City Roofs 2.0 – Making use of existing roofs to extend the urban green and user functions in the city

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ABSTRACT – City growth needs to be addressed within the city borders to preserve surrounding green areas and make use of urban facilities. Next to this, cities suffer from a severe lack of urban green. Existing flat roof surface can provide extra space for expansion of the green space in cities, as well as accommodating new user functions. In order to execute these building transformations several technical and structural aspects need to be taken into account, as well as local legislation. Both roof extensions and urban green will only flourish when applied on a big scale, which is why there’s a need for a generic roof structure to provide for new functions.

BACKGROUND

INTRODUCTION

Urban densification
Existing roofs are often poorly designed, if they are designed at all. Instead of functioning as the ‘fifth façade’, the roof is just considered the end of a building. However, these forgotten building surfaces provide an abundance of unused floor space in the city. Making use of this space can mean extra dwellings, office space, or other user functions, as well as an extension on the public realm and urban green. This approach is in sync with the current ideas of city growth. When multiple functions are solidly stacked and combined into a compact built environment, it becomes harder to provide the required space for new functions in case of city growth. This growth needs to be done within the city borders to prevent the surrounding green area from shrinking for example, which is especially relevant in the Netherlands. Expansion within the city enables the new user to make use of the existing infrastructure and facilities. This urban growth however, puts even more pressure on the available space in cities and rarely leaves room for green.

Amsterdam, Weesperstraat
The Weesperstraat in Amsterdam can be described as a wide urban axis with big, single building blocks. The street image changed completely after the post-war city planning in the 1960’s. The axis became one of the most important car routes to connect the north and south of Amsterdam, which now results in unacceptable fine dust levels on the spot and a neighbourhood barrier that’s unsafe to cross. The street hasn’t flourished ever since and needs to be refurnished. The street especially lacks qualitative public space and functions, mixed-use and urban green. (Stipo, 2011)

Lack of green
Not only the Weesperstraat, but cities in general deal with a severe lack of green. Urban green has numerous benefits, some of vital meaning for human health. Others provide climactic or social solutions. The city as dense ‘concrete jungle’ causes an overloaded sewer system, expels urban wildlife and increases human stress levels. Urban green improves urban conditions and helps restoring the balance between citizens and nature.

CITY ROOFS
Making use of existing roof surfaces as renewed building ground can be a helpful tool by expansion within the existing core. The city of Amsterdam contains an unused, flat roof surface by the size of 4,000 soccer fields (Leeuw, 2013). Most Weesperstraat buildings have flat roofs as well, in contrary with most of Amsterdam. The general lack of green in cities can, for the greater part, be solved on the roof as well. Green roofs are quite developed worldwide and have proven to be successful in many ways. A green roof is a way to give back the green surface that the building took away. Green roofs are often chosen for their quality of retaining storm water, but have numerous of other benefits. Not only greening roofs, but multiple ground use in case of rooftop architecture, are sustainable things to do. and sharing facilities is sustainable in the first place. Furthermore savings can be done in terms of money, material and energy and the city life will gain quality.

TECHNICAL ASSIGNMENT
Rooftops are not used or explored to their full extent. They’re a burden to the eye, have climatic disadvantages and run behind on innovation. Existing roofs can be transformed into an extensive or intensive green roof. Green roofs can play an important role in greening cities. In most cases roofs are not designed for this extra load, which limits the possibilities and asks for a smart solution.
Currently green roof solutions for existing buildings are more or less custom-made. Since the city only benefits from green roofs when applied on a big scale, there’s a need for a generic (green) roof system for existing buildings.

**APPROACH**

This paper is an observational study on the status quo in rooftop architecture and green roof technology. The goal is to design a flexible roof structure in combination with green, to place on top of existing buildings. This paper is written with help of several research methods. In the first place the experience of operating roof companies in the Netherlands is used. An interesting interaction with De Dakdokters in Amsterdam provided specific technical knowledge and information on what knowledge is missing in the field of green roofs. Second is literature from various books, professional journals and online research papers, to understand general (green) roof construction. Next to that, the analysis of inspiring reference projects delivered answers through creative, technical solutions. Finally, research by design helped to fit existing ideas into a new concept and technical design. At last, sustainable development is an obvious starting point for the paper as basics for this graduation project. This will be a leading motive when making design choices throughout.

