

# Understanding the Urban Metabolism

## Material Flow Analysis as part of sustainable design

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Thesis "Mining for Black Water: a valuable resource"

## I The need for a proper assessment

This paper is written for the Lecture Series on Research Methods as a theoretical basis for the Harvest graduation studio of Architectural Engineering. Because the built environment is a very diverse field and attracts a wide variety of research approaches, the intention of this paper is to define and formulate what sort of research methods could be opted for my graduation project. Other than in science, architecture cannot use an universal application and step by step procedure to come to a final result. Therefore architectural design is a very complex and diverse profession. A methodology helps to understand what steps to take, in what order, how to perform those steps and most importantly the reason why these steps should be taken.

During the lecture series of Research Methods a number of possible approaches were presented that could help to understand the object of study from different methodological perspectives. We discovered the various ways in which architects could obtain and use research and what the benefits and opportunities are to bring the knowledge to the quality of work. The research helped to evaluate my project context and to assess the performance characteristics. This ensured to work in a way that I discovered relevant issues that I want to discuss during my research. In my opinion multiple approaches are necessary to give a deeper meaning to the design. I was inspired by the incorporation of the subsurface within the design process and social practice as a nuanced architectural attitude towards the public. These two aspects are integrated in my context-led research as well to empowered the uniqueness of the site of studying.

### The Urban Metabolism of Parkstad Limburg – Problem statement

Comparable to a scientific approach, I start by describing the problem statement of my thesis topic. Economic and social growth are strongly accompanied by an increasing amount of waste, causing unnecessary losses of materials and energy.<sup>1</sup> This rapidly altered our climate, depleted natural resources, disrupted the ecosystem and severely damaged biodiversity.<sup>2</sup> With the worldwide growing population, fossil fuels, raw materials and surface minerals are depleting. In order to maintain our population, we have to change the relationship between people, energy and the environment in the coming decades. We need to understand the relation between the consumption of resources and the production of products and wastes and learn to design in such a way that local resources are optimally seized before an demand is posed upon other areas. To ensure a sustainable future, an urgent increase is required in energy generated through local available and renewable sources and circular waste streams. It is therefore important to take local available resources into account when designing and making plans.<sup>3</sup> The question arises how we can understand these relationships and how it can be implemented in architectural design.

In my graduation project I aim to explore the current urban metabolism of Parkstad Limburg to understand if energy, water, materials and nutrients are used efficiently and to find out where an intervention is possible to decrease system-level inputs and outputs. This formerly agricultural area in the South of the Netherlands rapidly developed around the 19<sup>th</sup> century as the Dutch epicentre for coal mining. With the disappearance of the mining industry in 1974 Parkstad is now suffering from environmental, socioeconomic issues such as changing demography, unemployment, low education levels, high vacancy rates, identity loss and a lack of social cohesion.<sup>4</sup> Other than that the region is using almost 96% fossil fuels of the entire demand to supply the households and the industries.<sup>5</sup> By creating symbiotic systems that simultaneously increase the resource efficiency and incorporate the spatial characteristics, a sustainable solution

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1. Lema, J.M., Suarez, S. (2017). *Innovative Wastewater Treatment & Resource Recovery Technologies: Impacts on Energy, Economy and Environment*. London: IWA Publishing, 325.
  2. Zhang, Y. (2013). *Urban Metabolism*. *Environmental Pollution*, 178, 463-473, 464
  3. Dobbelsteen, A. van den, Stremke, S., Broersma, S. (2012). *Energy Potential Mapping for Energy-Producing Neighborhoods*. *International Journal of Sustainable Building Technology and Urban Development*, 171.
  4. Drippy, A., (2011). *Intergemeentelijke structuurvisie Parkstad Limburg: aanvulling Nuth. 'Ruimte voor Park en Stad'*. Parkstad Limburg, 15.
  5. Delheij, V., Straten, R. van der, Willems, R. Oudes, D., Broers, W. (2016). *Parkstad Energietransitie. Palet 3.0*. Stadsregio Parkstad Limburg, 10.

is found for the whole region. Exploring the existing qualities and describing the essential characteristics and weaknesses of the region formed a basis of the project. In the following design assignment I focus on one intervention and explore the program of requirements and the spatial characteristics.

## **II Searching for a 'cyclifier'**

As mentioned before the aim of this research is to understand the connections within the urban metabolism of the region to find out how the system works and where small scale interventions would be beneficial to improve the resource efficiency for a circular economy. Jongert et al (2015) introduced the term '*cyclifier*' as a way to identify a type of actor that improves the urban metabolic efficiency.<sup>6</sup> This approach requires a methodology that could lead to a betterment, a change, an innovation. A helpful method to simulate the urban metabolism is process analysis. Process analysis is a quantitative research of the input and output of a resource. To carry out the process analysis knowledge of the context is required as well. Quantitative and qualitative data is collected by literature studies, interviews and a site visit.

