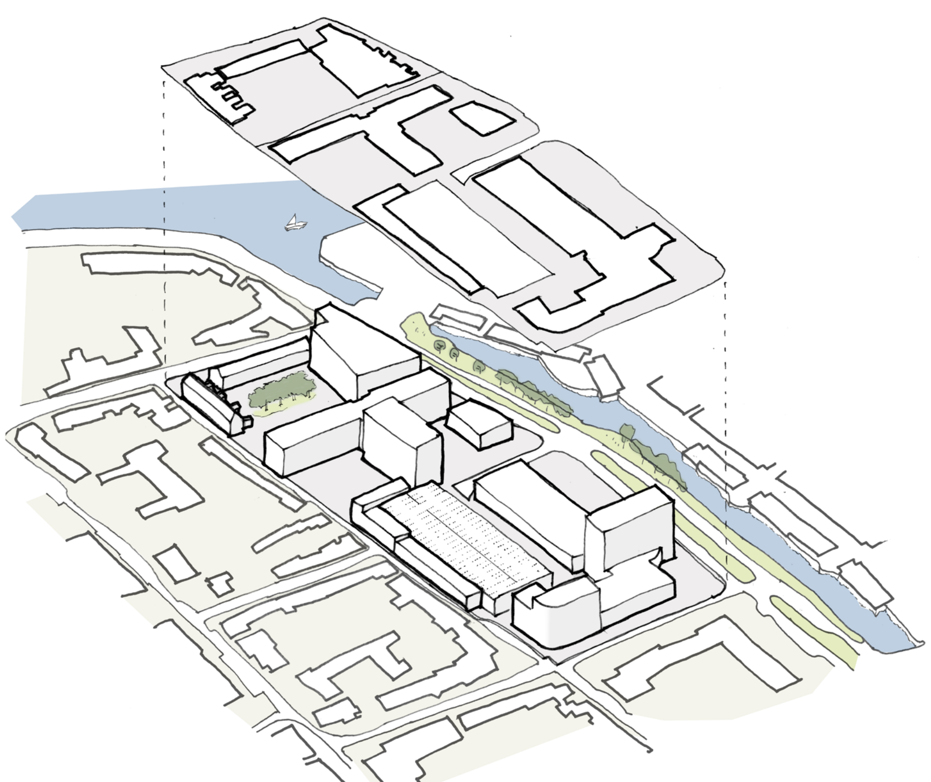


Image 117
Exploded isometric view of the urban fabric location in the focus location Dordrecht - Spoorzone

8.7 Focus: Dordrecht - Spoorzone/Krispijn
situation

The Spoorzone and Krispijn area in Dordrecht are potential for both densification and retrofitting. Current ambitions for densification in the Spoorzone are set to build 3.000 dwellings in this area. This activity will cause majorly in- and outflow of the building material concrete. Because of the scale of this area, an urban block will be highlighted to show the impact and possible changes.

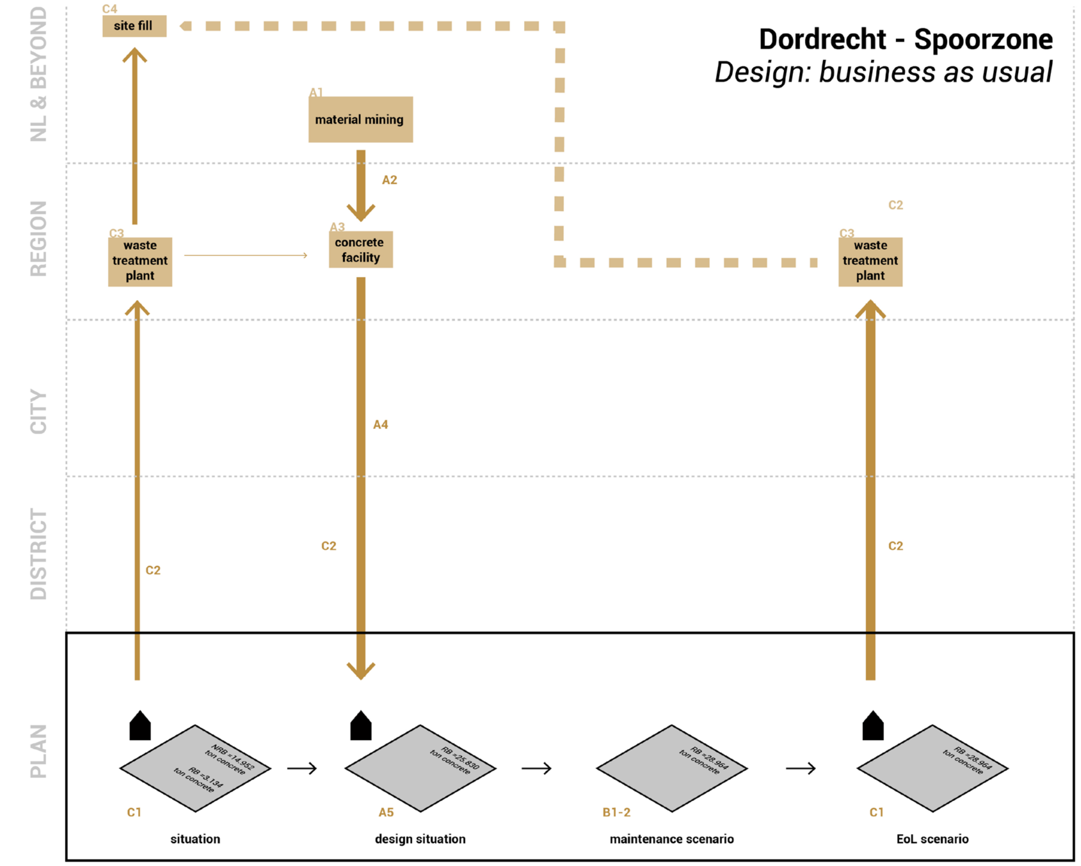
Image 118
Material stock of Dordrecht - Spoorzone

Spoorzone (Densification)		*Krispijn (Retrofitting)*
Concrete (RB) 199.528 tonnes	**Concrete (NRB)** 328.827 tonnes	**Concrete (RB)** 601.399 tonnes

Image 119
Situation impression of Dordrecht - Spoorzone

8.7.1 Business as usual

Densification and retrofitting will be done on urban fabric level where original buildings will be demolished and new buildings will be constructed. This event causes an in- and outflow of majorly concrete. The new construction contribute to a mixed used environment which can relates to the surrounded quality.



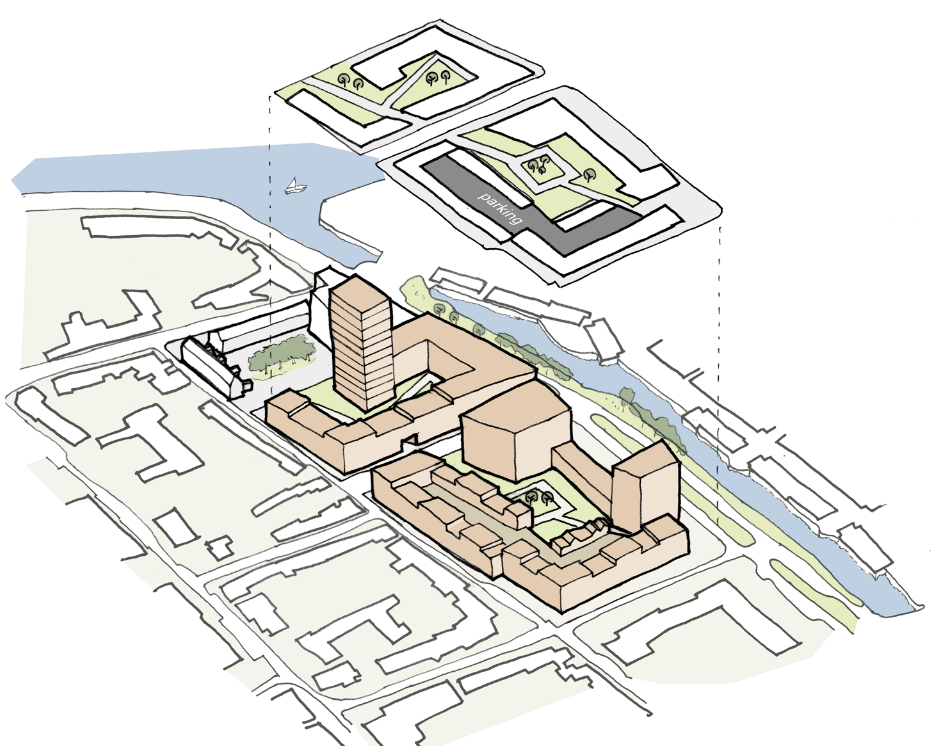


Image 120

Isometric map of the business as usual design of Dordrecht - Spoorzone

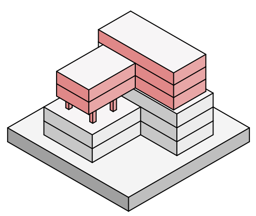
Image 121 (right-top)

TM-LCA of the business as usual design of Dordrecht - Spoorzone

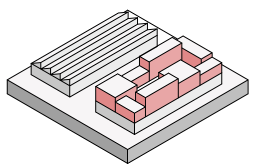
Image 122 (right-bottom)

Impression of the business as usual design of Dordrecht - Spoorzone

8.7.2 CwS01: Building transformation and elevation



#2: densification by elevation



#13: building transformation

Reduction can be achieved by transforming the current buildings into residential ones. Additional buildings can be achieved by elevation on the current structure. This type prevents an outflow of material and only causes an inflow for the new construction which can be biobased or recycled. The spatial impact remains quite similar to the current situation but it does not changes any current architectural or urban fabric quality which do not contribute to the new urban/centre function. Here, the spatial impact relates more to architecture than urban design related quality.

Image 123

Applied solutions in CwS01 design

Image 124

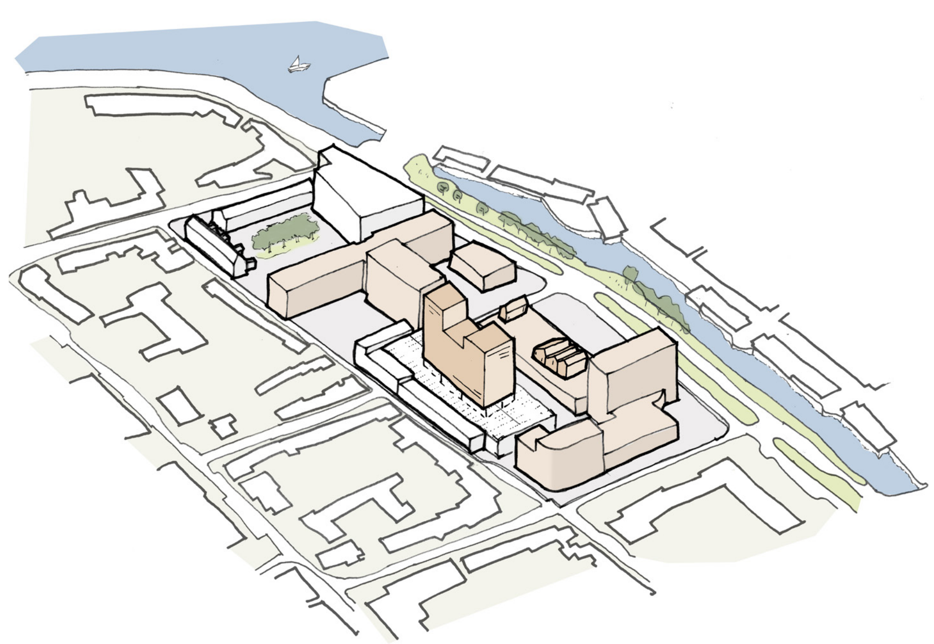
Isometric map of the CwS01 design of Dordrecht - Spoorzone

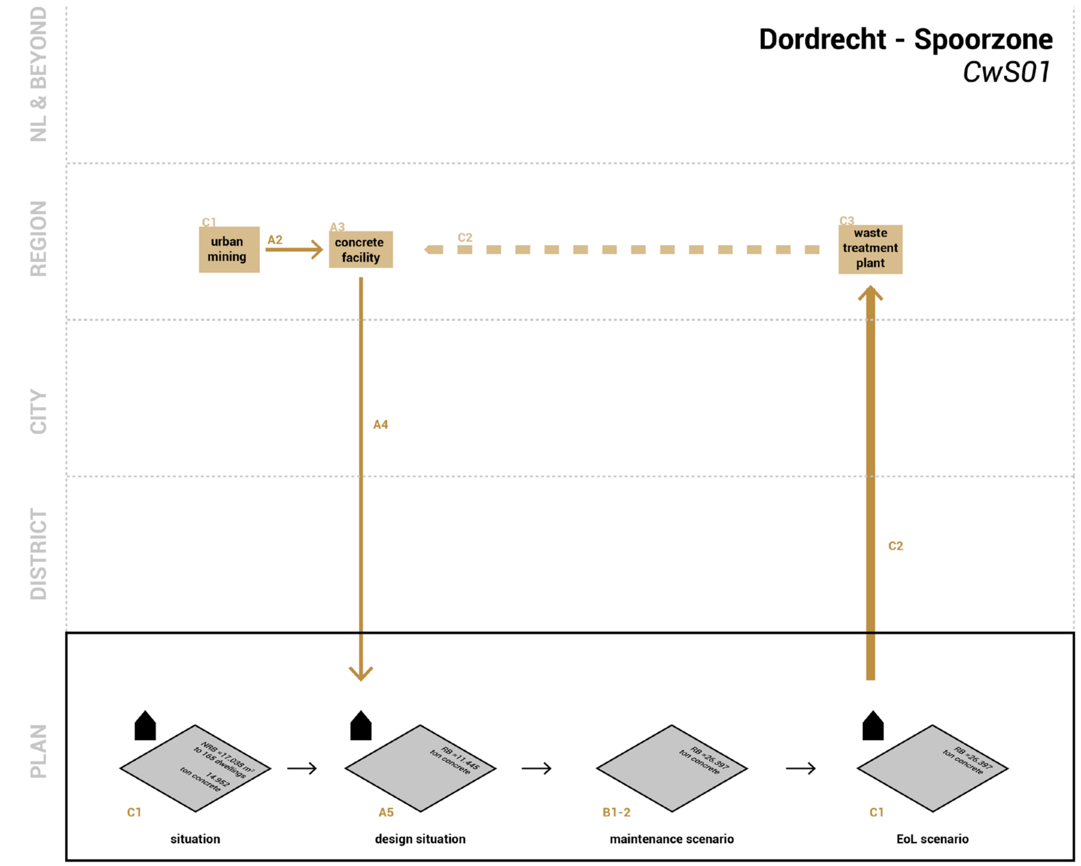
Image 125 (right-top)

TM-LCA of the CwS01 design of Dordrecht - Spoorzone

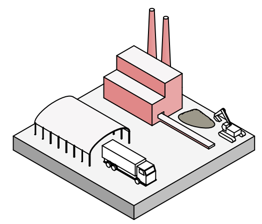
Image 126 (right-bottom)

Impression of the CwS01 design of Dordrecht - Spoorzone

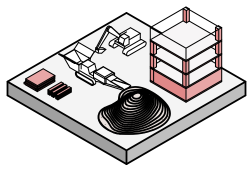




8.7.3 CwS02: 100% recycled material



#22: recycling facility



#20: on-site separation

The same urban design can be achieved as the business as usual scenario when the concrete is recycled from the original stock or sources elsewhere. This option depends on system performance outside this urban fabric and maybe requires space for local storage somewhere else in this area which can result in denser urban blocks. Here, the spatial impact relates more to architecture than urban design related quality.

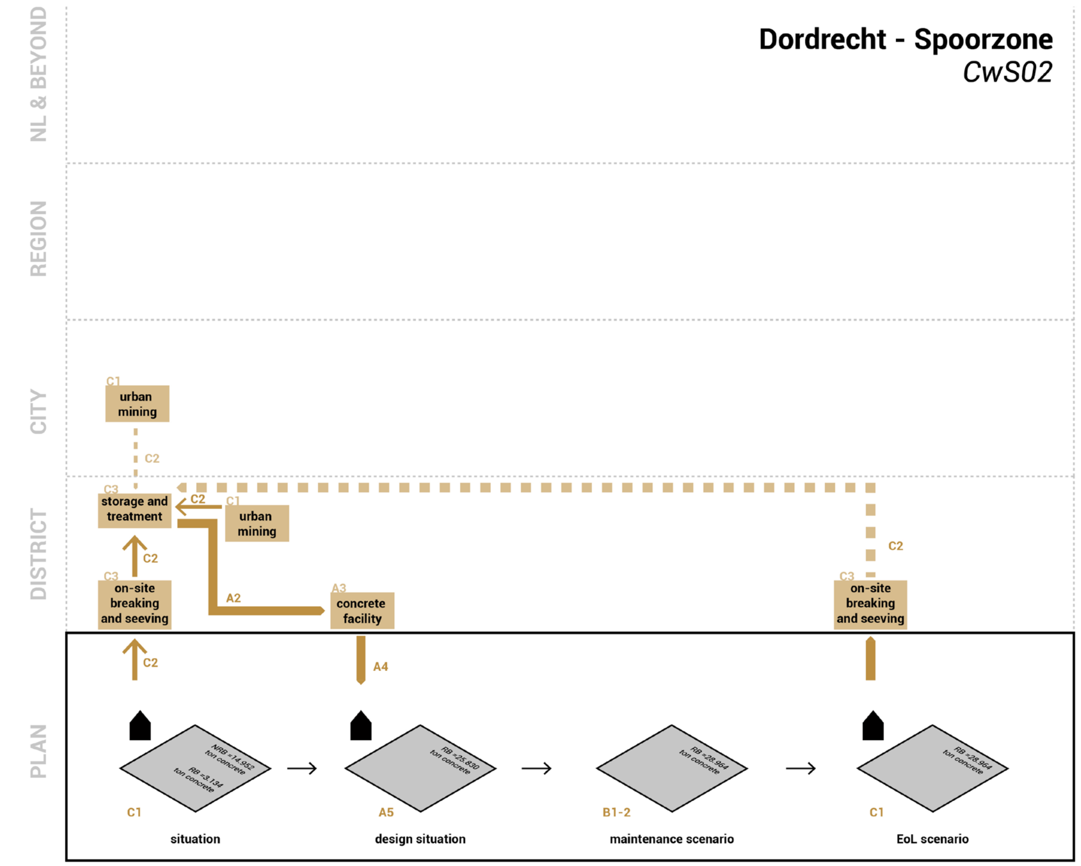
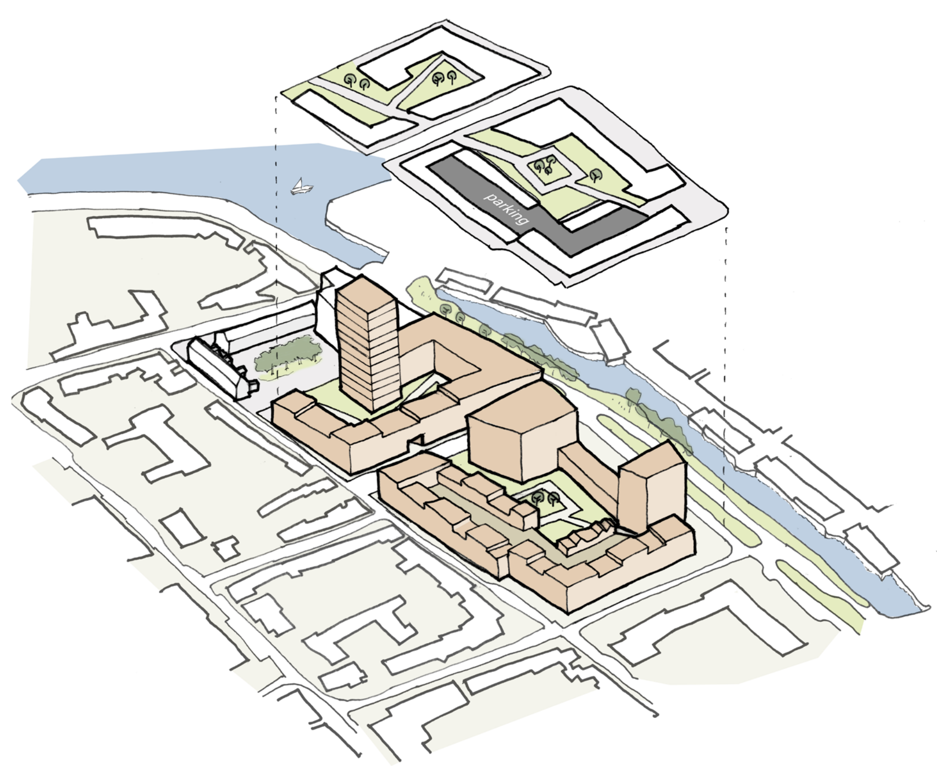


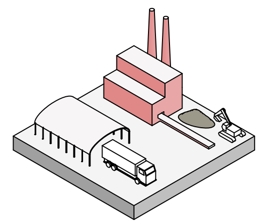
Image 127
Applied solutions in CwS02 design

Image 128
Isometric map of the CwS02 design of Dordrecht - Spoorzone

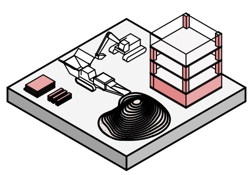
Image 129 (right-top)
TM-LCA of the CwS02 design of Dordrecht - Spoorzone

Image 130 (right-bottom)
Impression of the CwS02 design of Dordrecht - Spoorzone





#22: recycling facility



#20: on-site separation

8.7.4 CwS03: Reuse of the foundation

Instead of demolishment and the construction of a new urban fabric, former foundation in the block can be reused for the new construction. This can reduce the demand for concrete and provides the opportunity to construct material efficient recycled or biobased new structures which assembly cannot be higher than the current structures. The architectural quality can be changed but the new designs need to deal with the former urban fabric and its quality. Here, the spatial impact relates more to architecture than urban design related quality.

