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Hydrological cycle integrity within design strategy of large-scale warehouse facilities

DIPLOMA THESIS

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Faculty of Environmental Sciences

DIPLOMA THESIS ASSIGNMENT

Bc. Vít Pavelka

Landscape Planning

Thesis title

Hydrological cycle integrity within design strategy of large-scale warehouse facilities

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Objectives of thesis

To identify various measures in order to lower negative impact on the environment focusing especially on water management. Based on series of innovative case studies the author will recommend new design strategy for certain warehouse facility in Czech Republic, specifically, how to harvest and utilize rain water in more environmental friendly approach.

Methodology

Literature review – introduction to the topic of warehousing and its assessment methods, water cycle and water management.

The identification of several negative impacts of large-scale warehouses on local environment and water cycle based on the literature review.

The identification of various measures to lower negative impact on local environment based on the literature review.

Random selection of several case studies as reference projects and their complex analysis in order to represent the possible positive impact of water management measures.

Creation of recommendation on the selected site in the Czech Republic with implemented strategies and measures inspired by the case studies and literature review.

The proposed extent of the thesis

80 pages approximately

Keywords

Warehousing, water cycle, water management, sustainable measures

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Recommended information sources

Karia, N., Asaari, M.,H.,A., 2013: Green Innovations in Logistic Industry: Sustainability and Competative Advantage, in book: Entrepreneurship Vision 2020: Innovation, Development Sustainability, and Economic Growth, pp 456-462

University of Arkansas Community Design Center, 2010: LID – Low Impact Development, a design manual for urban areas

Vítek, J., Stránský, D., Kabelková, I., Bareš, V., Vítek, R., 2015: Hospodaření s dešťovou vodou v ČR, ISBN 978-80-260-7815-9

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Author´s Declaration

I, Vít Pavelka, declare that I worked on this Diploma thesis on my own and all literature, publications and other references were properly marked and stated in the attached list of literature sources.

Prague, 18th of April 2018 ....

Bc. Vít Pavelka

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Abstract

The impact of human activities upon the environment is alarming and almost immeasurable due to the complexity and sheer scale. Whereas some impacts may seem trivial, undoing or mitigating those impacts are complex and often not achievable. This Diploma thesis focuses on how to decrease the impact of new development on the environment with a focus on one of the most complex and far reaching natural systems: water. The main aim of this Thesis is to identify various achievable measures applicable at large-scale warehouse facilities, focusing especially on hydrological cycle integrity by using green infrastructure and water management techniques. Based on a review of literature and some innovative case studies, many impacts from large amounts of impervious surface areas in the form of urban heat islands or low infiltration of surface water runoff were found. This thesis identifies a broad range of sustainable measures and approaches and proposes model recommendations for a specific project in the Czech Republic.

Keywords

Warehousing, water cycle, water management, sustainable measures

Abstrakt

Vliv lidské činnosti na životní prostředí je alarmující a téměř neměřitelný kvůli složitosti a širšímu rozsahu. Zatímco některé dopady se mohou zdát triviální, odstraňování nebo zmírnění těchto dopadů je složité a často nedosažitelné. Tato diplomová práce se zaměřuje na snížení dopadu nového rozvoje na životní prostředí se zaměřením na jeden z nejkomplexnějších a nejrozsáhlejších přírodních systémů: vodu. Hlavním cílem této práce je identifikovat různá dosažitelná opatření aplikovatelná pro rozsáhlé skladové haly, blíže pak zaměřená zejména na integritu hydrologického cyklu pomocí tzv. zelené infrastruktury a hospodaření s dešťovou vodou. V návaznosti na literární rešerši a několik inovativních případových studií bylo poukázáno na značný negativní dopad rozsáhlých nepropustných povrchových ploch ve formě tzv. městských tepelných ostrovů či nízké infiltrace odtoku povrchových vod. Tato práce identifikuje širokou škálu udržitelných opatření a navrhuje modelové doporučení pro konkrétní projekt v České republice.

Klíčová slova

Skladování, vodní cyklus, hospodaření s vodou, udržitelná opatření

Content

1. Introduction

"The future belongs to those who give the next generations reason for hope."
- Pierre Teilhard de Chardin –

The fast development and the progress of human activities on Earth is overwhelming, but we should not overlook nature and natural processes because of that. Nature is mistakenly perceived as an inexhaustible source, which will simply deal with the influence of humans on the environment, including decreased water quality, increased pollution and greenhouse gas emissions, depletion of natural resources and contribution to global climate change. If we want to preserve at least current state of nature for future generations, we should create a more balanced relationship between human and natural processes. Fortunately, over time people are realizing that the only way to develop human existence is through the harmony of the offered possibilities by nature and the human needs.

One of the most precious element of life for the existence of living organisms on our planet, including the human race, is water. Water is an irreplaceable component and an exclusive medium in natural processes, where various transport and chemical reactions occur (Sobota, 2012). But do we appreciate it enough? Why do not we use water more efficiently? One of the most fundamental natural processes is the water cycle, which is the continuous self-sustaining movement of water over and beneath the Earth (Woods et al., 2015). However, there is a number of human activities that disturb the water cycle. Examples of this would be high demand on water for irrigation of crops (using more water than is naturally replenished) or changing the land-use by deforestation or urbanization (reducing the local evaporation and infiltration of water). Specifically, urbanization has a significant impact on the water cycle and the environment in general because it significantly changes the basic characteristics of the natural landscape (McGrane, 2016).

The main issue of the rapid urbanization process is a transformation of the surface from natural to artificial (roads, parking lots, public squares etc.) and replacement vegetation with is biotas for concrete buildings, which prevents water infiltration, influencing microclimate condition (temperature, humidity, water and air quality etc.) and increasing stormwater runoff. This has historically led to the use of the urban drainage approach, that should have provided health and property protection. The urbanization impact on the environment is increasing with the amount of impermeable surfaces, for example, in form of large compact cities, but also even as a large-scale compound industrial zones and logistic parks (McGrane, 2016). However, it is not only about large industrial zones, but also about individual large-scale buildings that can reach hundreds of thousands square meters of floor areas.

The most common and simplest way of drainage for new buildings has been through the rainwater sewage network system (ranks under conventional drainage methods) (Butler and Davies, 2004). But why is stormwater perceived as a problem that has to be drained away as fast as possible? In fact, this approach can cause serious negative impacts on the environment and threaten humans' health or properties (e.g. by decreasing water quality and biodiversity or by local floods that can occur more often). However, there are many alternative methods through which stormwater can be elegantly managed on site. Nevertheless, an effective reduction of the environmental impact can only be achieved by a synergy between naturally-friendly site and sustainable measures of the certain building.

The current approach of building environmentally friendly facilities is a globally increasing trend that is now forcing developers and investors to build ecologically if they want to keep pace with the real estate market (Development news, 03/2018). Therefore, many of them focus more on incorporating certification rating of sustainable assessment methods that assess buildings based on their total impact on the environment (Aspinall et al., 2012). Nevertheless, one of the main issues may be a lack of knowledge and a lack of effort to invest to the environment (from developers and investors). However, this thesis might change it by introducing new possibilities, simply, how the stormwater can be perceived as potential instead of problem.

This thesis is divided into several parts that lead the reader from theoretical to practical approaches and analysis, all of which are continuously connected to each other. First of all, a theoretical framework chapter will introduce the reader to the background of this thesis, specifically introducing warehouse development, building assessment methods, or the water problems with an emphasis on the hydrological cycle and urban drainage systems. Secondly, a variety of built projects that introduce the reader to what the current state-of-the-art is in the Czech Republic and other EU countries will be presented. From this assessment, a summary of the negative impacts associated with large-scale warehouse facilities and their impacts on the environment is presented with possible solutions; green infrastructure or water management applicable measures. And last but not least, are recommended measures for a specific project in the Czech Republic.

2. Objectives of Diploma Thesis

To identify various measures in order to lower negative impact on the environment focusing especially on water management. Based on a series of innovative case studies the author will recommend new design strategy for a certain warehouse facility in the Czech Republic, specifically how to harvest and utilize rainwater in a more environmental friendly approach.

3. Theoretical Framework

3.1 Supply Chain Management and Warehousing

3.1.1 Supply Chain Management

In general, warehousing is an essential part of the supply chain management (SCM) system, which is based on the fundamental idea that every single product that reaches its end customer has cumulative efforts from a network of independent organisations. And these organizations (consisting of e.g. suppliers, manufactures, transportation, warehouses and stores) are collectively referred to as the supply chain (Monczka et al., 2009). It is an extended concept of the organisations that adds value to its products or services and delivers them to the end customers. Simply, SCM comprises all of those activities associated with moving goods from the raw-materials stage through to the end user/customer (Lu, 2011). Burke (2005) remarks that supply chain can also be visualised as a river originating from a source, moving downstream and terminating into a sink. In addition, he claims that every supply chain can be visualized as consisting of sourcing stages, manufacturing stages and distribution stages.

But what is the main goal and importance of supply chain management? Nowadays, society has high demands on several fundamental aspects in relation to SCM, which are for example time, money or quality. Consequently, SCM has an important role to play in moving goods more quickly in the right quantities and to the right destination with the efficient integration of suppliers, factories and warehouses in order to minimize total costs and satisfy the end customer´s requirements (Zigiaris, 2000). Moreover, two major trends are benefiting from the SCM, which are customer service and information technology thanks to which the supply chain management is able to react faster for certain requirements (Lu, 2011). To be able to react fast and fulfil requirements of customers, warehouses buildings and distribution centres are playing a crucial role.

3.1.2 Warehouse facilities

As mentioned above, warehousing is an important integral part of supply chain management due to it providing useful services depending on the current economic scene. The major factor influencing the economic scene (in relation to warehousing) is a demand that has been changing very quickly. Warehouses can also buffer against sudden changes in supply, however, the supply takes longer to change and thanks to warehousing the issue of missing goods or gap in supplying can be mitigated (Lu, 2011). In other words, warehousing creates some kind of time utility by storing goods throughout the year and releasing them when are needed. In addition, the need for warehousing arises also due to seasonal production of goods, quick supply and large-scale production or price stabilisation (Tompkins and Smith, 1998).

It is also crucial to define what the warehouse is and what its parameters are. Based on the Oxford Dictionary (11/2017), a warehouse is *“a large building where raw materials or manufactured goods may be stored prior to their distribution for sale”.* Basically, it is a facility used for the storage or accumulation of goods that can vary in size / shape / function / or type, protecting goods against heat, wind, storm, moisture etc. (Kay, 2015). In fact, almost everything you use in your daily life – everything you touch, wear or eat moves through a warehouse (Bartholdi and Hackman, 2014). Warehouse facilities are usually located near important transport corridors (e.g. high-ways due to their great transport connection), as individual buildings or in logistic parks, commercial, industrial or agricultural zones. They are commonly used by exporters, importers, wholesalers, manufacturers etc.

For the purpose of this thesis there will be described development strategies of specifically **large-scale warehouse facilities** with considered area exceeding 10.000 square meters (sqm), maximum to 100.000 sqm. The standard size of these kinds of warehouses in Czech Republic is usually around 25.000 sqm, but we can find warehouse buildings exceeding the building area over 100.000 sqm. Current warehouse facilities are usually large plain buildings with a plain roof and are equipped with loading docks composed of several gates for easy loading and unloading trucks (Kay, 2015). The supporting structure of the building usually consists of prefabricated or steel columns and roof beams followed by horizontal sandwich panels with mineral insulation. The fibre reinforced concrete floor is also greatly important, where the flatness and load capacity for proper and safety working conditions are crucial (Bartholdi and Hackman, 2014). The standard tenants/occupants´ requirements for clear height (the inside usable height) of the warehouse is usually 10 meters, which makes the average height of the building approximately 12-14 meters in total.

The building is divided into storage/warehouse and administrative/office zones. Nevertheless, the storage zones commonly occupy the majority of the building (Kay, 2015). Storage zones usually have only roof windows (called skylights) with insufficient sunshine, complemented by artificial lighting; office zones have regular large windows due to norms, Construction Act and Standards. This affects how much artificial lighting needs to be provided to create appropriate working conditions depending on various space utilization and/or demands of a certain tenant. Regular artificial lighting and reinforced concrete are a very brief introduction to the inside conditions for employees. Moreover, there are generally goods placed on standardized pallets loaded into tall pallet racks inside. Cranes, forklifts and pallet jacks are used for moving goods.

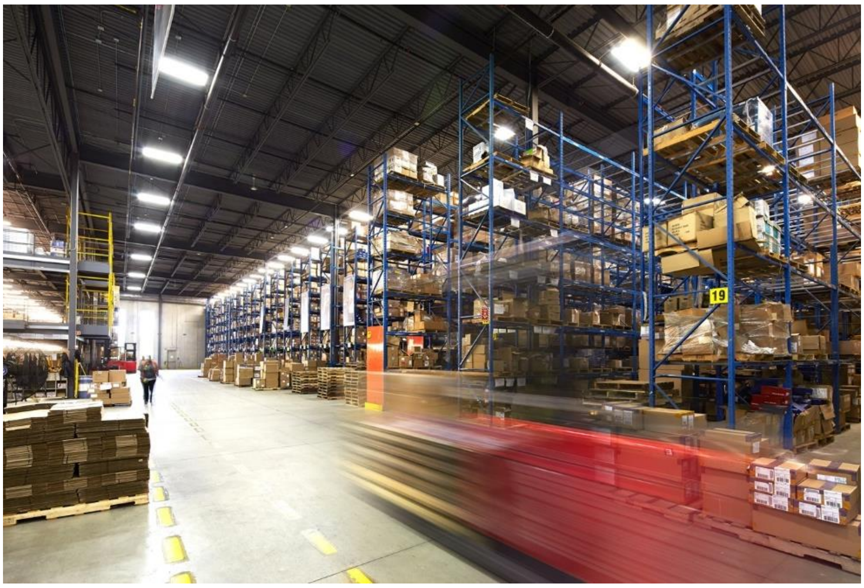

Fig. 1 – Archetypal view inside the warehouse facility on standardized parameters of aisle and pallet racks followed by artificial lighting (Photo and Copyright © 2017 Marni Grossman)

Industrial buildings are usually surrounded by paved areas serving as manipulative areas for trucks in front of gates called docks (usually approx. 35 meters) or parking areas for both cars and trucks. According to the mentioned above, the majority of the site is the hard-surface area (building and paved areas), depending on for example, the shape of the site, terrain morphology, territorially planning documentation or protection zones (of the forests or technical infrastructure) (Bartholdi and Hackman, 2014). Moreover, the hard surfaces usually bring much negative impact for the wider surroundings, especially negatively influencing the surface infiltration of stormwater runoff (increases risk of local floods) or local temperature, which can cause the so called urban heat islands (urban areas are significantly warmer than rural, temperature difference is larger at night than during the day).

Fig. 2 – Archetypal view of large warehouse building with truck gates (docks) in left half of the building and manipulative impermeable area in front of them. Additionally, there is also a small parking lot in front of the office zone located in the right front corner of the building. (Photo and Copyright © 2018 Filson)

Based on Czech legislation and norms (the fire safety of buildings) each warehouse in Czech Republic must have a fire-fighting equipment, which is usually provided by large water tanks close by outside (called sprinkler tanks). Their second purpose is to reduce the impact on local water infrastructure due to impact consumption of large quantities of water (showering, washing hands etc.), when shifts are changing. In addition, many large-scale industrial buildings also have a retention basin to collect stormwater runoff and lower the impact on local watershed. However, there is usually none or little treatment while collecting the runoff.

3.1.3 "Green SCM" and sustainable development

Aside from the "ordinary" and common development strategies mentioned above, there is another possibility in the whole development process that can be more environmentally friendly. In other words, not having such a significant carbon footprint (not only during the construction but also the operation of the building), saving energy (lighting, heating etc.) or maintaining/creating habitats for various local species etc. This approach can be implemented for any kind of building (office, residential, retail, industrial), but for the purpose of this thesis, the main focus will be on supply chain management, especially on industrial buildings that can have lower environmental impact and be more sustainable (Cognizant, 2008).

The Green supply chain management (GSCM) related to SCM brings another dimension – the environment. Cognizant (2008) defined it as: *"Green supply chain management (GSCM) incorporates the ecological factors into the supply chain system in order to address the environmental concern and increase efficiency and productivity. The GSCM as the process of using environmentally friendly inputs and* *converting these inputs into outputs that can be reclaimed and re-used at the end of their lifecycle thus, creating a sustainable supply chain."*

However, one could ask why green supply chain management is necessary for current business strategies? It has simple answer: companies can enormously benefit from these sustainable practices (Emmett and Sood, 2010). Those benefits are for example (i) law and regulation compliance (there are many globally operated and recognized ecological standards and certifications); (ii) Cost-saving and efficiency enhancement (reduction of energy consumption and water usage), or (iii) the green reputation ("green" marketing is a very popular way for businesses to attract customers or investors who are interested in the environment) (Emmett and Sood, 2010).

The intention to have a lower impact on the environment is not new. During the last several few decades many countries have related to the word ´sustainable´ globally with almost any kind of new development. Nowadays, the word ´**sustainability**´ has various definitions but still keeps the key concept as it was defined in 1987 in a report of the United Nations (also called Brundtland report) as *"development which meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Kenig-Witkowska, 2017). In other words, it is a better quality of life for everyone, not only for the current generations, but also for generations to come.

Sustainable development is a key objective of the European Union and it is implemented in many policies over EU countries. For example, in Construction Act No. 183/2006 Coll. In the Czech Republic, sustainability is based on Brundtland's report mentioned above, but in addition, it also identifies the term "sustainable development". This is defined as a balanced relationship of conditions (also called "three pillars") for a favourable environment, economic development and the cohesion of the community of the inhabitants of the territory, which satisfies the needs of the present generation, without endangering the living conditions for future generations (Act No. 183/2006 Coll., § 18, par. 1). Prerequisites for sustainable development ensure spatial planning through a permanent and comprehensive solution to the efficient use and spatial arrangement of the area (Act No. 183/2006 Coll., Section 18, paragraph 2).

And why is it important? Many scientists and politicians agree that human activity needs to be regulated if we want to preserve current environmental conditions (air and water quality, temperature, fauna and flora etc.) at least on the current level for next generations to enjoy the same quality of life as current generations are. The essence of this idea is a balanced and stable relationship between the natural world and human activity. However, this fundamental concept in form of relationship needs to be clearly defined to be able to successfully regulate and control new development. In real estate development is a used term “sustainable buildings” for buildings with low impact on the environment. Aspinall et al. (2012) adds that the major principles for sustainable buildings are e.g. to reduce resource consumption, reuse resources, use recycled resources, protect nature, eliminate toxicity, apply life cycle costing, and focus on quality.