The following step is to determine where in the metabolic system the interventions could be implemented. Through Energy Potential Mapping (EPM) different local potentials of the whole region are qualified by using GIS software. In this way the use of locally available potentials can play a directive role in the design for urban patterns. The final map can contribute and be a helpful tool in locating different functions at the right positions on the regional level.

The outcome of these two approaches give an understanding of the amount of energy, water and material is going in and out the city and will formulate to a possible set of interventions. To provide inspiration for the architectural design I need to understand the cultural and socioeconomic context of Parkstad as well. A way of establishing the importance of the social, physical and historical setting of Parkstad is to allow the context to take the lead in the research.<sup>7</sup> This helps to determine the site-specific characters establishes the limits. Through establishing the dialogue between the past and the future, the sustainability of the region becomes an enterprise that is driven by awareness and urgency of current problems. Lastly one of these intervention, the cyclifier, is described in further detail. Again a process analysis is carried out to explore the amount of energy and water going in and out the building and to develop a program of requirements for the design assignment. (Syllabus I) These findings are based on case studies of existing buildings and how they operate.

## **A review on Material Flow Analysis, Energy Potential Mapping and Mapping in general**

The urban metabolism and flow approach are adopted to provide an effective way to gain information on energy efficiency, recycling of materials and waste management characteristics of the urban system of Parkstad. Urban metabolism provides new insights for more sustainable resource management in cities and in their hinterlands.<sup>8</sup> A primary accounting method to understand the urban metabolism processes is a Material Flow Accounting (MFA), also referred to Material Flow Analysis. This method generates understanding of the inflows, outflows, and accumulations of the amount of energy, water and material in the urban system.<sup>9</sup> Moreover it provides the disaggregation of data and relatively quick way to characterize the dynamics of the urban metabolism.<sup>10</sup> One limit to the current applicability of the MFA are associated with the availability of statistical data. Therefore urban material flows may be overestimate if the

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6. Jongert, J., Nelson, N. & Korevaar, G. (2015). Cyclifiers: an investigation into actors that enable intra-urban metabolism. Rotterdam, SuperUse, 1

7. Lucas, R. (2015), *Research Methods for Architecture*. London: Laurence King Publishing, 11.

8. Pistoni, R., Bonin, S. (2017). Urban metabolism planning and designing approaches between quantitative analysis and urban landscape. *City, Territory and Architecture*, 4 (20), 1.

9. Brunner, P.H., Rechberger, H. (2004). *Practical Handbook of Material Flow Analysis*. London: Lewis Publishers

10. Niza, S., Rosado, L., Ferrao, P. (2009). Urban Metabolism: Methodological Advances in Urban Material Flow Accounting Based on the Lisbon Case Study. *Journal of Industrial Ecology*, 13 (3), 384-405, 384

phenomenon is not correctly identified. Setting a clear boundary for the area of studying could help to limit the amount of data that is needed for the research.<sup>11</sup> Moreover, often these studies tend to neglect the element of space and the qualitative characteristics of the landscape. Therefore I explore the use of urban metabolism as a basis of design, focusing on the design process, in attempt to bridge the gap between such an approach and the perceptions of the spatial characteristics. Energy Potential Mapping supports the insight into the spatial distribution of energy in particular and facilitate a built environment that more effectively seizes local energy opportunities before requiring import from elsewhere. It has been proven to be very useful in spatial planning at various scales: the country, region, city, district and neighborhood as well.<sup>12</sup> It is a detailed methodology that results in orderly readable maps, contributing in the development of spatial based on energy-effective foundations. All these maps joined together formed a useful tool in the process of planning by visualizing all local energy potentials.<sup>13</sup> These methodologies enable the quantification and localization of the built environment stocks with a bottom-up model. By doing this the most suitable location could be determined for redevelopment.