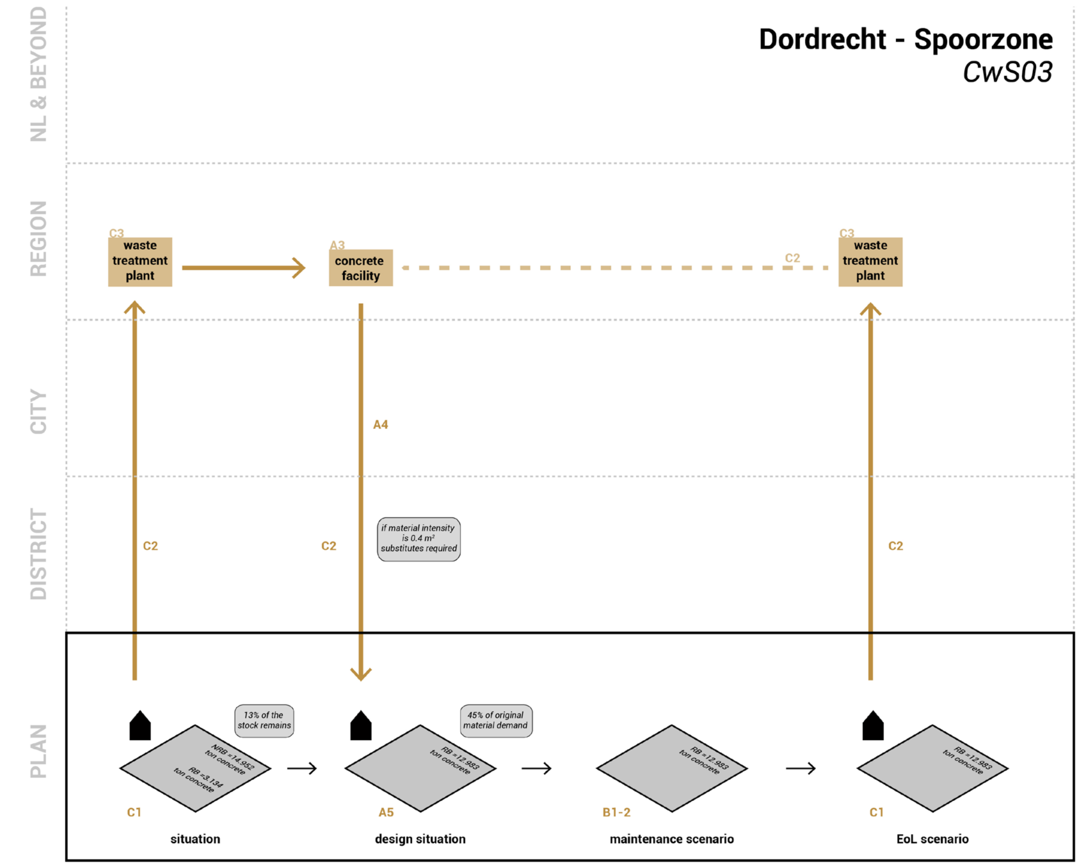


Image 131

Applied solutions in CwS03 design

Image 132

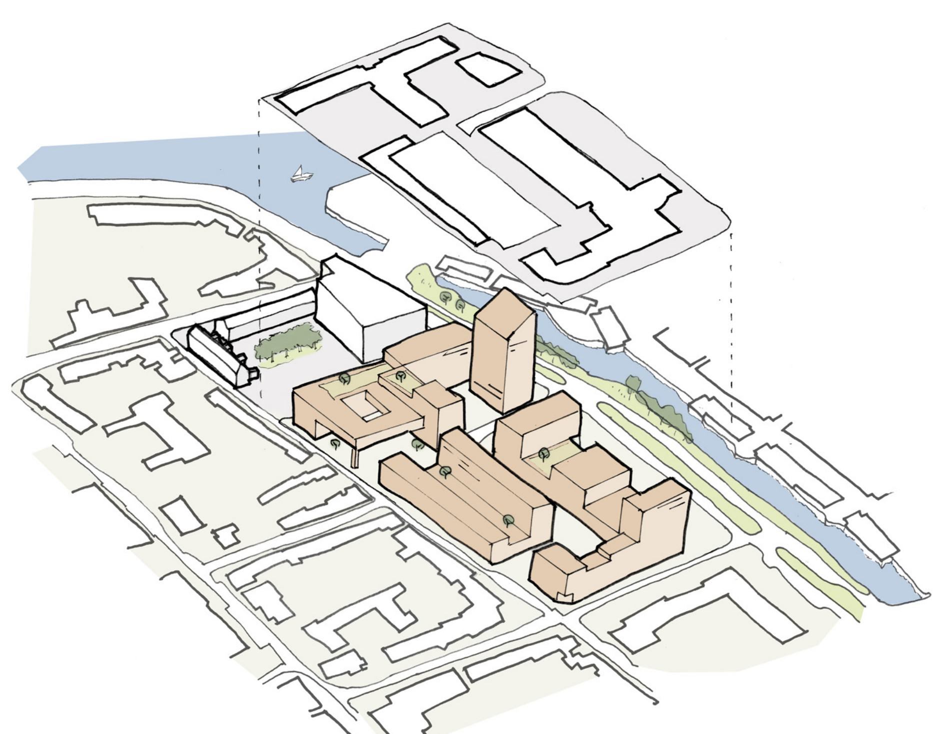
Isometric map of the CwS03 design of Dordrecht - Spoorzone

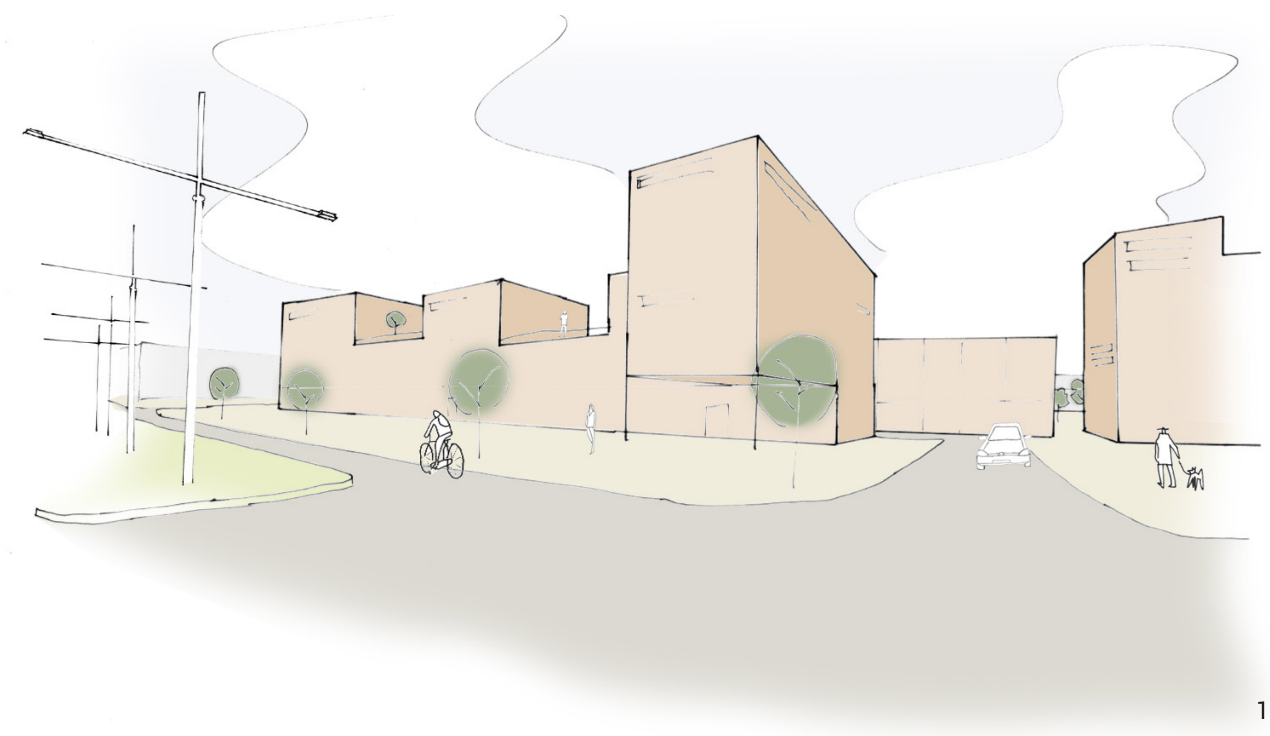
Image 133 (right-top)

TM-LCA of the CwS03 design of Dordrecht - Spoorzone

Image 134 (right-bottom)

Impression of the CwS03 design of Dordrecht - Spoorzone





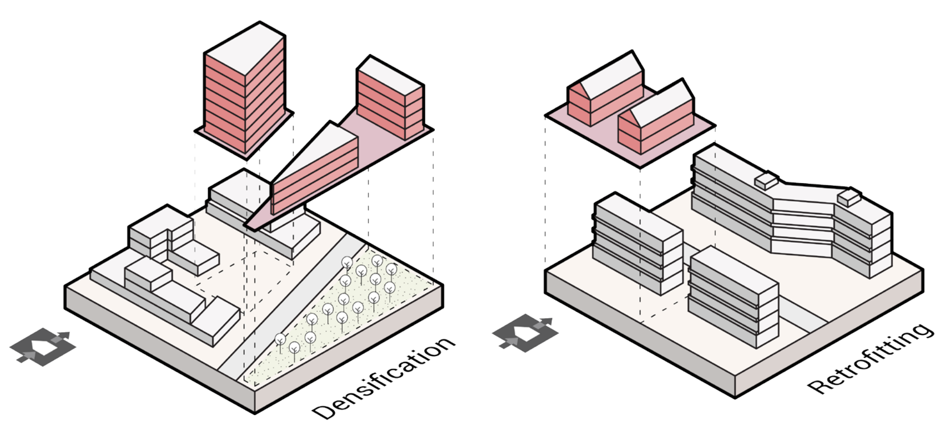
8.7.5 Dordrecht Spoorzone/Krispijn: conclusion and evaluation

The design study for Dordrecht Spoorzone/Krispijn is an example of the conditions 'densification' and 'retrofitting'. These two conditions are very similar because the cause the same material flow and the same solutions can be applied on both situations. In the case of Spoorzone Dordrecht, a net growth in material is always occurring, around 70%. This is always the case unless material efficiency in a recycling scenario is possible. Secondary sources or alternatives should be sought and introduced in the region which have an environmental impact outside this urban ecosystem (as seen in the TM-LCA scheme; all designs relate to the 'region' scale) In all the cases, regional input is necessary for the developments. Only in the second option, local sources are used but is still not enough for the entire demand. The regional input of secondary resources relies on the regional material balance.

A reduction strategy in demolition through renovation (option 1) has a significant impact on the spatial quality which maybe could not meet the demands from urban development. The reduction should be combined with a tailor-made strategy of where should be demolished and not combined with a new inflow.

Image 135

Related condition of Dordrecht -Spoorzone/Krispijn



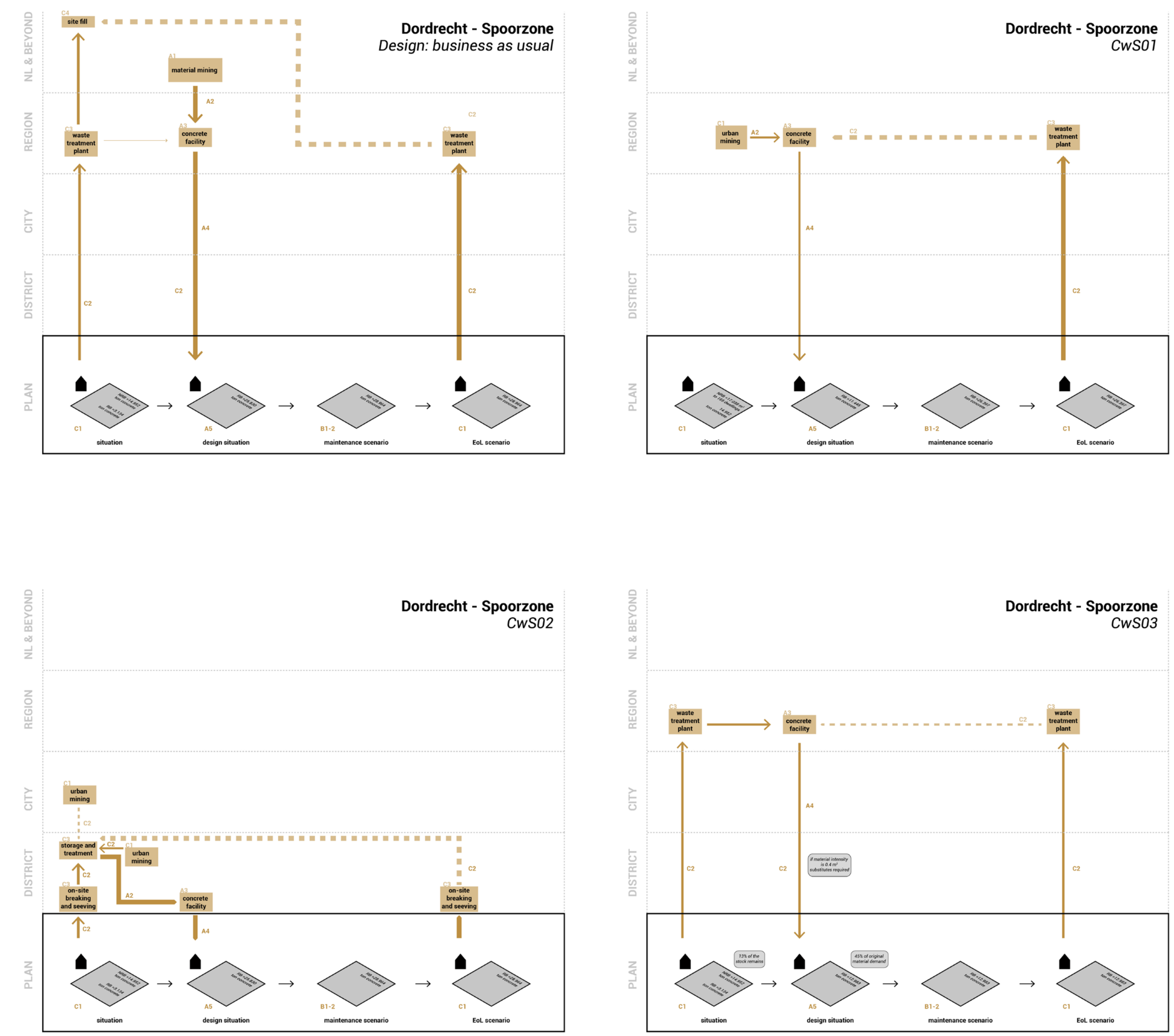


Image 136

Overview of the TM-LCA of the design research for Dordrecht - Spoorzone

8.7.6 Spoorzone & Krispijn

The urban fabric improvements as shown on the previous pages are dependent on interventions elsewhere. To facilitate circular use of construction material, construction and demolition waste needs to be linked and located somewhere in the urban environment. The image on the right is the first step in extrapolating the improvements to a higher scale, the district level.

The transformation in the Spoorzone (such as the three improvements on the previous pages) requires construction materials and generates demolitions waste. These flows are linked with the Maastteras, which is the local storage for this location. Here, material is treated and stored for the supply and demand in the development of the Spoorzone and Krispijn. The local storage is an active stock environment where production activities and residential functions are combined. Its situation at the Oude Maas is potential for water transportation. This connection improves the material balance in this area.

In the spoorzone, a balance between complete new construction, densification by elevation and building transformation is explored which reduces the material consumption. Krispijn focuses on retrofitting through interior building transformation. Material can be reduced with these solutions but is also an opportunity to promote the circular material metabolism where outflow from here can be used elsewhere and new material originates from secondary or biobased sources.

The next chapter focuses on the impact of the interventions on the regional scale.

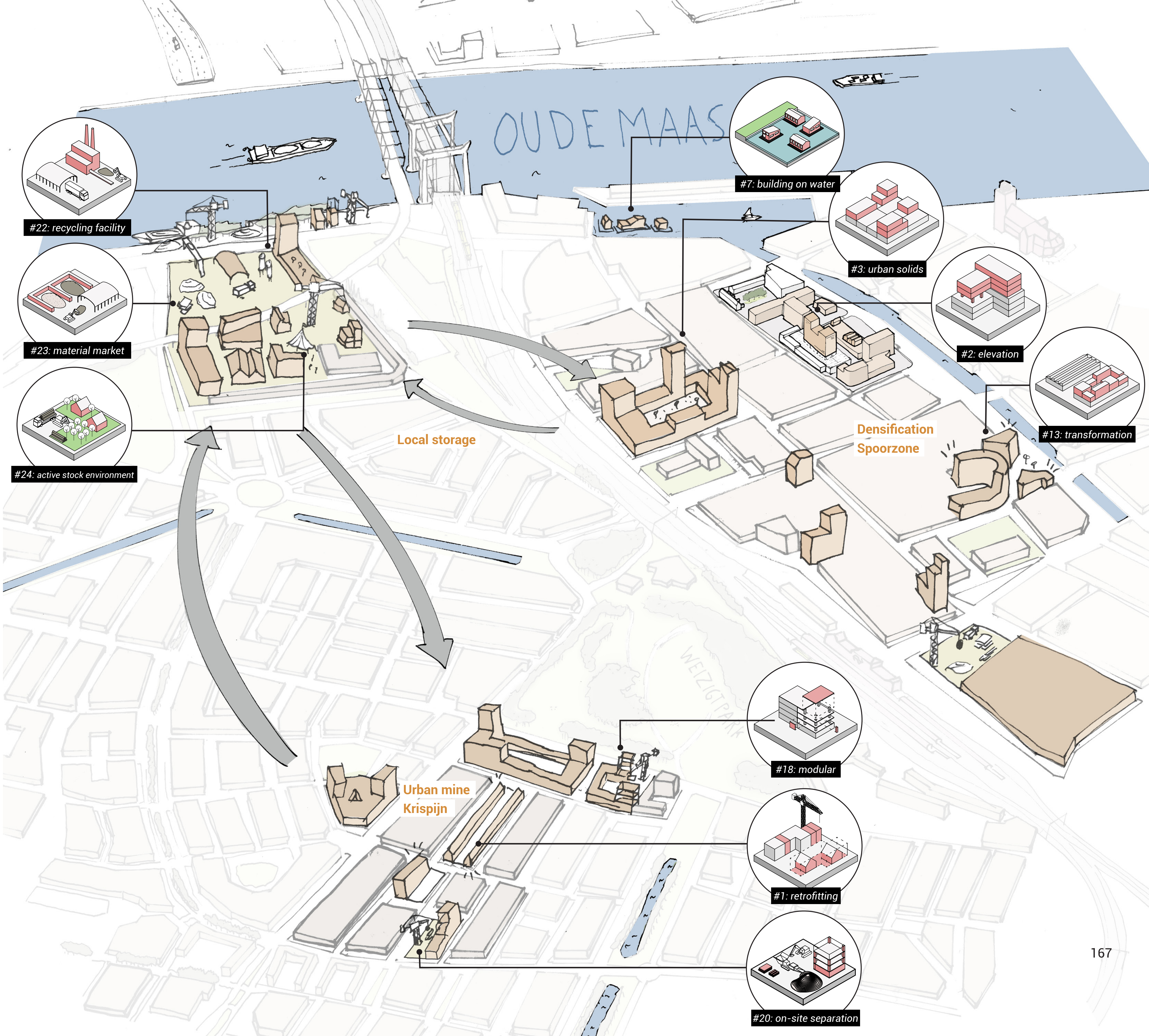


Image 137

Impression of solutions, the metabolic flows and activities on district level in Dordrecht - Spoorzone/Krispijn

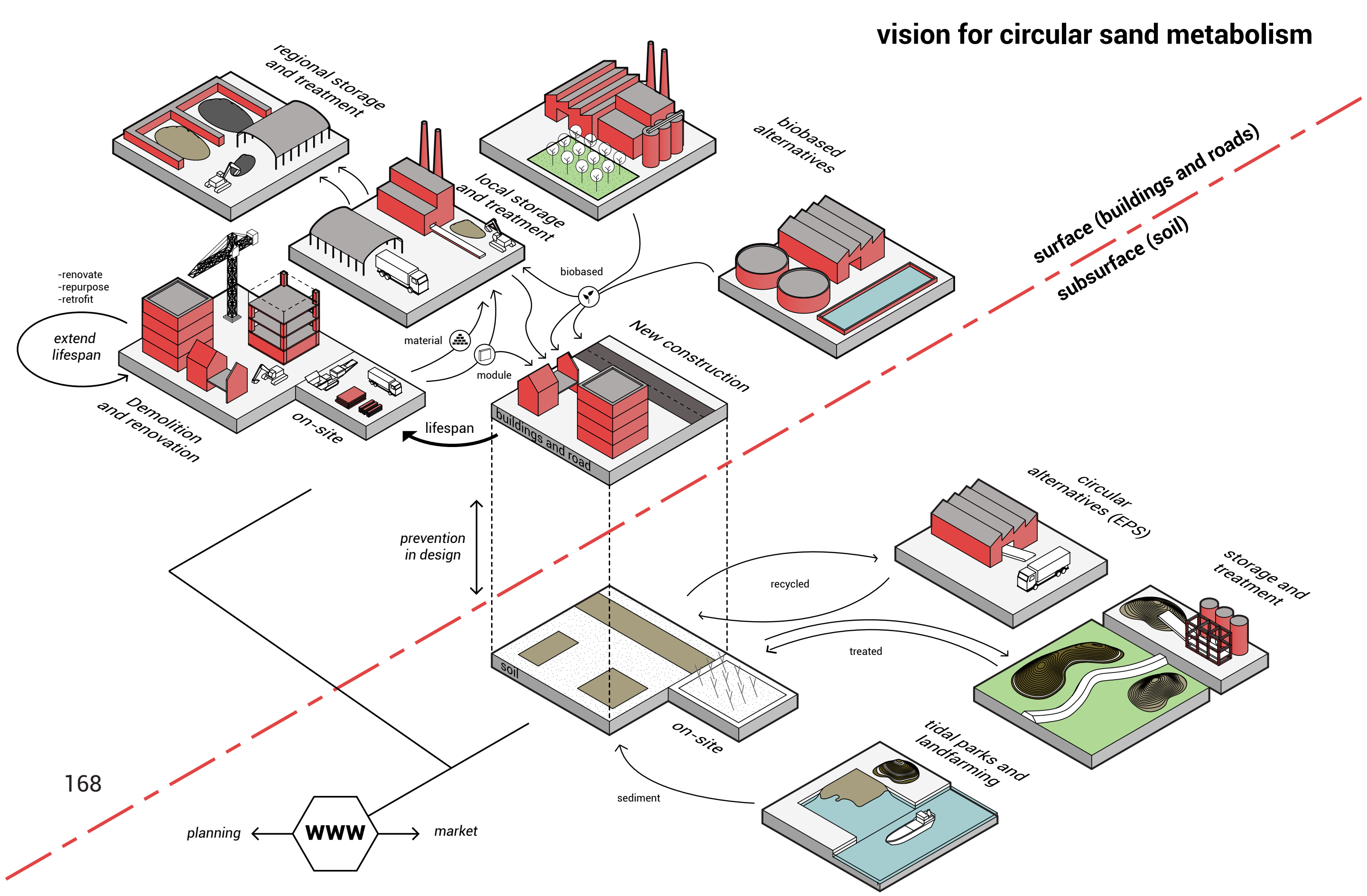
8.8 Regional sand metabolism

An overall conclusion from the four small scale design is that there is a dependency on regional intervention for recycling or substitute possibilities. In this part, the regional impact will be explored in order to realise a circular and reduced sand and gravel metabolism in the RMDS region. Eventually, this will visualise the potential reduction of primary construction sand and gravel through urban design. This is done by a spatial study for the production scapes and an extrapolation of the design results towards the regional metabolic system. But first, the vision for a circular sand metabolism will be repeated to visualise the context.

The material efficiency strategies are integrated within the regional metabolic system of sand and gravel (see image 138). This means that consumption is reduced through the extension of the lifespan of constructions through reuse of its entity or components. Furthermore, consumption is prevented through material conscious design. The four design studies are examples of this prevention through design. In the construction, modular (reuse) or recycled material will be used which originates from urban mining resources or biobased substitute. These materials are treated and stored in the region on different scales in order to balance the consumption of sand and gravel.