3.2 Building environmental assessment methods

The environmental impact from the building construction industry varies on many different levels, depending on for example used materials, building approaches, local policies and climate conditions etc. Many forward-thinking companies and individuals are developing new approaches/manners to how to meet both, the human needs for new buildings and also how to minimize the impact of the above-mentioned activities on the environment. There are key concepts that are being considered in designing green and sustainable buildings, such as energy efficiency, water management, CO_2 emission, material selection indoor conditions or waste reduction. Terms such as sustainability, sustainable development, construction or green design have become popular and are very commonly implemented in new projects. However, their meaning varies for each facility in their factual impact on the environment. But how to distinguish which buildings really have low impact on the environment?

To be able to identify and differentiate buildings with low / high environmental impact, the buildings are being evaluated and assessed by various methods. The environmental assessment methods aim to quantify sustainability through subjective rating within a set of criteria (Aspinall et al., 2012). Rezaallah et al. (2012) remarks that *“The building environmental assessment methods have emerged as a legitimate means to evaluate the performance of buildings across a broader range of environmental considerations.”* There are two kinds of environmental assessment tools – one is purely based on criteria scoring and the second is based on life cycle assessment, however, both assessment tools were formatted over the last decade (Aspinall et al., 2012). Nevertheless, the implementation of all these methods has fostered green and environmentally responsible practices.

According to Cole (2005), there are various building assessment methods from different countries fitting to their climate conditions, building construction industry and/or market requirements. However, despite their diversity, all agree on sustainability and low environmental impact. From several recent assessment tools there is, for example, the Japanese CASBEE (Comprehensive Assessment Scheme for Building Environmental Efficiency) that breaks away from the simple addition of points to derive an overall building score, e.g. to determine building environmental efficiency, which describes the ecological efficiency of the built environment (Menting, 2016). The SBAT (Sustainable building Assessment Tool) from South Africa, identifies performance criteria that acknowledges social and economic issues. Moreover, in Hong Kong the CEPAS (Comprehensive Environmental Performance Assessment Scheme) organizes performance criteria which makes a clear distinction between anthropogenic and physical performance issues as well as between building and its surroundings (Cole, 2005).

However, in relation with the above mentioned, many scientists and researchers agree that the most widely recognized environmental assessment methods are BREEAM (Building Research Establishment's Environmental Assessment Method) and LEED (Leadership in Energy and Environmental Design), which are globally used in the construction industry. Both methods consider current and future environmental impact of a building as well as a social and economic impact (Menting, 2016). Nevertheless, there are some advantages and disadvantages with small changes in strategies and philosophies, differing especially in rating methods, labels and scales (Menting, 2016).

Besides BREEAM and LEED, there is also another, even more environmentally focused, certification – Living Building Challenge (LBC). This certification could be described as one of the most advanced measurements of sustainability in the built environment. It has a different approach to the rating of a project´s sustainability compared to BREEAM and LEED, because it does not focus mainly on a building´s environmental loadings, but rather on a building´s added quality (Menting, 2016).

3.2.1 BREEAM

According to the BREEAM In-Use International Technical manual (2016), BREEAM (Building Research Establishment's Environmental Assessment Method) is an international standard rating method for the built environment that originates from the UK, where it is still very commonly used. BREEAM focuses strongly on sustainable building design, construction and use. It is locally adapted, operated and applied through a network of international operators, assessors and industry professionals. BREEAM serves its clients as tool to measure and reduce environmental impacts from their buildings, while creating a higher value and lower risk asset of the building. "*BREEAM sets the standard for the best practice in sustainable building design, construction and operation and has become one of the most comprehensive and widely recognised measures of building´s environmental performance"* (Rezaallah et al., 2012).

The first version of BREEAM was launched in the UK in 1990. The system was administrated and developed by BRE (Building Research Establishment) (Aspinall et al., 2012). BREEAM identified that there is a large difference between the environmental impact of a poorly performing building compared to what is achievable by using current best practices (Rezaallah et al., 2012). The main aims of BREEAM are (i) to mitigate the life cycle impacts of buildings on the environment; (ii) to enable buildings to be recognised according to their environmental benefits; (iii) to provide a credible, environmental label for buildings; or (iv) to stimulate demand, create valuable sustainable buildings, thus building products and supply chains; etc. (BRE, 2016). There are different categories in which a domestic or non-domestic (in-use, new building or refurbishment) project is assessed. Standard BREEAM schemes assess projects using a system of "credits" in ten main categories (BRE, 2016):

- **Energy** *(operational energy and carbon dioxide (CO2))*
- **Management** *(management policy, commissioning, site management etc.)*
- **Health and Wellbeing** *(indoor and external issues -noise, light, air quality etc)*
- **Transport** (*transport-related CO2 and location related factors)*
- **Water** *(water consumption and efficiency)*
- **Materials** *(embodied impacts of building materials, including lifecycle impacts)*
- **Waste** *(construction resource efficiency and operational waste management)*
- **Pollution** *(external air and water pollution)*
- **Land Use** *(type of site and building footprint)*
- **Ecology** *(ecological value, conservation and enhancement of the site)*

There are many factors which determine the overall performance of a new construction project. Briefly, a calculation method should proceed in logical order through the environmental impact categories and criteria. Each measurement begins by checking, if mandatory criteria have been achieved (Hamedani and Huber, 2012). In each category, the number of achieved credits is divided by the total available points and then multiplied by the category-weighting factor that gives a percentage point score for each category. All categories are then summed together to produce a single overall score (Rezaallah et al., 2012).

BREEAM rating	% Score
Outstanding	≥ 85
Excellent	≥ 70
Very Good	≥ 55
Good	≥ 45
Pass	≥ 30
Unclassified	< 30

Table 1 - BREEAM Certification rating scale (Reference - BRE, 2016)

3.2.2 LEED

LEED (Leadership in Energy and Environmental Design) is a certification program that is intended to define high quality of ecological building methods for healthier, profitable and environmentally friendly buildings (Ebert et al., 2011). Moreover, according to Ebert et al. (2011) *“The main aim of LEED green building rating system is to provide developers, owners and operators with information that assist them to apply different solutions and technologies to the building for sustainable design, construction and maintenance and to identify the sustainability measures of their buildings.”* LEED was developed by the non-profit organisation USGBC (U.S. Green Building Council) in the late 90´s in the USA. The original intention was to encourage and accelerate the global adoption of sustainable green buildings development practices through the creation and implementation of a universal assessment tool and performance criteria (Rezaallah et al., 2012).

Nowadays, the LEED certification method is applicable to buildings with various functions (from residential, commercial or industrial buildings to hospitals etc.) anywhere, regardless of where they are in their life-cycle (USGBC, LEED v.4, 2018). In general, BREEAM and LEED are similar assessment methods with a similar original intention, however, they are different in basic criteria. For example, in comparison to BREEAM, LEED covers more environmental criteria (energy, waste, climate change, water management etc.), but on the other hand it lacks in measuring economic issues (life-cycle costs, management and maintenance, innovation etc.) (Hamedani and Huber, 2012). Many countries around the globe have accepted the LEED certification system and adjusted it to their specific conditions and requirements – for example: LEED Canada, LEED India and LEED Italy. (Ebert et al., 2011) Similarly as BREEAM, the LEED assessment method is based on points, which are given to individual credits. Credits are divided to eight categories (USGBC, LEED v.4, 2018):

- **Location and Transportation** *(LT)*
- **Sustainable sites** *(SS)*
- **Water efficiency** *(WE)*
- **Energy and Atmosphere** *(EA)*
- **Materials and Resources** (*MR)*
- **Indoor Environment Quality** *(IEQ)*
- **Innovation and Design** *(ID)*
- **Regional Priority** *(RP)*

The LEED rating system is similar to BREEAM in its certification system, where criteria have different weight based on their importance (Ebert et al., 2011). There are 43 different criteria in LEED and four certification levels. Thus, everything lower than 39 points (included) is assessed as unclassified. LEED certification levels are Certified, Silver, Gold and Platinum, see rating scale below (Fig. 3) (USGBC, 2018).

Fig. 3: LEED rating benchmarks (Reference – U.S.G.B.C. official website 2018)

3.2.3 Living Building Challenge (LBC)

The LBC is another kind of sustainable building certification program with similar idea to BREEAM or LEED. The main approach of LBC is not “only” to lower the negative impact of buildings on the environment, but also to do something more/back for the local environment. In other words, we should not build less harmful buildings, but rather build truly sustainable buildings with positive impact on the environment (Menting, 2016). This is main point where LBC differs from others in crucial philosophy – “What if every single act of design made the world a better place?” The Challenge claims to be the most advanced sustainability measure in the built environment today. Regardless of the size or location of the project, it aims *“to transform how we think about every single act of design and construction as an opportunity to positively impact the greater community of life and the cultural fabric of our human communities”* (ILFI, 2016).

The LBC was firstly launched in 2006 by the non-profit organisation called the Internal Living Future Institute (ILFI) offering green building and infrastructure solutions on every scale. The Institute defines LBC firstly as a philosophy, secondly as an advocacy platform and then as a certification program. It provides a framework for design, construction and the symbiotic relationship between people and the environment, including fauna and flora (ILFI, 2016). The sustainability benchmark of LBC is represented by a simple symbol - a flower. According to the ILFI team (2016), the Living Building Challenge *“uses the metaphor of a flower because the ideal built environment should function as cleanly and efficiently as a flower”.* Therefore, the framework is structured around seven “petals”: Place, Water, Energy, Health + Happiness, Materials, Equity, and Beauty (ILFI, 2016). The se petals are subdivided into a total of twenty ´Imperatives´, where each focus on a specific sphere of influence.

PETALS		IMPERATIVES
Place	Restoring a healthy interrelationship with nature.	01. Limits to Growth
		02. Urban Agriculture
		03 - Habitat Exchange
		04 - Human-powered Living
Water	Creating developments that operate within the water balance of a given place and climate.	05 - Net Positive Water
Energy	Relying on current solar income.	06 - Net Positive Energy
Health and Happiness	Creating environments that optimize physical and psychological health and well-being.	07 - Civilized Environment
		08 - Healthy Interior Environment
		09 - Biophilic Environment
Materials	Endorsing products that are safe for all species through time.	10 - Red List
		11 - Embodied Carbon Footprint
		12 - Responsible Industry
		13 - Living Economy Sourcing
		14 - Net Positive Waste
Equity	Supporting a just and equitable world.	15 - Human Scale + Humane Places
		16 - Universal Access to Nature + Place
		17 - Equitable Investment
		18 - Just Organizations
Beauty	Celebrating design, the uplifts the human spirit.	19 - Beauty and spirit
		20 - Inspiration and Education

Table 2 – Petals and related Imperatives - This table shows the Living Building categories called Petals and related Imperatives (Reference – ILFI, 2016: The LBC 3.1)

The specific methodology of how to reach sustainability is freely left on design teams. Thus, LBC allows every project to have its own solution instead of predefining the applicable credits per section, which is a much more meaningful approach (Menting, 2016). The Living Building Challenge certification is based on actual performance, not on modelled or anticipated performance as BREEAM or LEED. In addition, according to ILFI (2016) “projects must be operated for at least twelve consecutive months prior to evaluation to verify Imperative compliance”. There is just an exception for some Imperatives that can be verified after construction, through a preliminary audit (ILFI, 2016). There are three types of LBC certification (ILFI, 2016):

- **Living certification** (all twenty Imperatives are required for buildings)
- **Petal certification** (it requires at least three of seven petals, one of which must be the Water, Energy or Material Petal)
- **Net Zero Energy certification** (one hundred percent of the energy needs on a net annual basis must be supplied by on-site renewable energy; no combustion as allowed)

Since this thesis is focusing specifically on water management and hydrological cycle, it will briefly introduce how LBC deals with this issue. The Living Building Challenge perceive the water differently than BREEAM or LEED, which assess certain buildings “only” by questioning e.g. the presence of potable water, what and how waste water is treated. For example, LEED building “only” need to achieve a marginal improvement over the standard water efficiency building code. However, the LBC requires that the building or project use only water that arrives on site naturally and requires that the water must be treated on site and returned to its natural hydrological cycle. In addition, LBC buildings have to achieve “net-zero water use” (ILFI, 2016). *“Project water use and release must work in harmony with the natural water flows of the site and its surroundings”* (ILFI, 2016).

3.3 The water issue

Water is one of the most crucial essentials for life on the Earth and an indispensable part of the environment. It is an important life element with rare exceptions for all fauna and flora species including humans e.g. for their basic needs as drinking or process of photosynthesis, etc. Furthermore, it is also one of the major environmental issues in 21st century according to FAO website (Food and Agricultural

Organization of the UN) that there is a growing population and less than 2% of water on Earth is suitable for drinking, which is not even distributed evenly for everyone. Therefore, there is an increasing demand for water as for natural resource.

Although water covers roughly 70,8% of the area of the Earth, approx. 97,2% of the Earth´s water is represented by saline water and only 2,8% is fresh water (Sobota, 2012). The mass of water is basically distributed in different states – liquid, solid or gas (Sobota, 2012). The greatest portion of the fresh water (approximately 68%) is in the form of ice or permanent snow cover in the Arctic, Antarctic and mountainous areas. The rest of fresh water is in the form of subsurface (approximately 30%) and surface water (approximately 2%) presented by rivers, lakes or streams (Shiklomanov, 1993).

3.3.1 Introduction to hydrologic cycle

Depending on a wide range of climatic variable conditions, water mass continuously moves. This movement of water is called water cycle or also known as the hydrologic cycle and is labelled as one the most important of all the cycles and processes that operates on Earth (Šálek et al., 2012). The hydrologic cycle is the natural complex process where water is transported between various reservoirs (e.g. oceans, the atmosphere or land), and characterized as a balance of water circulation through evaporation, runoff, infiltration, condensation, sublimation, precipitation, groundwater flow, transpiration and melting (Woods et al., 2015). The water cycle is partially run by solar energy. The cycle has no beginning or end.

There are two distinctly different types of water cycles, the ´large water cycle´ and the ´small water cycle´. The large water cycle is specified as movement of water between the oceans and mainland with all associated processes (Kravčík et al., 2007). Huntington and Williams (2012) describe that during the large water cycle *"water evaporates from oceans and lakes and precipitates on land as rain or snow. The cycle transport runoff from rivers and streams, by subsurface movement through aquifers, through animals, plants, and other organisms, through the soil and stores water in oceans, lakes, and glaciers".*

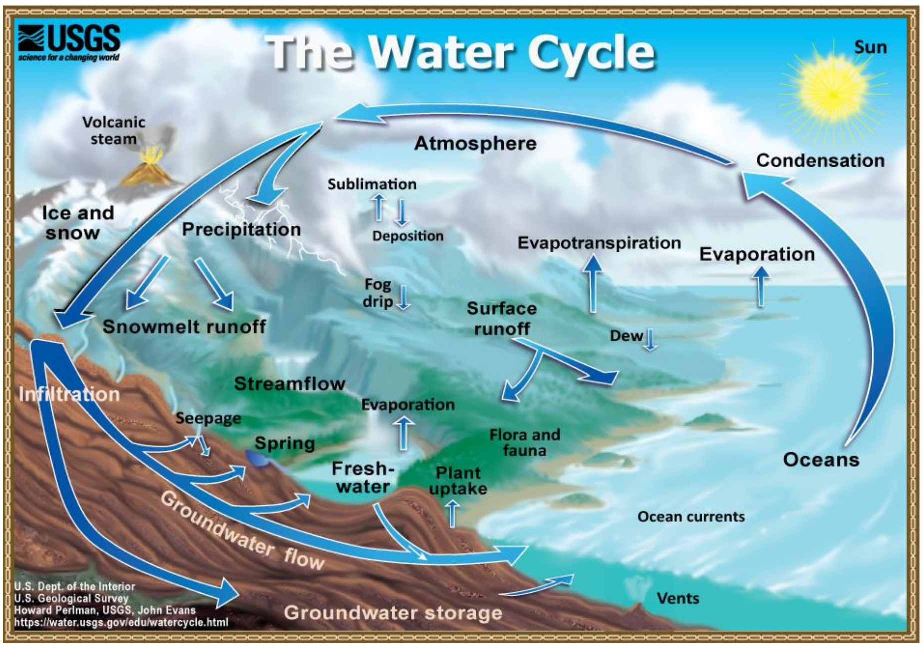

Fig 4: The global (large) hydrologic cycle (Data from USGS)

The small water cycle can be defined as *“the closed circulation of water in which water evaporated on land (or water) falls in the form of precipitation over this same environment”* (Widows, 2015). Although it is called the ´small water cycle´, it is more important to local precipitation patterns than the large water cycle. In fact, approximately two thirds of precipitation on land actually comes from the small water cycle (Kravčík, 2007). In addition, it is the small water cycle which is more affected and influenced by human activity and vice versa, which brings up the issue of water management (Widows, 2015).

The hydrological cycle can be also divided according to place and conditions where the water cycle is considered. Therefore, the **natural hydrologic cycle** and urban hydrologic cycle are recognised. The definition of the natural hydrologic cycle was described above in this chapter as a balance of water movement through precipitation, evaporation, infiltration, transpiration, groundwater flow etc., in the environment (Kravčík, 2007). The **urban hydrological cycle** is characterized for its artificial components, which replace natural conditions and transform them into a more linear engineered water system that include the import and export of water via piped network and artificial routing, also known as the urban drainage system (McGrane; 2016). For detailed information about urban drainage systems please see the chapter 3.3.3. and 3.3.4 .

According to Mitchel et al. (2001) *“the urban hydrologic cycle comprises water supply, wastewater disposal, and stormwater runoff systems, making up the total urban water system”.* With a second breath he claims that the interaction is rarely considered within the same modelling framework between potable water supply vs. wastewater discharge network and the stormwater/rainfall vs. stormwater runoff network (Mitchel et al., 2001).

3.3.2 Water categories in urbanized areas

The water categories in urbanized areas can be divided into potable water, rain water, stormwater, surface water, groundwater and wastewater, based on how polluted or clean the water is. All these components are considered as key elements of the urban drainage system. (Mitchel et al., 2001) Potable water is water that is safe to drink or to use for food preparation without a risk of health issues. In order to meet legal requirements in many developed countries potable water is also recognised as hygienically clean water required for basic hygiene – personal hygiene, washing food, dishes, clothing etc. (Butler and Davies, 2004).

Wastewater, also known as sewage water, is one of the two major urban water-based flows which form the basis of concern for the drainage engineer. Basically, it is any water that has been negatively affected by humans. Wastewater can contain physical, chemical and biological pollutants. Therefore, it is very important to safely and efficiently treat and drain wastewater to maintain and protect public health as well as the receiving environment (Butler and Davies, 2004). Furthermore, Butler and Davies (2004) describe wastewater as the main liquid waste of a community that consists of domestic wastewater, non-domestic wastewater (commercial, industrial or agricultural) and infiltration/inflow (surface runoff).