Another issue of this methodology in general could be the legibility of the schemes that are developed during the MFA and EPM. Harnessing the power of graphic design can help us to understand a terrain or region as the surface of a complex and social and natural processes.<sup>14</sup> James Corner explains that mapping is a collective enterprise that both reveals and realizes hidden potential. He describes that it is not only a link between study and design but it is somehow the design itself. According to Corner, mapping allows designers and planners not only to see certain possibilities in the complexity and contradiction of what already exists, but to actualize that potential as well.<sup>15</sup> Therefore it can help to make better decisions. When using this method in architectural design it is important to choose one certain method of drawing for the analytical part of the research. In my opinion different methods of analytical drawings lead to a different design project. Therefore it is of great importance to decide in this stage of the research process what type of drawings I would like to use. For this research maps and schemes are used to emphasize how wasteful our current economic system is and what impact the intervention will have on the resource efficiency. (Syllabus II & III)

### III The story behind Urban Metabolism

Urban metabolism has become an important tool for the study of urban ecosystems. Over the past years our understanding of the urban processes improved continuously. In the critique of industrialization in 1883, Karl Marx, a man with deep roots in socialism, was the first who discussed the material and energy exchanges between nature and society. He mainly used the term to describe humans' interaction with nature and how we were in the process of colonizing nature and its resources. A few decades later Wolman (1965) developed a concept of urban metabolism, a linear model that included the in- and output of energy and material.<sup>16</sup> Wolman found out that environmental problems emerged when the city would expand to a certain extent. Even though his model was quite simplistic, it was nonetheless an important attempt to generate an overview and provide objective data to support urban planning.<sup>17</sup> In 1990 Giradet proposed circular system where resources are used more efficiently. Giradet realized that the linear model did not accurately emulate how real organisms influence Earth's life-support system.<sup>18</sup> Because his approach made use 'black box' models, in which the inner system was unknown, Zhang et al

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11. Niza, S., Rosado, L., Ferrao, P. (2009). Urban Metabolism: Methodological Advances in Urban Material Flow Accounting Based on the Lisbon Case Study. *Journal of Industrial Ecology*, 13 (3), 384-405, 402.
  12. Dobbela, A. van den, Stremke, S., Broersma, S. (2012). Energy Potential Mapping for Energy-Producing Neighborhoods. *International Journal of Sustainable Building Technology and Urban Development*, 173.
  13. Dobbela, A. van den, Stremke, S., Broersma, S. (2012). Energy Potential Mapping for Energy-Producing Neighborhoods. *International Journal of Sustainable Building Technology and Urban Development*, 171-172.
  14. Lucas, R. (2015). *Research Methods for Architecture*. London: Laurence King Publishing, 182.
  15. Corner, J. (1999). *The Agency of Mapping: Speculation, Critique and Invention*. London: Books, 214-252.
  16. Wolman, A. 1965. The metabolism of cities. *Scientific American*, 213, 179-190.
  17. Zhang, Y. (2013). Urban Metabolism. *Environmental Pollution*, 178, 463-473, 466.
  18. Zhang, Y. (2013). Urban Metabolism. *Environmental Pollution*, 178, 463-473, 464.



(2009) tried to improve the system. She proposed a network process for urban metabolism and integrated metabolic stages and object from a bottom-up perspective. From then on scholars approached urban systems from additional perspectives (e.g. households and industrial metabolism, single flows and spatial explicit models). This enriched the early research on urban metabolism. Currently the urban metabolism approach has been widely opted because it provides a very effective way to generate an overview on energy efficiency, recycling of materials and waste management.<sup>19</sup>

As mentioned earlier, MFA is a primary tool that is used to understand the urban metabolism. Before MFA was used in the field of urban metabolism to manage the environment, wastes and resources, it has been applied in various fields. The basic principle of MFA, which is the conservation of matter to balance the in- and output of processes, was already postulated more than 2000 years ago by Greek philosophers. A few centuries later a French chemist, Antoine Lavoisier (1743-1794), found out that neither man made experiments nor natural changes can create matter. Eventually he formulated the principle that during every process the amount of matter does not change. This principle was applicable for the process and chemical engineering, the economic field and medical field. In the 1970s the first studies appeared in the field of environmental management for the urban metabolism.<sup>20</sup> Nowadays MFA as a method to research the urban metabolism is often used to support decision makers in understanding the metabolism of their region. In comparison to other environmental management tools that are focusing on the concentrations, MFA emphasizes on loading and the relations between a city and its surrounding hinterland.<sup>21</sup> Currently the progress of MFA has been given in three forms for three research levels: the national level, the regional level and the industrial level. Standard methodology systems are even unified on the national level. This is not yet the case for regional and industrial levels.<sup>22</sup>

The second approach that I would like to put in a historical perspective is Energy Potential Mapping. Historically the distribution of energy has hardly interfered with spatial planning.<sup>23</sup> Looking at the tool of Energy Potential Mapping, this methodology has evolved from cartoonish charting climatic features with energy consequences to a manner for the development of spatial plans based on energy-effective foundations.<sup>24</sup> Initially this method was developed to visualize local (renewable) energy potentials and demand of energy, in order to support spatial planning towards more energy-efficient urban or rural environments.<sup>25</sup> However, gaining inside into the parameters of energy demands and local renewable and residual energy sources enables matching energy demand with a fitting potential also takes into account location, temporality and quality as well.