Image 138

vision for a circular sand metabolism



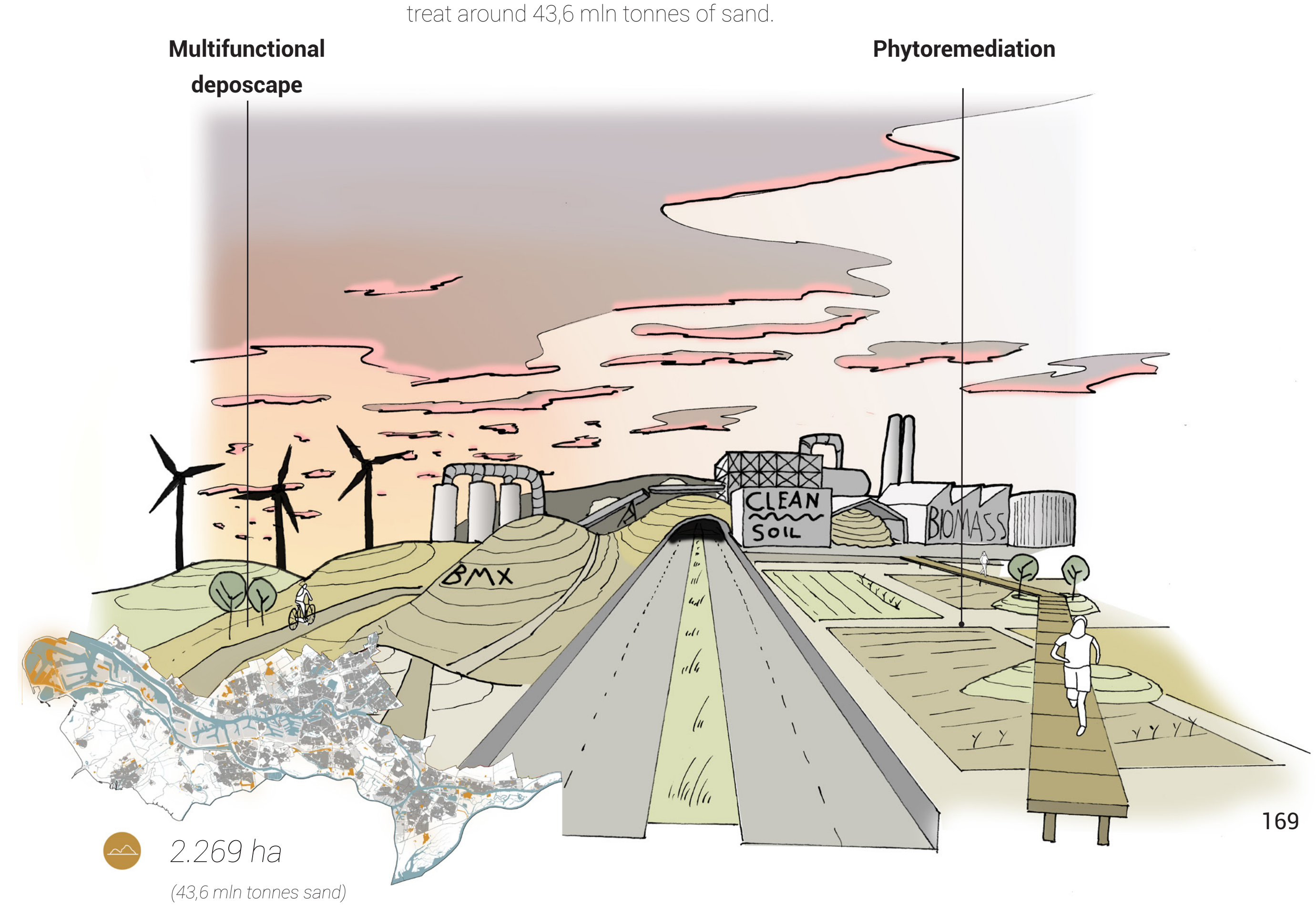
8.8.1 Production scapes

This treatment and storage requires transformation of landscapes in the region to facilitate these production plants. Three types of production scapes are visualised, which represent the solutions; (5) multifunctional dike (15) soil treatment, (16) tidal park, (17) deposcapes, (19) landfarming & (21) biobased facility. These solutions were not integrated in the previous research by design study but they are important at the background of these designs (as can be seen in the TM-LCA schemes).

The first production scape is the deposition and treatment landscape (solution 15 & 17). These can be located along wastescapes such as highway buffer zones. Contaminated soil can be stored and cleaned here through thermal treatment or phytoremediation. During this process, the landscape can be used as, for example, landscape park with platform above the phytoremediation fields or as BMX park where the stored soil creates elevation for the track. A notion should be considered on health issues of contaminated soil. This type of material could be unhealthy for humans and their presence, and especially the use of the soil, is not recommended. Furthermore, contaminated soil needs to be secured from the groundwater and underlying soil layer which requires technical measures such as a protection seal. A spatial integration for the region is made, based on the available wastescapes in the region. This results in 2.269 hectare of potential available land which could store and treat around 43,6 mln tonnes of sand.

Image 139

Impression of a deposition and treatment production landscape



The second production scape is the tidal park (solution 16) where dredged sediment can be stored, treatment and transferred to construction sites. The development of tidal park is integrated in vision and ambitions of the municipality and Port of Rotterdam (van Veelen et al., 2018). Tidal parks reduce the transportation of sediment to the North Sea and contributes to the tidal experience and biodiversity in the urban environment of the RMDS region. An idea is to treat the sediment in these tidal parks, through phytoremediation, whereafter it can be used as fill sand substitute. However, this idea needs to be further studied for feasibility.

On the other hand, tidal parks contribute to the transformation of non-residential areas and former industrial spaces could be used as material storage. The extrapolation of tidal parks to the region results in a potential to store 57,6 mln tonnes of sediment in former harbours. This amount is 22% of the total dredged material of the metabolic scenario until 2040. This percentage could increase if the material would be treated in the tidal parks and eventually be used in urban construction. However, this potential needs further study.

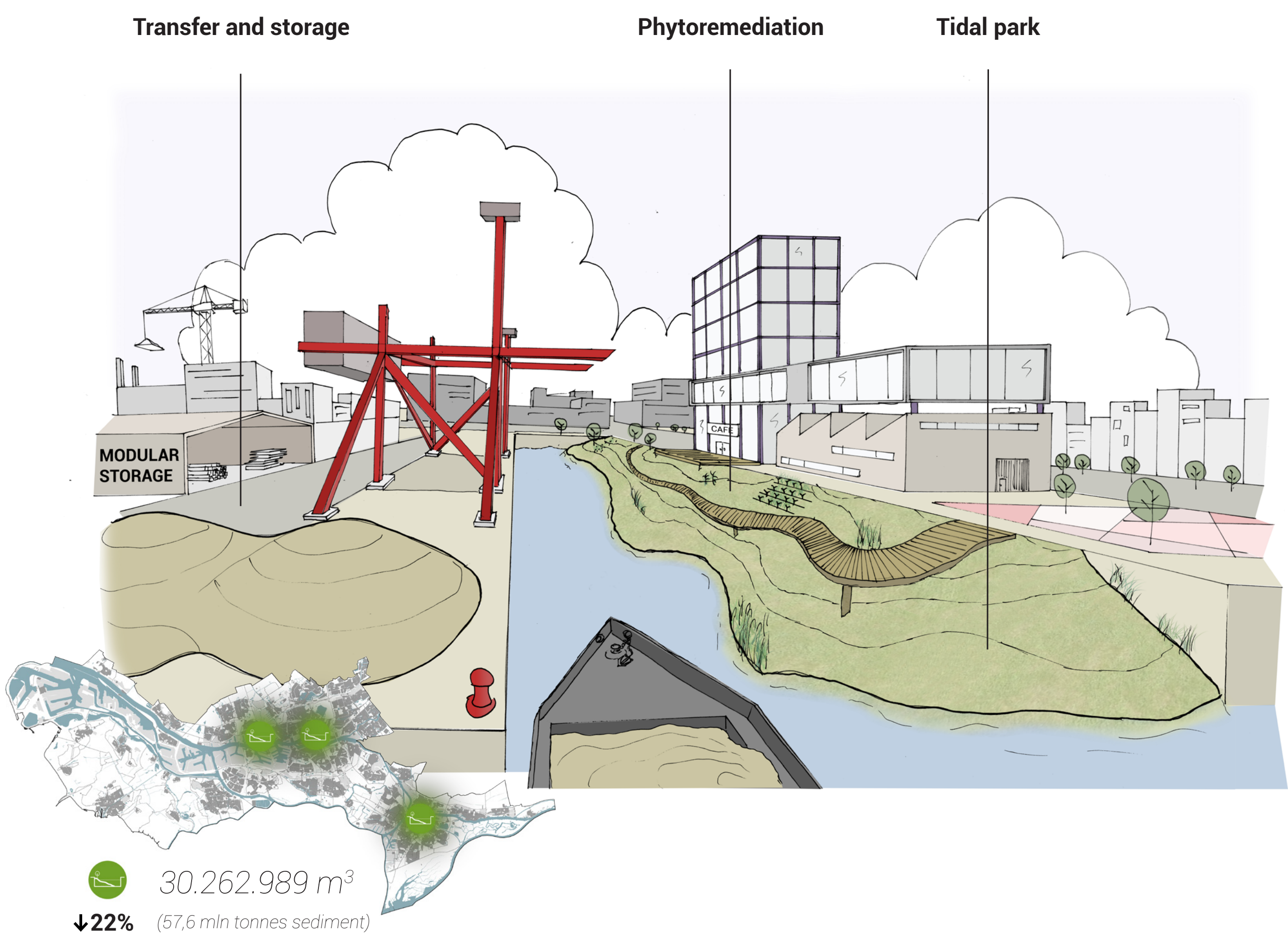


Image 140

Impression of a tidal park production landscape

The third production scape is landfarming of dredged sediment along waterways (solution 19) in combination with biobased production and multifunctional dike (solution 5 & 21). Sediment can be deposited and treated or ripened behind the dikes along the waterways. Same as the first production scape, multifunctionality can be realised by the addition of a landscape park. The dikes can also become multifunctional by combining dike reinforcement with the development of dwellings or other building structures. The impression also shows potential areas for biobased production on wastescapes in the Port of Rotterdam. The landfarming could be realised on wastescapes along the waterways, which is 1.525 hectare. This space could store 79 mln tonnes of sediment, which is 30% of the total dredged sediment in the regional metabolism. However, landfarming, and the biobased production, will compete with the first production scape for the available land.

The overview on the next pages shows how all solutions and interventions are integrated and linked in the region.

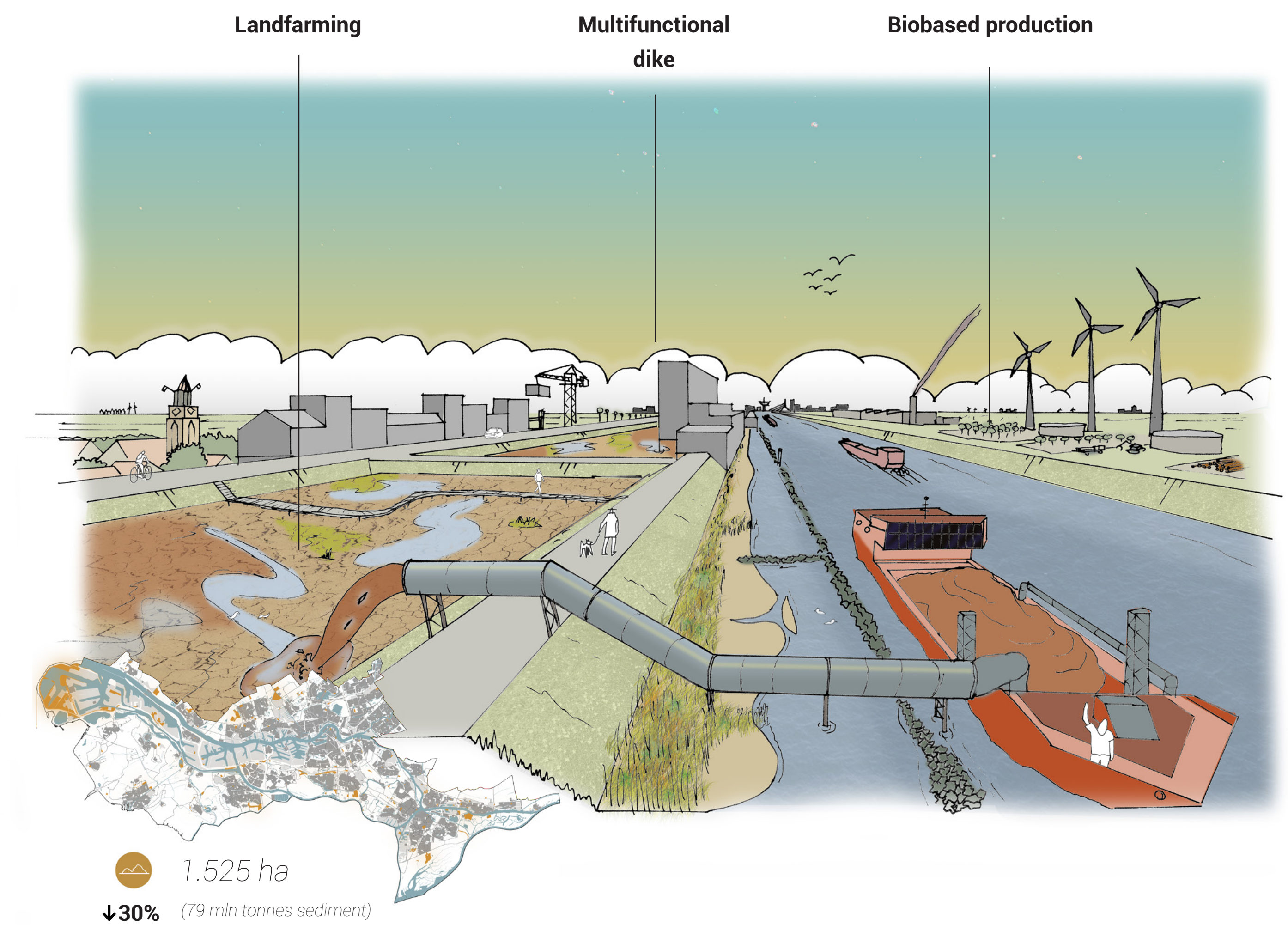


Image 141

Impression of landfarming along a waterway

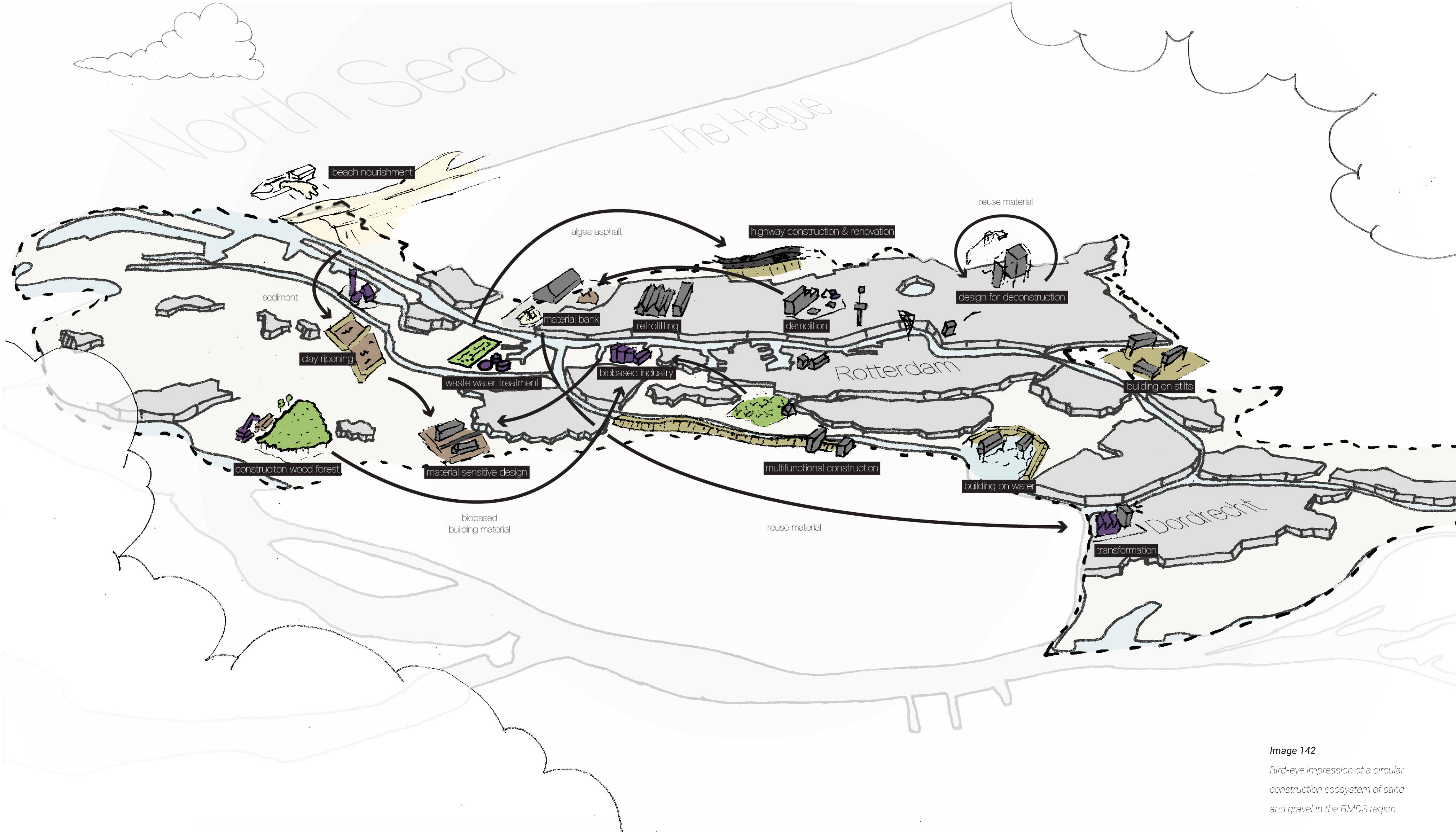


Image 142

Bird-eye impression of a circular construction ecosystem of sand and gravel in the RMDS region

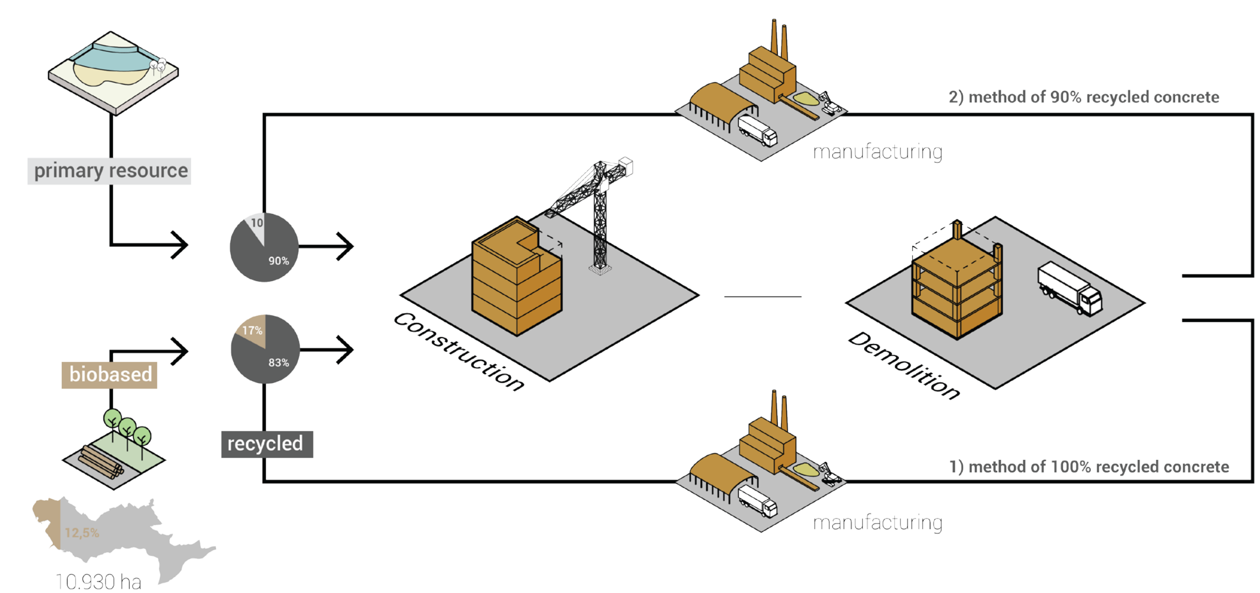
8.8.2 Regional impact of recycled materials

Building material such as concrete from secondary or biobased sources should also meet the demand for space and quantity in the region. The quantitative impact of recycling concrete depends on the used manufacturing methods. In this study, two methods are chosen; completely recycled concrete (according to Schenk and Schipper (2016)) and partly recycled concrete(according to Nusselder et al.(2015). The first method of completely recycled concrete could be used to assume that all the outflow of concrete waste can be completely used in the new construction. The amount of construction waste could fulfil around 87% of the construction demand. This means that the remaining 17% (equivalent to almost 33.250 dwellings) should be constructed from primary concrete or biobased material. In the case of the biobased material CLT (see solution 21), around 10.930 hectare is needed in the region to produce this biobased material. This is 12,5% of the total area of the RMDS region. In this situation, the reduction of primary sand and gravel for concret is 100%.

The second method of using partly recycled concrete still relies on some amount of primary sand and gravel. According to Nusselder et al. (2015) (see table) one tonnes of new concrete requires 0,754 tonnes demolition concrete waste (or EOL concrete). In the case of the RMDS region, this results in a remnant of EOL concrete 2,7 mln tonnes. This is 13% of the original EOL concrete which normally is recycled as foundation material. This reduction could prevent this stock from saturation. The primary material of sand and gravel is reduced by 90% and 83% respectively. Compared to the previous method, it does not reduces the primary consumption to 100% but it does not have an impact on the land competition in the region. The RMDS is a dense functional situation which means that the second method is assumed to be more suitable. A detailed LCA could justify this decision.

Image 143

Schematic balance of concrete recycling and the impact in the RMDS region



However, in both cases a reduction in demand due to prevention of material in the (urban) design of the construction would alter the balance. When less material is needed it would results in a higher remnant and when less EOL concrete is generated it would result in a shortage for recycled concrete production).

Another interesting quantity study is done for the secondary resource of EPS as a substitute material for fill sand. From an environmental perspective, this substitute is only environmentally better when it is 100% recycled. If the material is applied in all of subsidence prone areas, it would require an amount of EPS that is the equivalent of 13,86 mln demolished houses. In other words, almost 14 mln houses needs to be demolished for its urban mining potential of EPS to reache the demand for the RMDS region. The current supply of secondary sources is 105.000 houses in the region which is a huge mismatch with the demand, less than one percent. The conclusion can be drawn that other alternative solutions should be applied which could reduce the primary material demand, for example the design in chapter 8.5.3. Another option is to expand the urban mining market to increase the potential supply.