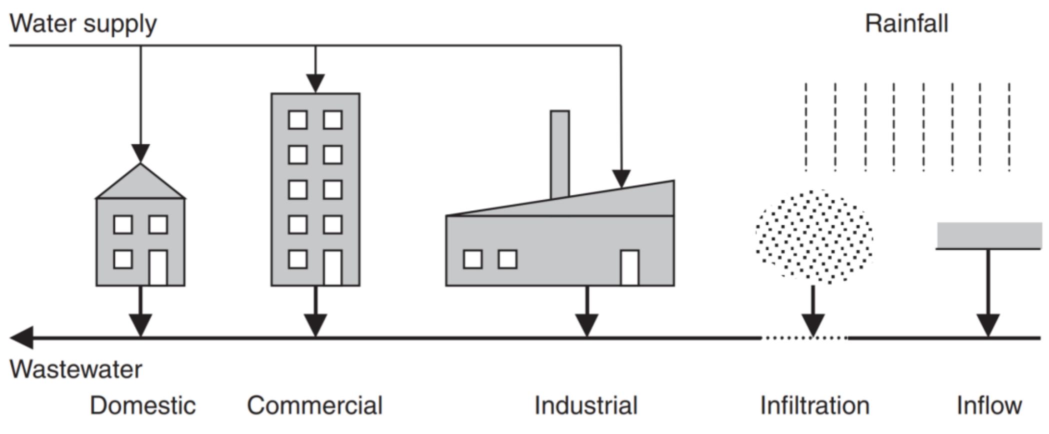

Fig 5 – Sources of Wastewater (Reference – (Butler and Davies, 2004)

Moreover, the wastewater is divided into more categories such as blackwater and greywater. **Greywater** is all wastewater generated in household or office buildings except wastewater from toilets. Maimon et al. (2014) use a definition from The European Standard EN 12056-1, which defines greywater as *"wastewater with a* *low pollution level and no faecal matter such as produced by showers, baths, hand washbasins and washing machines and that can be used to prepare service water, excluded kitchen sink waste water"*. Grey water can be potentially used for secondary utilisation to lower consumption of potable water for example for flushing toilets, car/road washing or industrial use, however, it requires treatment first (physical and chemical) due to potential health risks threats (Maimon et al., 2014).

On the other hand, **blackwater** is defined as water from flushed toilets, consisting of yellow water and brown water, thus water that contains faeces and urine often also mixed with toilet paper that likely contains pathogens and is considered hazardous (Arpit et al., 2016). He adds that black water is generally not recyclable because it mostly contains so much sewage that it is hard to clean. Black water can be potentially used as organic fertilizer under certain conditions (Arpit et al., 2016).

Rain water and surface water/runoff are the second major urban flow that has to be considered by drainage engineers. Basically, it is caused by rainfall that reaches the ground as the part of water cycle (Vítek et al., 2015). In general, rainwater can be labelled as pure water, as rain clouds are formed from evapotranspiration process, thus they do not contain any dissolved substances (Šálek et al., 2012). However, the quality of rainwater is heavily influenced by air pollution because it comes into contact with different chemicals in the atmosphere. Therefore, rainwater can contain various amount of chemicals (e.g. heavy metals), which is varying in different regions on the Earth depending on different level of pollution (Šálek et al., 2012). For the purpose of this thesis the rain water and surface runoff will be considered as interconnected.

There is also the environmental term **stormwater**, which is defined as rainwater (or water resulting from any kind of precipitation) that has fallen on built-up areas and flow over land or impervious surfaces (Butler and Davies, 2004). The runoff usually contains pollutants such as trash, chemicals, oils, and dirt/sediment that can harm rivers, streams, lakes, and coastal waters. Lastly **groundwater** is considered as a crucial natural resource and together with rainwater are fundamentals of hydrologic cycle. The groundwater category represents all water stored beneath the Earth´s surface level in soil or underground reservoirs (Butler and Davies, 2004).

3.3.3. Conventional urban drainage systems

The approach to use river systems and to influence water runoff can be dated back some 2000 years BC, when more developed civilisations (e.g. Mediterranean Minoan civilisation or Egyptian civilisation) began to change riverbeds to irrigate agricultural fields to achieve better production and yields (Novotný et al., 2010).

However, more sophisticated water systems, such as the first urban drainage systems including primitive treatment began to appear during the Roman Empire to bring more water and also to protect urbanized areas against floods (Butler and Davies, 2004). Water began to be used for flushing toilets and cleaning, therefore the first sophisticated sewer systems were built as well. During the Middle Ages primitive urban drainage and sewer systems occurred only in larger and wealthy estates (Novotný et al., 2010).

In the 19th century, the extent of impervious surfaces increased with the expansion of urbanized areas, industrialization, and as such many diseases occurred and repeatedly returned in larger cities (with higher population density) due to primitive street level sewerage systems (Novotný et al., 2010). During rainfall, all wastewaters were mixed and overflowed to the urban spaces; the network of subsurface drainage pipes co-joined sanitary water (waste) and storm water. These early urban drainage systems are still in use today (Vítek et al., 2015). For almost two centuries, the most common urban drainage and sewer systems are usually based on completely artificial features that collect and dispose water from large urbanized areas and metropoles (Butler and Davies, 2004).

There are two different approaches of urban drainage systems – conventional and decentralized drainage systems. According to the University of Arkansas Community Design Center (2010), drainage systems can be defined also as a hard engineering approach (pipe-and-pond) or a soft engineering approach (natural concept: watershed approach). The **conventional drainage system** is based on the principle to get rid of all wastewater and stormwater as fast as it possible to the closest recipient, thus the sewerage or water body (Vítek et. al, 2015). There are two archetypes of conventional urban drainage systems – combined sewer systems, also called as combined sewer overflow (CSO) and separated sewer systems (Butler and Davies, 2004).

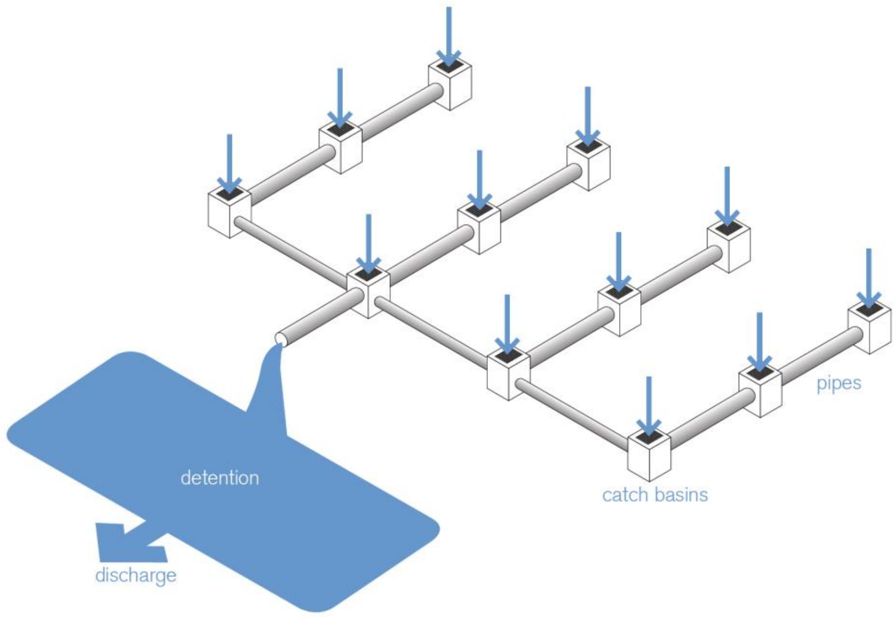

Fig. 6: Conventional management – “pipe-and-pond” infrastructure – this diagram represents treatment of water in urbanized areas, where used to be the main intention to get rid of it as fast as possible (Reference – University of Arkansas Community Design Center, 2010)

The **combined sewer system** was traditionally used in the past (based on the model from first civilisations including Rome) and can be still be found in use in many older cities or smaller settlements (Vítek et. al, 2015). The main purpose was to get all wastewater to the nearest water body, originally with none or little treatment (Butler and Davies, 2004). Nevertheless, the weakness of the combined one pipe sewer system is that burdens unpredictable wastewater treatment plants (WWTP) that can reduce the efficiency of treatment process (Woods et al., 2015). During periods of high storm flows, the water is diverted away from the WWTP resulting in the discharge of untreated wastewater into rivers and streams. One technique to lower the impact on WWTPs are relief retention basins built near receiving water bodies.

The **separated sewer systems** consist of separated pipes, where stormwater runoff cannot get mixed with the foul water (black and grey wastewater) is the case of combined sewer systems. The Separated sewer systems have been preferred and more commonly used in practice, in fact, many developed countries force developers to separate stormwater from other wastewater by legislation or extra fees in case of using CSO (Combined Sewer Overflows) (Woods et al., 2015). Currently only the foul water is sent to the wastewater treatment plant, meanwhile the stormwater runoff is piped to the water body with usually none or little treatment (Butler and Davies, 2004).

The advantage of both systems is the solution to the immediate issues of stormwater runoff, hence the protection against local flash floods, and in addition to drain away the polluted stormwater runoff from streets (Vítek et al., 2015). However, this might be very harmful not only for the local environment, but also for further water bodies and water basins (threatens both fauna and flora) along the stream due to all pollutants from the air and impervious surfaces (especially in large cities) flushed into the nearest river and taken by flow to the sea (University of Arkansas Community Design Center, 2010). It is called the urban stream syndrome. Specifically, it describes the unhealthy stream flow regimes marked by chronic flooding, loss of species diversity, elevated contaminants and nutrients or excessive sedimentation. In addition, the riverbeds (both bottom and walls) are threatened by erosion and organic material and the water bodies are losing their ecological and aesthetical functions (Vítek et al., 2015).

According to Vítek et al. (2015) *"the essential deficiency of this method is hidden in its basic premise, where the stormwater is perceived as a problem, which can be solved only when it is drained away as fast as possible"*. Furthermore, he also summarizes very well that both of these conventional urban drainage systems manifested as unsustainable over time. The following by Vítek et al. (2015) summarizes some of the weaknesses of both **conventional and centralized drainage systems**:

- Do not eliminate the essence of the problem, however, it just shifts its results to a different place from where it originated
- Insufficiently protect the health and properties of urban dwellers at the current rate of urbanization (due to large impermeable areas) and changing climate conditions
- Burdens waterbodies and river basins by polluted urban water varies in the amount and rate of pollutants

3.3.4 The impact of urban surfaces on water cycle

The first major manifestation of the urbanization process appeared in the 19th century with the industrial revolution, but the rapid change occurred after World War II and is still increasing today (Mitchel et al, 2001). Moreover, urbanization is considered as one of the most significant demographic trends of the 21st century along with population migration from rural areas to cities. These urbanization definitions are related to population density, migration of population from rural areas to urban areas, expansion of impervious surfaces, and elimination of natural or endemic species from the surrounding environment (McGrane, 2016).

The urban hydrological cycle is very much influenced by urban drainage systems and the level of urbanization, where the amount of built-up areas contrasted with natural areas is crucial. And since larger urban areas are specific to their extensively paved and built-up areas with usual impervious surfaces (e.g. buildings/roofs, roads, parking lots, pedestrian sidewalks, paved public squares etc.) there is a lack of unpaved areas in cities. This prevents stormwater from infiltration and disturbs the urban hydrological cycle, but even more it also decreases the percentage of the evapotranspiration, another very important part of the water cycle (McGrane, 2016). Moreover, this all results in the increase of stormwater runoff, which then causes flash floods and negatively influences the groundwater level due to pollutants (Vítek et al., 2015).

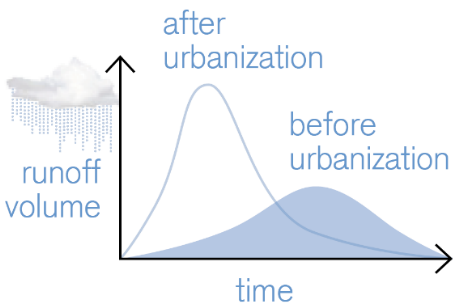

Fig. 7: The influence of urbanization on surface runoff - This hydrograph illustrates the influence of urbanization on surface runoff – the amount of runoff volume contrary to time (Reference - University of Arkansas Community Design Center, 2010)

On the contrary, natural zones can positively influence the urban water cycle by increasing the evapotranspiration, increasing the infiltration and lowering the stormwater runoff, which enhances the groundwater level and lowers the chance of flash floods etc. (McGrane, 2016). Natural zones are also much more beneficial for example by rapidly increasing biodiversity, filtration and natural treatment of polluted runoff, climate regulation, aesthetical effect, recreation and economic development etc. (University of Arkansas Community Design Center, 2010).

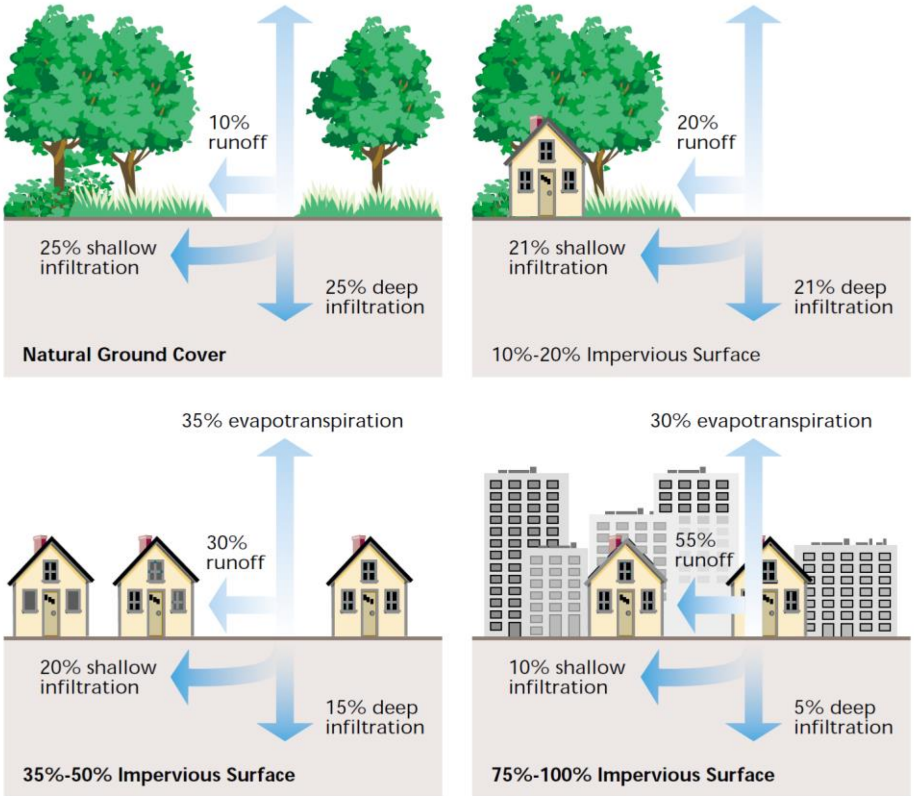

Fig. 8: Diagram of the increasing risk of flash floods - These four diagrams show relationship between impervious cover and surface runoff, where stormwater runoff is increasing with the level of urbanization, thus impervious surfaces. This increasing risk of flash floods, urban heat islands with polluted runoff, results in increased watershed degradation with large amount of pollutants. (Reference – FISRWG, 1998)

3.3.5. Decentralized urban drainage methods

There are many deficiencies of conventional approaches (please see chapter 3.3.3. and 3.3.4) and since the urbanization and the impact of urban stormwater on both human and aquatic ecosystems is increasing worldwide, the management of urban drainage is a critically important challenge (Fletcher et al., 2015). Furthermore, considering also the fact of climate change, conventional approaches are perceived as long-term unsustainable towards the built environment and further development (Vítek et al., 2015).

Therefore, there has been an increasing emphasis in adopting alternative approaches, which are intended to bring and integrate water back into the landscape and restore the small hydrological cycle and all-natural systems in urban context. Novotny and Brown (2010) claim there might be a solution for the negative impact of currently preferred conventional methods and the increasing amount of impervious extents through transition from centralized drainage systems to decentralized drainage methods. Or in other words, the transition from ´fast-conveyance´ to a

´closed-loop´ system, which is considered as a balance between anthropogenic and natural processes.

The basic difference is in how the stormwater is perceived in general, where decentralized methods consider stormwater as a resource/potential rather than a waste product. Therefore, the basic perception is to treat stormwater on-site by using “slow, spread, soak” techniques – **slow** (flow control, detention, retention – to temporary storage stormwater runoff), **spread** (filtrating, infiltrating – movement of stormwater runoff through porous media such as sand or man-made filters), and **soak** (treatment – processes to metabolize contaminants by utilizing e.g. phytoremediation) (University of Arkansas Community Design Center, 2010).

Fig. 9: Diagram of the using “slow, spread, soak” techniques - Instead of using conventional approach (drain, direct, dispatch), a decentralized approach can be applied, where complex stormwater infrastructure can positively influence a hydrologic regime by using “slow, spread, soak” techniques that infiltrate, filter, store, and evaporate stormwater runoff (Reference - University of Arkansas Community Design Center; 2010)

The environmentally friendly decentralized approaches first began to be practiced globally beginning in the late 1970s, however broader application of this approach did not become more common place until the late 1980s and onward in the USA (Vítek et al., 2015). The specific terminology of those methods varies according to region, industry or original purpose, where certain principles, concepts and techniques are applied. For example, in the USA and Canada the terminology commonly used is Green Infrastructure (GI), Low Impact Development (LID), Stormwater Control Measures (SCMs) or Best Management Practices (BMPs); in France the practice is known as Alternative Techniques (ATs). In the United Kingdom the terms Sustainable Urban Drainage Systems (SUSD) or Water Sensitive Urban design (WSUD) are used, and in New Zeeland this approach is known as Low Impact Urban Design and Development (LIUDD) (Fletcher et al., 2015). In the Czech language the most commonly used term is “Hospodaření s dešťovými vodami (HDV)”, translated as Water Management (Vítek et al., 2015).

Many definitions have been developed on this topic, therefore it is difficult to cover all aspects in one short paragraph. Nevertheless, according to the Environmental Protection Agency in the United States (EPA US, 2016) *“decentralized wastewater systems may provide a cost-effective and long-term option for meeting public health and water quality goals, particularly in less densely populated areas*”. The main aim of decentralized approaches is the integration of natural areas into the urban framework to re-establish the urban hydrological cycle. Or in other words an ecologically-based stormwater approach to manage rainfall as close as possible to its source through a vegetated treatment network. (University of Arkansas Community Design Center, 2010)

Moreover, it also provides flood protection, microclimate temperature regulation, cleaner air and water, ecological and aquatic health environment, habitats, ecological awareness, recreational zones etc. In fact, the integrated urban water approach has countless benefits (Massoud et al., 2008). However, regularly it is very difficult to prove a monetary value of these benefits due to the natural cohesive part, because there is lack of studies on each natural feature, for which it is difficult to prove their value (for example for its benefits). Therefore, it might be difficult to assert the integration of decentralized approaches especially in densely urbanized areas, which is mainly governed based on the amount of profit per particular piece of land.