### **Incorporation of the everyday users**

One of the drawbacks of applying these methods is that this quantitative and scientific model of the urban metabolism might disconnect design from the everyday users and needs of the city. The technical approaches of MFA and EPM do not take into account the uniqueness of the site and its past. Therefore I try to incorporate these in the research as well to provide a coherent and renewed productive urban landscape which is in line with the desires of the inhabitants. As a

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19. Kennedy, C., Cuddihy, J., Engel-Yan, J. (2007). *The Changing Metabolism of Cities*. Toronto: University of Toronto, 54.

20. Brunner, P.H., Rechberger, H. (2004). *Practical Handbook of Material Flow Analysis*. London: Lewis Publishers, 5.

21. Niza, S., Rosado, L., Ferrao, P. (2009). Urban Metabolism: Methodological Advances in Urban Material Flow Accounting Based on the Lisbon Case Study. *Journal of Industrial Ecology*, 13 (3), 384-405, 384.

22. Bao, Z., Zhang, S., Chen, Y., Liu, S., Zhang, Y., Wang, H. (2010). *A Review of Material Flow Analysis*. Dalian, Dalian University of Technology.

23. Broersma, S., Fremouw, M., Dobbela, A. (2013). Energy Potential Mapping: Visualising Energy Characteristics for the Exergetic Optimisation of the Build Environment. *Entropy*, 15, 491.

24. Dobbela, A. van den, Stremke, S., Broersma, S. (2012). Energy Potential Mapping for Energy-Producing Neighborhoods. *International Journal of Sustainable Building Technology and Urban Development*, 170.

25. Broersma, S., Fremouw, M., Dobbela, A. (2013). Energy Potential Mapping: Visualising Energy Characteristics for the Exergetic Optimisation of the Build Environment. *Entropy*, 15, 490.

result, the social consequences of functional spatial revolutions are included in the design process. The fields of design will influence each other and lead to new types of space and materialization in both architecture and landscape architecture. To anticipate the future and understand the urban metabolism, existing qualities also need to be explored. Reflecting on what there was and describing what historical event structured it, new functions can be concealed. Moreover due to the mining past, the subsurface has a high potential to generate renewable energy. Therefore I also integrated the subsurface in the MFA and Energy Potential Mapping to make use of the existing and local resources (Syllabus IV).

#### **IV The architect as a facilitator**

The world is ever changing and so is the built environment. The industrialized day of today would need more of operate methods and techniques rather than just creative expressions. The role of the architect within a project team is now more crucial than ever. I decided to graduate in the field of Architectural Engineering because I firmly believe that the architect must respect and interact with its local environment and incorporate techniques for a circular economy design. The Harvest studio, a graduation program of Architectural Engineering, works together with students from architectural engineering and landscape architecture and researchers on integrated architectural design solutions, using the energy transition as a handle for a renewed and healthy living environment. In combination with the spatial potential from the area itself, this studio aims to design solutions that strengthen the social activity, economy and its spatial identity.

To this day designer, both landscape architects as architects, do not perceive the urban metabolism approach as altering their practice, but as a tool to reveal additional information.<sup>26</sup> The same issue applies for the subsurface within spatial design. According to Hooijmeijer (2014) designers are not considering the sub-surface in their work while the sub-surface presents opportunities in terms of solutions for flooding and decentralized energy systems. Because the lack of spatial planning for the subsurface, it is becoming increasingly important to work across disciplines.<sup>27</sup> It is important to give your research access to what these fields of study have to offer and making their work relevant to architecture and the built environment.<sup>28</sup>

But there is more than working across disciplines. We as architects should be part in society as well. We are not just shapers of buildings, but invariably public space and its realm as well. Tom Avermate mentioned two different attitudes towards the public and described how different roles can inspire contemporary architectural discourse and practice. The first is the activist, who fights for spatial justice and is engaged with the reality of the community. He is not complied with the traditional role of the architect as craftsman anymore.<sup>29</sup> The second type of role toward architecture is the facilitator, who engages inhabitants to realize a project. A good example of the facilitator-approach is the project of Renzo Piano and Peter Rice. In their design for the Mobile Workshop, a temporary structure in the center of ancient towns to facilitate a platform for discussions, they worked together with inhabitants on issues of information, education, planning and construction to show the inhabitants new techniques that are available.<sup>30</sup>

Another example is from John Habraken, who held that the architect-facilitator should be involved in the design of new structural building components to be manufactured industrially. In this way Habraken's new position offers a basis for architecture rooted in society.<sup>31</sup>

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26. Pistoni, R., Bonin, S. (2017). Urban metabolism planning and designing approaches between quantitative analysis and urban landscape. *City, Territory and Architecture*, 4 (20), 8

27. Hooijmeijer, F., Bacchin, K., Lafleur, F., Van de Ven, F., Clemens, F., Broere, W., Marinetti, C. (2016). *Intelligent SUBsurface Quality: Intelligent use of subsurface infrastructure for surface quality*. Delft: University of Delft, 1.