The next page shows the impacts of these extrapolation and solutions on the regional metabolic system. This will be explained on page 178.

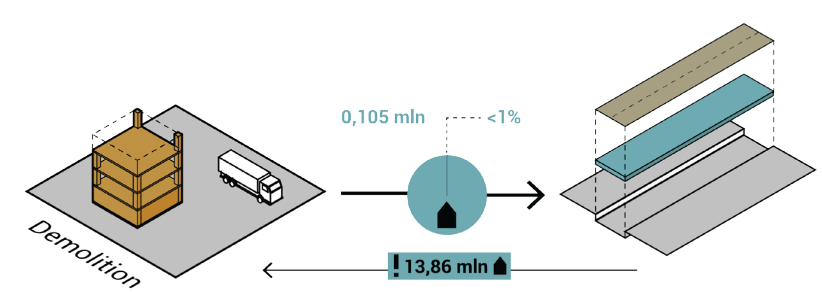
Table 6

Composition of one tonnes of concrete from recycled materials (Nusselder et al.,2015)

Material	kg per ton concrete
Cement	71,4 kg
Portland cement with 80% EOL cement fines	47,6 kg
Sand	35 kg
Sand, from EOL concrete	311 kg
Granulate, from EOL concrete	443 kg
Gravel	50 kg
Concrete Iron from recycled iron	42 kg

Image 144

Schematic balance of EPS recycling from secondary resources



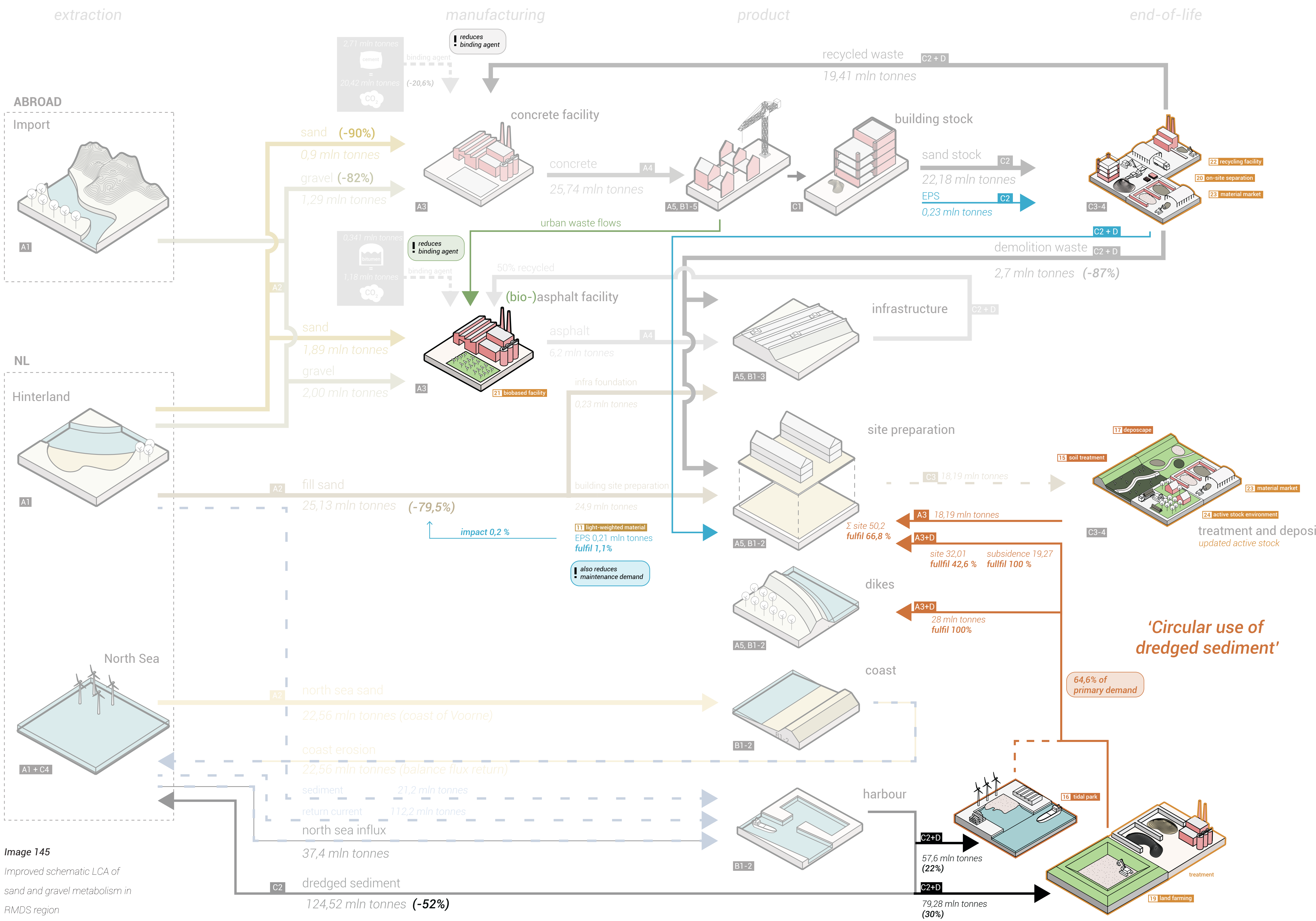


Image 145

Improved schematic LCA of sand and gravel metabolism in RMDS region

8.8.3 Improved regional metabolic balance of construction sand and gravel

The results from the regional impact study influences the consumption of the entire metabolic system. Some of the solutions and design results are extrapolated to the regional system which is summarised in the LCA scheme on the previous page. The solutions which are applied are all the production scapes from chapter 8.8.1, requirements from the vision for the circular sand metabolism (includes solution 20 to 23), and the recycling of concrete and EPS as described above.

In the improved model, it is assumed that sediment can be recycled within the urban ecosystem. Solution 16 and 19 contribute to the recycling opportunities and flows which in total reduces the transport of dredged sediment with 52%. The recycled sediment fulfil the entire demand of both dike improvement and subsidence maintenance. The primary material for building site preparation is reduced with 67% with some input from treated contaminated soil via deposcape (36%) and a negligible input from EPS (only 1,1%). Circular sediment reduces the demand for primary fill sand with almost 80%. Sand and gravel for concrete consumption are reduced with an average of 86% according to the second method as explained in chapter 8.8.3. Another opportunity for reduction lies within the use of biobased material in asphalt production. This links residual urban flows with asphalt production but its potential should be further researched.

The result of this system can be compared with the business as usual scenario of the sand and gravel metabolism. This comparison is summarised in table x. The total inflow and outflow of material are both reduced with 63% and 52%. This means that less resource depletion and dredged sediment deposit are occurring in the improved model. However, transportation and flows within the ecosystem are drastically increased with 272%. This is due to the new links between stocks and extra treatment options for materials. This increase in transport contribute to the environmental impact of the metabolic system.

The consumption can further be reduced through changes in urban development types and small scale urban designs which are presented in the research by design study. This extrapolation is not executed because it requires a more detailed design and spatial planning for the entire region. Nevertheless, the result from this extrapolation could advice the regional planning and urban design outcome. For example, the current reduction of fill sand reduces the remaining demand to 24,9 mln. This demand is primarily for the building site preparation of greenfield development and the remaining amount is required for the development of 1.733 hectare, which is the equivalent of around 13.375 dwellings. The remaining demand can be totally reduced to zero when all of these dwellings are constructed on piles and living platforms, as represented in the design in chapter 8.6.4.

Table 7

Reduction in flows in the improved LCA system scheme.

Flow	Business as usual scenario	Reduced scenario
Total inflow	146,52 mln tonnes	53,77 mln tonnes **(-63%)**
Transport within ecosystem	94,49 mln tonnes	256,67 mln tonnes **(+272%)**
Total outflow	261,8 mln tonnes	142,52 mln tonnes **(-52%)**

8.9 Conclusion: A multiscalar challenge

This chapter answers the research questions: ***'How can the sand system of RMDS be improved?'***, '***How can the sand sensitive solutions be implemented in the urban development of RMDS region?'*** and ***'What is the impact of the new urban designs for the RMDS region?'***. These questions are necessary to reach the objective: ***'Improve the sand and gravel metabolic balance in the RMDS region by minimising the consumption'***, which will eventually be the foundation for the answer of the mean research question.

The material efficiency strategies are the basis for the improvement of the sand metabolism which are integrated in the systematic vision for a circular sand metabolism. The improvement is further done by choosing focus location in the region which represent the urban design related conditions.

The sand sensitive solutions from the Catalogue of Solutions are applied in three locations according to the material conscious approach. The TM-LCA scheme also contributed to the consciousness of material consumption and impact on another scale such as the city or region.

The impact of the urban design depends on the extrapolation of the results. This is difficult for the urban design because each location requires a different approach and results in different designs. Even in this design study, several design options per location were made which each had a different impact on the region. This impact reaches from spatial and systematic to environmental where material demand is reduced, structures are reused or material is recycled. The last one has a significant impact on the region because it requires treatment, storage or secondary resources elsewhere. This impact on the region is explored through extrapolation and design study of solutions. The solutions have a spatial impact which could result in land competition but also requires further research for technical feasibility. Furthermore, a balance between in- and outflow of material is made. The integration of these solutions on the regional system reduces the consumption of primary material to a certain extend but increases the transportation of material within the urban ecosystem. This regional result from extrapolation can be used as a feedback for urban design and regional planning decision which could reduce the demand even more but could also alter the balance of the current recycling improvements.

Overall, the development of a circular sand metabolism is a multiscalar system where regional demand and supply is embedded in the local urban designs. These improvements require new flows and supplies which results in industrial spatial transformation of environments elsewhere.

Does design matter?

9. Evaluation, conclusion, discussion & reflection

This chapter rounds up the research with the evaluation of the overall design research, conclusion derived from this, discussion on the choices and methods and reflection on the overall process and position of the project in a broader context. The four contents chronologically looks back at the project from a close perspective towards a wide and more abstract perspective.

9.1 Evaluation

The evaluation will focus on the impact of the sand-sensitive city according to the research question: 'What is the impact of the new urban designs for RMDS region?'. The extrapolation at the end of the previous chapter explored the implication of the improvement to the sand metabolism in the region but the impact can also be evaluated based on the territorial metabolism life-cycle assessment scheme which is created for each design option. The TM-LCA scheme visualises the impact of the design on the system but also the requirements the design demands from the construction ecosystem. The impacts can be divided in two topics; environmental impact and spatial/governance impact

9.1.1 Environmental impact

Land competition in relation to production/storage (capacity)

The development of a circular construction ecosystem requires space for functions such as production of biobased products or temporary storage of (modular) building material. This required space contribute to a competition of land within a dense region. The design study of production scape in chapter 8.8.1 and quantity study in chapter 8.8.2 show that these function can compete with each other and how much space is required

Transportation

Using secondary material requires transport which might cause more emission due to higher transportation rates. Within this also the question of best location for storage or treatment is important for an efficient system. In the extrapolation study in chapter 8.8.3, the increase of transportation is 272%.

Treatment and time

Secondary material or dredged sediment needs to be treated and tested before it can be reused. This treatment requires energy which can be more harmful to the environment or it requires time for natural treatment, such as phytoremediation, which need long-term planning for an unforeseeable future demand and requires space. In the RMDS region, spaces for treatment are designed as deposcapes or tidal parks.

Fragility in supply and demand

Lots of material input in design are based on material from urban mining. The balance between supply and demand can differ or mismatch within time or amount of material. This fragility requires alternatives which can fill the gaps. A big mismatch can be found in the urban mining potential of EPS which can only fulfil (and thus reduce) 1% of entire demand. This mismatch can be solved by reducing the areas which requires EPS (only the areas which are the most vulnerable to subsidence) or by expanding the area outside the borders of the RMDS region to search for secondary resources. Another option might be biobased EPS but the production most probably impacts the environment due to the required production land in order to reach the demand.

9.1.2 Spatial/governance impact

Interrelation and trade-offs between location with demand of secondary material and supply for material

Some areas depend on a specific input for maintenance such as EPS for subsidence. Due to the availability of material, decisions need to be made about which area can use which secondary material from where. This decision can cause inequality within a region. The quantity study in chapter 8.8.2 shows the mismatch in the region which means that another option should be found.

Impact on property

Some improvements within the urban environment have an impact on the current land use property in order to reduce material demand, for example the designs in chapter 8.5. Gardens need to be transformed into public green structures which are currently private property. The feasibility of this strategy is questionable because it requires a lot of expropriation processes.

Land competition in relation to production

Land competition is already mentioned in the environmental impact part but the quantity of land needed is a spatial impact about where this is possible and who will facilitate this. However, these areas can contribute to spatial quality of current wastescapes, such as highway buffer zones or abandoned harbour quays.

Impact on generic spatial standards

The current urban neighbourhood standard can be described as a house with a garden and parking space in front of your house. These standards can relate to the general demand of housing standards which are changed in some design options, as can be seen in the design in chapter 8.4.

Relation with transition in climate change, mobility and CO2 emission due to peat oxidation

A majority of the improvements also contribute to current transition in climate change (more green structure within a city,) mobility (car-free neighbourhoods) or CO2 reduction (transforming peat farmland into wetlands in order to prevent peat oxidation), as seen in the designs in chapter 8.6. These contribution makes some urban metabolic improvements a win-win scenario.

9.2 Conclusion

Urban construction material consumption is coupled with urban development which can be new construction for housing demand or maintenance due to subsurface conditions. The Rijnmond-Drechtsteden region is an example of these consumptions where the urban metabolism of construction sand and gravel is notable for its quantity and environmental impact due to end-of-life disposal and CO_2 emission. Sand and gravel is needed for primary needs such as fill sand for stability and accessibility and concrete for structures and shelter. Current development dynamics are causing major flows of these materials for the construction of 88.000 dwellings and replacement of around 100.000 until 2040 while at the same time sand is also required for subsidence maintenance. The consumption and the related environmental impact from extraction, manufacturing and disposal in the life-cycle of these products are reasons for governments to set ambitions towards a circular economy with no input from primary fossil resources, such as the city of Rotterdam and Dutch national government.

Other events such as flood and coastal protection are also requiring primary sand for construction or maintenance but the focus lies on concrete, asphalt and fill sand due to its relation to the profession of urban design and planning. The concept of urban metabolism and the related methods such as material flow analysis are useful within the discipline of urbanism to tackle the challenges which comes with the impact of the material consumption and ambition of circular economy within the context of construction sand and gravel metabolism. The development of a business as usual scenario of the construction sand and gravel metabolism in the RMDS region sets the field for small scale urban design examples in order to answer the research question:

"How can ***urban design*** *reduce the consumption of* ***primary construction sand and gravel*** *in the* ***construction ecosystem*** *of the Rijnmond-Drechtsteden region?"*

The answer of the research question can be explained according to three key words and the main objective of the research question; ***urban design, construction ecosystem and its consumption***, and ***reduction***.

Construction ecosystem and its consumption

The construction ecosystem is research according to a literature review, material flow analysis and dynamic stock model with input from a material intensity model. This ecosystem has a very low dynamic pace which makes fluxes within a stock quite long. For example, a building has a lifespan of 75 to 125 years but buildings still stand after this assumed service life. Another aspect is the 'grave' characteristic of the urban/anthropocentric stock. Every flow of sand remains, after demolition, within the urban ecosystem where, as a stock reach its end-of-life, a new stock is created with primary resources. Some stocks require/demand a continuous material input in order to meet its standard condition, such as subsidence maintenance. Only natural flows of sediment leaves the ecosystem but with artificial support in the context of RMDS region. Material efficiency and reduction of demand is a task which is difficult in a setting where there is a future and/or continuous demand of sand and gravel. However, there are opportunities to recycle or reduce material in the construction ecosystem of RMDS region.

Urban design

The consumption of sand and gravel with a focus on concrete and fill sand can be distinguished in different conditions which causes supply and demand. These conditions are divided in two groups; urban development activities (densification, retrofitting, transformation of non-residential areas and greenfield development) and maintenance activities (due to subsidence, sea level rise, dredging or infrastructure status). Each of these conditions have a certain relation with how it consumes sand and gravel, and which urban construction it contains. For these conditions, it is important to become conscious about where which material flow is required and occurring. This approach is introduced as the material consciousness through the research of improvement and solutions. A material consciousness approach integrates the four stages of a construction process from the lifecycle perspective (situation, construction, maintenance and end-of-life). The approach is expanded by its relation with material consumption and the possibilities to integrate the material efficiency strategies (prevention, reuse, recycle) within the design.With the territorial metabolism life-cycle assessment (TM-LCA) scheme the impact and consumption of the design can be explored and evaluated on urban design scale but also within the construction ecosystem. By using this in the iterative process of design for making different improvements, reduction can be achieved with a clear transparency in environmental and spatial impact. The TM-LCA and overall approach helps urban design and planners to integrate and improve material consumption in planning.

Reduction of the primary consumption

Main reduction in urban design is done by prevention of the material through reduction of the demanding condition, for example an urban design which requires less fill sand or a strategy where buildings are not demolished. Another reduction is done by reusing or recycling material from the circular construction ecosystem or biobased substitutes which requires changes and improvement on different levels within the ecosystem. These changes can have an environmental impact which needs to be compared with the business as usual scenario in order to make the right decision. Substitutes such as dredged material or recycled EPS are applied, current spatial quality in maintenance examples can be preserved. However, environmental impact via LCA should be investigated in order to decide whether this solution is an improvement or not. For example, dredged sediment needs treatment which requires energy, transportation and land use which all could have an negative environmental impact. In the case of EPS, treatment and quantity from the secondary source for implementation is questionable. This is why a life-cycle approach and assessment are important in the reduction process. Both to make the best environmental/technical decision but also to highlight focus point within the system from a (urban) designer perspective. Urban design can thus reduce physical sand demand on site but does not definitely reduce the consumption within the construction metabolism. Systematic solutions and treatment beyond the urban design scope can have similar to greater impact on the consumption within an urban design. Urban design and development projects need to be integrated in a balanced regional planning and strategy in order to have significant impact on the consumption. This makes the development of a circular sand and gravel metabolism a multiscalar challenge. A first exploration of this circular metabolism is visualised on page 178.

Advices for the region 'A regional game board for circular construction'

The ecosystem which is required for circular construction is quite complex but planning on a regional scale is necessary to meet and link supply and demand and locate and promote the facilities. Recycling and substitutes of sand should be monitored by government in order to prioritise areas with high-demands for subsidence maintenance. The region should provide a circular ecosystem which functions as game board where urban designers, architects and innovators can react on and provide from in their projects to find the supply and demand of material. The material consciousness approach in combination with TM-LCA strengthens the decision process toward environmental friendly urban development.

However, because of the lack of a material passport of the current material stock in construction (an exact quantity of available material can be made during the deconstruction phase), a governmental strategy and management of the flows at construction but especially demolition should be developed. A transparent market of supply and demand of materials is necessary where available material from demolition can be stored, tested and reused in a as small as possible ecosystem in order to reduce transportation. This system requires further research and study on a possible business model and stakeholder system.

9.3 Discussion

Use of assumptions

The design research combines quantitative system thinking with design interventions. The quantitation of the ecosystem, here construction sand and gravel, is based on assumptions in order to develop a scenario for the future sand supply and demand. These assumptions are done with top-down or bottom-up methods for data or a generic database for certain numbers. The resulting outcome can differ significantly when changing one of the assumption used in the models. However, the method and theoretical framework behind the assumptions are justified and changes or improvement in the used numbers can be integrated in the model in order to improve the outcome. This change can lead to different outcomes for the design TM-LCA. This is why further research from environmental and/or technical disciplines on the model is necessary in order to generate better advice for the society.

Currently, technical feasibility of recycling potential is done by the quantity of in- or outflow of materials. The question remains if this number is realistic and requires on site evaluation of each building. When less material is available from demolition then required for the new construction, the 100% recycling option which is sometimes proposed, is not possible. If this is the case, another source or substitute should be found.

Quality of material

The quality of the material is not integrated in the model and improvements in design. This is an important aspect in the recycling of material because it needs to meet the new products requirements such as strength in concrete. Sediment and concrete are recycling in the improved consumption model for the RMDS in chapter 8.8. The quality and technical requirements are not integrated in the model but are crucial for the new implementation. Sediment can be contaminated with for example salt which requires treatment. These processes have a certain impact and time frame which, when not possible, could hinder the recycling possibilities of the material and indirect the reduction of primary material in the region.

Including stakeholders

The consumption of sand and gravel is, just like every market product, related to private market decision and relation. The stakeholder analysis and decision model is now absent in the research and design proposal but should be a key element in further research for the implementation and succession.

Why build in vulnerable delta areas?

A complex discussion can be done about the fact why we built and expand in delta regions. Weak soils, sea level rise and climate change are all threatening the liveability in these regions while at the same time the majority of the housing demand is located here. As the study shows, subsidence requires vast amount of material which does not have a recycling potential and on the same time, recent study estimated the increasing amount of sand required for coastal protection (Deltares, 2018). From these perspective, a movement towards location on higher and stronger grounds would be more sustainable and resilience in order to reduce material demand for maintenance until the tipping point that the these landscapes become unliveable. Dutch landscape architecture firm LOLA visualised a future for 2200 where this occurred (LOLA, 2019). A vast majority of the Dutch landscape has become waterscapes, where some urban environments have been abandoned and bigger cities become strongholds protected with dikes. Cities such as Breda or Zwolle become coastal cities where urbanisation and development has continued. This futuristic image should be included in the discussion of circular construction and development in the Randstad region.

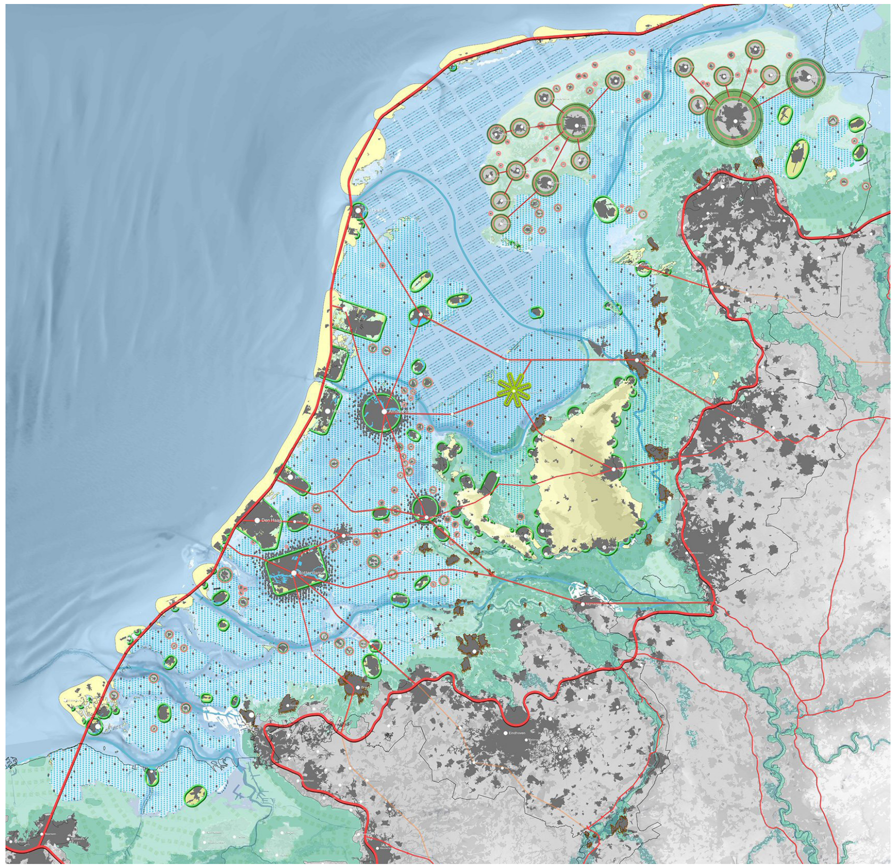


Image 146:

The Netherlands in 2200.