Nevertheless, the integration of decentralized systems can be sometimes less expensive as well in urbanized areas, for example, in case of multiple decentralized systems that provide treatment at the source of the runoff (e.g. by building large municipal treatment ponds that have also several secondary benefits) (Massoud et al., 2008). In case of large-scale buildings can be decentralized methods often less expensive contrary to construction of extent rainwater sewage network system on site and reach the closest waterbody that might be several meters far. There are many Best Management Practices (BMP) that have been globally used, for example, filter strips, bioretention facilities, rain gardens, vegetated rooftops, bioswales or permeable pavements etc. For more possible techniques please see the Fig. 10 below.

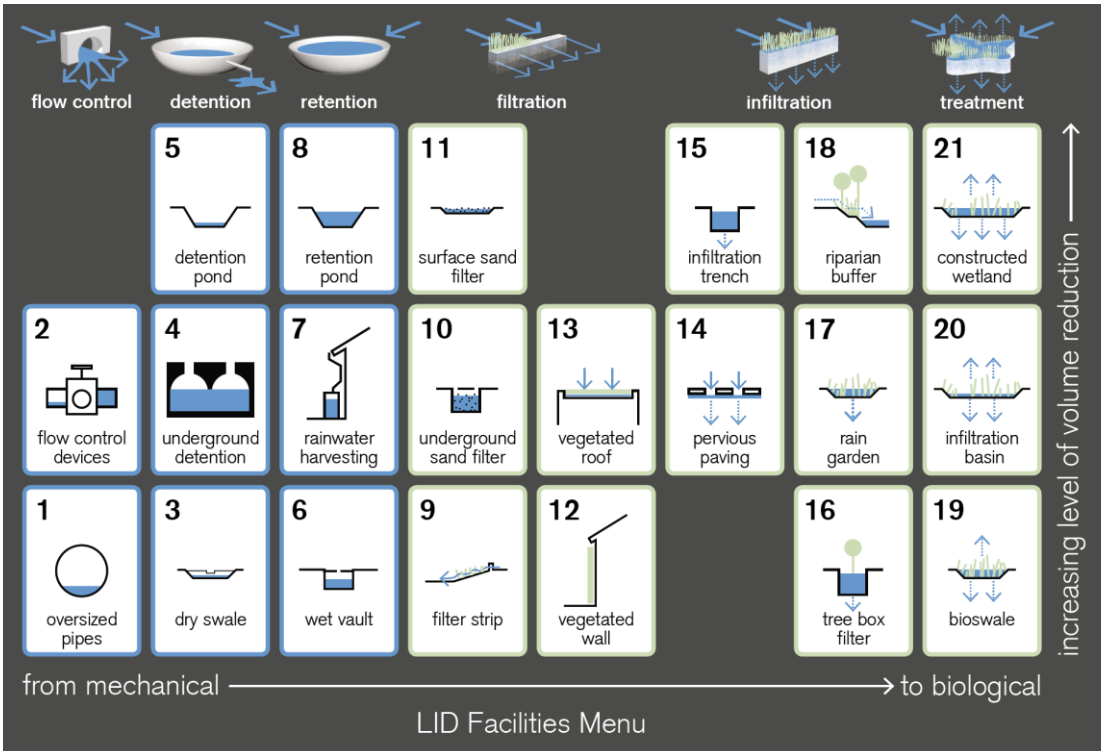

Fig. 10: LID Facilities Menu - "*LID Facilities Menu organized based on increasing level off treatment service (quality) as well as increasing level of volume reduction (quantity).*" Thus, the number one (1) controlled device offers the least amount of treatment and consequently number twenty-one (21) offers the most. (Reference - University of Arkansas Community Design Center; 2010)

The main difference between conventional and decentralized methods is the usage and types of drainage systems. For example, the conventional approach is typical to drain stormwater specifically to the closest separated drainage systems or sometimes even combined sewer overflow (CSO) systems (typical for old urbanized areas or small villages). However, this approach of draining stormwater into the CSO is perceived as the last possible solution (Vítek et al.; 2015). In addition, the separated drainage systems sometimes have to be used especially for highly urbanized landscape with more than 85% of impervious surfaces, when it is very difficult to achieve on-site treatment.

In that case, the separated drainage systems are combined with some levels of green infrastructure and conveyance to larger infiltration basins or ponds with extended detention and pollutant removal is the option. Again, dealing with flood control in highly urbanized areas where the time of concentration is very short in periods of high rain fall is critical. Nevertheless, it is usually not only about one facility, but also about a complex network. Despite the conventional approaches, separating the horizontal infrastructure from the individual property development, decentralized methods focus on the integrity of patterns that include treatment facilities connected to regionally scaled systems.

The most important influence of decentralized approaches summarized

- Preserving, recreating and integrating natural landscape features within the urban development area (e.g. filtrate polluted stormwater runoff, increasing infiltration and evaporation, etc.);
- Considered as an effective tool to cope with the negative effects of climate change;
- On-site treatment instead of sending (polluted) water elsewhere as much as possible;
- Stormwater not mixed with wastewater due to effective and safe modern dual systems, infiltration, evaporation or secondary usage without negative impact on the environment;
- Can maintain or restore a watershed's more natural hydrologic cycle and ecological functions;
- Minimizing the effect of imperviousness to create functional and efficient site drainage that treats stormwater as a resource rather than a waste product; and
- Can effectively slow, spread and soak stormwater runoff.

On the other hand, disadvantage of decentralized methods is the requirement on the extent areas to provide efficient water management as it was mentioned earlier. Therefore, in areas with extremely high urbanization with over 85% of impervious surfaces, stormwater needs to be conveyed and moved somewhere for flood control and treatment. In that cases it is necessary to combine both conventional and decentralized methods, usually in form of to use oversized pipes and flow control devices. Furthermore, decentralized systems are not typically maintained by one central authority, therefore, good design, monitoring and maintenance is critical for long term effectiveness.

4. Methodology and Case studies

Part of the research for this Thesis includes a series of site visits to existing large-scale warehouse facilities. There will be three reference projects evaluated in order to present current trends and practices in industrial development. These case studies were selected based on specific parameters, which are size and age of the warehouse, weather conditions, and a level of sustainable development approach. For the purpose of this Thesis, the size of selected warehouse facilities should be similar to the one for which recommendations will be proposed (i.e. approximately 40,000 sqm). Considering the fact that the average size of a large-scale warehouse facility in the Czech Republic is around 25,000 sqm, further identified measures and proposed recommendations might be variously applied.

The age of the state-of-the-art building will be established to be no greater than five years. For the purpose of this diploma thesis, newly built industrial buildings are especially considered in order to be able to compare current developmental strategies and show their negative impacts. This could then be mitigated particularly by preferring soft ("green") engineering (green infrastructure or LID) instead of hard ("grey") engineering (conveyance approach using technical hard-surface methods).

Industrial buildings with different levels of sustainable development approaches, to best demonstrate different influences upon the environment and various implemented measures, were intentionally selected. Moreover, to establish differences in new development, in both the Czech Republic and also the EU, large-scale warehouses were selected, which are (i) a standard building with no additional effort over the legal requirements; (ii) a state-of-art building in Czech Republic based on the BREEAM certification final score; and (iii) one of the state-of-art buildings in the EU based on the BREEAM certification final score.

Fig. 11: Location of case studies (red labels) in comparison to project in Rumburk (blue label) (created by Author, original picture from Wikipedia)

The precipitation varies in time and space in the Czech Republic due to its large vertical differences, thus, the main focus was on Bohemia (i.e. "west half" of CZ). The annual total precipitation in the Czech Republic fluctuates from 410 mm (e.g. in the Žatec Basin) to more than 1700 mm in the Jizera Mountains. The average annual precipitation is approximately 600-800 mm on over 60% of the area in the Czech Republic. The similarities and differences of weather conditions between level of precipitation for certain locations are represented in following tables (Fig. 12).

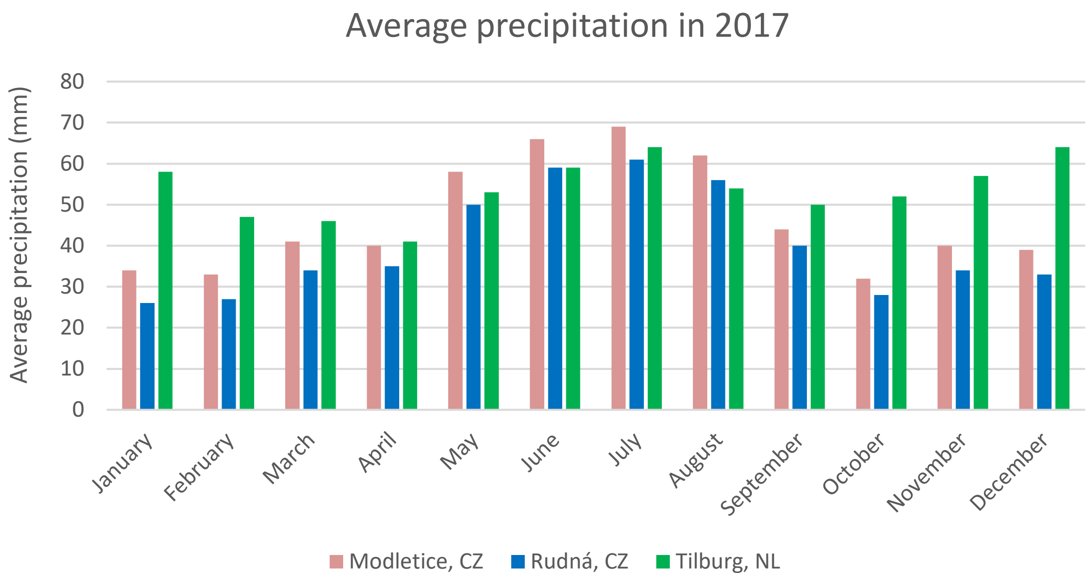

Fig. 12: Average precipitation in 2017 - This graph present average annual precipitation in Modletice, Rudná and Tilburg, to show similar weather conditions of all case studies. There is just slight difference at Tilburg during winter months caused by marine climate (caused by North Sea and Atlantic Ocean), which is in comparison to continental climate (in Czech Republic) more humid in winter months. (created by Author, original data from MeteoBlue)

Depending on the hydrogeological and meteorological conditions (sometimes including the level of pollution) in the certain location and, several methods of water management and dealing with stormwater runoff are offered. Moreover, it also depends on the surrounding and size of the site with potential requirements from the municipality (based on the Master plan) or concerned authorities (e.g. "Catchment authorities" of certain catchment area). Basic principles are:

- Permeable paved surfaces
- Green roofs and green facades
- Accumulation and utilization of water
- Retention with regulated outflow

- Infiltration with regulated outflow
- Infiltration without regulated outflow

4.1 Standard industrial warehouse facility in the Czech Republic

First selected was the standard industrial warehouse facility in the Czech Republic to present development strategies of many developers/investors, who are usually focusing on a profit instead of local environmental conditions. The standard industrial building is considered as the “regular” facility which just fulfils the legal requirements for new development without any or just little effort of to do something more (e.g. to mitigate impact on the environment, provide habitats for local species or better working conditions for employees etc.). According to the problematic cooperation with the many developers in the Czech Republic due to author´s conflict of interests, a bit smaller and older warehouse facility was selected than was expected.

Fig. 13: Location of standard warehouse in Czech Republic at logistic zone Modletice next to the D1 highway (green line) and Prague´s Ringroad D0 (yellow line), near Prague (in the north) (Created by Author, original data are from Geoportal, 2015)

Fig. 14: Situational plan of the site of standard warehouse in Czech Republic (Created by Author, original data are from Geoportal, 2015)

Nevertheless, the selected warehouse is located in an industrial hub of the capital city of Prague near the Modletice municipality, approximately 20 km from Prague´s city centre. This industrial zone has great transportation accessibility due to direct connection to highway D1 and the Prague ring road R1. There are approximately 30 large-scale industrial buildings and many other smaller facilities varying in shapes and the level of quality. The size of the selected warehouse is approximately 16,000 sqm and is divided longitudinally and leased to two tenants (Italinox s.r.o. and Eurinox s.r.o.), where each has the same total size of the building (8,000 sqm), which serves as cash and carry warehouse with many kind of stainless steel products. The building as itself was built in 1998 and has no sustainable accreditation, however, it is very well maintained so it still seems in very good condition.

The stormwater runoff is drained to the infiltration basin on the west (back) side of the site and then to local watercourse nearby that is collecting water from several buildings in this logistic park. In addition, there are planted trees along the north, west and east sides of the site followed by some climbing plants on longer sides of the building. Moreover, there is a small green area (lawn and trees) behind the building (in the western part of the site) allowing some on-site infiltration of the stormwater runoff. Lastly, there are integrated permeable surfaces for parking lots with additional vegetation in form of trees and bushes.

Fig. 15: The side view on the Standard site – The photo shows portion of impermeable surfaces and vegetation. (Photo by Author)

Fig. 15: Large infiltration basin – The photo present large infiltration basin that provides beside infiltration also habitats for local habitat, however only for small species due to fence around the site. (Photo by Author)

4.2 State-of-the-art warehouse facility in the Czech Republic

According to BREEAM Certification system, the state-of-the-art industrial warehouse facility in Czech Republic is located near to the capital city of Prague. It precisely sits in a modern distribution park with a total of 18 buildings called Prologis Park Prague-Rudná named after its owner and location. It is situated just off the D5 highway, 25 minutes from Prague's city centre. What makes this distribution park so popular and successful is the combination of its location, accessibility, favourable construction conditions of the site and the developmental strategy of the Prologis company. The building was finished in December 2016.

According to the official website of Prologis, the official name of the warehouse building is "Prague-Rudna DC18" and it was built for the Czech sportswear dealer Sportisimo as part of an expansion of the original industrial building. The rectangular building comprising of 33,450 sqm of two facilities that was built as the expansion attached to the existing building from each side, which make in total 58.530 sqm all leased by Sportisimo in total. During the construction period, a sustainable approach implementing strict requirements to mitigate any unnecessary pollution, health and safety threats were applied. The building materials were chosen according to life-cycle analysis with a regard to minimize the amount of waste by reusing and recycling a large share of it as rebuilding the brownfield site.

Fig. 17: Location plan of Prologis Park-Rudná next to the D5 highway with lighted Building 18 - middle blue as an original part and lateral red as an expansion part assessed as "Outstanding" with a final score 88,1% base on BREEAM accreditation (reference – Prologis Website)

The sustainability of the building was assessed using the BREEAM rating method where it received a final score of 88.1%, which is classified as “Outstanding”. It is the first warehouse facility in the Czech Republic, which was awarded with the highest BREEAM certification and ranks among the top three industrial buildings with this rating within Central and Eastern Europe (CEE). The assessment boundary for BREEAM Outstanding ranking is 85% (please see chapter 3.2.1). It demonstrates its low environmental impact and eco-friendliness (incl. construction period), but also the most significant operational savings of energy as possible (e.g. due to better insulation and LED lighting). The score increased also due to its public transportation (near bus stops and train station), sheltered parking for bikes and carparks for car sharing. Furthermore, there are also placed constructed shelters providing habitats for local species such as “hotel for bugs” (constructed shelter for insect) or shelters from stones for reptiles.

Fig. 18: Constructed shelter for insect – The shelter on the photo provides habitat for local insect. On the left side from the shelter is another artificial habitat, but for lizards. These kinds of shelters are often cheap compensation of natural habitats. (Photo by Author)

Aside from energy management and additional measurements, which reduce the energy consumption, the building also provides comfortable conditions for employees by ventilating and utilizing natural air circulation, natural light or thermal control. Additionally, for the purpose of this thesis, the reduction of potable water was crucial and was reduced by 56% in comparison to the original building. Primary energy consumption was reduced by 20% beyond the most stringent regulations. In addition, the energy consumption is constantly monitored by state-of-the-art metering systems. For example, the water pipes are equipped with a leakage detection system. However, the project does not treat fully storm water runoff on site. Although, there are green areas around the building to increase storm water runoff infiltration and reduce the heat island effect, the water is particularly conveyed via a storm water utility network to a near retention tank with outflow. Moreover, the retention tank is made of concrete. Consequently, it does not allow any infiltration and it just retains the storm water runoff.

Fig. 19: Concrete retention tank – The retention tank collects water without providing any infiltration. The main intention was to reduce the stormwater runoff and regulate the outflow. (Photo by Author)

Fig. 20: Filter strip – This photo shows the filter strip along the whole east and north side of the site. Bushes under the slope slow the stormwater runoff and provide the infiltration. The site does not provide any other habitats, except newly planted trees (Photo by Author)

4.3 State-of-the-art warehouse facility in the EU

Although, there are several state-of-the-art warehouse buildings in the EU, the selected project is located in the Netherlands. Further, the warehouse facility is part of the industrial zone in northwest of Tilburg city next to the ring-road N260, approximately 20 minutes from the city centre. The warehouse facility was built in October 2014 by the development company DOKVAST, who sought to build the state-of-the-art facility as sustainable as possible with none or low impact on the environment. The warehouse is called Distribution Centre NewLogic II and was “built to suit” to Tesla Company and the building is comprised from four connected halls for storage and one two-floors administrative part providing offices. Total floor area of the building is approximately 49,000 sqm out of total 72,000 sqm of the site area.

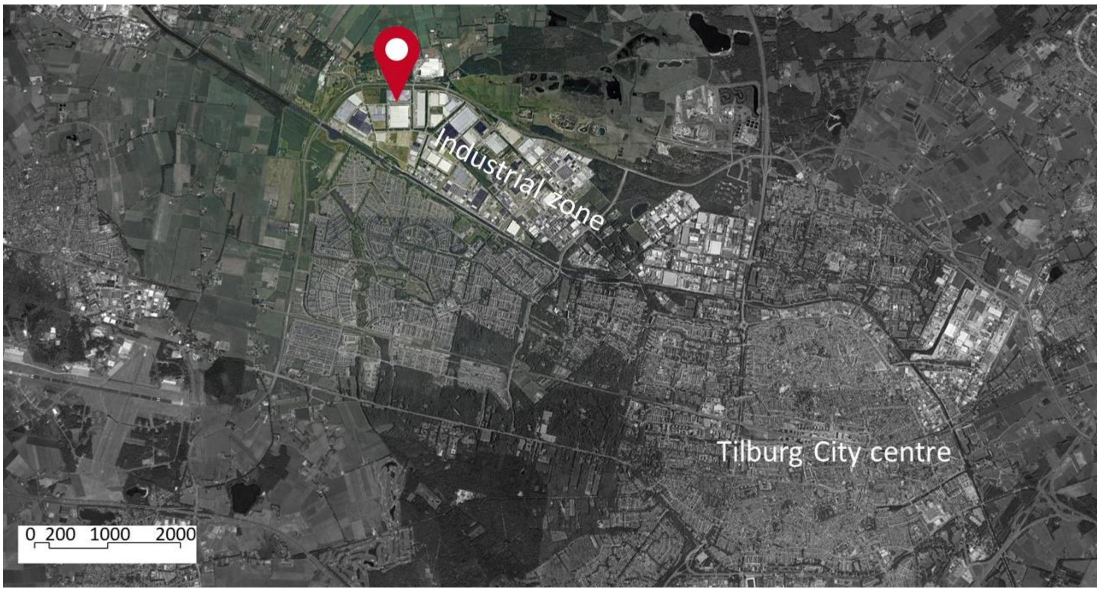

Fig. 21: Location Diagram of ‘NewLogic II’ - This diagram show location of ‘NewLogic II’ in the industrial zone of Tilburg in relation to the city centre. (Created by Author, original picture by Google Maps 22.3.2018)

The sustainability of the building was assessed by BREEAM Certification with total score of 91.2 %, classified as “Outstanding”. In comparison to the Czech Republic, the Netherlands has far more industrial buildings awarded with BREEAM Outstanding score. However, the building NewLogic II is very unique for its large floor area (very similar to the selected project in Rumburk) and numerous sustainable measures. The intention was to reduce both construction and maintenance costs (i.e. reduce energy and CO2 consumption) and also to integrate the warehouse with its surrounding. Therefore, there are photovoltaic (PV) panels situated all over the roof providing power from solar energy for the entire warehouse. There are also integrated smart technologies to lower the energy consumption and to improve working conditions for employees (controlled regular ventilation and providing natural or LED lighting).