28. Lucas, R. (2015). *Research Methods for Architecture*. London: Laurence King Publishing, 59.

29. Avermate, T. *The Architect and the Public: Empowering People in Postwar Architecture Culture*. HUNCH14, 59.

30. Mein, M. (1983). *Design Analysis for Collective Spaces. Piazzas and contradas in Siena*. Department of Architecture, Brussels, 31.

31. Avermate, T. *The Architect and the Public: Empowering People in Postwar Architecture Culture*. HUNCH14, 61.

I believe enhancing the urban metabolism within your work and force yourself to think in terms of synergies will in the end strengthen the project. In my research I did not only try to understand the urban metabolism, but also the demand of society. The program of the building that I opted for in my research is not only rooted in the community of Parkstad but it is also an intervention that will stimulate a more sustainable region.

### **Individual architectural position**

In light of environmental burdens and the finiteness of the earth's material resource capacity, it is important to determine the quantities of existing materials and their potentials for reuse and recycle. By having knowledge on the material stock, which in the future influences material flows, the interconnecting and closing of material loops can be better managed in a circular economy. Therefore we as architects should be encouraged to understand the urban metabolism of cities and explore if energy, water, materials and nutrients are used efficiently. By using the above mentioned methodologies I tried to understand the specific environment and the characteristics of the Parkstad. MFA should become a standard tool for the design of buildings and processes. Based on MFA designers, engineers and government authorities would be able to improve their decisions about certain waste-management scenarios.<sup>32</sup> I believe that the architect should take into account how the architecture can be connected to the metabolism of the city in a wise way.

Moreover I believe that architects need to learn to design and plan in such a way that local resources are optimally seized before any demand is posed upon other areas. Beautiful and functional architectural and social design solutions can be created using the existing resources, materials and systems. We only need to utilize it.

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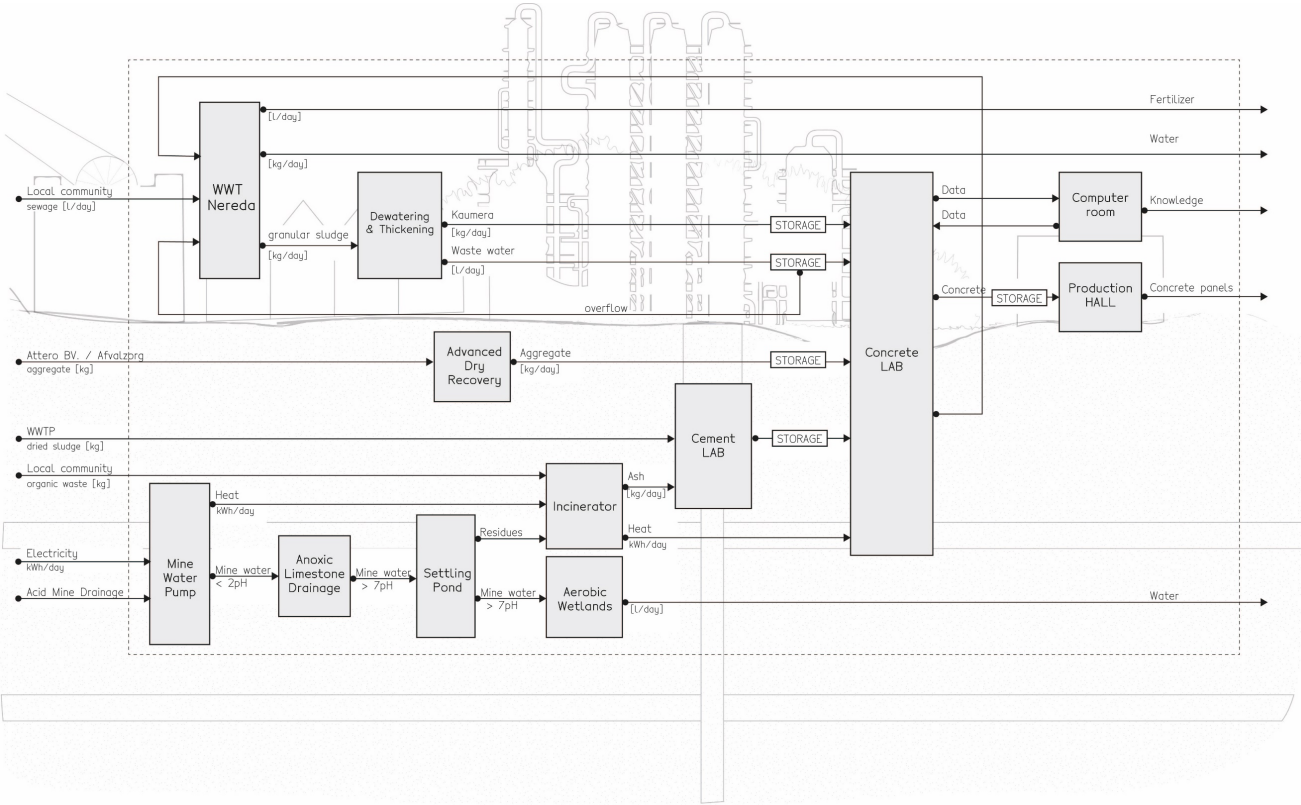
32. Brunner, P.H., Rechberger, H. (2004). Practical Handbook of Material Flow Analysis. London: Lewis Publishers, 307.