Soruce LOLA, 2019

9.4 Future research recommendations

Lessons from a history MFA model

The current MFA is executed as a forecast for future consumption through a dynamic stock model. This resulted in a scenario for the RMDS region which was the basis in the material conscious approach and designs. However, a MFA of a past period (e.g. of the year 2017) could also have an important contribution to the field of study. This type of MFA for the sand and gravel metabolism would be clearer on several aspects. First of all, data would not be assumption because facts of past construction can be used which can be collected via survey of the involved stakeholders. Both in- and outflow would be based on facts, which creates a more detailed and reliable MFA model. These results contribute to the understanding of the conditions and drivers of the sand and gravel metabolism which eventually could contribute to the forecast of future consumption.

Interdisciplinary exploration and collaboration

The study had an interdisciplinary approach because it covered topics from urbanism and civil engineering. However, this interrelation needs to be further explored for (1) the technical feasibility of design improvements and (2) their impact on the drivers and the environment (with the LCA). These two interrelation will be explained in the next two paragraphs. Although, a note needs to be made on the interdisciplinary collaboration. Several topics do not lie within the expertise of urbanism, for example the use of building site preparation or alternatives for beach nourishment. Instead of an individual project, an interdisciplinary expert group could be formed around the topic. Civil engineering experts could contribute to the technical feasibility and environmental impact while urban designers could explore the spatial possibilities and integration. An interdisciplinary group could integrate the next four comments and eventually comes with new findings and improvements.

LCA execution

The LCA evaluation can be extended when the material consumption is quantified during the design process. Reduction rates can be made explicit in the business as usual versus improvement model process. For example, a CO2 reduction can be used as a parameter for quantitative environmental impact in the design process when strategic decision on reduction of demolition is made compared to a business as usual scenario where everything is demolished because no transportation or manufacturing of new concrete is needed. These outcomes can be used in development discussion in order to make fundamental environmental friendly designs. However, an academic implementation of this LCA in close relation to design needs to be further developed and tested. The approach is also similar to the GeoDesign method which also evaluates impact within the iterative process of design (Steinitz, 2012) but it does not focus on an entire life-cycle of an urban construction.

Technical feasibility

On a more practical level, research needs to be done based on the quantitative feasibility of recycling possibilities. Some alternative material, for example EPS as fill sand substitute, area interesting to be recycled and implemented but the quantity originated from secondary stock mismatches the demand. This requires studies towards a balance in circular material consumption and its alternatives which can continue on finding and methods from this research.

Urban design exploration

The design research demonstrates how the application of the material conscious approach on urban design projects. Thanks to the TM-LCA scheme, the relation between material consumption and urban design has become visible. Examples of the material reduction can be found in design choices such as the decision to demolish and renovate or in spatial composition or typologies such as smaller plots or buildings on piles. The starting point of the graduation project was not the urban design process and research (which would be the case with a mentor from the Urbanism chair 'Urban Design - Urban Composition'). However, a design exploration would be an interesting next step within the field of urban design to expand the possible impact of spatial design choices and the integration of the material conscious approach within the discipline.

Regional planning integration

The current designs relate to a regional systematic improvement and integration. Regional and local storage and treatment need to be facilitated. This task demands further research from both regional planning and environmental studies. Based on the environmental impact of e.g. transportation, suitable and strategic locations need to be found for these plants, both geographical and governmental.

9.5 Reflection

The relationship between research and design

Design and research are quite interwoven in the graduation project. This is also reflected in the research question where urban design was the main key word. However, a comprehensive research was executed in order to understand the metabolic system of construction sand and gravel. This research eventually became the context of the design research where improvements were proposed. The design research had a 'research through design' characteristic because it, following Frankel & Racine (2010), had an action-reflection character in the approach thanks to the application of the LCA. Design results can be seen as improvement to the situation as an exploration of the system.

Relation between graduation project topic, the studio topic, master track and master programme

The research to reduction of material consumption within the construction sand and gravel metabolism is done within the graduation studio Urban Metabolism. The studio focuses on the understanding of the metabolism of urban environments with a focus to develop new urban system which are less damaging the environment (TU Delft, n.d.). The graduation project focuses on one particular flow within the urban metabolism, sand and gravel, and reveals its ecosystem. Another aspect in the studio is "Metabolism tools can help to assess and aid the growth (and decline) of cities [...]." (TU Delft, n.d.) which is also explored because the context of the project was the development of housing in the Rijnmond-Drechsteden region. This aspect can also be seen as a core element within the master track. The dynamics within cities and the related development is where the urbanism profession focuses on. A notable element within the graduation project is the interdisciplinary aspect due to the second mentor from the Faculty of Civil Engineering and Geoscience. This interdisciplinary aspect was introduced in the context of the Infrastructure and Environment Annotation, which stimulates the synergy between design and engineering (Delta Urbanism TU Delft, 2017). With the introduction of my second mentor Henk Jonkers from the Sustainability Chair in the section of Materials & Environment, the environmental impact in the development of new urban system in the graduation project was better covered and supported.

The relation between the methodical approach of the graduation lab and the chosen method in the developed framework

The material flow analysis is a general method within the field of urban metabolism (Newell & Cousins, 2015). This method was used and extended with dynamic stock model and material intensity model methods in order to analyse the (future) construction ecosystem. The life-cycle assessment is related to the concept of urban metabolism but currently not integrated in the field of urbanism. This and the material consciousness idea can be an interesting approach to bring urban design and material flows closer to each other in the design process. The TM-LCA can be used to elaborate between different disciplines in order to emphasise the interdisciplinary character of the topics and concepts within urban metabolism.

Transferability of the project results

Research and design approach is well suitable for transferability to current challenges and projects in circular construction. The proposed approach of material consciousness and tools such as the TM-LCA scheme are interesting to develop further for societal application. However, the quantitative results are questionable due to the high level of assumption, as mentioned in the discussion section of this chapter. A environmental and technical evaluation should be done on the results in order to justify the quantitative results.

Societal and scientific relevance

Circularity and consumption reduction are global challenges which several governance and institutions want to achieve. The related environmental impact can be related with the Paris Agreement for CO2 reduction which can be achieved when for example biobased material is used with an end-of-life scenario without incineration or peat land transformation to wetland to prevent peat oxidation. This project contributes to the understanding and approaching of the systems which relate to these challenges and visualises examples of future design outcomes.

Within the scientific field of the concept of urban metabolism, focus has rarely been on the construction ecosystem (Zhang et al., 2018). This study unravels the relation between urban metabolism and the construction ecosystem and links it with theories from civil engineering studies. The approach in both the analysis and design are useful for studies on the topic and its impact. The TM-LCA scheme can contribute to the studies towards environmental impact and improvement within the design and strategy for urban regions.

Ethical issues

The graduation project promotes a circular construction ecosystem where secondary resources are used in new construction. However, some potential solutions, such as EPS for subsidence solution, have a low availability, according the assumption. We want to consume responsible and achieve a zero material take from the remaining reservoirs but this means that we need to balance the current material stock within our ecosystems. Scarce but demanded material can thus cause inequality between urban regions where some areas can benefit from the use of recycled EPS for subsidence maintenance, while other cannot.

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A. Appendix

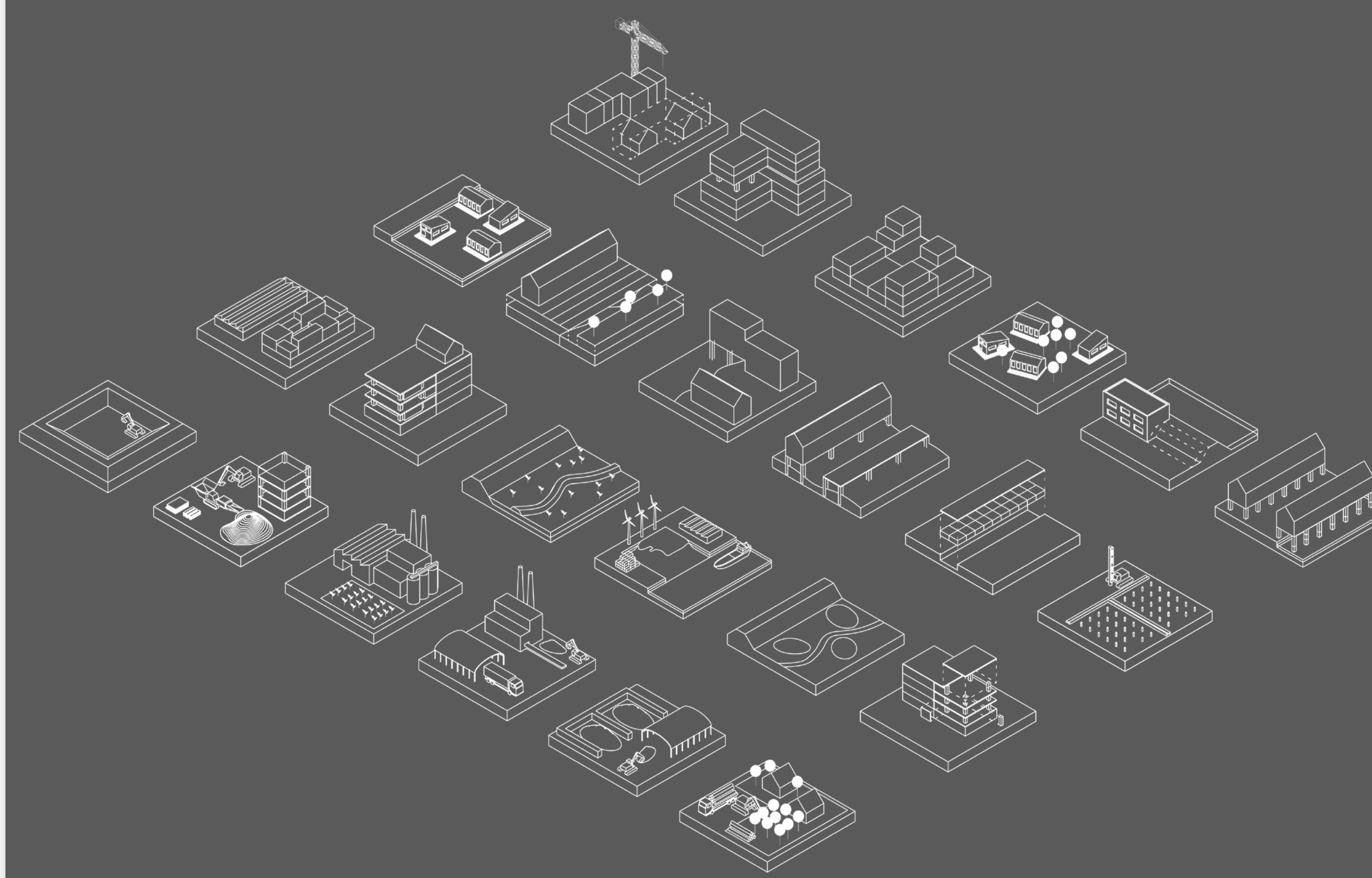
Catalogue of solutions

The Catalogue of Solutions is added as an external issue of this MSc thesis.

Catalogue of solutions

Exploration towards sand-sensitive solutions

Appendix of the graduation project:
'**City** without **Sand**'



Wouter ter Heijden

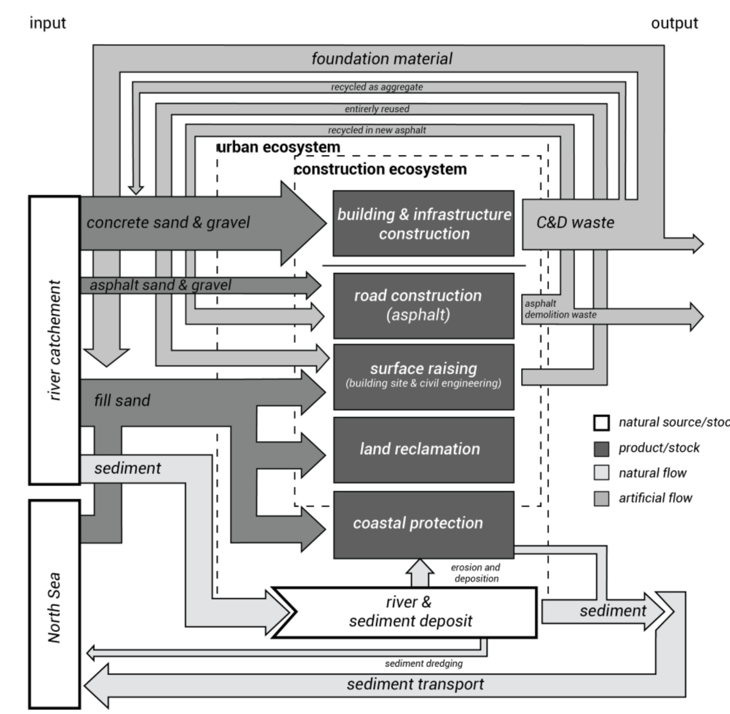
TU Delft

B. Appendix

This appendix contains the calculations and assumption for the material flow analysis in chapter 6.

Quantifying the MFA model

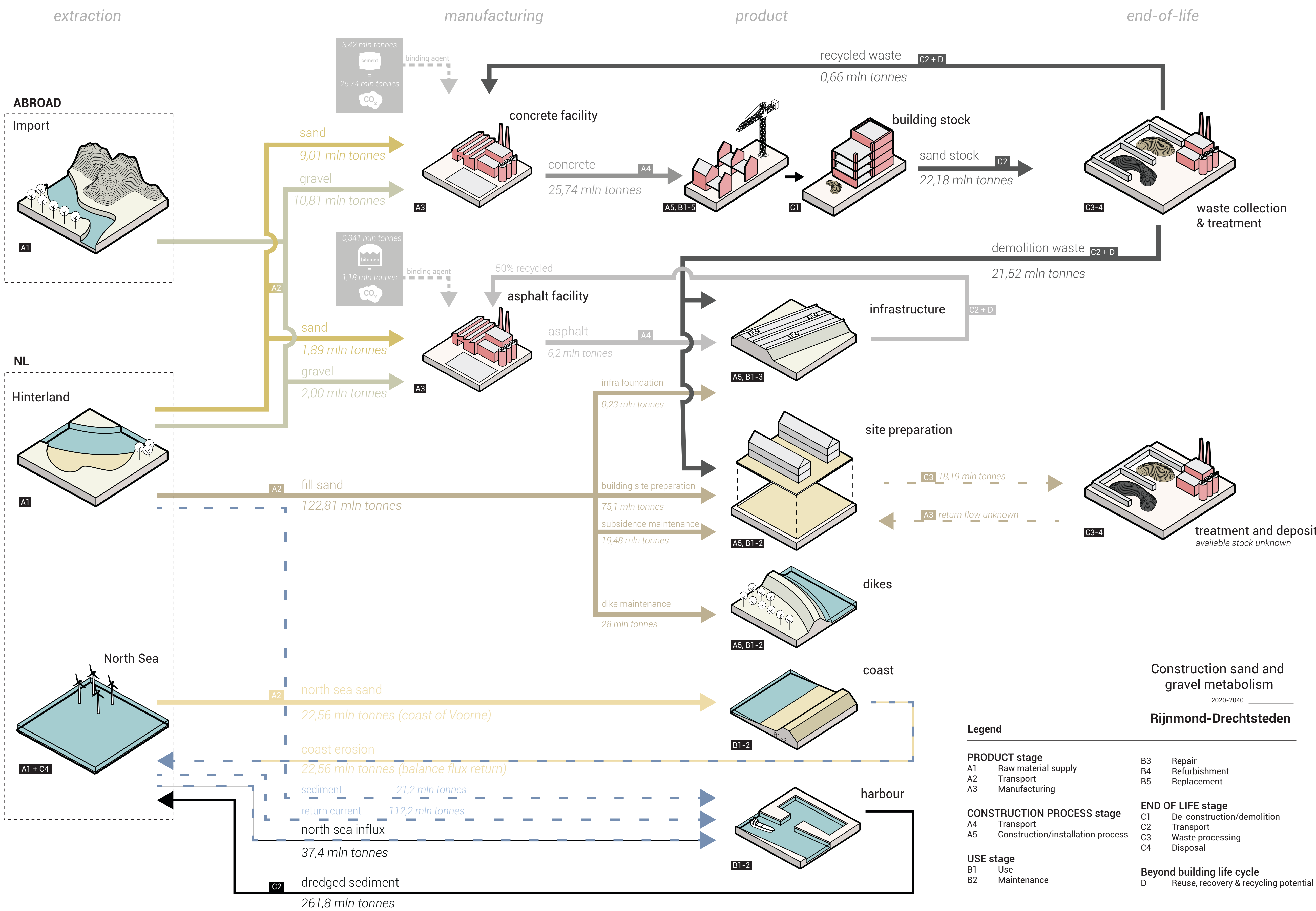
Sand and gravel metabolic framework



This document explains the quantification process of the construction sand and gravel metabolic model in the RMDS region from 2018 until 2040. The model is generated with models and assumptions generated by GIS data. The models are divided in the four stock/product in the metabolic framework; [1] buildings & infrastructure construction, [2] road construction (asphalt), [3] surface raising (building site preparation & civil engineering), [4] coastal protection, (land reclamation is ignored because of there are assumedly no land reclamation projects).

The approaches applied are based a dynamic stock model (Müller, 2006)which takes population and lifestyle change as a driver for dwelling (stock) demand, joined with the service lifetime of the stock. For the RMDS region, the variables of population and lifestyle change are

Each product has an internal and external factor which drives the metabolic framework. Internal factors are based on the characteristics of the product, such as service lifetime of the stock. External factors are plans and strategies which causes construction activity. The models of each product are explained below.



extraction
manufacturing
product
end-of-life
ABROAD
Import
A1
NL
Hinterland
A1
North Sea
A1 + C4
3,42 mln tonnes
cement
=
25,74 mln tonnes
CO_2
binding agent
recycled waste
C2 + D
0,66 mln tonnes
concrete facility
A3
sand
9,01 mln tonnes
gravel
10,81 mln tonnes
A2
concrete
A4
25,74 mln tonnes
A5, B1-5
C1
building stock
sand stock
C2
22,18 mln tonnes
C3-4
waste collection
& treatment
demolition waste
C2 + D
21,52 mln tonnes
0,341 mln tonnes
bitumen
=
1,18 mln tonnes
CO_2
binding agent
50% recycled
asphalt facility
A3
sand
1,89 mln tonnes
gravel
2,00 mln tonnes
asphalt
A4
6,2 mln tonnes
infrastructure
C2 + D
A5, B1-3
infra foundation
0,23 mln tonnes
site preparation
A2
fill sand
122,81 mln tonnes
building site preparation
75,1 mln tonnes
subsidence maintenance
19,48 mln tonnes
A5, B1-2
C3
18,19 mln tonnes
A3
return flow unknown
C3-4
treatment and deposit
available stock unknown
dikes
dike maintenance
28 mln tonnes
A5, B1-2
coast
A2
north sea sand
22,56 mln tonnes (coast of Voorne)
B1-2
coast erosion
22,56 mln tonnes (balance flux return)
sediment
21,2 mln tonnes
return current
112,2 mln tonnes
north sea influx
37,4 mln tonnes
harbour
B1-2
C2
dredged sediment
261,8 mln tonnes
Construction sand and gravel metabolism
2020-2040
Rijnmond-Drechtsteden
Legend
PRODUCT stage
A1 Raw material supply
A2 Transport
A3 Manufacturing
CONSTRUCTION PROCESS stage
A4 Transport
A5 Construction/installation process
USE stage
B1 Use
B2 Maintenance
B3 Repair
B4 Refurbishment
B5 Replacement
END OF LIFE stage
C1 De-construction/demolition
C2 Transport
C3 Waste processing
C4 Disposal
Beyond building life cycle
D Reuse, recovery & recycling potential

How to calculate the material consumption of sand and gravel in the region?

The Material Flow Analysis (MFA) is a key analysis method for an urban metabolism. This method can be described as: 'a systematic assessment of the flows and stocks of materials within a system defined in space and time'. Before constructing the MFA, a definition of the spatial boundaries of the ecosystem and time period are required. The spatial boundaries are set at the administrative boundaries of the municipalities within the RMDS region. The period is from 2018 until 2040, the period of when the research is executed until the projected aim for the housing demand in the region. The flows and stocks of the material are the urban construction related to sand and gravel as described in the theoretical framework and visualised in the metabolic framework.

The MFA is extended towards a dynamic stock model, according to Müller (2006).

[1] Buildings & infrastructure construction + [2] road construction

<u>Buildings</u>

-Internal factor:	durability=service lifetime *Result: outflow of EOL buildings (3 scenarios [low-medium-high]) --- inflow of replacement buildings*
-External factors:	Plan & strategy *Result: inflow of new buildings (based on number) --- outflow of demolished buildings (based on location VDM)*

<u>Infrastructure</u>

-internal factor:	durability=renovation *Results: inflow of new asphalt --- outflow of old concrete (directly as landfill)*
-external factor:	plans for new infrastructure (RWS) *Results: inflow of new asphalt *related to surface raising and building site preparation* Plans of new neighbourhoods: requires a rule of thumb about the added m^2 road per constructed dwelling

[3] Surface raising

<u>Building site preparation</u>

-internal factor:	subsidence = site raising of public space *Result: inflow of fill sand for maintenance*
-external factor:	new neighbourhoods (from VDM)

Dwellings External

Based on: Development plans

A) *Regional scale*: Deltametropool & Zwarte Hond

Deltametropool Verstedelijking en Agglomeratie

Conclusion

Vereniging Deltametropool researched the potential and capacity for urban development in the province of South Holland (PZH) based on the accessibility and the related identity of international, national, regional, public transport and local/car (2014). The potential areas were focussed in the areas in the municipality's urban boundaries. The areas were linked with the type of development which is possible on the location, such as transformation or retrofitting. The capacity exceed the prognosis set by national government and does not directly related with current plans and visions of the region (except the integration of approved development plans). However, the capacity study gives insight if there is space to realise the demanded dwellings in the future.