Fig. 22: Photo of the finished construction 09/2014 - Photo was taken, when the construction was finished (09/2014). You can see the front façade with main entrance, where you can see the infiltration basin with fountain in front of office part and the bioswale out of the fenced are in left part of the photo. (Photo by Dokvast; References – http://newlogicii.com/newlogic.php)

Additionally, there was the intention to integrate the project into the local conditions with regard to preserving the previous greenery and, together with landscape architect and ecologist specialist, provide new vegetation and habitats to enhance local biodiversity. An example of this is to preserve the wooden area in the west side of the facility, which also provides natural treatment and infiltration of the stormwater runoff. In order to lower the fresh water consumption, the front terrain is equipped with greywater tanks, which provide toilet with flushing water, which have maximum flush use 4 litres per flushing. The building and site have used modern technologies, such as modern metering to provide constant monitoring of energy consumption. Thus, any water leakage is quickly discovered.

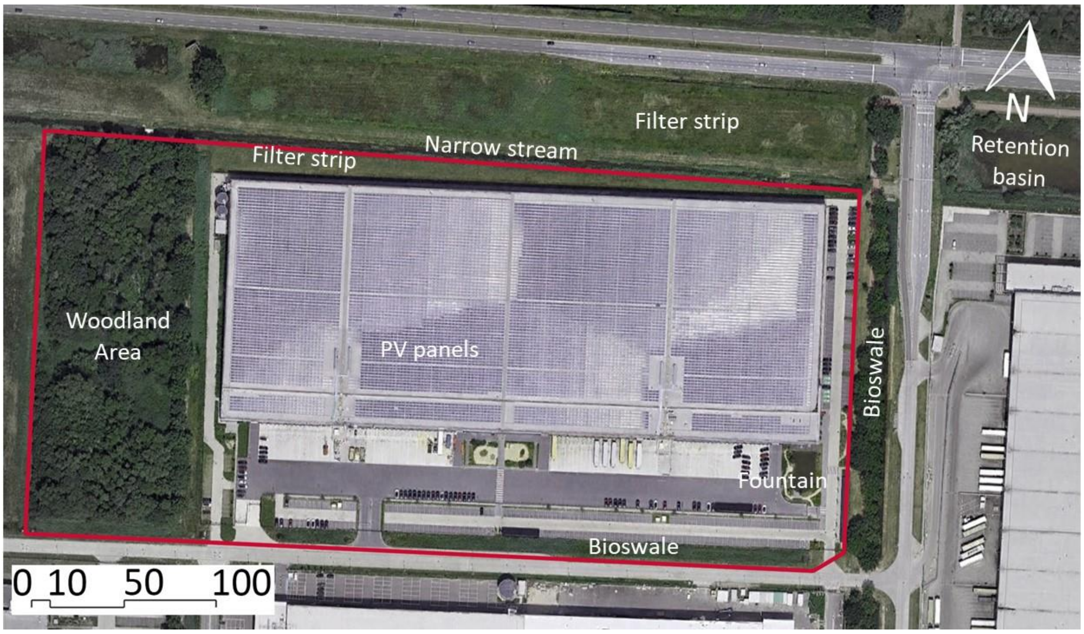

Fig. 23: The satellite picture of the 'NewLogic II' warehouse facility in Tilburg, where you can see PV panels on the entire roof, wood area on the west side of the site, bioswales on southern and eastern sides. Moreover, there is a small narrow stream on the north of the site collecting the stormwater runoff from the road through filter strip and draining it into the close infiltration basin. (created by Author, original picture from Google Maps 22.3.2018)

Even though there has not been treatment of total rainwater on site, there was a significant approach to mitigate stormwater runoff to lower, filter and retain the runoff that has regulated outflow to the close infiltration retention basins. For example, there were integrated bioswales along southern and eastern sides, in the already mentioned wooden area and the retention basin with a fountain in front of the office area at the main entrance. This serves to slow and retain the stormwater and also makes more comfortable conditions for employees.

Fig. 24: Surroundings of the warehouse – Photo shows many opportunities for infiltrating the stormwater by green areas, enhanced by bioswale, rain garden or meadow in the background. (original picture from Google Maps)

5. Negative impacts of large-scale warehouse facilities

Changes in landscapes have occurred more often as urban areas are developed. For example, where permeable surfaces with vegetation used to appear, now impermeable surfaces with buildings are located, or where meandering rivers with rich aquatic biodiversity once used to be, are now straightforward concrete riverbeds. Based on the Theoretical framework and case studies, this chapter summarizes and quantifies many of the negative effects of large-scale industrial buildings on both the environment and humans. Even though warehouse facilities have significant importance in supply chain management, many of these large-scale buildings also have detrimental impacts on the environment, specifically on water quality.

These effects are usually caused by extensive development without an appropriate approach to integrate new development within certain local conditions or by insufficient prevention of these impacts. New development does not only mean the building, but also the site and its adequate usage. The rest of the site (without building and paved areas) is usually left as lawns for easier maintenance, infiltration and good resistance to erosion. Thus, the sites are lacking in design, adequate plan review or absence of governmental regulations.

5.1 Urban heat island effects

Urban heat island effects (UHI) are defined as the difference between temperature in urban (and suburban) areas and the temperature in rural surrounding areas (Nuruzzaman, 2015). This difference in temperatures is even noticeable during the night, when the green areas of land cools down, however, the built-up areas remain at high temperatures. Thus, surface and atmospheric temperatures vary over different areas of land use, due to different radiative and thermal properties. The crucial role played by different types of surface area, materials and their parameters, and the amount of natural areas are the drivers of the urban heat island effect. In fact, urbanized areas such as roads, buildings (both roofs and walls), parking lots or sidewalks have the ability to concentrate and retain the solar radiation, which leads (especially in densely built-up areas) to raise the temperature by several degrees in comparison to natural areas with pervious surfaces, greater amounts of vegetated land cover, and bodies of water. Lower temperature of vegetation is caused by the water kept in plants, which slowly releases during the evapotranspiration.

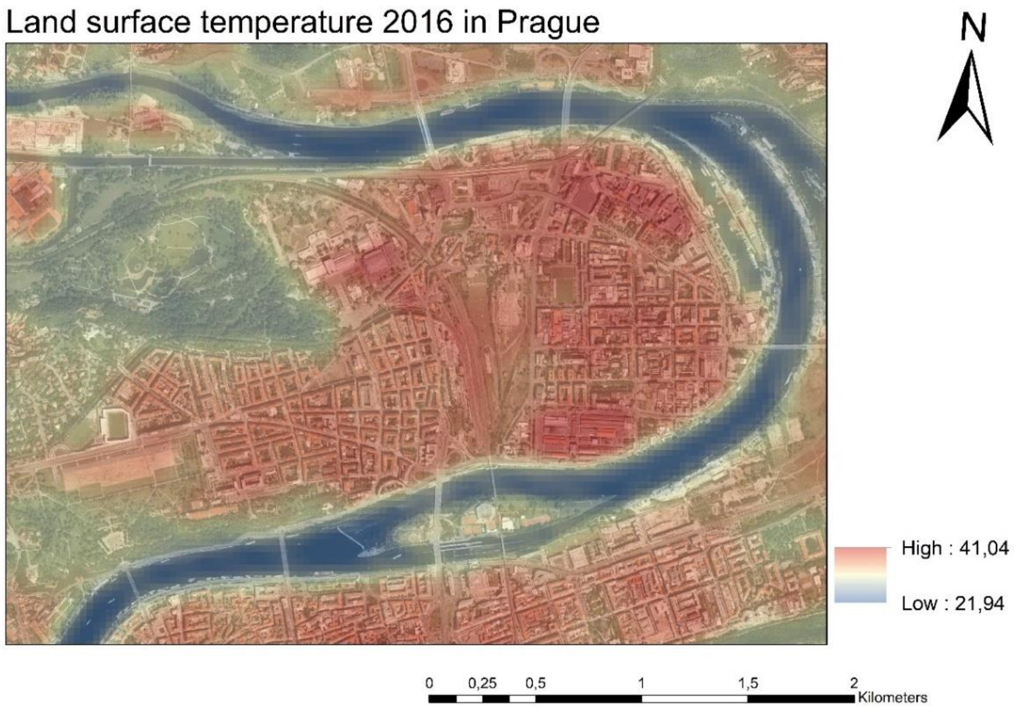

Fig. 25: Land surface temperature image – This image presents different temperatures of compound impervious surfaces (the highest temp.) and vegetated areas and water (the lowest temp.). The data is from Landsat 8, taken in June 2016 of Prague, Czech Republic (Designed by Bc. Tomáš Sedláček, original data from Landsat 8, TIRs)

In the case of industrial buildings, the effect of UHI is specifically caused by the scale of compound impervious surface, which is due to a demand for structures with such parameters. However, aside from the large building area, there is also a request for large paved areas along the building for the purpose of simple truck handling and large parking lots (incl. cars and trucks). In addition, the effect of UHI may also be caused by a lack of vegetation due to easier maintenance or that newly planted greenery is still too young to cover some area with their crowns. In fact, surface water harvesting, abundant amounts of vegetation or permeable surfaces (due to retention and subsequent evaporation of water from soils) might be precisely the solution for this negative environmental and health influence.

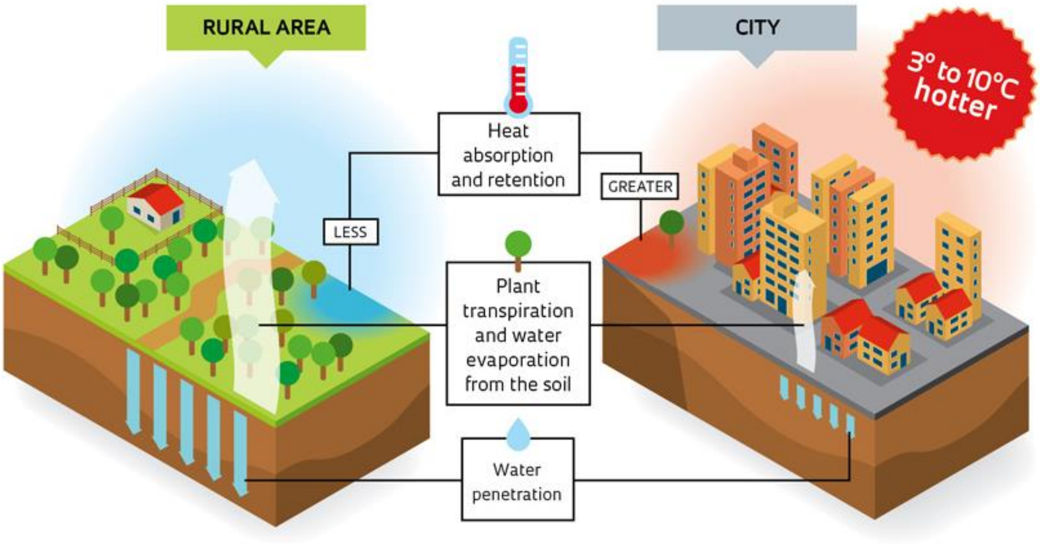

Fig. 26: Scheme of the heat island effect (Designed by Alexandre Affonso)

5.2 Water contamination and minor surface infiltration

In general, the concentration of pollutants near large cities is undeniable and brings significant risk to human health and the environment. Higher concentration of air pollution depends primarily on the amount and relief of emission sources and the meteorological conditions of a certain site. Moreover, urban areas and human activities can pollute the water in many ways. In fact, these affect the water quality directly in the atmosphere (pollutants are directly bounded to water particles during rainfall) or through stormwater runoff, which washes away pollution with itself.

The storm water runoff carries pollutants and other compounds from the surfaces it crosses, which is usually a problem of impermeable surfaces in urban areas. There are different types of pollution in urban areas usually caused by heating, traffic, industry, and other compounds such as suspended solids (dust, soil particles, tyres or concrete particles etc.), trash or organic debris and fallen leaves. One of the leading pollutants associated with cars, planes, power plants, and other human activities that involves the burning of fossil fuels such as gasoline and natural gas, is carbon dioxide. Other very typical pollutants are heavy metals (Cd, Cu, Pb, Zn, Fe), road salts with chlorides (and small amounts of chromium, nickel) and organic compounds (pesticides).

Fig. 27: Polluted storm water runoff drained away by conventional drainage methods (Author – Not found, reference - https://www.ways2gogreenblog.com/2016/03/24/understanding-stormwater-management/)

Furthermore, all these pollutants are deposited on all kinds of surfaces until they are washed away by the first upcoming rainfall or by humans (e.g. cleaning streets, watering, etc.). This phenomenon, called first flush, shows that most of the polluted substances are removed during the initial part of the discharged volume event (Taebi and Droste, 2004). Or in other words, the first portion of storm water runoff in a storm event is the most contaminated. Additionally, the first flush pattern is associated with the rainfall intensity, the hydrological properties of the catchment and the temporal pattern of the storm, meaning it is applicable especially for locations with seasonal rainfalls.

In case of large industrial and logistic parks with high concentration of traffic and large impermeable areas, pollution is spread to its closest surroundings both horizontally (surface runoff) and vertically (deep leakage). Nevertheless, almost every industrial complex uses barriers (in the form of curbs) or moderate sloping of paved areas to control storm water runoff and mitigate the spread to the closest environment. However, this development strategy just leads to contamination of further watersheds, where the polluted storm water runoff is usually drained by conventional urban drainage systems. Thus, instead of treatment and infiltration on site, the polluted storm water is sent to the closest water body, which carries pollution within itself and the burden is then put on someone else.

Nevertheless, large impervious and densely built-up areas are not only associated with pollution, but also with a lack of green areas providing vegetation and functioning as a natural filtration of polluted surface runoff, retaining water and increasing the infiltration. As it was already mentioned in chapter 3, this approach leads to the disturbance of the small hydrologic cycle (also affecting the large hydrologic cycle), resulting in a decrease of groundwater level, more frequent flash floods, worse adaptability to extreme weather conditions and a decrease in aquatic biodiversity in large river basins.

In fact, the storm water is usually drained by conventional drainage methods which are simply not as efficient as natural features in contradiction to flash floods, which have begun to occur more often in recent years. Flash floods are caused by a combination of large impermeable areas, local rapid heavy rains and low capacity of drainage systems. Additionally, during long-term summer droughts, soil with only grass, or no cover loses its retention ability and becomes as hard and compact as rock, which leads to increased stormwater runoff that can result in flash floods. Moreover, when heavy rains fall on steep terrain, it can also weaken the soil and cause the mudslides. Therefore, designing a warehouse facility should also go along within flood protection measures (e.g. in form of retention ponds), which can mitigate risk of flash floods not only for the certain warehouse, but also for surrounding buildings.

5.3 High energy consumption

For decades, one of the main goals of owners or investors of industrial buildings was to increase productivity regardless of energy consumption. Aside from the water supply, sewer and drainage systems, large warehouse facilities also require electricity and a natural gas supply, providing occupant comfort and necessities like lighting, heating, air conditions, and warehouse and office equipment, etc. Nowadays, developers and investors are forced to consider a sustainable factor from man's perspective due to the high demand from potential tenants.

This approach includes, among other things, reducing high energy consumption, which presents other negative impacts of standard warehouse buildings on the environment. It is often caused by insufficient construction parameters, the usage of inappropriate materials, or by inefficient use of energies and management. For example, insufficient insulation and inappropriate ventilation increase the consumption of heating; the lack of windows and skylights result in a larger need to illuminate indoor spaces with artificial lighting (considering the use of ordinary light bulbs). Though outside spaces are usually illuminated to be more productive without any limitation.

Nevertheless, current trends force owners to integrate state-of-the-art technologies and measures to reduce energy consumption. It is not only about current trends, but also a requirement from tenants/occupants of certain buildings, who have to pay for energy and thus, of course, want the lowest consumption possible according to building parameters. Besides that, each building can be classified based on its energy consumption similarly as in the case of home appliances (e.g. fridges or washing machines). The assessment is part of every sustainable method and varies only in benchmarks, focusing on all periods of development also considering the source of energy (renewable or non-renewable sources) and carbon footprint. The greatest potential for how to reduce the energy consumption of large warehouses is a combination of building parameters, renewable resources and the use of new technologies.

5.4 Loss of local habitats

Furthermore, human activity and human manipulation of land have also caused significant native wildlife loss, which is threatening global biodiversity and socioeconomic sustainability. This human urban expansion on a massive scale has been converting or fragmenting the spatial extent of natural habitats (e.g. forests, wetlands, grasslands, deserts, etc.) into large farming and logging areas or artificial impervious surfaces with fences (e.g. settlements, transport infrastructures, etc.). In addition, the term “habitat” refers to an area with resources (food, water, cover, etc.) and conditions (spatial needs for survival and reproductive success) present to produce occupancy by a given organism (Hall et al., 1997).

In case of a new development in Czech Republic, frequently construction prevails on greenfields (arable land or grassland) than on brownfields (previously developed land which is currently abandoned). Furthermore, the previous land-use with previous habitats are usually destroyed and replaced by a new development without almost any added compensation, even though the whole site is rarely for the facility and related paved areas only. This phenomenon is mainly caused by the owner´s/investor´s effort to reduce as much maintenance as possible to save costs for his activity. Therefore, there are usually lawns applied and additional trees, which are often used specifically as visual barriers to lower visual impact of large-scale buildings. On the other hand, lawns are also applied for their strong ability to protect the soil from erosion; however, for example, meadows have even a greater potential to protect the soil and to reduce storm water runoff.

Thus, the rest of sites considered as green areas have huge potential to be used as new habitats for local species with several benefits not only for the environment, but also for investors. For example, it could be considered as a secondary benefit for employees as a relaxation place or to improve negotiations with local/regional authorities involved in permit process, which seek to protect and enhance conditions for local biodiversity.