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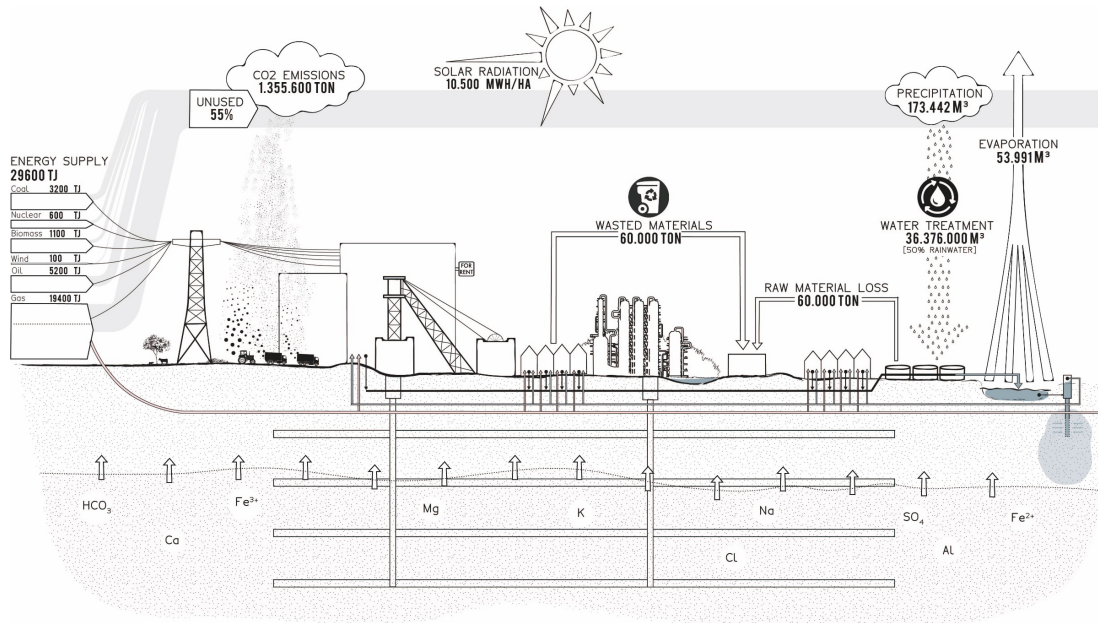
# Syllabus I – Building process

This image show a program of requirements for the system of the building. It requires a waste water treatment facility, a mine water facility and a laboratory where the waste streams of the water purification facilities can be converted in a valuable resource again. The focus is in the end to use the waste streams in the production of a building component: concrete façade panels.