Related data

Total development capacity RMDS region: = **105.064 dwellings**

Transformation offices	= **524**
Transformation commercial	= **809**
Transformation sport area	= **10.943**
Transformation glass houses	= **655**
Transformation industry	= **9.007**
Transformation farms	= **15.240**
Retrofitting neighbourhoods	= **14.374**
Brownfields	= **1.976**
Existing plans	= **51.536**

--PRELIMINARY INPUT MODEL--

Based on the data of de Zwarte Hond, an input quantity of dwellings can be developed for the region until 2040. Two additional data is required in order to calculate the preliminary input; assumed (total) built area and material intensity per square meter.

Assumed (total) built area – Based on CBS

The average GFA of a dwelling in PZH is 103 m^2

Material intensity per square meter – Based on Metabolic/database

Material per square meter:

Concrete	= **0,878 tonnes**
Sand and soil	= **0,363 tonnes**

Material intensity per square meter – Based on own assumption (see appendix C)

Material per square meter:

Concrete = **1,29 tonnes**

Preliminary calculation

If we assume that the 88.300 dwellings will be built according to the average GFA and material intensity database, the following formula needs to be applied for concrete input:

$$Input_{dwellings,\ concrete} = (total\ dwellings * average\ GFA) * MI_{concrete}$$

Resulting in:

$$Input_{dwellings,\ concrete} = (88.300 * 103) * 1{,}29 = \mathbf{11.732.421\ tonnes\ concrete}$$

Detail material composition (Based on Copuroglu (2017)*)*

41% rock (coarse aggregate) = gravel

26% sand (fine aggregate)

Thus:

Gravel	= **4.810.293 tonnes**
Sand	= **3.050.429 tonnes**

Sand for buildings site preparation is, according to the above method, estimated on:

= **7.447.814 tonnes**

Dwellings Internal
Based on: BAG data

Data received from the stock data of the area can gives us an insight on the estimated end-of-life (EOL) of a structure and its assumed demolishment. The model for material input due to EOL is influenced by the following parameters: the life-span (low/medium/high) and the demolishment probability (in percentage).

Lifespan
According to Sartori et al. (2008) the low, medium and high lifespan of buildings is respectively 75y, 100y and 125y. Based on the BAG data a calculation is made in GIS of the current building stock. A baseline measurement is made of the stock with the assumption that buildings which reached their EOL in 2020 are monuments.

According to the lifespan method and assumption with low lifespan (75 year), **64.878** buildings are theoretically reaching its EOL in 2040, thus will be demolished.

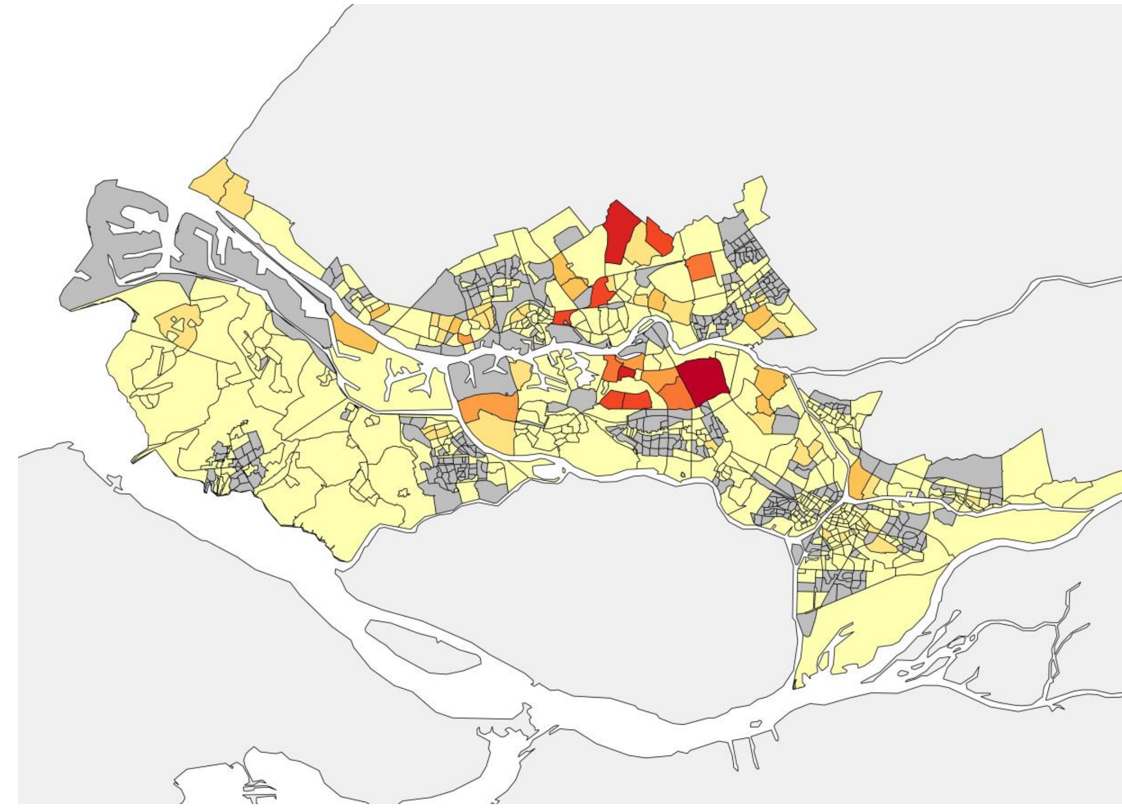
NOTE* *output data is based on buildings and not dwellings (buildings includes several dwellings). An assumption needs to be made of the dwelling per building (of Multi-Family typo's)*

The material intensity is based on the database of Wiedenhofer et al. (2015). Going on from the previous note, an assumption is made based on the division of typologies within the EOL y=75. The typologies Multi-Family and High-Rise includes multiple dwellings per building. For this assumption, NEN statistics about standard apartments in the Netherlands are used. An average dwellings (including corridors and stairways in the buildings) has an area of 112,4 m^2. This average is used in the division of the total GFA of the MF or HR typology in the EOL y=75. (source)The division is as followed:

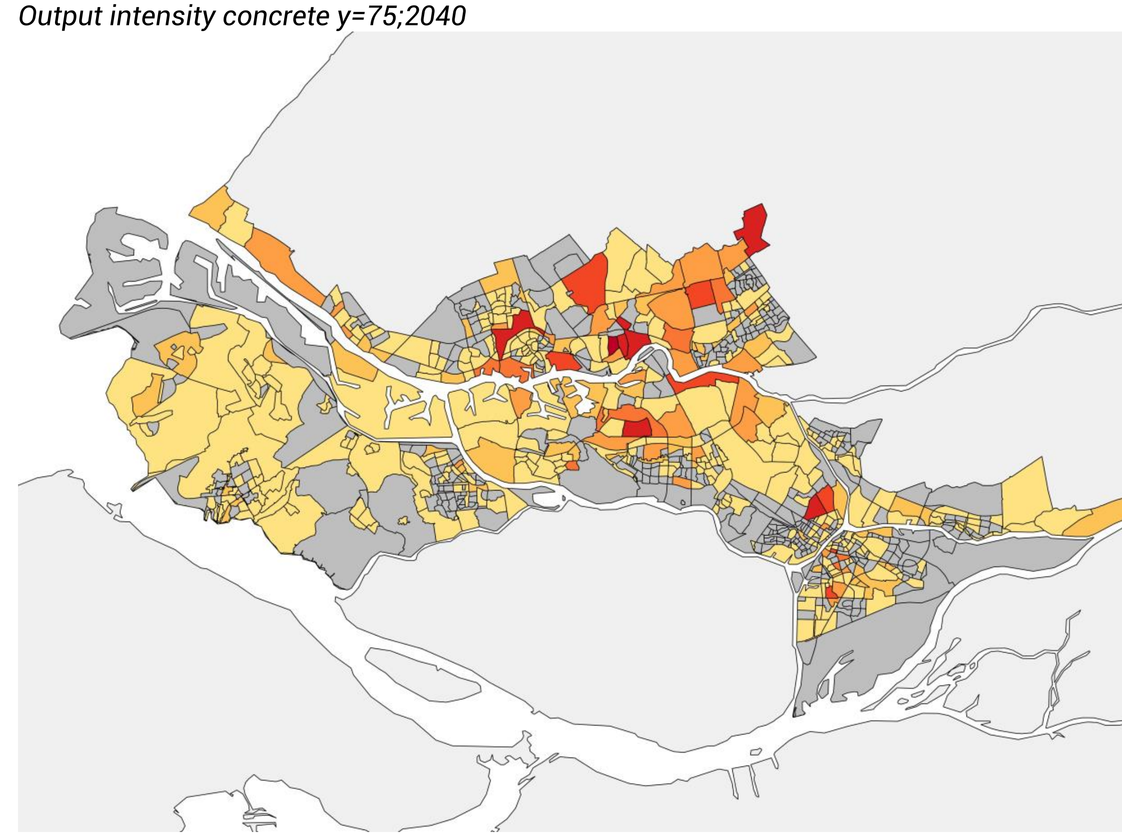
Total demolished:	**64.878**	buildings
Single family:	**58.187**	buildings (=dwellings)
High Rise:	**11**	buildings
Total GFA:	**90.215**	m^2
Dwellings*(=GFA/112,4)*	**803**	dwellings
Multi-Family:	**6680**	buildings
Total GFA:	**6.835.857**	m^2
Dwellings*(=GFA/112,4)*	**60.817**	dwellings
∑ dwellings:	**119.807** dwellings	

These dwellings have an output of **14.008.864** tonnes concrete which will be recycled as foundation material (fill sand replacement).

NOTE* *The total to be demolished dwellings can be corrected with the statistics from Deltametropool where the retrofitting neighbourhoods input is subtracted from the total to be demolished dwellings. (119.807-14.374= 105.433 dwellings)*



Output intensity concrete y=75;2040



Infrastructure Asphalt External

Infrastructure and asphalt is not calculated on with bottom-up/spatial input but from top-down CBS data on area of road and material intensity per road typology.

Roads	*Provincial roads (km)*	*Highway (km)*	*Total (km)*	*Asphalt consumption (mln tonnes/year)*
NL	5.000	8.000	13.000	7,5-8
RMDS	78	404	482	0.,28

Based on Cobouw (n.d) the total asphalt consumption for all roads is given. From this fact, the asphalt consumption per km road can be calculated. This number will be multiplied by the total km road in RMDS. This results in **0,28 mln** tonnes per year. In the projection of 2018 until 2040 this mean **6,2 mln tonnes asphalt for the RMDS region.**

Infrastructure Asphalt External

The region is also realising new infrastructure project such as the connection of the A16. With the dimension of 11.000 and 24,5 the project will require the following material:

sand	**229.075**	tonnes
aggregate	**129.899**	tonnes
asphalt	**614**	tonnes

Fill sand External
Based on: Development plans

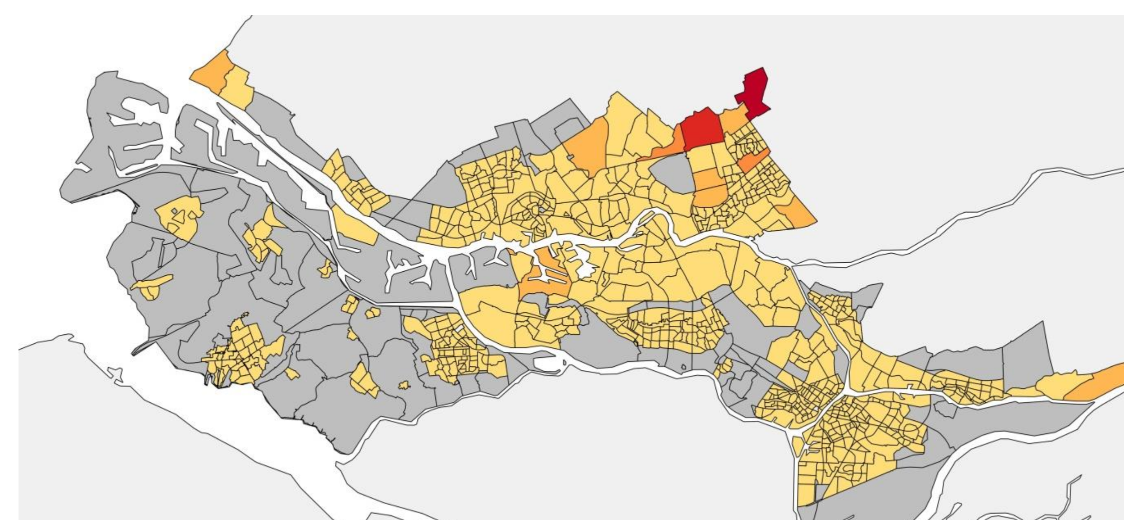
New city extensions requires fill sand for building site preparation. According to Deltares fill sand is applied with the following technique: raising until NAP +1. The only type of development that requires fill sand is greenfield development. Based on the study of Vereniging Deltametropool, the total area of greenfield development is estimated which would result in an inflow of **49,46** mln tonnes fill sand. On the other hand, transformation of industry and brownfield requires the replacement of possible contaminated soil with clean fill sand. This activities results in an inflow of **18,19** mln tonnes of fill sand and an equal amount which is deposit at treatment or storage facilities.

Fill sand Internal
Based on: Klimaateffectatlas/subsidence map

The fill sand input for the maintenance of subsiding areas is based on the expected subsidence which will occur in the area. According to the maintenance regime of Rotterdam (WEAMP) which follows the Dutch Building Regulations (article 4.27), the surface level of the roads and sidewalk should not exceed the limit of 2 cm, which can be solved with a constructed slope. A limit of 100 cm is not allowed.
Maps of predicted subsidence gives an insight, despite the maintenance regime, of how much fill sand should be added in order to reach the accessible limit of the neighbourhood. An expected subsidence of e.g. 40cm mean that 40cm of fill sand should be added.

Subsidence pace per neighbourhood unit. Subsidence maintenance is done on paved surface. Based on paved surface percentage minus built area. Based on the subsidence pace per neighbourhood, the estimation is done by multiplying the expected subsidence level with the paved surface. (e.g. when a neighbourhood with a paved area of 15000m^2 is experiencing a subsidence pace of 10-20 cm until 2050, 20cm sand is required for maintenance thus the calculation is 15000*0,2.

This method is applied on every neighbourhood in the region based on subsidence maps of Deltares with the following outcome for required fill sand: **19.475.454 tonnes**



Beach nourishment External

Beach nourishment is the application of North Sea sand on the Dutch coast. This activity is annually not equally distributed along the coast but by several projects. The annual consumption of coastal protection sand is divided along length of Dutch coast, **30,2** mln tonnes a year for **278** km coast. The coastal protection of the RMDS region can be divided in adjacent coast (Voorne, 9 km with 0,91 mln tonnes a year) or the entire coast which protects the water safety region in which the RMDS region is located in (incl Voorne+Delftland+Rijnland) which is 71 km and shares **7,71** mln tonnes a year. In the projected period with no increased demand, this would result in a total of **169,68** mln tonnes. The MFA study focuses on the ecosystem boundaries of RMDS which would only include Voorne. This results in **22,56** mln tonnes total

Deltares recently projected the scenario of sea level rise and its impact on the Dutch coastal safety which influence the demand of sand. According to this scenario, the annual sand demand would increase as follow:

Deltares scenario		Sand demand				
			total		**RMDS**	
10mm/year	**3**	times	**90,6**	mln tonnes/y	**23,14**	mln tonnes/y
14mm/year	**5**	times	**151,0**	mln tonnes/y	**38,56**	mln tonnes/y
60mm/year	**20**	times	**604,0**	mln tonnes/y	**154,26**	mln tonnes/y

When the sea level rises 60cm/year, the same amount of sand for beach nourishment per year is required that is normally the demand of 30 years.

Dike maintenance External

According to Klimaatatlas maintenance to the current dike structure is required for water safety. With the length of these critical dike structures and the key figure of 135 tonnes sand and gravel per meter of dike (Huang & Hsu, 2003), an assumption is made of the sand demand for this activity which is **28** mln tonnes.

Natural flow

Thanks to the estuary, sand is also introduced in the region through natural flows, as sediment. According to Van Veelen et al. (2018)the following natural flows, and artificial alterations, are occurring in the region:

natural river inflow ***(N. Maas/ Waterweg)***	**0,58**	mln m^3	
natural sea influx	**1**	mln m^3	
ouput a year **dredged to North Sea**	**7**	mln m^3	/sand

Converted to tonnes and projected in the period of 2018-2040, the following figures applies:

natural river inflow	**21,69**	mln tonnes
natural sea influx	**37,4**	mln tonnes
Dredged to N. Sea	**261,8**	mln tonnes

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Theory paper

'Sand-dependent' built environments

A theoretical metabolic framework of urban construction sand and gravel in urban ecosystems of the Netherlands

Abstract – Cities are consuming resources beyond earth's limits. The study of urban metabolism clarifies the in- and output of materials in urban environment and aims to reduce the generation of waste by promoting reusing and recycling. Construction metabolism is a still underexposed though significant consumer in the urban ecosystem. Construction activities in cities demand large amounts of construction material with sand and gravel as a key components. Although it is widely used, the sand and gravel metabolism is relatively unknown. By clarifying the sand metabolism in cities, the systematic behaviour of construction and demolition becomes clear in terms of input, output and related ecosystem. The framework of construction sand and gravel metabolism is reflected on the Dutch case where sand is demanded for site preparation, coastal defence and concrete where it is essential for safety, stability, durability. The study reveals that sand and gravel is for great importance in the construction in the Netherlands. The metabolic framework is the answer to the questions: "what is the metabolic flow of construction sand?" and "How is sand involved in the urban ecosystem?".

Key words – Construction sand and gravel, urban metabolism, construction metabolism, C&D activities

1. Introduction

Cities are responsible for the consumption of 75% of the natural resources and produce 50% of the global waste while they are only covering 3% of the Earth's surface (UNEP, 2012). This consumption of a city relies on the hinterland and ecosystems beyond its limits (Huang & Hsu, 2003). The urban consumption is expected to grow from 40 billion tonnes to 90 billion metric tonnes due to population growth and urbanisation (IRP, 2018). The materialisation, i.e. construction, of the urban structures is mainly responsible for resource depletion and consumption. 40% Of the extracted materials are stored in the buildings and infrastructure of cities (Kibert, Sendzimir, & Guy, 2003). According to Sawin and Hughes (2007), 40% of the global waste stems from the construction industry. The global urbanisation and population growth thus involves resource depletion and waste generation, which will result in a negative impact on the environment.

In order to achieve urban sustainability (less resource consumption and waste generation), urban metabolism has become an important perspective (Fischer-Kowalski & Haberl, 1998; Gandy, 2004; Haberl, 2001; Kibert, Sendzimir, & Guy, 2000; Newman, 1999). Urban metabolism can be defined as *"the sum total of technical and socioeconomic processes that occur in cities, resulting in growth, production of energy and elimination of waste"* (Kennedy, Cuddihy, & Engel-Yan, 2007). Zhang et al. (2018) explain it further as *"to describe how material, food, water and energy flow through an urban ecosystem, and are consumed to support its metabolism, then grow and reproduce, consequently generating products and by-products (e.g. GHG, pollutants, and waste)"* . Zhang et al (2018). also note that the industrial ecosystems of urban metabolism, including the construction industry, have received little attention in urban metabolism studies. Construction is key for urban environments because it is responsible for the materialisation. This construction industry is also responsible for a large share of the resource consumption and generation of greenhouse gasses (GHG), pollutants, and construction and demolition (C&D) waste (de Wit, Hoogzaad, Ramkumar, Friedl, & Douma, 2018; Shen L. Y., Tam Vivian W. Y., Tam C. M., & Drew D., 2004; Tam & Tam, 2008).

Sand and gravel take a large share in the consumption of construction resources (Krausmann et al., 2009). United Nations Environmental Panel (UNEP) recently published an alarming report that states that these minerals are currently extracted at a greater rate than their natural renewal by erosive processes (2014). Sand and gravel are the second most consumed natural resource, with construction and urbanisation as the main driver (Gavriletea, 2017; Torres, Brandt, Lear, & Liu, 2017). Around 22 billion tonnes of sand and gravel are mined globally (UNEP, 2016) and this extraction rate increases (Krausmann et al., 2009). Sand and gravel are widely applied in products such as concrete, mortar, and glass for buildings and bridges, asphalt for infrastructure, land reclamation and building site preparation, and for flood protection (Beiser, 2018; Gavriletea, 2017; Huang & Hsu, 2003; United Nations Environment Programme (UNEP), 2014).

The construction sector is consuming resources unsustainably. It is based on a linear process where a small quantity of the materials are reused. In some cases, such as the Netherlands, C&D waste is used for foundation material but this is an example of a cradle-to-grave process because the material is downcycled and can be compared to landfill (Schut, Crielaard, & Mesman, 2016). The linear aspect of the construction industry is nowadays broadly covered by studies of design for deconstruction (DfD) and urban mining (Johansson, Krook, Eklund, & Berglund, 2013; Koutamanis, van Reijn, & van Bueren, 2018; Stephan & Athanassiadis, 2017). However, most of the time these focus on materials with shorter lifespan and non-structural elements. The application of sand and gravel is characterised by a long lifespan and structural elements (Brand, 1994).

Circularity and waste reduction are global challenges in every sector, as well as the construction industry (Adams, Osmani, Thorpe, & Thornback, 2017; de Wit et al., 2018). The Netherlands is currently aiming to become circular in 2050 (Ministerie van Infrastructuur en Milieu & Ministerie van Economische Zaken, 2016). In the Dutch case, half of all resources that the nation uses is consumed by the construction sector (Schut et al., 2016). Sand and gravel were also applied in Dutch planning history for building site preparation on weak soil and areas with high water levels, thereby creating the unwanted effect of subsidence (Hooimeijer et al., 2016). A recent study by Deltares on the effects of climate change and rising sea level on the flood safety concluded that in the status quo coastal maintenance will demand more sand related to the projected sea level rise (2018). According to the latest projection of construction resource extraction (see Fig.1. sand for building site preparation, fill sand, is half of all extracted construction resources ('t Hoen, 2017). Around 20% is for beach nourishment and concrete and mortar production. Because of several 'sand stakeholders', the Dutch case for sand, gravel and urban construction is interesting.

1.1 *Aim & scope*

Construction sand and gravel is massively extracted and consumed in a linear process and metabolism which is still unexposed. This is why the aim of the paper is to extract the construction sand and gravel metabolism from the urban metabolism theory and to clarify the application of sand and gravel in the urban construction in the case of Dutch lowland areas. In order to achieve this the following research questions will be answered: *"what is the metabolic flow of construction sand?"* and *"how is sand involved in the urban ecosystem?"*.