6. Sustainable Best Management Practices (BMP) measures

Conservation of the hydrological cycle and good water quality is essential to sustain human health, livelihoods and healthy environments on which humans are dependent. Based on the review of literature and a few case studies, this chapter summarizes possible sustainable measures that could prevent or mitigate the negative impact of warehouse buildings on the environment. For example, the small hydrological cycle in urban areas is disturbed due to a high-level of development and impervious surfaces, which prevent deep infiltration and lower the evapotranspiration of storm water runoff. Therefore, the recharging of ground water is diminishing while the storm water runoff is directed elsewhere, which might lead to a lack of water during extreme dry seasons.

Furthermore, using BMP´s Green infrastructure (GI) or Low Impact Development (LID) methods can renew the small urban hydrological cycle. Both methods especially use natural sources with the aim to preserve, restore and create green spaces using soils, vegetation, and rainwater harvest techniques. In other words, the intention is to create or mimic natural conditions to manage the storm water treatment as close to its source as possible, considering the soil as sponge, vegetation as filter, organisms as decomposers and digesters, and the combination of them represent natural water treatment facilities. In addition, there is the term “blue-green infrastructure,” which defines the combination of water and green areas such as wet bioswales, retention basins or constructed wetlands.

Nevertheless, before choosing certain measures, whether conveyance or naturally focused, it is necessary to ask why and for what purpose the water should be treated/utilized and based on the answer choose a suitable solution that will affect the cost of the investment. In the case of using natural features/measures, the cost of investment can vary due to different hydrogeological conditions, location/geography, soil types, vegetation, local species, and watershed catchment. Due to this, every project requires an individual approach. There are many different measures and techniques that can be applied, however, all depend on the primary function of their purpose.

Furthermore, there are many other sustainable measures that could be applied among BMPs measures, however, it is not included in such details, because it is not exactly related to the topic of this thesis. Briefly, for example, there could be also considered Photovoltaic panels (such as at NewLogic II building), wind/water turbines or cogeneration units to provide energy from renewable sources. Moreover, many “smart technologies” in form of smart innovations/apps can reduce costs for energy consumption or labour costs, for example, by robotization, by automatically switching off the lights systems when nobody occurs in certain place or by automatically ventilation systems to provide healthy environment.

6.1 Green infrastructure (GI) facilities

According to the European Commission programme ‘Enhancing Europe´s Natural Capital’ (2013), the GI is defined as “a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas.” According to the EPA (2015), GI is a cost-effective, resilient approach to manage wet weather impacts. Specifically, it reduces and treats storm water at its source while delivering environmental, social, and economic benefits. There are several techniques on how to provide filtration, retention and infiltration, the most common examples suitable even for large-scale warehouses are listed below.

Permeable paving

The current trend of urbanisation and increasing compound areas of impervious surfaces leads to several negative impacts such as heat island effect, flash floods and contamination (see chapter XY), which pose a risk of harm to health and property. Many of these water issues are the direct result of the presence of asphalt and concrete paving, which increase storm water runoff and prevent the ground from properly absorbing it. To reduce the impact of impervious surfaces there has been an approach to replace them by permeable surfaces and permeable paving. Permeable paving allows movement and infiltration of storm water runoff through the pavement surfaces (US Departement of Transportation, 2015). Nowadays, there are many innovative methods and techniques on how to increase the infiltration.

The most common method is interlocking concrete pavement, also known by its trade name Turf-block, which allows the movement of water through the joints/gaps between paving bricks or natural stones US Departement of Transportation, 2015). Other techniques are porous asphalt or pervious concrete, which allow the water to drain through its porous material. However, these techniques are very expensive especially when applied for large-scale areas. Further, the gravel system can be used, however, it is more suitable for smaller areas such as small parking lots, secondary pedestrian trails or paths for the fire brigades. There are also alternative paving systems, for example, recycled rubber paving, which is not so expensive, but it is not suitable for heavy trucks. Thus, this technique is more suitable for pedestrian paths. A final example is grass concrete and turf paver systems that provide significant infiltration while also protecting vegetation root systems. Costs are similar to interlocking concrete pavement as well as the high load capacity. However, the watering and mowing of grass is required.

Fig. 28: Usage of grass concrete paving system - This photo demonstrates a usage of grass concrete paving system for parking lot (Photo by Grass Concrete Ltd.)

In general, the integration of permeable surfaces for large-scale warehouse facilities might be very difficult due to a high occurrence of contamination from traffic. Therefore, it is not recommended to use permeable pavement for industrial storage and loading areas (in front of dock doors along sides of the warehouse) Otherwise, it is necessary to control the infiltrated runoff with geotextile and underdrain and provide appropriate treatment (e.g. by coalescence separator with sludge trap).

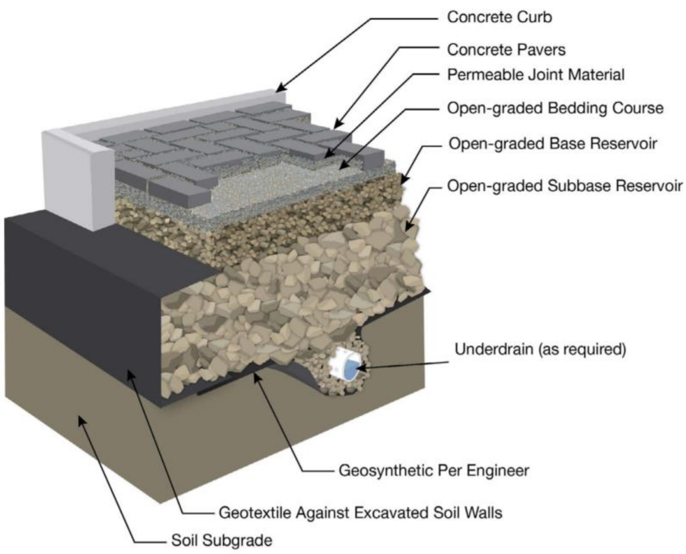

Fig. 29: Technical structure diagram of the permeable pavement system - This diagram shows technical structure of permeable pavement system (Image by USDT team, 2015)

Green roofs and green facades

Green roofs are vegetated multi-layered systems placed on the vertical or sloped roof providing social, aesthetic, environmental and economic benefits. For the purpose of this thesis, plain roofs will specifically be considered as typical for warehouse facilities. There are vegetated and gravel roofs that are designed to mitigate heat island effect, energy consumption (as great insulators during summer and also extreme winter weather) and reduce the storm water runoff (EPA, 2013). The additional benefits are to reduce the peak flow, to increase the evaporation and to increase the biodiversity.

The green infrastructure multi-layered system includes roof construction, filter layers and vegetation cover or gravel (EPA, 2013). The filter layers must be permeable, must have high retention capacity and low weight. The vegetation part should be designed based on the purpose and function of the roof. Usually vegetation which is resistant to sun exposure is used, for example, different kinds of grass, herbs or low shrubs. In the case of warehouse facilities, the main disadvantages are high costs, not because of the green belt but due to the high demands on the construction statics. The maintenance of the roof vegetation is also required.

Furthermore, green facades are vegetated vertical walls, which have similar functions as green roofs, but with different requirements. Basically, there are two types of green facades differing in soil medium or providing a suitable condition for climbing plants (University of Arkansas Community Design Center; 2010). Both have significant aesthetic, environmental and economic benefits. However, green facades with vegetation in the soil medium provide effective insulation and better water absorption and filtration, which can be used especially in the confined conditions. On the other hand, climbing plants are suitable when their main function is to increase the aesthetics; but this does not provide insulation. Large-scale facilities have their own purposes for parameters with particular emphasis on height and compact size, which might deteriorate the landscape character. Therefore, planting vegetated walls in the form of climbing plants can mitigate this aspect and, in addition, it is usually not an expensive solution even for warehouses with these parameters.

Fig. 30: O'Hare International Airport in Chicago - The FedEx has integrated green roof system on one of their facility at O'Hare International Airport in Chicago (Authors: Green Roof Solutions, Inc.; reference - http://www.greenroofsolutions.com/)

Surface Filter Strips

A surface filter strip is a sloped vegetated area usually adjacent to a specific natural or anthropogenic corridor that provides filtration and slows storm water runoff (Vítek et al., 2015). In relation to this Master thesis, surface filter strips are typically parallel to impervious areas such as roads, parking lots or manipulative areas along warehouse buildings. The primary function of filter strips is filtration and treatment of polluted storm water, which also slow the runoff. Filter strips are also effective at removing polluted solids; vegetation (usually various types of grass) traps organic and mineral particles that are then incorporated into the soil, and then carry up nutrients (Elliot and Trowsdale, 2005). Moreover, through its root systems, vegetation removes pollutants from soil by degrading contaminants into simpler molecules or elements.

Nevertheless, in case of storm water runoff from large impervious surfaces with significant pollution from traffic and limited soil permeability, surface sand filter facilities should also be used. It consists of coarse sand with gravel on top followed by a filter fabric and fine sand underneath. This is supported by a perforated under-drain to control the water course during heavy rains. Surface sand filters have a better ability to trap nitrates, phosphates, hydrocarbons, metals and other sediments compared to filter strips, especially during the “first flush” process. In addition, the combination of these two methods result in a facility called bioswales.

Fig. 31: The infiltration strip between two strips of bushes (Photo by Author)

Rain Gardens

Rain gardens are another sustainable bio-retention facility for managing storm water runoff. Rain gardens are usually smaller and more suitable for residential systems rather than other facilities such as bioswales. The main purpose of rain gardens is to slow, temporarily collect, and infiltrate storm water runoff (Elliot and Trowsdale, 2005). Thus, they usually have sloping sides and high permeable topsoil –mulch is used very often in this part. When designing a rain garden, due to its infiltration ability, it is necessary to keep away some distance from buildings (at least three meters) to protect the foundation.

Moreover, they are also improving storm water quality with planted vegetation, which is the key role for rain gardens. Additional benefits of rain gardens include the aesthetic benefits and improvements to parking areas, while also enhancing the local biodiversity by providing food and habitat for various species. It is recommended to especially plant native plants, soils and other species without using chemicals or fertilizers to preserve synergy with local climate conditions. In addition, selected plants also need to be able to withstand moisture regimes ranging from flooded to dry. A great benefit, among others, is the occasional maintenance in the form of removing trash and pruning of vegetation. In the case of warehouse buildings, it is recommended to apply rain gardens near to parking lots or a main entrance for its aesthetical function, where more people are moving.

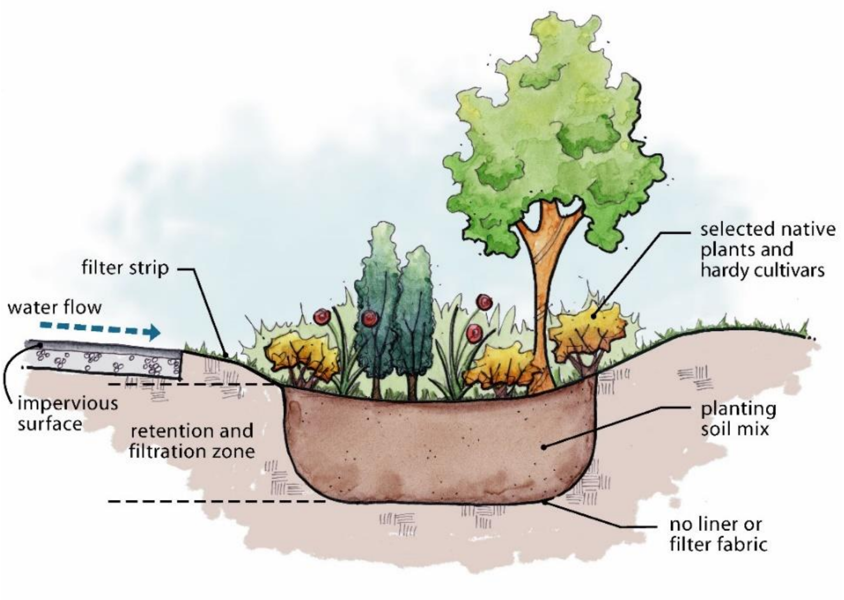

Fig. 32: The section scheme of the rain gardens (Authors: Snohomish Conservation District; Reference - http://www.betterground.org/rain-gardens/)

Bioswales

Bioswales are open linear, gently sloped, vegetated strips that effectively slow, collect and treat stormwater runoff. They also combine the conveyance function of a grass swale with the filtration and biological treatment mechanisms of bioretention (Elliot and Trowsdale, 2005). Bioswales are located along roads or large impermeable areas, therefore, they are very similar to rain gardens or filter strips. However, bioswales are more efficient in all their primary functions (filtration, treatment and infiltration). Moreover, due to facultative vegetation, they can also achieve good removal of metals, nutrients or phosphorous that are attached to suspended soil particles that were flushed by stormwater runoff (University of Arkansas Community Design Center; 2010). This process of treatment is called phytoremediation and it provides mitigation of contaminated soil, water, or air by using plants to contain, degrade or eliminate pollutants (University of Arkansas Community Design Center; 2010). The effectiveness of bioswales depends on the amount of vegetation (fully vegetated bioswales leads to better phytoremediation) and upon the retention time of the stormwater in the bioswale.

Bioswales are designed for a certain storm event such as a 24-hour storm event occurring every two or ten years. While they maintain stormwater conveyance on the surface during large rainfall events, bioswales also promote infiltration and filtration largely through the sand media (mixed with soil), gravel and perforated underdrain (if soil permeability is limited). Furthermore, bioswales require curb cuts providing uniform distribution of water and the whole bioswale increases its filtration process. It increases even more when bioswales are part of the complex network related to other measures resulting in efficient water treatment and infiltration. In cases of extremely high pollution (large amount of trucks and cars) a coalescence separator with a sludge trap that can eliminate the possible occurrence of oil or petroleum leakage should also be applied.

Fig. 33: Local neighbourhood bioswale, State of Pennsylvania (Photo by Clarion Associates, Reference - http://sustwatermgmt.wikia.com/wiki/File:Bioswale.jpg)

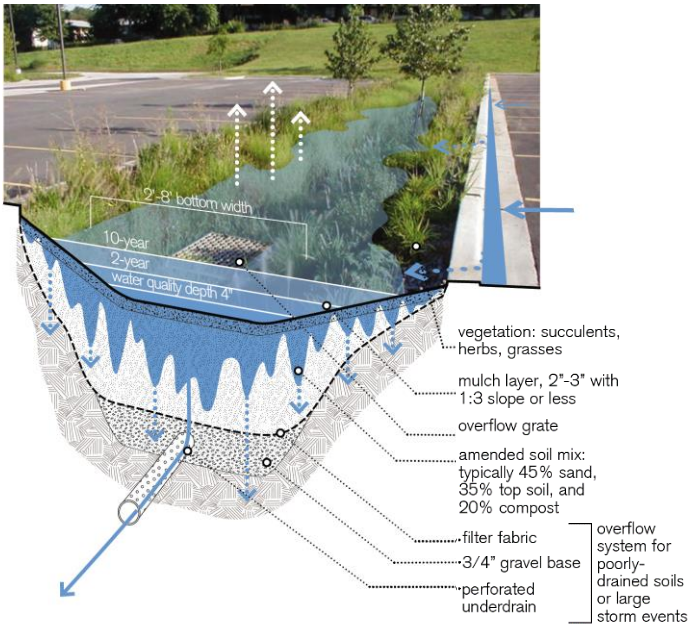

Fig. 34: Green infrastructure techniques such as bioswales filtrate, infiltrate and treat stormwater runoff, which can also help reduce peak flooding (Reference - University of Arkansas Community Design Center, 2010)

Retention and Infiltration Basins

According to the Water Act (Act No. 274/2001 Coll. about water supply and sewage systems) retention on site is mandatory, otherwise investors have to pay fees to certain sewerage network administrators or owners of the stream (usually Catchment or municipality Authority), if they give them a permit to drain water there. Both retention ponds and infiltration basins are facilities that can have significant positive influence on the small hydrological cycle by providing retention, evaporation, filtration and infiltration of stormwater runoff. Thus, the stormwater is infiltrated on-site or at its closest surroundings, hence groundwater is recharged. The main difference of retention or infiltration basins from rain gardens or bioswales is in the scale of the facility. On the other hand, this is a similar approach in providing facilities with appropriate vegetation to enhance phytoremediation treatment. Both can also be constructed for residential, commercial, and industrial sites depending on hydrogeological conditions and the level of precipitation.

Retention ponds are open constructed permanent stormwater ponds that retain water with minor biological treatment. Wet ponds are primarily used for water retention, to reduce the flood risk and secondarily also used as an additional source of water during fire interventions. Thus, when retention ponds are designed, it is important to maintain appropriate access for fire brigades. Since retention ponds are considered as permanent water facilities they should not be constructed in areas with permeable soils, otherwise, the construction has to be provided with additional insulation layers such as clay soils or concrete slabs. Other key elements of retention ponds are continual drainage input to sustain permanent pond levels as well as drainage output to provide natural circulation in case of long-term heavy rains. In addition, maintenance is required to provide proper functioning by removing accumulated sediments, debris and trash.

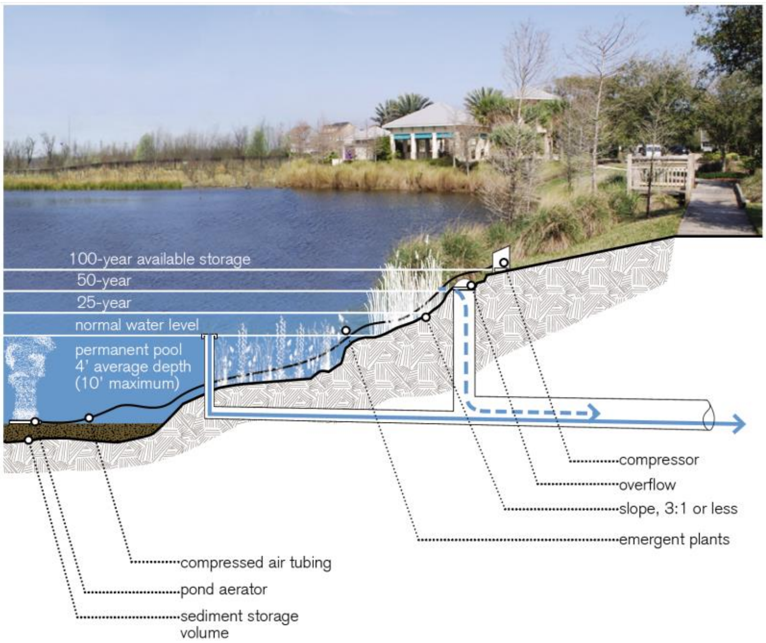

Fig. 35: Technical parameters of large retention pond - This diagram shows technical parameters of large retention pond (Reference - (University of Arkansas Community Design Center, 2010)

Infiltration basins are shallow impoundment facilities – or ponds, which temporarily store and infiltrate stormwater runoff. Infiltration basins do not retain permanent pools of water as retention ponds, therefore, the key element is highly permeable soils with high infiltration rate. When designing infiltration basins, moisture-loving vegetation with deep root systems should be integrated to increase the infiltration. Infiltration basins are used to significantly slow stormwater runoff by providing filtration of pollutants and groundwater recharge, flood protection, aesthetic improvement and providing ecological habitats. Infiltration basins are also called wet meadows due to large amounts of various vegetation rich in species increasing local biodiversity. The proper functionality of infiltration basins may be threatened by sediment deposits. Therefore, the appropriate maintenance is required in the form of annual or semi-annual removal of trash, sediments and mowing of surrounding vegetation. The sedimentation can prevent some sediment-reducing facility being used upstream.