**RESEARCH QUESTION**

This paper is based on the following research question. Together with sub-questions it provides the papers structure. The research question is as followed:

"How to develop a flexible, fast and affordable generic green roof structure for existing buildings in a sustainable way?"

This question is divided into five sub-questions, that will lead the chapters of this paper:

- How can a roof be used as a new building ground?
- What is needed for an intensive green roof structure?
- How to create an elementary roof system?
- How to make this economically attractive?
- How to make this in a sustainable way?

**CHAPTER 1 ROOFTOP ARCHITECTURE**

**1.1 URBAN STRATIFICATION**

Due to several factors, like growth of single households and world population in general, more space is needed in cities. The urban infrastructure and economy needs to grow along and the green areas outside the city are supposed to be preserved, which is why cities need to extend within the city borders. This asks for creative city planning in the future.

In the 1920’s a separation of functions was advocated by the CIAM community. First the heavy industry settled in suburban areas. In the 80’s and 90’s also enterprises and offices moved out of the city, to increase their accessibility and pay less for the ground. No other industries ever arose in the city after that. The city was no longer centre for society, more of a destination for passengers and tourists. The city collected its income from these tourists, which is part of the reason why our traditional facades are being preserved with so much care. This conservation can obstruct evolution of the built environment and along with that important developments in essential urban transformations. Also building on the roof, which can be part of these transformations, is not often permitted. Especially in the city centre of Amsterdam building on the roof can mean trouble with the aesthetics committee and other organisations (Schuiling & Mulder, 1994).

In 1956 the Hungarian-French architect Yona Friedman pleads for a continuously changing city. If the city doesn’t evolve constantly, its inhabitants will eventually leave it, is what he said. In his visionary designs he created a second ground floor level through a steel mega structure. This structure could be filled up systematically with living units, floors, walls and other functions, so unique spots could be created (fig. 1.1.1). Also Michael Sorkin (in Variations on a themepark, 1993) and Rem Koolhaas (in Generic City, 1995) share this idea of constant urban transformation. These theories on the flexibility of the city focused on providing for changing needs of the city inhabitant. Making use of city roofs might provide this flexibility, so adding an extra urban layer has high potential, although it’s challenging.

Successful cities are characterized by an abundance of possibilities and various activities. Diversity and complexity are key terms for this success, however in contrast with what CIAM pleaded for. It’s comparable to systems of nature, also in nature complex systems proved to have a bigger chance of survival than unambiguous ones. Innovation partly arises from chaos that’s fed by new streams of information. This is why it’s impossible to predict innovation, but yet a climate in which innovation can happen can be created. This climate is always somewhere between order and chaos. On an urban level, this is where formal city-planning meets our spontaneous society. This could explain our preference for flexible spots like old warehouses or other industrial complexes. This is where a variety of multifunctional hybrids are set up, places that become more scarce with the rise of Vinex areas for example. This is another reason for reconsidering a roof landscape, a new way of making a spontaneous built environment, in order to create a
more informal and creative city. (Melet & Vreedenburgh, 2005)

1.2 EXISTING ROOFS
The existing roof surface could be an interesting place to build and design, in the first place because there’s a lot of it. A rough estimation for the city of The Hague shows that only 2.3 percent of the existing flat roof surface is needed to create 3600 new dwellings (surface of 500,000 m²). Building on roofs in the Netherlands is difficult for a number of reasons. First, there’s a need for use of lightweight building structures, which is unusual for the Netherlands. Designing the internal traffic of the new function is challenging as well, especially when this needs to be done autonomously. Furthermore the building owner is usually not favouring a redesign of the roof by another party. The new build roof function also has to follow up the more strict legislation for newly build buildings, even when the building below is (way) older. (Melet & Vreedenburgh, 2005)

1.3 NEW FUNCTIONS ON TOP
Using the roof as a second ground floor can deliver rooftop architecture or an extension of the green surface in cities for example. This can lift up the image of the building below, or even the entire neighbourhood. Below two inspiring precedents are shown to picture this potential.