As sand is used for different purposes (e.g. glass or silicon), the construction sand metabolism focuses only on the application of sand and gravel for urban construction, which comprises sand for; concrete & mortar, land raising and coastal protection. Urban metabolism and construction often integrate and analyse the emergy, or embodied energy, in urban environment (Huang & Hsu, 2003). Emergy can be defined as *"all the available energy that was used in the work of making a product and expressed in units of one type of energy"* (Odum, 1996). This study neglects the concept of emergy in order to focus on the application and integration of sand and gravel in

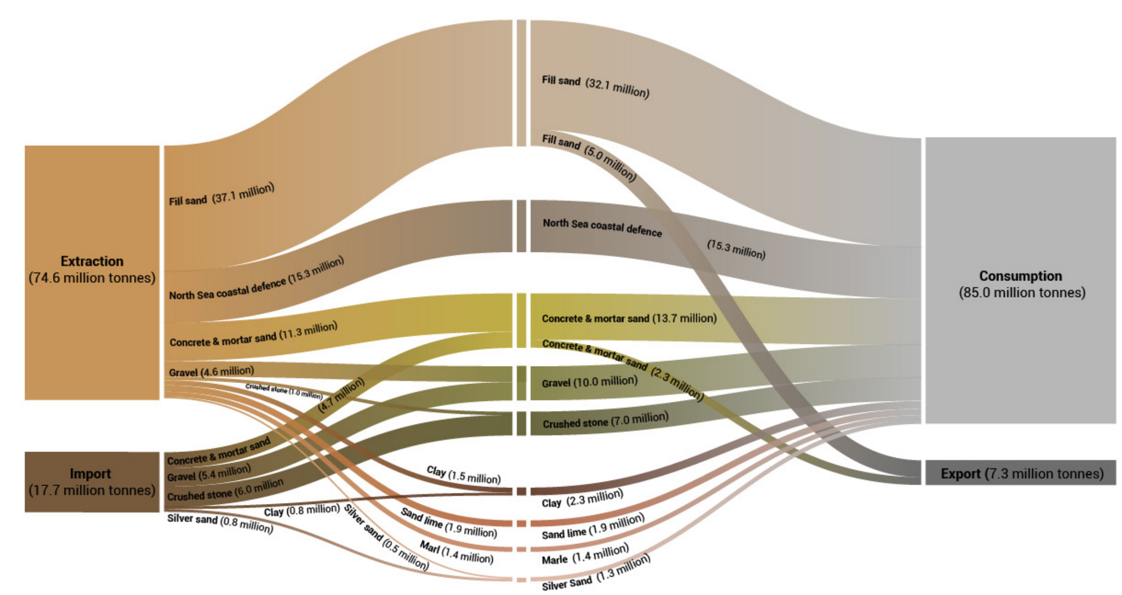

Fig.1 Flow diagram of the extracted construction minerals in the Netherlands in 2015-16. Based on 't Hoen, 2017. Image by author

1.2 *Structure*

The paper is structured as follows: (1) first the concept of construction metabolism will be discussed from the studies of urban metabolism. (2) Then, the application of sand in urban environments and its qualities are used to construct a theoretical material flow analysis of construction sand and gravel within the construction metabolism. (3) After, the effects of sand consumption are clarified in order to better understand the environmental impact of the construction sand and gravel metabolism which is finally (4) concluded at the end of the paper.

1.3 *Methodology*

In order to make the sand consumption visible in urban construction, a material flow analysis (MFA) is constructed which is derived from theoretical research. The MFA is a key instrument in order to understand the urban metabolism (Decker, Elliott, Smith, Blake, & Rowland, 2000; C. A. Kennedy et al., 2015; Newell & Cousins, 2015; Niza, Rosado, & Ferrão, 2009) The framework methodology is derived from Zhang et al. (2018), who focused on the entire construction metabolism of cities (in particular on the city of Shanghai). They state that a general urban metabolism framework consists of three principle components which are: (1) the input of natural and non-natural resources, (2) ecosystems, and (3) outputs of various products and by-products. These components are used in this paper to construct the construction sand metabolism in Dutch context and to link the related environmental impact of sand consumption.

2. From urban metabolism to construction metabolism

2.1 Origin of the urban metabolism concept

The concept of urban metabolism was introduced by Wolman (1965). Ayres and Knees continued on this concept within industrial ecology whereby nature serves as a model for the analysis of existing industrial systems and for guiding new forms (Newell & Cousins, 2015). The industrial metabolism was further developed when the analogy was made between industrial systems and organisms in terms of energy and waste. Urban metabolism thus became a discipline within the industrial metabolism defined by Kennedy et al. (2007) as per the definition cited earlier in this paper. Important to notice is that nature is used as a model for man-made systems because waste does not exist in natural systems and cycles. Cities are thereby seen as linear metabolism which should be shifted more towards a circular metabolism based on lessons from nature (Broto, Allen, & Rapoport, 2012).

2.2 Construction metabolism in urban metabolism

Although the construction can be considered as the most relevant system in materializing the urban, most urban metabolism studies rarely focus on the physical construction and life-span of the city (Zhang et al., 2018). Kennedy et al. (2011) reviewed the studies in the field of urban metabolism but only four of the 47 considered studies focussed on the materialisation of cities. Recently Zhang et al. (2018) took notion of

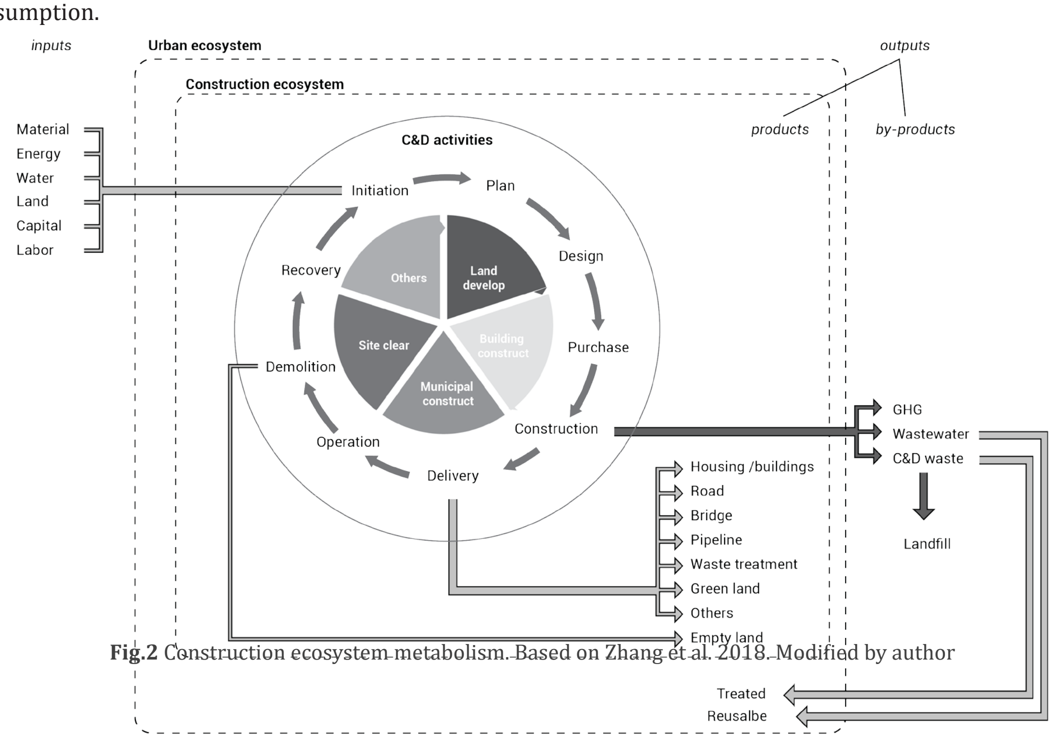

Fig.2 Construction ecosystem metabolism. Based on Zhang et al. 2018. Modified by author

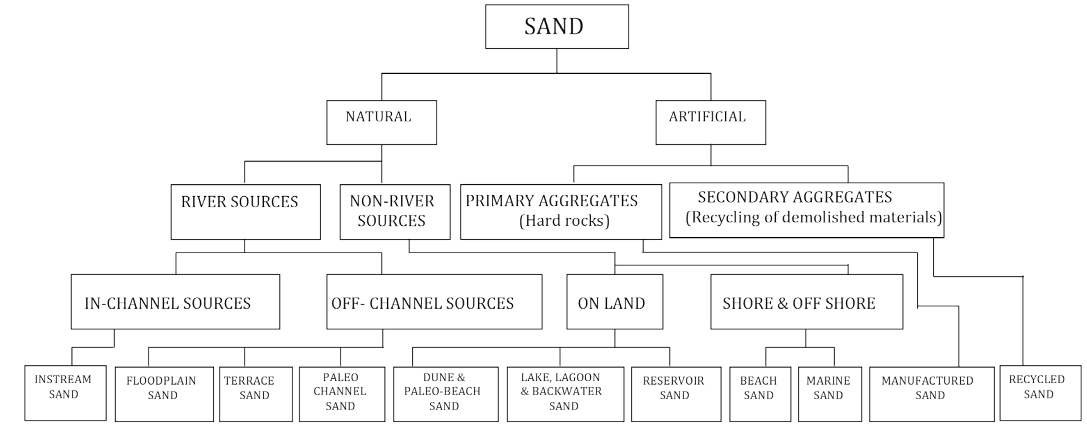

Fig.3 Various sources of sand. Source: Padmalal & Maya, 2014

the fact that, despite its relevance, studies on the integration of urban metabolism and construction ecosystem are rare. They developed an urban metabolism framework of the construction ecosystem consisting of the components of input, output and urban ecosystem (see Fig. 2.). This framework can be seen as a development of the construction ecology by Kibert et al (2000, 2003). He used the concept of industrial ecology on the construction industry in order to learn lessons from nature to achieve sustainability. This is related to the construction and demolition (C&D) activities which are key in the construction ecosystem, which is part of the greater urban ecosystem. The C&D activities in the context of flows and stock links the construction process with the metabolic context. Notable is that Zhang et al. (2018) did not include C&D waste in the demolition part of C&D activities, which is important for sustainable and ecological construction.

The study by Huang et al. (2003) of the metabolism in the urban construction in Taipei, Taiwan is highly notable because of the inclusion and emphasis on sand and gravel. The urban construction includes; road, bridge, mass railway transit, dike and levee for flood prevention, and storm drainage and sewerage pipes, and buildings, which are products in the construction metabolism. This notion will be discussed further in the next section which continues on developing the sand and gravel metabolism framework.

3. Sand in urban construction

The metabolism of sand and gravel is based and derived from the construction metabolism framework of Zhang et al.(2018) and the resource flow of Taipei's urban construction of Huang et al. (2003), because these are the most related and relevant MFA studies on the construction material and ecosystem. Before reflecting on current metabolism frameworks and developing the construction sand and gravel metabolism, the definition of construction sand and its natural ecosystem is clarified.

3.1 Origin of sand and gravel

When developing the metabolic framework, the natural ecosystem should be taken into account. Sand and gravel are natural aggregate formed by rock erosion (Gavriletea, 2017; Kondolf, 1997). The natural aggregate is part of a greater geological rock cycle where sand erodes from mountains and is transported by rivers towards the sea as sedimentary rock. There it deposits and gets transformed by high pressure into metamorphic rock in the Earth's crust. Eventually, metamorphic rock is transformed into igneous rock, which close the loop on a geological timescale (Copuroglu, 2017). Sand and gravel are composted out of the silicate mineral (silicon dioxide, SiO_2) and differ from each other by grain size, with the grain size of sand between 0,063 and 2 mm and gravel between 2 and 63 mm (Zimmermann, 2011). The grain size also defines the application of the mineral, sand for coastal defence and land reclamation and the mix of sand gravel for concrete ('t Hoen, 2017; Zimmermann, 2011).

The natural system of sediment transport still impacts urban ecosystems. Especially in the Dutch delta, rivers flow through urbanised and industrialised areas. Human actions alter these rivers and sediment deposition for maintenance of its ecosystem services, i.e. the transportation of ships (van Veelen, Jansma, & Kalogeropoulou, 2018).

In order to develop a metabolic framework of construction sand and gravel, the input, ecosystem and output of the topic need to be clarified.

3.2 Input of construction sand and gravel

The input for construction sand and gravel are the natural or artificial sources of the substance (see Fig. 3) (Padmalal & Maya, 2014). These sources are mined from their natural geological cycle, which are terrestrial (including rivers) and marine (Gavriletea, 2017). Rivers, sand pits and oceans are most common source. The source also relates to the application. Marine sand for example is less suitable for concrete because of chemical composition and silt ('t Hoen, 2017).

Artificial sources include manufactured sand or crushed rock sand by drilling, blasting, washing, and sieving (Padmalal & Maya, 2014). Also recycled sand is considered an artificial source. This type of source is still minimal. In the Dutch context less than 3% of aggregates in construction comes from recycled aggregate (Schut et al., 2016).

3.3 Ecosystems of construction sand and gravel

Huang et al. (2003) and Zhang et al. (2018) described the ecosystem which is related to the urban construction. The construction sand and gravel ecosystem is part of this construction ecosystem where it is used as material. The framework and analysis of both studies exclude sand ecosystems in building site preparation, land reclamation and flood protection. The ecosystem for flood protection is difficult to clarify because in the Dutch case flood protection is done by beach nourishment, the maintenance of the coastal line with sand (Prins & Hulsman, 2009). This is notable because the natural source is turned by artificial actions into an output which is required for urbanised coastal areas to be safe from natural hazards. This makes construction sand still part of its natural cycle where erosion and disposal along coastal areas is still related. However, human interference is necessary for flood resilience. In the Dutch case, this will become more important because of rising sea level (Deltares, 2018).

This means that the ecosystem of construction sand is both in the construction ecosystem of the urban ecosystem, as well as part of the natural ecosystem of sedimentation and erosion and deposition. Fig. 4 illustrates the construction sand and gravel ecosystem based on the image of Dirk Sijmons for the IABR (Brugmans, Strien, Aboutaleb, & International Architecture Biennale Rotterdam, 2014).

3.4 Output of sand and gravel products

The metabolic process of the construction ecosystem produces products and by-products.

The products where sand is applied are; roads, bridges, dikes and levees for flood prevention, and storm drainage and sewage pipes, and buildings (Huang & Hsu, 2003). It is important to add that building site preparation and land reclamation are also important sand consumers in the Dutch case, because these activities were important for the construction of large parts of the Netherlands (Hooimeijer et al., 2016; Hooimeijer, 2014), demanding a large amount of sand or gravel ('t Hoen, 2017). The products and by-products are discussed separately in order to clarify the conditions within the metabolic framework. The products are summarized in Table 1.

3.4.1 Concrete, asphalt, structures and buildings

Sand and gravel are the key ingredients for concrete which is massively applied in modern (building) structures because of its strength and durability (Beiser, 2018; Copuroglu, 2017). Buildings are the biggest consumers of sand and gravel for concrete globally (UNEP, 2016). Asphalt is also a sand and gravel product which is applied on the Dutch roads. The difference between asphalt and concrete is that asphalt is binding material. Bitumen in asphalt and cement in concrete (Beiser, 2018; Copuroglu, 2017).

3.4.2 Building site preparation & land reclamation

In the Netherlands, building site preparation is necessary in order to construct buildings and infrastructure (Hooimeijer, 2014). In several areas, the top layer of soil is clay or peat making it unstable for civil structures. Next to unstable soil is the high water table. By adding sand, buildings and infrastructure can be placed on a strong, stable and permeable surface without (or minimised) seepage. Sand is applied through several methods which differ from integral filling under the entire constructed district to only the infrastructure (Hooimeijer et al., 2016).

3.4.3 Beach nourishment

In order to remain safe from flooding, protection is necessary in the Netherlands. This is done by beach nourishment where sand is mined from the North Sea and applied on the Dutch coastal area or dikes (Prins & Hulsman, 2009).

Product		Purpose/quality
Buildings and infrastructure (roads, bridges etc.)	*Manufactured sand (concrete/mortar/asphalt)*	*Durability and strength for shelter or passability*
Building site preparation	*Sand as fill sand*	*Stability and passability/land reclamation*
Beach nourishment	*Sand as nourishment*	*Safety/resiliency*

Table 1. Application and purpose for construction sand and gravel

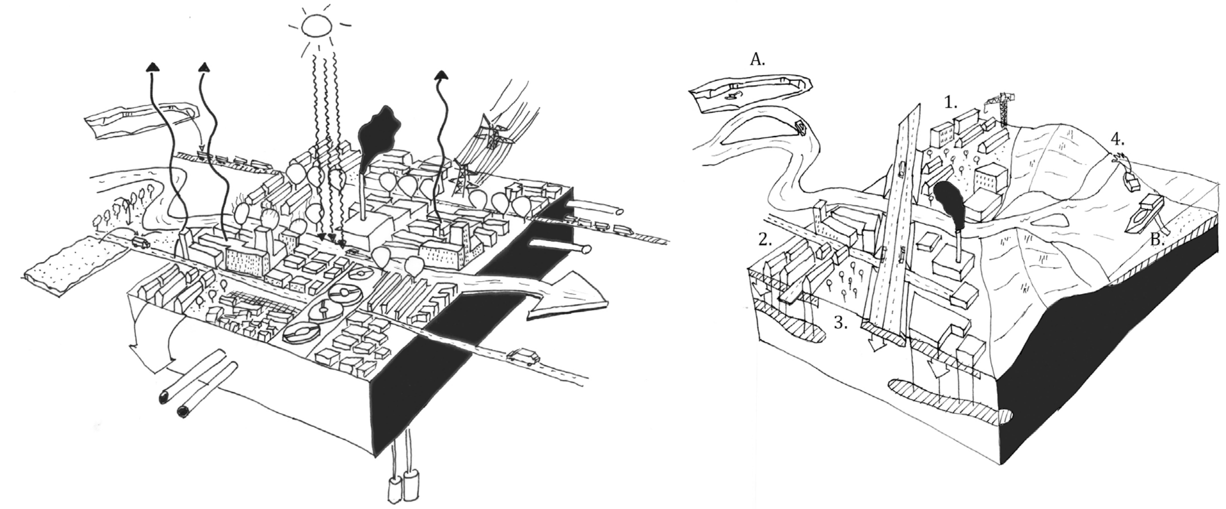

Fig.5 (left) Urban Metabolism model by Dirk Sijmons and Jurra Raith. Source: Brugmans et al. 2014. Modified by author. (right) construction sand and gravel metabolism model. *A.) mining sand pits and rivers; B.) mining ocean bed; 1.) concrete; 2.) roads; 3.) building site preparation; 4.) beach nourischment.* Drawn by author.

3.5 Output of sand and gravel by-products

The construction ecosystem is also responsible for the production of a massive amount of by-products such as GHG and C&D waste (Zhang et al., 2018). The GHG emission is caused by the production of cement which is substantial in the production of concrete (Copuroglu, 2017). The bitumen used in the asphalt production is a residual product in the oil production (Schut et al., 2016).. The C&D waste is notable after the life-span of buildings which can be between the 50 and 100 years, depending on several drivers and maintenance regimes (Sandberg et al., 2016; Stephan & Athanassiadis, 2018) After the demolition of buildings in the Netherlands, most C&D waste is used as foundation material in the site preparation of infrastructure (Schut et al., 2016). This is an end-of-life and downcycle solution because the material remains in this location in a lower quality and is reused on site in renovation and maintenance activities. This is causing the foundation market to become saturated because the rate of generation of C&D waste is higher than the realisation rate of new infrastructure. Some C&D waste is reused in the production of new concrete and asphalt. Respectively less than 3% and 50% (Schut et al., 2016).

The application of fill sand for building site preparation is also an end-of-life process because sand is relocated into a new deposit. The building site preparation areas are also prone to subsidence (Hooimeijer et al., 2016), resulting in sand addition in the maintenance regime. This means that the building site preparation rarely generates waste.

3.6 Construction sand and gravel metabolism framework

The metabolic framework of construction sand and gravel is illustrated in Fig. 5. The metabolic framework is constructed around the urban ecosystem and construction ecosystem, similar to the one from Zhang et al. (2018). However, the river ecosystem is part of the urban ecosystem because it crosses through. The framework clarifies the source of sand and gravel (input), the main products in urban construction (products), the destination and flow of waste generation (by-products/output) and their interrelation within the ecosystem. From the model, it can be clarified that the output of C&D waste is depended on the input capacity and demand, which also results in a continuously growing urban ecosystem in sense of materialisation. Coastal protection is still integrated in the natural system of sediment deposit but is 'fed' by an artificial flow. These events have an impact on the environment which will be discussed in the next part.

4. Environmental effects of construction sand

Currently, construction sand and gravel is consumed at a greater rate than its renewal (United Nations Environment Programme (UNEP), 2014) with significant impact on the environment (B. Müller, 2006; Kondolf, 1997). The impacts are summarized in Table 2. The impacts are not well researched or indicated in every mining location, for example the Netherlands, resulting in insufficient evidence or studies to state that these also occur in the Dutch case.

The report on sand consumption of the UNEP does not take the linear metabolism of the construction into account, which is a contemporary problem and reason for construction ecology and metabolism (Kibert et al., 2000; Zhang et al., 2018). This missing link between consumption in the built environment and recovery of used resources and returning it to natural systems should be added to the environmental impact in order to strengthen and highlight the depletion character of sand and gravel consumption.

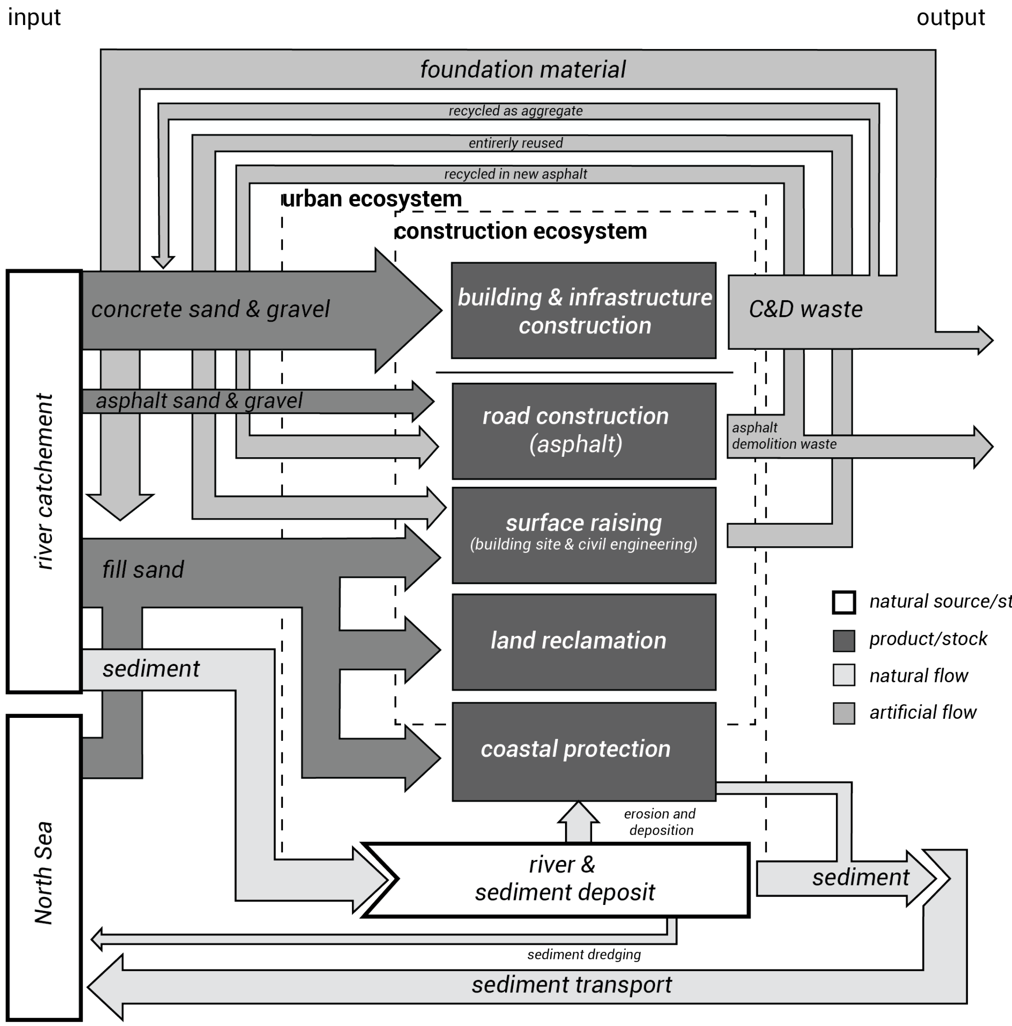

Fig.5 Metabolic framework of urban construction sand and gravel

Impact on	Description
Biodiversity	Impacts on related ecosystems (for example fisheries)
Land losses	Both inland and coastal through erosion
Hydrological function	Change in water flows, flood regulation and marine currents
Water supply	Through lowering of the water table and pollution
Infrastructures	Damage to bridges, river embankments and coastal infrastructures
Climate	Directly through transport emissions, indirectly through cement production
Landscape	Coastal erosion, changes in deltaic structures, quarries, pollution of rivers
Extreme events	Decline of protection against extreme events (flood, drought, storm surge)

Table 2. Summary of the main consequences of extraction of aggregates. Source: UNEP, 2014.