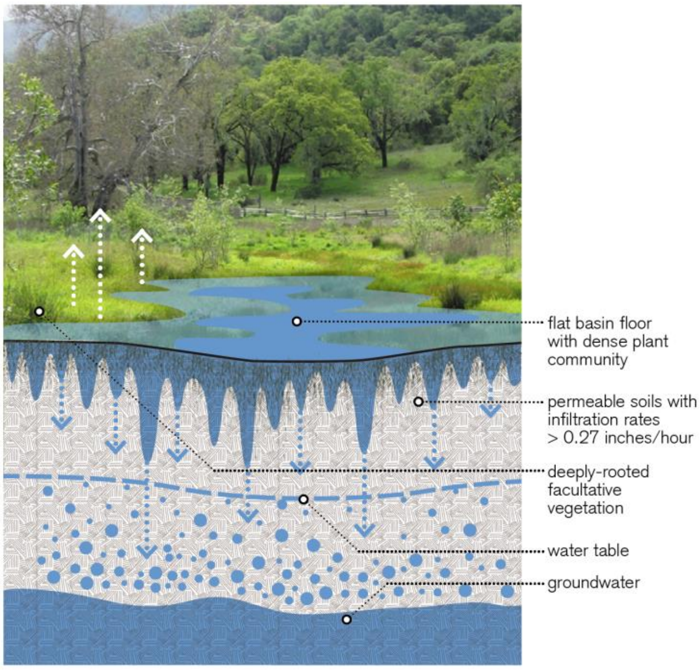

Fig. 36: Schematic image of infiltration basin providing the groundwater recharge, flood protection and increasing local biodiversity (Reference - University of Arkansas Community Design Center; 2010)

6.2 Rainwater management (RWM) systems

Rainwater management techniques are a continuation of GI, which use natural features as mentioned above predominantly more or less. On the other hand, the RWM approach provides particularly technical facilities, however, both natural and technical facilities can be combined. There are three archetypes of RWM methods – rainwater retention, harvesting and accumulation. The stormwater retention was already described above (see chapter 6.1). Therefore, the fundamental focus of this chapter is rainwater harvesting and accumulation approaches suitable for large industrial buildings, for example in a case where there is need to use technical facilities instead of natural, because of site properties, lack of space or weather conditions.

Rainwater harvesting systems

Rainwater harvesting is considered to be one of the decentralized methods since it provides on-site treatment of stormwater runoff and mitigates the environmental impact. In general, the rainwater harvesting approach is an alternative water technology, which is designed to collect and store rainwater, but also to slow and reduce the stormwater runoff. This also provides a source of water that can reduce the need of potable water (University of Arkansas Community Design Center; 2010). Rainwater harvesting can be divided based on its purpose as an infiltration or accumulation technique (with secondary utilization) or based on the location of the facility to aboveground or underground facilities. Both approaches rely on site properties such as hydrogeological, morphological and weather conditions. However, there are several technical-oriented methods with great potential to improve the hydrogeological conditions.

In fact, aboveground naturally based infiltration in the form of retention and infiltration basins was already mentioned above (see in chapter 6.1). However, some technical-based facilities should be considered as well, in cases of inappropriate hydrogeology conditions where GI measures may not be the solution but could pose a threat (e.g. increase the risk of floods, erosions or landslides). In such cases it is possible to incorporate retention ponds with reinforced walls in order to control and regulate the infiltration. Similarly, dams can be implemented to slow stormwater runoff, retain the water and increase infiltration. This method is particularly suitable while designing long bioswales on a sloping site, where it can ensure high efficiency of the certain GI or RWM facility.

In the case of large-scale buildings with large impermeable areas (roof and surrounding concrete areas), the volume of rainwater that must be drained during the rainfall reaches very high levels, possibly even tens to hundreds of litters per second. Thus, it is usually very challenging to infiltrate stormwater on site even though the soil has a high infiltration rate due to its limited capacity of absorbed water. To enhance the infiltration with lack of space underground infiltration facilities can be considered to retain large amount of water, which is gradually released and infiltrated. This technique uses the stormwater infiltration plastic blocks/panels (also called eco-rain tanks), which can create underground space for water when blocks are connected together in prepared large trench/pit. Further, it also requires filters (to prevent access of larger physical particles) and textile as permeable insulation that allows water to infiltrate, but also be retained and slowly released. Nevertheless, this method can be applied only under appropriate hydrogeological conditions. These eco-rain tanks are used very often under parking lots. However, then it is necessary to use oil separators to prevent any groundwater contamination.

Fig. 37: Photo of stormwater infiltration blocks near South Coast of England - Individual blocks were put together, insulated with permeable textile and covered back with soil (Photo by Cole Easdon)

Accumulation and utilization of rainwater

Rainwater accumulation systems collect and store rainfall for secondary later usage. When designed appropriately, it also reduces stormwater runoff and serves as an alternative source of water. Accumulation of rainwater can be integrated in any kind of scale – for a family house, administrative building, large collective farm or industrial buildings. Accumulation and utilization of water depends on many factors such as amount of precipitation, roof (or collection area) properties and purpose of using water (due to treatment, amount etc.). The design type and size of collectors, which can be barrels, accumulation tanks or large reservoirs varying in used material and treatment are based on these factors. There are plastic, concrete, fibreglass or steel accumulation tanks differing in price and suitability of their usage. The size of the tank for large-scale buildings can vary from 750 to 25,000 litres depending on certain demand.

There are both aboveground and underground accumulation tanks, depending on the site conditions and investment budget. Moreover, to maintain the hygiene of stored water, it is recommended to place the accumulation tank in a cold place, where it is not directly exposed to sunlight (Mudroch, 2008). Mudroch (2008) does not recommend storing water in tanks long term without being used and instead being replaced with “fresh” rainwater. Additionally, even though aboveground tanks are less expensive, they are exposed to temperature fluctuations or sunlight. Underground tanks can mitigate these impacts and are also preferred for new buildings, where excavation work is a necessity anyway.

Furthermore, before storing the water in tanks, pre-treatment is required, which is provided by filter systems. In fact, there are many filter systems such as artificial filters with sieves for large particles (leaves, small branches etc.) or semi-natural filters with sand-based filters. All storage tanks also have an overflow regulator to prevent tank overloading during heavy rains. This water is drained as other stormwater to the closest decentralized facility. In addition, to ensure water purity when reaching water, there is are suction baskets placed on the float, which mitigate pollution soak from the bottom of the tank. The suction systems also have a bottom alarm in case of a lack of water, which automatically changes the water supply to potable water.

Fig. 38.: Utilization of rainwater – the picture represents utilization of water for irrigation, flushing toilets or washing (Designed by Stomrsave Ltd.)

Utilization of collected rainwater can significantly reduce the use of potable water; according to some references the reduction can be up to 50% (reference). In general, according to the parameters of rainwater, Utilization is more suitable for several activities other than potable water because, for example, it does not contain minerals, fuel pollution or pesticides. It “just” contains pollution during rainfall and roofs. If necessary, rainwater can be utilized as potable water, however, it requires better and more efficient treatment (usually including UV treatment to have hygienically clear water). The biggest disadvantage of utilizing rainwater is the necessity to have a special distribution network along certain facilities. This means that the building has two water distribution systems – one for potable water and a second for rainwater. In cases of industrial buildings, rainwater can be used for several activities without advanced treatment (but this is dependent on the legal framework of the particular country). It is usually necessary to provide hygienically clear water (potable water quality) for kitchen activities and sinks for washing hands, otherwise rainwater can be used. Summary of activities, for which rainwater can be utilized:

- **flushing toilets**
- **cleaning** of both inside and outside hard surfaces
- **washing** cars / trucks
- **watering** plants / lawns
- **utilized as service water** in case of light manufacture
- **cooling** (for heating systems)

7. Results

Diploma Thesis first sets out a clear theoretical framework that comprehensively introduces readers to the whole issue with the development strategies, the sustainable assessment methods, the hydrological cycle and the differences between conventional and decentralized drainage approaches. This theoretical framework is subsequently verified in practice by several investigative case studies. These studies were selected to show the widest spectrum of development strategies, but also still allow their mutual comparison. The state-of-the-art sites were selected primarily based on their BREEAM rating score, in order to assess the most modern industrial buildings in the Czech Republic and the EU. Due to large amount of state-of-the-art industrial buildings in the European Union other selection factors have also been taken into account such as similar size and weather conditions to the state-of-the-art facility in CZ and project in Rumburk for which.

Comparison of individual development strategies shows that the standard industrial facility in the Czech Republic has similar approach in case of rain water management as well as the state-of-the-art sustainable building (due to BREEAM) in the Czech Republic. On the other hand, this “the most sustainable” building has several other measures, for example, sustainable parameters of the building to lower energy consumption (e.g. a modern insulation, LED lighting, innovative “smart” technologies) or providing new habitats for local species. More significant was the difference between mutual comparison of the state-of-the-art buildings, where the project in the Netherlands integrated many sustainable building and BMPs measure to reduce energy consumption and impacts on the environment (e.g. by providing smart technologies, photovoltaic panel system, green infrastructure measures, LED lighting, etc.).

Based on the review of literature and several case studies, there were identified numerous negative impacts of large-scale industrial buildings on the environment. For example, there were identified urban heat island effect, water contamination and flash floods, high energy consumption, loss if habitats etc. Many of these effects are caused especially by large compound impervious surfaces, lack of vegetation and none or inappropriate water treatment. This step was important because it is necessary to know on what measures to focus on when designing / recommending new measures for certain building (in case of this thesis for the project in the Czech Republic).

However, several possible measures or techniques can be applied to mitigate the environmental impact. In general, water retention and infiltration on site with additional vegetation can positively influence the hydrological cycle and mitigate for example the heat island effect, pollution of stormwater runoff or risk of flash floods. In addition, for example specifically green roofs and green facades as efficient insulation can influence energy consumption and also increase the aesthetical view of warehouse buildings. Among others, the mimic natural conditions also influence biodiversity by providing food and habitats for local species.

Summarized benefits of sustainable measures (listed in chapter 6):

- Slow, reduce and treat stormwater runoff on site
- Stormwater runoff control – lower the risk of flash floods
- Increase the water quality and mitigate contamination of other watersheds
- Increase the ecological stability – enhance a local biodiversity by creating habitats for local species
- Support of the natural hydrological cycle by increasing infiltration on site
- Improving local microclimate by increasing moisture and evapotranspiration that mitigate urban heat island effect
- Increase the amount of retained water to reduce the impact of dry periods
- Reduce the energy consumption – save the energy and costs
- Increase evaluation criteria– increase BREEAM and LEED score

- Increase marketable image of both stakeholder and also leasing company
- Improving the working environment

7.1 Rumburk Project

Another task of this Master Thesis is to recommend suitable sustainable measures based on previous chapters (especially chapter 4 and chapter 6) for a certain project in the Czech Republic. The selected project site is located in Rumburk, in the eastern part of the Ústí nad Labem region, on the border of Germany. This site was selected according to its suitable parameters for future construction of a large-scale warehouse facility, suitable hydrogeological conditions and the fact that there is a lack of underground water capacity. The investor of this project will be the Accolade Group, which prepares industrial buildings in cooperation with other developers. Accolade´s development strategy is to build industrial buildings (from logistics to light manufacturing) for specific tenants (it is called “build to suit”), therefore, they do not build anything speculatively. However, that means that they go through a permitting process with a speculative project, which is later improved and applied for a specific tenant. In addition, since the buildings remain the property of the Accolade Group, they have an interest to offer state-of-the-art buildings in the real-estate market, thus to meet the current trends (e.g. to have the least possible impact on the environment).

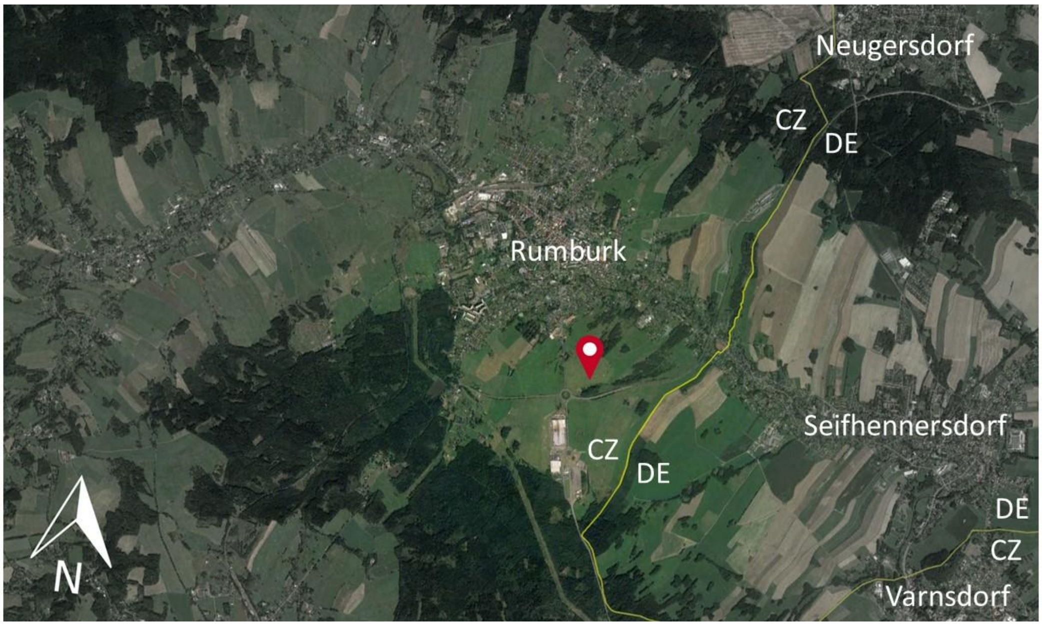

Fig. 39.: Photo of the boundary between Czech Republic and Germany - This aerial photo shows site location and its relation to the close surrounding, where the yellow line represent boundary between Czech Republic (CZ) and Germany (DE) (Created by Author, original data are from Geoportal, 2015)

Introduction to Rumburk Project

The town of Rumburk is located in the very north of the Czech Republic, next to the border, crossing with the German towns of Seifhennersdorf and Neugersdorf. Rumburk, famous for its beautiful historical inner city (e.g. old monastery), has approximately 11,000 inhabitants. The project site is situated approximately 300 meters south of Rumburk, adjoining and developing the current industrial area. Moreover, the site is near the roundabout of the first-class road I/9, which is the important transport corridor to Prague - Mělník - Česká Lípa - Rumburk - Bautzen (DE) or Görlitz (DE). The size of the site is approximately 120,000 sqm with a planned development of one compound large-scale warehouse with a total size of 40,000 sqm.

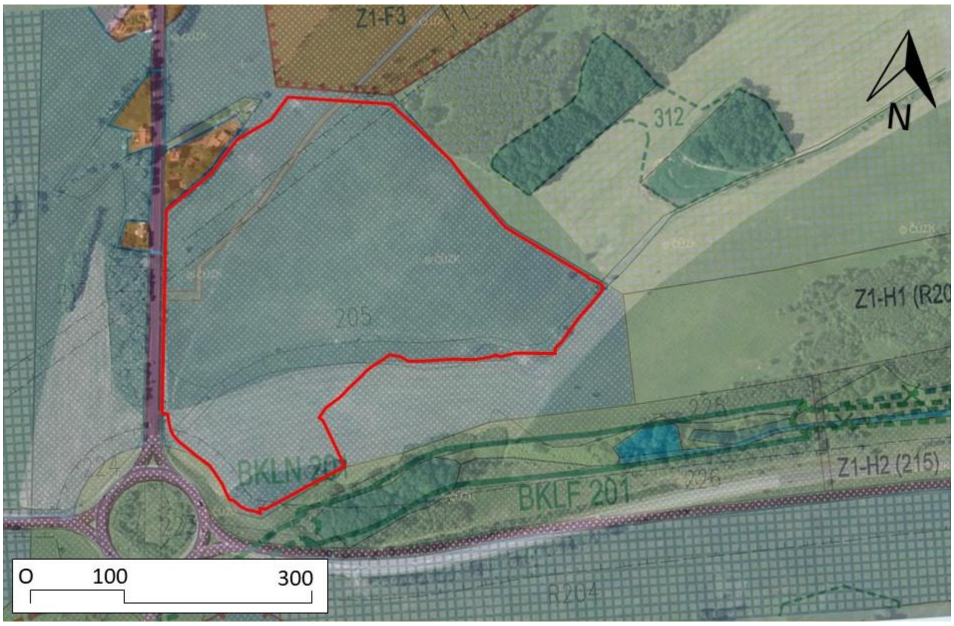

Fig. 40: Current state with highlight site (red line), where aerial photo and Master plan are merged - This diagram shows current state with highlight site (red line), where aerial photo and Master plan are merged. The site is currently used partially as meadow and arable land. Very important is local ecological biocorridor (marked as “BLKF 201”) with Hornojindřichov stream south-east from the site for further recommendations. In the north-east from the site there is proposed new interaction element (Marked as “312”). (Created by Author, original data are from Geoportal, 2015, Master plan of Rumburk)

The size, proportion and limits define Master plan, property relations and topographical conditions of the site and its surroundings. For the purpose of this thesis is important that the Master plan of Rumburk defines in this area not only the industrial (or residential) areas and roads, but also the territorial system of ecological stability (TSES). TSES is mutually interconnected complex of natural or semi-natural ecosystems, which is in case of Rumburk represented as the local ecological bio-corridor in the south side of the site and the interaction element in the east of the site.

Fig. 41: Diagram of the investor intention - This situational diagram presents an intention of the investor at the highlighted site embedded in the current state. The image shows portions of the warehouse (red areas), impermeable surfaces (light grey area), permeable surface (dark grey area) and green areas with vegetation. The original project was designed by Rota Group, who cooperates with the investor (Created by Author, original data are from Geoportal, 2015, Warehouse design from Rota Group)

Rumburk Analysis

The site is in a slightly warm climate area (MT2), which is characteristic for its mild to mildly wet summer, a temporary transition period of mild spring and autumn, and regularly long dry winter. The rainfall during growing season is approximately 450-500 mm while the rainfall in the winter season reaches approximately 250-300 mm. Considering the hydrological conditions, the project site belongs to the fourth-class catchment area – Rumburk stream (2-04-08-003), which flows into the small river Mandau. To the south of the site is the Hornojindřichov stream buffered with vegetation, which flows to Mandau as well. A total elevation of the site is about 20 meters high and 420 meters long, sloping to the south-east. However, the building part and paved areas will be flat by using an equal earthmoving technique (equal excavation and embankment) to provide flatness without a need to move surplus soil away or to bring suitable soil there. To be able to provide flatness only on the site, supporting walls have to be applied in order to manage different elevations, which might limit the use of some measures.