1.3.1 High Line, New York (2004-2009)
The High Line is a result of the collaboration between James Corner Field Operations (project lead), Diller Scofidio + Renfro and planting designer Piet Oudolf. It’s a transformed historic freight rail line, elevated above the streets on Manhattan’s West Side, owned by the city of New York (figure 1.3.1). Maintenance and operation of the High Line is done by Friends of the High Line that was founded in 1999, out of the conviction that the highline should be preserved.

Highline is an extremely popular park for inhabitants and visitors to withdraw from the city into a green oasis still without leaving the city centre. (Friends of the High Line, n.d.) The transformation of the High Line is an example of creating a green, public function within the city. The existing structure of the elevated rail track has an over capacity, so no structural problems occurred. However, the way this initiative became such a success is unique and shows what qualitative contribution a green space can make in the city.

1.3.2 Lighthouses, Groningen (2004)
In 2003-2004 DAAD Architecten designed a cluster of lightweight houses on top of an existing building block in Groningen. Columns were punched through the old building to carry the lightweight timber frame constructions. All houses have their own access route, independent from the building below. A new ground level arose on the roof (see figure 1.3.2). (Vries & Teeuw, 2007) This example shows an extraordinary structural solution, by adding an autonomous structure through the existing building. Depending on the possibilities the underlying building has to offer, this option strongly widens the possibility for roof architecture. It also shows the increase in value of the building ground in the centre of Groningen.

1.4 OBSTRACTING FACTORS
Despite the proven success of green roofs and rooftop architecture, only a small number of roofs is transformed. Constructing rooftop architecture means dealing with challenges on technical, social and political levels. Investors, that are interested in short term profits, need to be convinced of this sustainable concept and more research need to be done on the costs that are involved when making a green roof. (Snodgrass & McIntyre, 2010)
1.4.1 Ownership
The owner of a building automatically owns the roof and everything that arises above that. This is one of the reasons why it’s mostly impossible to treat roof surfaces as new building ground. These rules can only be changed in development plans for new buildings, in which regulations can force new owners to (partly) green their roofs for example. A golden mean for existing buildings could be to rent roofs to new ‘owners’ that will use the roof for a different function. This is done in Germany, where in 2003 about 14% of all flat roofs were greened (Castleton, Stovin, Beck, & Davison, 2010). When a building owner rents its roof to someone that wants to exploit solar panels for instance, they can agree on splitting the profit. This approach requires free minds and clear, long-term contracts. (Leeuw, 2013)

1.4.2 Mass production
Cities will only benefit from green roofs when applied on a big scale. Only in Amsterdam an unused flat roof surface of about 4,000 soccer fields is available, which shows the huge space potential for this city. Due to highly splintered ownership a mass solution is hard to achieve. The municipality subsidizing small scale projects is a way to stimulate this fragmented market of potential roof renovators. The municipality of Amsterdam does have an extended vision on sustainable, multifunctional use of both new and existing roofs. This vision is called MaxDak and focusses on energy, use and green, water and ecology. (Gemeente Amsterdam, 2011b)

1.4.3 Building permits
Binding prescriptions coming from Building Regulations Act. are often obstructing revolutionary building plans of any kind. In the field of renovation and transformation too (especially in the case of monumental buildings) this is often a tight restriction. National building regulations (in Dutch: Bouwbesluit) set an obligatory set of rules concerning e.g. fire safety or maximum heights. This is a quite developed regulation body to secure safe buildings. However, creating a highly consistent set of rules doesn’t leave much room for the interpretation of the architect.