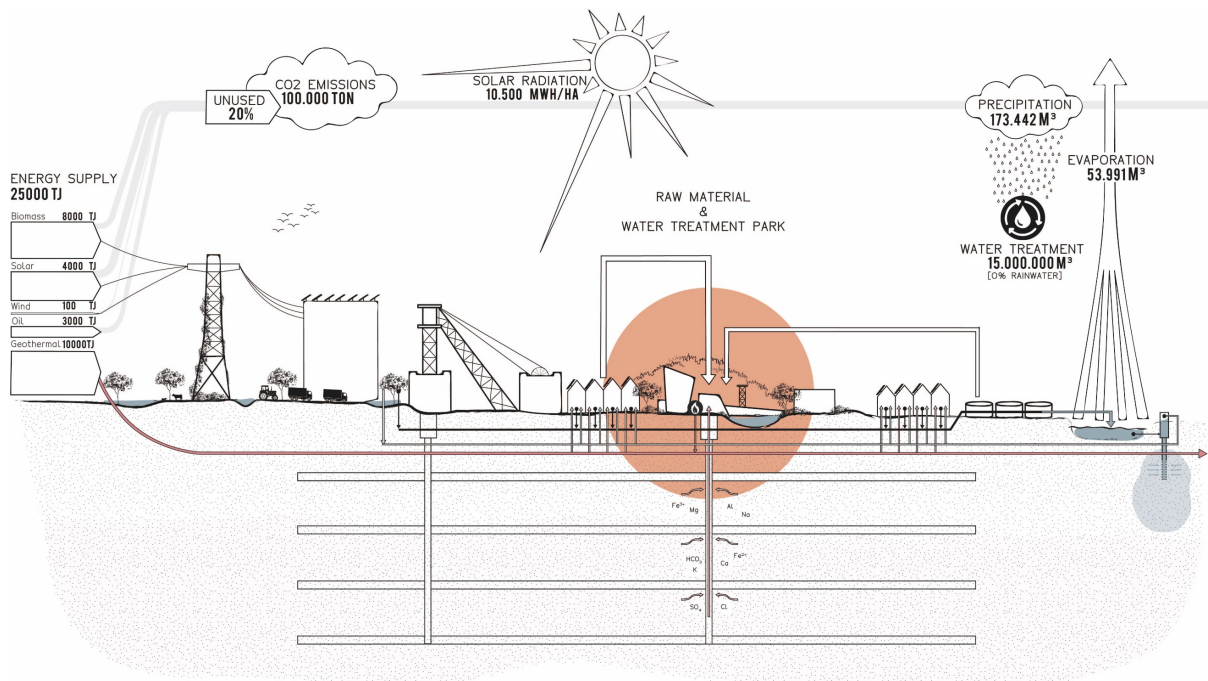


## Syllabus II – Material Flow Analysis

### Current situation



### Situation after Cyclifier: Raw material & Water Treatment Park

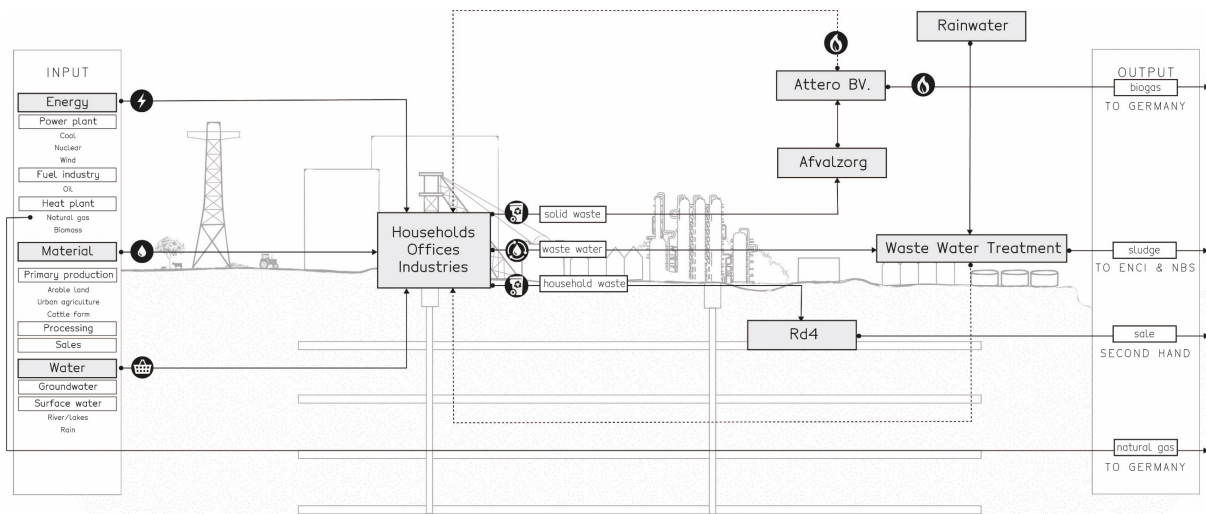


Due to the mining past of this region the subsurface was integrated in the urban system as well. After closing the mines the mine water has risen the whole area in South Limburg and reached a hydraulic equilibrium. This could eventually lead to problems regarding the quality of the groundwater. However it seems that there is a high potential of using the mine water as a renewable energy sources to lower the use of fossil fuels.