Fig. 42 – Diagram of the topography at the site with 2 meters contour lines - This diagram represents a topography at the site with 2 meters contour lines. This diagram help visualizes natural stormwater runoff based on the typography, including Hornojindřichov stream in the bottom of the site (Created by Author, original data are from Geoportal, 2015)

Furthermore, from a regional geological point of view, this site is situated in the Lagoon granite massif, which is made up of several types of granitoid rocks - the most widespread being the medium-grained granodiorite. In addition, the hydrogeological conditions are classified as 'hard rocks' (igneous rocks) in approximately 10 meters depth or more, which is characterized as the area with a relatively high underground runoff (5-11 l/s/km^2). Soil is composed of topsoil (0.2 – 0.4 m), sandy-loam soils (0.4-0.8), loam-clay soil below, a gravel part with stones (1.7 – 2.5 m) and then a hard rock horizon. Therefore, the soil provides good infiltration, however, deep infiltration that might enhance the groundwater (for wells) will probably not be reached. The amount of precipitation during the year including the average maximum and minimum temperature is presented in table (Figure 46) below.

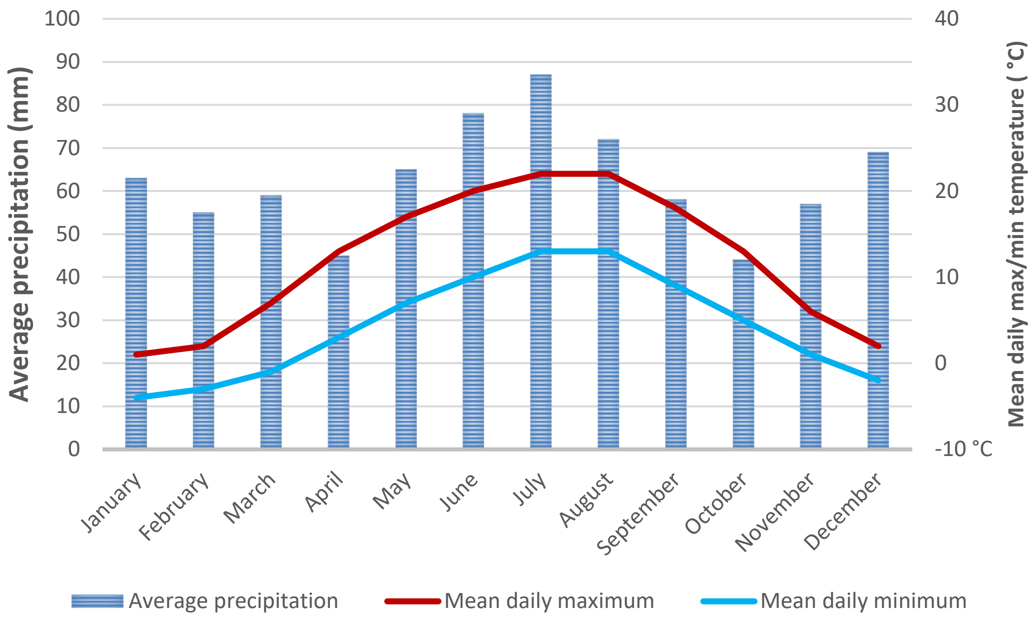

Figure 43 – Average total annual precipitation and mean daily temperature in 2017 - This table shows average total annual precipitation and mean daily maximum/minimum temperature in 2017. (created by Author, original data from https://www.meteoblue.com/)

Recommendations

Based on the above analysis, several environmentally-friendly measures are recommended. All measures respect the basic requirements for the parameters of the building, handling areas and parking lots as it was designed by Rota Group company. Therefore, the intention of the investor is not negatively affected by any recommended measure, even though it was often very limiting. For example, to preserve as many parking spaces as possible, or to respect designed “supporting walls”, which were used to support differences of landscaping and to keep them only on the site. In addition, landscaping changes and using supporting walls significantly affected natural behaviour of stormwater runoff. Moreover, limiting was also the high voltage network in the north part of the site and its protection zone (7 meters from the line) that were very limited for design, because no trees or water elements can be placed there. To increase the infiltration efficiency on site there was an intention to divide site into more fragments (please see Fig. 47 below).

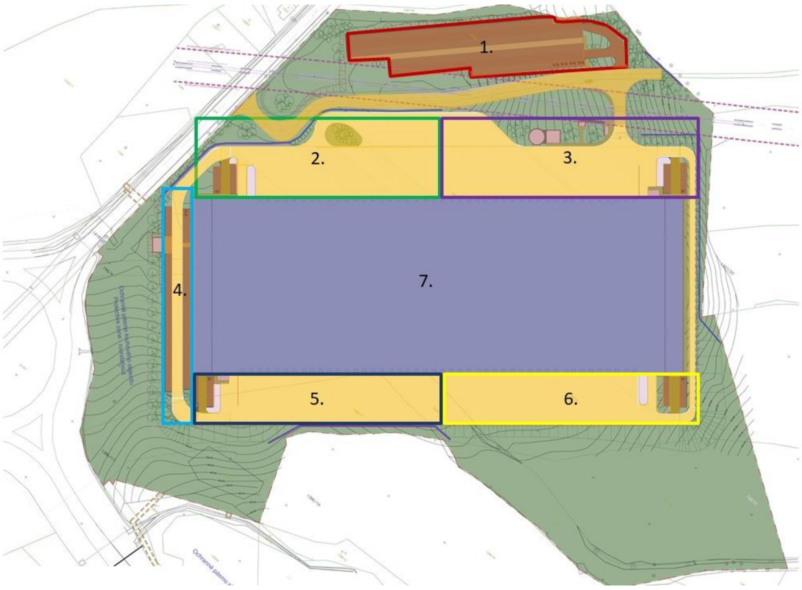

Fig. 44: Divided site into the more fragments - This diagram shows divided site into the more fragments to provide functional and efficient solution for the whole project. Moreover, it also recommends surface types – yellow are impermeable and brown permeable. In fact, large areas were kept with impermeable surfaces to protect underground water from any direct contaminated. (created by Author, original data from Rota Group)

The main intention was to slow and spread the stormwater runoff and maximize the efficiency of the infiltration on site, reduce the pollution of the stormwater runoff and increase local biodiversity. Therefore, the BMP measures are recommended (please see chapter 6) to reduce the impact on the small hydrological cycle. The key elements are oversized pipes, bioswales and infiltration basins, followed by an accumulation tank. Oversized pipes were selected according to limiting conditions due to large impermeable surfaces and supporting walls designed right next to them, which make it impossible to use different measures due to lack of space. To mitigate any direct contamination there using a separator of petroleum substances for the areas in front of docks (gates) right next to the warehouse are recommended where trucks park and wait until they are loaded/unloaded.

The fundamentals for infiltration are bioswales, rain gardens and an infiltration basin. Bioswales on the west side of the warehouse include dams due to steep terrain. This bioswale ends in an infiltration basin, which retains and infiltrates all stormwater runoff. It was intentionally placed in the south-west corner of the site to follow and enhance the local bio-corridor. For area number 6 the retention pond to collect the water from the right half of the building and surrounding areas was established. It is recommended to preserve access for interventions in case of a fire and to regulate flow with additional drainage (In the form of oversized pipes) connected to the local stream. For the large parking lot (area 1) permeable surfaces with bioswale in the middle ending in rain gardens are recommended. In cases of high pollution, it is recommended to apply a separator of petroleum substances.

It is also recommended to accumulate water for its secondary utilization. Thus, the accumulation tanks are recommended to place in the west from the warehouse (where the administrative part including toilets is placed), to minimalize costs for additional pipes from the accumulation tank, which are required. Retained water is possible to use for flushing toilets, watering the vegetation, cleaning, or for the purpose of the tenant as service water (in case of light manufacturing purposes). Investor expect that 500 employees will work there (460 in the warehouse part and 40 in administrative).

According to Rota Group, the considered consumption of water for mentioned purposes is 40 litres/day per person, which makes total consumption approximately 20,000 litres/day. Based on the calculations, four accumulation tanks with capacity of 50,000 litres per each should cover the main non-potable water consumption. The amount of rainwater was calculated for 13,000 sqm roof with the rainfall intensity (based on the region precipitation, considering regular 15 minutes rain) of 0.0164 $l/s/m^2$ and it is approx. 213 l/s. Therefore, tanks should be filled during 15-20 minutes of the regular rainfall. When tanks are full, the water is designed to drain into the bioswale and ends in the infiltration basin.

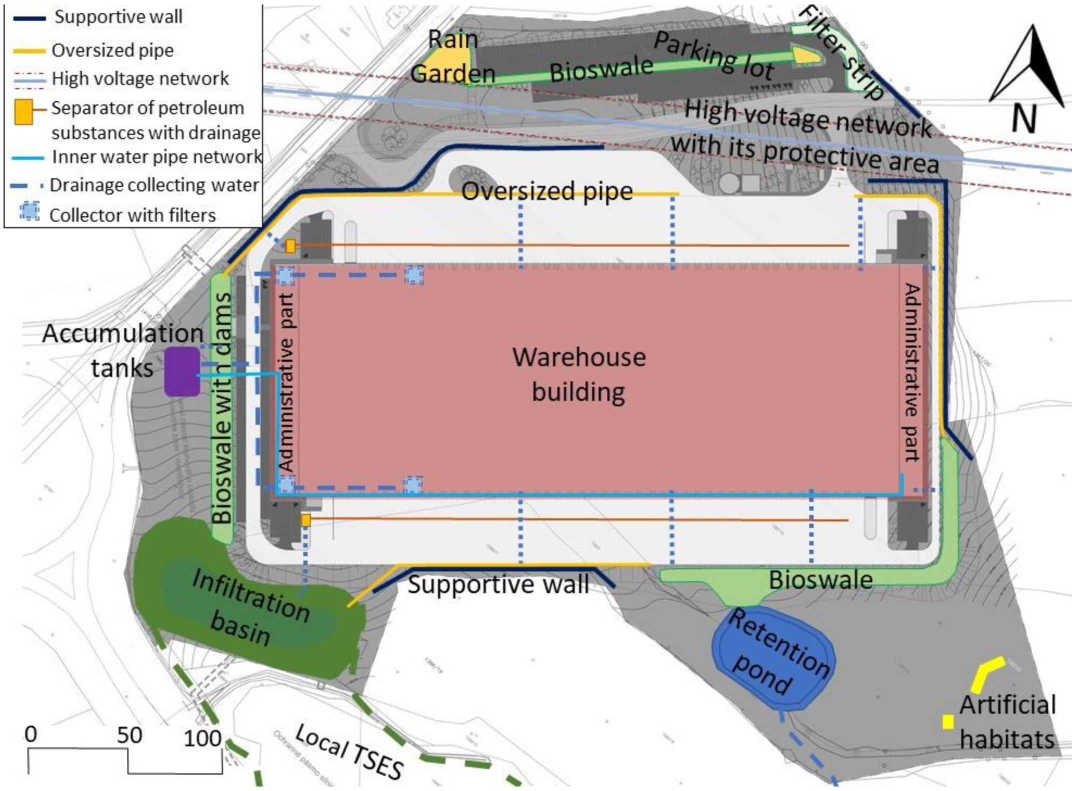

Fig. 45: Recommendations - Situational map – this diagram support above described recommendations, where the key intention was to harvest rainwater on site and provide efficient infiltration. Secondary, there are recommended accumulation tanks in order to lower the water consumption. (created by Author, original data from Rota Group)

8. Discussion

One of the key limitations was a fact that I have been an employee of the Accolade Group, which made difficult communication and cooperation with other development and investment companies, who did not want to provide me with specific data and information that I asked for. This conflict of interest represented an obligation with the owner of 'NewLogic II' (the state-of-the-art building in the Netherlands), who did not allow me visit their industrial facility, but I was at least provided by necessary information and materials by previous owner Dokvast. This protection of development strategies and additional information from competing companies is occurred phenomenon across many different industries, which in my point of view generally slows the evolution. However, there are still many people and companies (Prologis Company, Tesla Inc., etc.), who are not afraid to share information in order to improve new strategies, for example, to reduce the impact on the environment, which is the global task for everyone.

Similar issue occurred when selecting the Standard warehouse building in the Czech Republic. Many owners rejected cooperation that led to select a smaller sized warehouse building, however, all other requirements specifically for this case study were preserved. Further, the approach of selecting the state-of-the-art buildings based on the BREEAM certification rating score turned out as not very suitable. Even though both were assessed with the Outstanding rating (i.e. the most sustainable buildings), there were significant differences between them, which is caused by complexity of the BREEAM evaluation. Buildings are assessed with the overall rating scores based on the total score from individual sections. Therefore, a certain sustainable building can reach high total rating without having highest scores from each section, thus for example, accessibility or innovative technologies can compensate less attention to water management.

Nevertheless, the BREEAM certification is still one of the crucial motivators for investors to integrate sustainable measures to their projects, because it might bring several benefits such as higher property value, increased marketable image or reduced energy consumption, etc. In fact, the integration of sustainable measures to large-scale industrial buildings and potential secondary utilisation of rainwater is rather rare in the Czech Republic. The reason might be an insufficient return on the investment considering costs for secondary water network pipes to provide for example toilets with rainwater, costs for maintenance and low water consumption. This is the right opposite to, what is the most crucial for him - return on the investments and the profit. Thus, investors will probably never reduce the size of the building (i.e. his profit) for such measures, if it would not be required from the Master plan or local authorities (if it is within their competence). Therefore, if the investor will not be motivated or forced to change his perception about rainwater, he will probably use only the "surplus areas" instead of lawns only on suitable sites.

But what has to be changed in order to push investors to implement these kinds of measures? For example, in the Czech Republic several legislation frameworks that regulate rainwater management were already applied. The most fundamental is the Act. No. 254/2001 Coll. (called the Water Act), which in its fifth paragraph imposes to each builder the obligation to manage rainwater directly on its site by retention or infiltration, without that the builder should not be allowed to receive construction building approval infiltration (Act No. 254/2001 Coll.). However, builder can ask for the exception due to unsuitable hydrological conditions and get a permit to drain water by conventional methods, but in this case, he has to pay extra fees, which might be in case of large-scale warehouse very expensive.

Maybe better than to force them, might be better to motivate them or provide investors with subsidies from the government or the EU. In fact, the government announced the subsidy programme called Dešťovka (grant for rainwater treatment on site for family houses and public buildings) last year, through which they allocated over CZK 340 million (Development News, 3/2018). What is interesting that there was significant interest, because the grant was distributed within one day. Therefore, I believe that subsidies from the government for industrial buildings might be the right impulse for many investors/owners integrate rainwater and decentralized approach more often into their development strategies or already built facilities. The other option is to increase regulations and force more investors to treat rainwater only on their site. However, this approach might completely stop the development in some areas not suitable for infiltration, even though with high demand (from the municipality or government, tenant, or unemployment inhabitants, etc.).

Interesting fact for me was that some investors sometimes do not want to integrate such measure, because it would increase the local biodiversity. Even though it sounds ridiculous, it is because of fear that investor might not to obtain the positive expression for EIA (Environmental Impact Assessment) from the Department of the Environment. This is an obligatory part of the permitting process based on the Act No. 100/2001 (about EIA) in order to approve that the intention is not in the conflict with any endangered local fauna and flora. This concern is related especially for larger industrial centres, where by implementing some measures might stop the other development when some endangered species occurred on the site (then investor is not allowed to build there anything). But some companies use this to prevent competition companies from other development.

Nevertheless, I am afraid that investors often see decentralized alternative methods (instead of regular conveyance methods) as a threat instead of the opportunity, which might be caused by lack of knowledge or perceived difficult position for negotiation with local authorities during permit process. Moreover, I believe that the relationship between investor´s intention and local environmental condition should be balanced, when both sides can profit from that, not only one (investor) as it is now.

9. Conclusions

This diploma thesis's main aim was to affect current development strategies of large-scale warehouse facilities in order to reduce the impact on the environment, particularly on the hydrological cycle. The main focus was specifically on reducing the stormwater runoff and its efficient treatment on site. To achieve this goal, it was firstly necessary to define the fundamental concepts and facts that gave the reader a comprehensive overview of this issue. Subsequently, several innovative case studies were selected in order to verify how it is in practice. Based on selected case studies and the theoretical framework, the most frequent negative effects of large warehouses on the environment were identified. Afterward, several sustainable measures focusing primarily on green infrastructure and rainwater management techniques were also identified, and thus, how to treat rain water. Finally, the outcome of this thesis are recommendations of numerous mentioned measures for the project in Rumburk in the Czech Republic. Therefore, the objectives of the work were fulfilled.

This work can serve as an inspiration and a clear guide for development and investment companies that choose to integrate such measures into their projects, whether on the basis of their own initiative or being forced by local authorities. Although the main thesis focus was especially on large warehouse buildings, this work can be also applied for facilities with similar functional uses (e.g. for commercial centers). Likewise, it is possible to apply similar measures to differently sized objects, but it is advisable to proportionally modify the parameters of the given measures. This diploma thesis can be followed, for example, by a detailed proposal for rainwater management, an economic study with the total amount of costs and probable return on investment, or a proposal for a legislative framework changes or new naturally-friendly development strategies.

Globally, the variety of development strategies is very heterogenous due to different approaches and different perceptions of the environment. For example, in the Czech Republic, it is rare to see the utilisation of rain water for large-scale warehouse buildings. Nevertheless, there are a lot of sustainable buildings that harvest rain water to reduce the stormwater runoff and treat water on site. Furthermore, Best Management Practices (BMP) techniques can be applied on almost every scale – from a family house to large-scale building, depending especially on the site parameters and the effort to reduce the environmental impact. In fact, the effort of investors to support alternative / decentralized methods is a key factor because it is they who make decisions and cover the costs.

Nowadays, the most common motivation is a good sustainable building assessment score rating to have such sustainable certification. Secondary, may be requirements of the tenant, who usually has the power to ask for special requirements. Investors from different companies claim that in case of greater demand, these methods would be applied more often. Until then investors often prefer conventional methods, with whom they have rich experiences and which appear as easy to maintain and cannot surprise them. Therefore, it is necessary to convince (or to force) investors to prefer the decentralized approach instead of the conventional, even though decentralized methods do not provide immediate return on investment. However, there are several significant benefits and positive influences not only for the local environment, but also for the investor and the municipality, but their value is typically difficult to determine. Thus, I would like to close this thesis with the quote from Albert Einstein:

"Not everything that counts can be counted and not everything that is counted truly counts." Albert Einstein

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