5. Conclusion and discussion

The development of the metabolic framework of construction sand and gravel in urban construction metabolism is essential in order to answer the research question of "what is the metabolic flow of construction sand?" and "How is sand involved in the urban ecosystem?". Figure 5 illustrates the metabolic flow of construction sand. It can be concluded that in the Dutch case, construction sand is still integrated in the natural ecosystem due to beach nourishment. Overall, sand and gravel is applied in a linear and end-of-life way, which sustains its high demand as a new construction material in the current construction ecosystem. On the one hand, construction sand and gravel are completely extracted from their natural ecosystems because the absence of return flows to the natural system due to relocation of deposits for building site preparation, and the manufacturing and downcycling of concrete. On the other hand, construction sand is still part of its natural system in beach nourishment where it is applied in order to maintain the natural coastal defence, related to 'Building with Nature' solutions (Hooimeijer et al., 2016).

The metabolic framework is useful for policy makers and stakeholders in order to track the construction material for improvement strategies. However, the quantity is missing in the model which is necessary to complete the material flow analysis. Nonetheless, the model reveals the qualitiative flow of construction sand and gravel which is quite fundamental in the Dutch case in order to keep the built environment stable and liveable in the future. Sand is needed to make the ground buildable, the buildings durable plus stable and the area flood resilient. This makes it also necessary for the sustainability, as in existence and maintence, of the built environment. In other words, without sand and gravel, the Netherlands could not be occupied the way it is nowadays. This also raise the question if the Dutch coastal areas with weak soil, most of the Randstad, are the right location to continue urban development

The results of climate change and subsidence in conjuction with resource depletion and linear metabolism of construction sand and gravel makes it a difficult challenge in urban metabolism perspective to reduce sand and gravel production. Further research is necessary on the effects of mining in the Dutch case but also on detailed application and reduction, including impact, in urban environments. This will result in alternative methods and systems for the 'sand-dependent' built environments.

6 Literature

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D. Appendix

Results from the design process

This appendix includes the two design examples which were made during the research process. The examples, Nieuw-Kralingen and Maashaven, are eventually replaced with the four integrated in the main report. Nieuw-Kralingen is an example of a first attempt to integrate material flow analysis in the urban development type of the transformation of a non-residential area. The Maashaven example explores and demonstrate the extrapolation of small scale design result to regional scale.

D.1 Sand-sensitive Nieuw Kralingen

In this report, the urban design scale casus of urban transformation is executed in order to demonstrate the application of the proposed method and its related possible outcome. The demonstration site is Nieuw Kralingen in Rotterdam. This area is currently a commercial/industrial site but will transform into a high-class neighbourhood with maximum 800 dwellings (ERA Contour & Heijmans, 2017). The development is expected to start in 2020 according to the design of West8 (Gemeente Rotterdam, n.d.). The material flow of construction sand and gravel is exposed according to the data received from the analysis and database (see MFA chart).

The current situation has a total gross floor area of 54.492 m^2 which will be, together with the roads, demolished resulting in an outflow of respectively 77.421m^3 and 60.491m^3 of concrete/asphalt. The site is also contaminated which means that the ground partly needs to be removed for treatment, which is a stock of 434.990 m^3 of soil. The total outflow is 572.902m^3. The new inflow will be an increase of 41,7% in stock, 811.875m^3. The concrete for the new buildings account for 353.280 m^3 , the road for 23.605 m^3 and the soil for the building site preparation is 434.990 m^3 . The new gross floor area is 144.000 m^2.

With this data in mind, new strategies can be implementation based on the sand-sensitive solutions from the catalogue of solutions. These demonstrated solutions here are:

A) Retrofitting the commercial buildings.

The current buildings can be transformed from commercial to dwellings. This will reduce the new build floor area to 89.508m^2, what is 62% from the original concrete inflow. However, this type of retrofitting does not meet the standards set for the high-class neighbourhood.

B) In situ soil treatment.

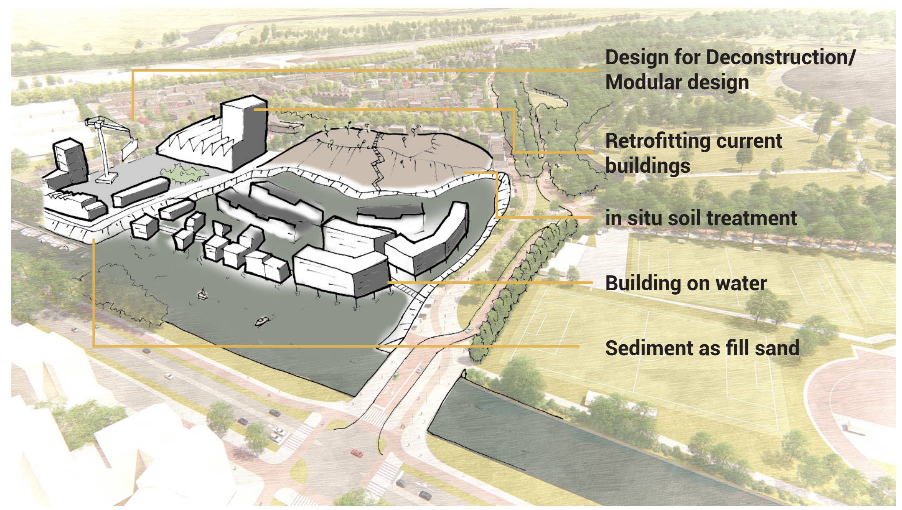
The contaminated soil can be treated on the site itself resulting in an elimination of soil in- and outflow. However, in situ soil treatment is a long process which means that some areas will not be available for housing development.

C) Design for Deconstruction (DfD)

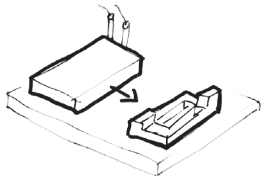
The new urban constructions can be based on the Design for Deconstruction concept meaning that the EOL scenario is integrated in the design process. Materials can be used which are fully recyclable. However, this still requires an inflow of new material and does not includes solutions for the outflow.

D) Sediment for soil

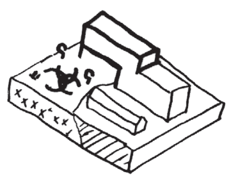
The inflow of soil can be replaced with sediment dredged from the rivers in the region. This solution links the waste flow from the river maintenance with the inflow of the case area. However, data needs to be included of the amount of dredged sediment and its conditions. It is possible that the sediment needs to be treated or collected over time. This solution asks for implementation elsewhere in the region and a strategy over time related to the construction sand and gravel metabolism.



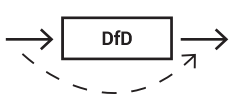
Applied solutions



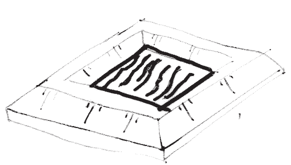
A) Retrofitting buildings



B) On-situ soil treatment

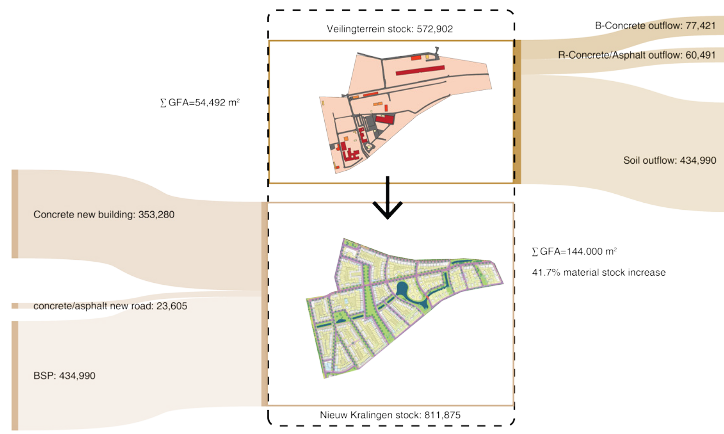


C) Design for Deconstruction



D) Sediment for soilt

The strategies only envision the possible direction in the design part of the research. Each strategy also requires further development in order to integrate quality and feasibility. The strategies are now still standalone solutions which not result in an integrated scenario for the case area. However, the strategy visualises the link between the material flow analysis, which clarifies the consumption, and urban design. This demonstration also shapes the method further of aspects which needs to be integrated in the design such as EOL scenarios, although this outreaches the objectives and the goals because the 2050 is now set as a goal.



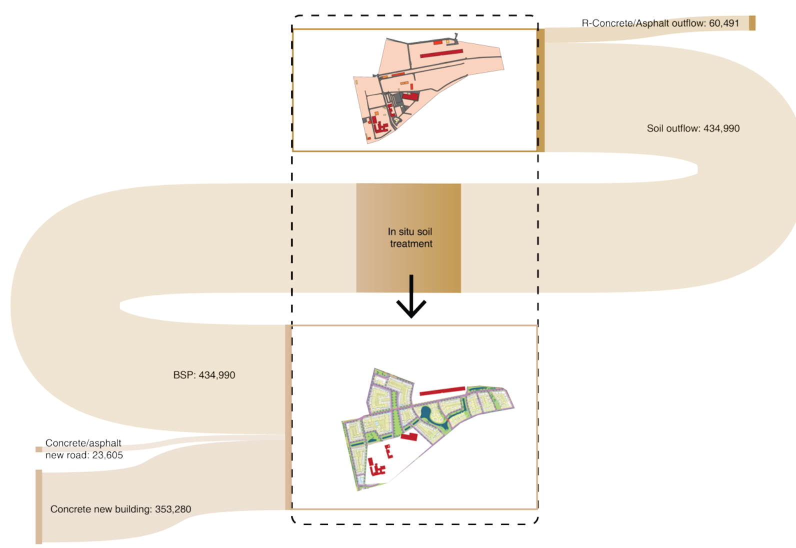
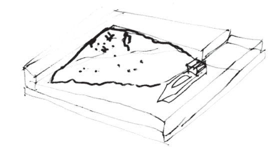


Image 25

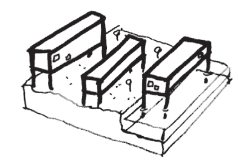
Flow diagram of the construction activity of Nieuw Kralingen

D.2 Extrapolation example Maashaven

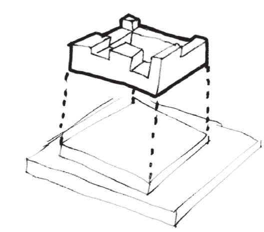
Applied solutions



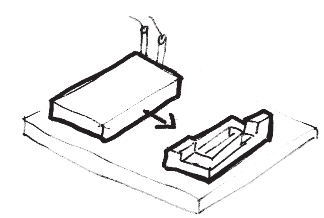
Tidal park



Building on stilts



Elevation



Building tranformation

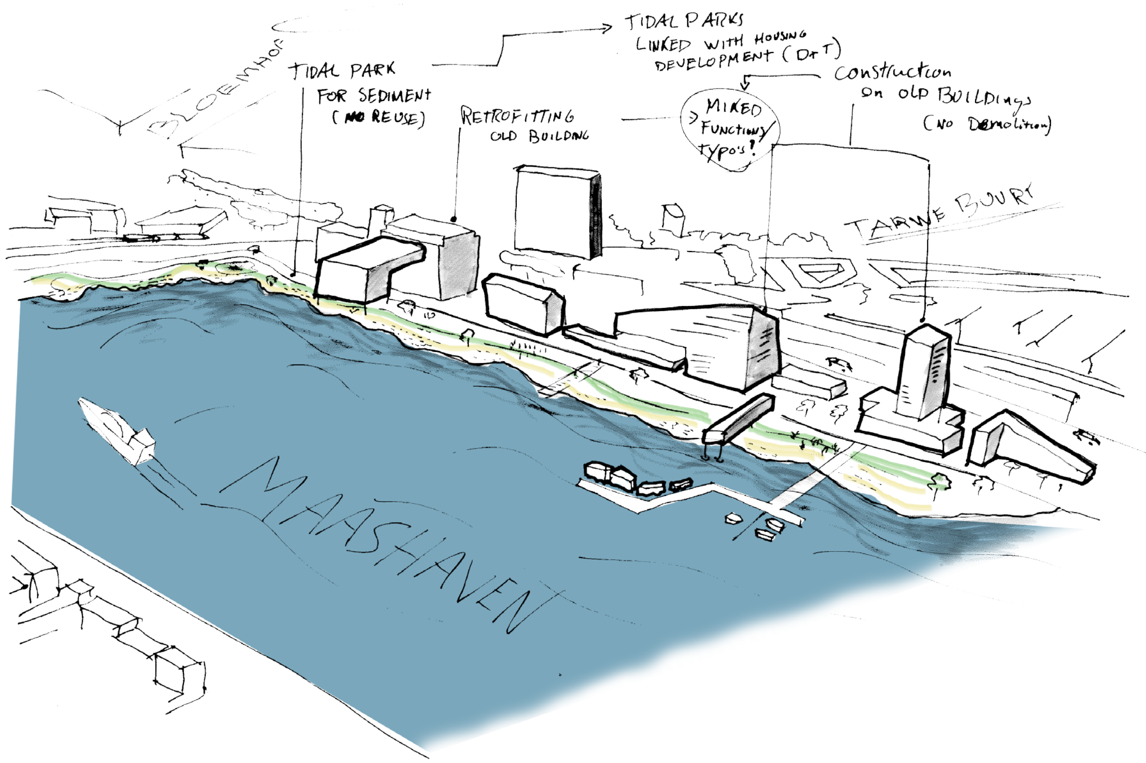
The urban designs will function as pilot project for the achievement of a circular construction metabolism in the RMDS region. As explained in the methodology, the designs will be extrapolated towards potentials for similar design subjects and challenges. The steps in extrapolation will go as follow:

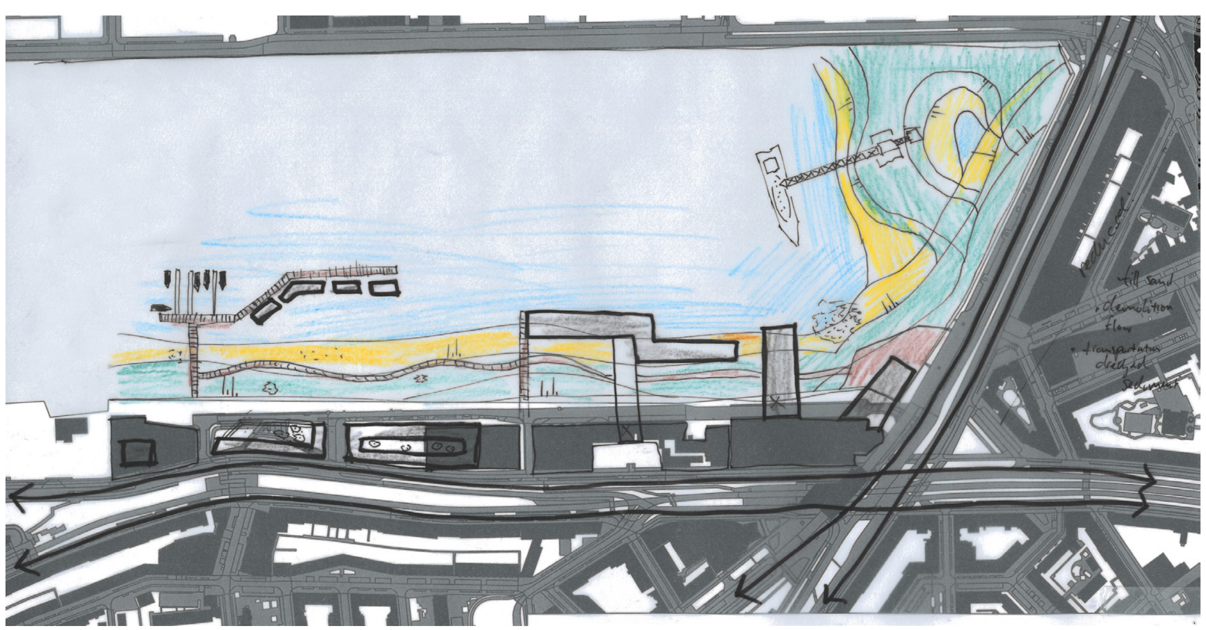
1) Translate design into generic numbers
2) Set/point out similar location/situation in the region
3) Calculate potentials in locations based on generic numbers
4) Translate impact in metabolic framework/system
5) Evaluate within the LCA-tool

Design Maashaven, Rotterdam

The Maashaven is one of the focus locations in the research. This first sketch both visualise the application of solutions (as displayed on theleft) and the extrapolation of the design into the potential impact on the regional level. A tidal park could be a solution for the dredging material and fits in the ambition of the city. Next to park fuction, tidal parks could also be used for new living environments and, because tidal parks are located in previous harbours, to transform former industrial buildings into new functions.

The Maashaven has the dimension of 400m to 600m and has a depth of 10m. The area could store 4.544.800 m³ of sediment which is 18,75 m³/m². The development of dwellings on and around the harbour 0,014 house/m² **(1)**. In the region, there are 8 potential location (incl. Maashaven) for the development of tidal parks in combination with housing **(2)**. The total of all locations are 30.262.389 m³ or 58.16.312 tonnes of sediment (sand) and 2.596 houses **(3)**. The current dredged sediment is 261,8 mln tonnes, or 11,9 mln tonnes annually. The tidal parks have an impact of 22% on the total dredged sediment and can be a alternative deposit for 5,3 years **(4)**. For the LCA would this mean that transportation (C2) is reduced because of a deposit location which is closer by. However, the tidal parks are a temporary solutions and after realisation of the parks, sediment is probably only needed for maintenance **(5)**.



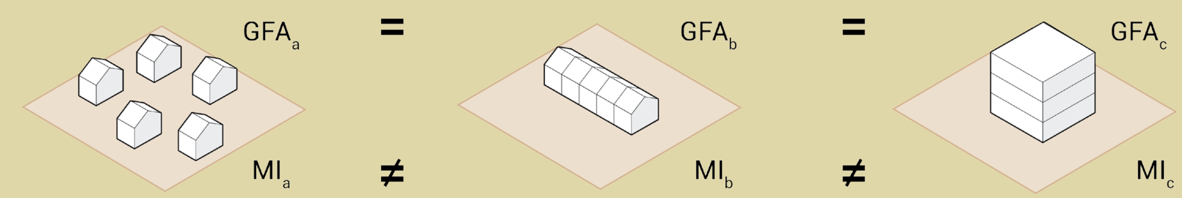


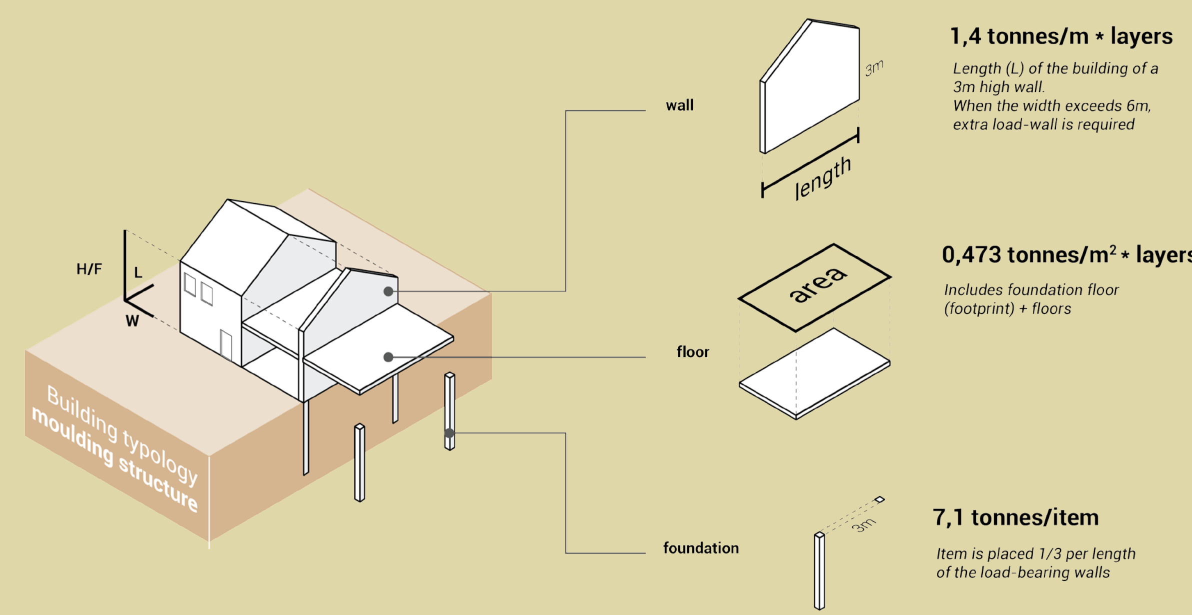
MDI *(material demand index)*

Integrating material demand in design process

The estimation of inflow of construction materials in the building stock is based on the GFA of new buildings (as explained in the analysis). However, in designing this estimation is not sufficient enough in order to calculate or achieve reduction of construction materials. According to the estimation based on GFA, a composition of single family houses would have the same material intensity as a family rowhouse or an appartment with a similar GFA. In order to add more detail to the design, a new index is made for design which informs the designer in the material demand for the structure, from now on called the Material Demand Index (MDI).

The page on the right dissections the typology of a house into three core components which contains concrete (thus sand and gravel); load-bearing walls, floors and foundation piles. The material intensity of each component is translated into patterns which can easily be used and applied in a design or sketch.





A material conscious approach for the urban construction metabolism of sand and gravel in the Rijnmond-Drechtsteden region