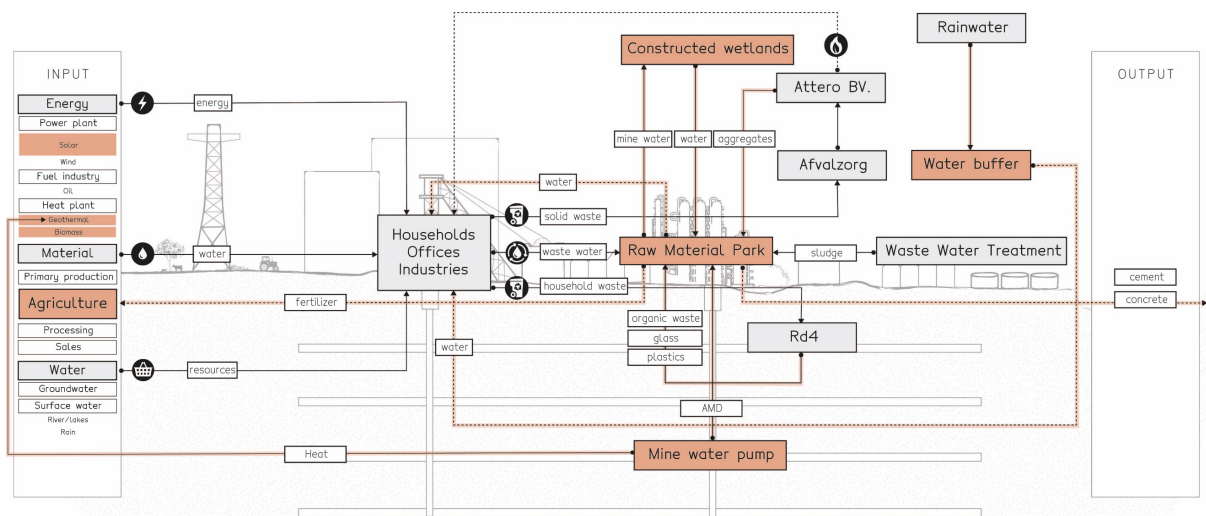


## Syllabus III – Process Analysis

### Current situation



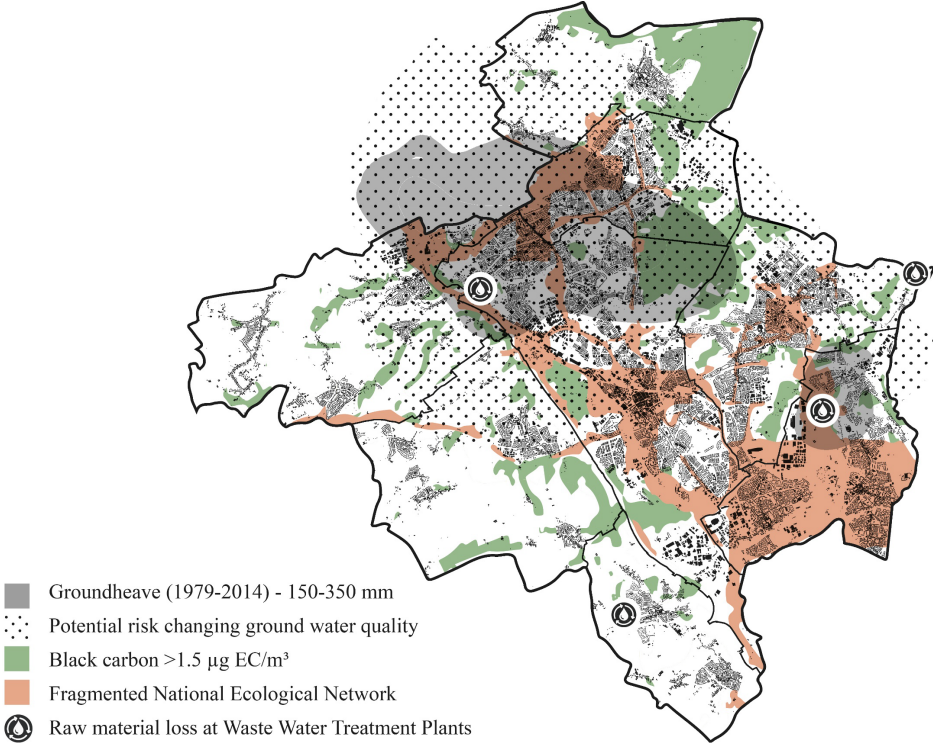
### New situation



People are used to separate factory, nature and city. Instead of relocating the factories and facilities further away from the nature and city, we have to rethink the relations between them. The following design assignment aims for interactive community experience through linking state-of-the-art technology with the purification process and the surrounding ecosystem within the building. The Raw Material Treatment Park invites communities and visitors to gather and learn about the purification process of the mining water. This innovative water park refers to the black gold and therefore tries to restore the lost identity of the region.

**Syllabus IV – Selection of location**

Problem Map



Opportunity Map