1.4.4 Aesthetics committee
Creating an extra layer on an existing building can be obstructed by rules fixed by the local aesthetic committee. In some cases, including Amsterdam, entire city parts even have a protected view, which is why building toppings are likely to be rejected. (Groenen, 1995) The entire Grachtengordel in Amsterdam is on the UNESCO world heritage list since 2010, which means that none of these buildings is permit free. Owners need to request an environmental permit in case they want to change their property. Every plan is considered by Bureau Monumenten en Archeologie (BMA) and Commissie van Welstand en Monumenten (CWM), based on a ‘Waardenkaart’ (value map), made in 1999. This map shows the architectural value for the city view, of every building from before 1940. (Gemeente Amsterdam, 2011a)

1.4.5 Development plans
City densification plans need to stroke with existing governmental development plans concerning property ownership. These plans fix certain rules, like alignment of buildings and maximum heights of nibs and roof gutters, which can clearly obstruct rooftop architecture. (Groenen, 1995)

1.4.6 Money and investment
Green roofs are generally more expensive than conventional roofs. First of all, the construction of a green roof in terms of materials and man-hours is more costly. Second is the required maintenance resulting in an increased amount of working hours. This factor can be turned around when the roof contains one or more exploitable functions. This will turn the rooftop into a full-fledged ground floor level that adds value to the urban life. Maintenance won’t only serve the roof, but will be done for the same reasons as on normal street level. A green roof is a long-term investment. Normal rooftops need to be replaced twice as soon as green roofs that protect the roof membrane.

1.5 SOLUTIONS
In extension on the previous section, three possible solution are given below.

1.5.1 Roof renting
When the owner of the roof topping is not the same owner as the mother building, it might be possible to come up with a roof renting solution, as mentioned in paragraph 1.4.1.

1.5.2 Progressive city planning
Roof renting solutions don’t change the regulations regarding roof topping. In order to respect the existing rules, without exiling every creative renovation operation, two main options are given. First, regulations can be liberalized, considered some rules are based on nostalgic feelings and obsolete views and could use some change. In order to give cities room for growth, this needs to be taken into account. The second option is to extend the permit body by writing a progressive growing plan, in supplement to existing plans that protect special buildings (Groenen, 1995). A planning in dense city growth needs to be worked out in order to determine the opportunities and threats of rooftop architecture.

1.5.3 Realistic restrictions
New rooftop functions depend on the mother building, for example when it comes to accessibility and escaping routes. However, new rooftop architecture is treated as new built constructions, which means much stricter building regulations apply for this part than for the building below. This can directly result in denied building plans. This is quite unrealistic since the mother building is the weakest link in fire safety for example. In order to really consider rooftop architecture, this should be liberalized in the existing building regulation act. (Groenen, 1995)
CHAPTER 2 ROOF TECHNOLOGY

Focussing on the extension of urban space through usage of rooftops, this paper discusses flat roofs only.

2.1 ROOF BASICS

2.1.1 Roof functions and forms

As part of the outer skin of a building, the roof fulfils a number of functions. The most essential one is to provide shelter from weather conditions like rain, sun and wind. Roofs also prevent other people from looking in, providing privacy. Roofs are part of the building structure, conducting the various loads to the foundation through walls and columns. Next to this, most roofs have a strong aesthetic function as well. Appearance is an important criterion when a roof or roof material is chosen. Obviously this is more relevant for roofs in plain sight, then for (flat) roofs that are not meant to be seen. For the structure of the roof, the chosen method and materials are ought to fit the project in terms of production and detailing. For example, prefabricated steel constructions are no commonly used for private houses. Local traditions are another reason for the emergence of different roof shapes, like the shallow-pitched roofs in alpine regions. Mostly these shapes can directly be related to the local weather conditions. Even building functions can dictate the shape of the roof, like a vaulted barrel roof that follows the track of a tennis ball in tennis court halls.

In order to avoid leakage a simple structure is the best choice. Combining different roof types and shapes usually results in complicated roof details. (Brotrück, 2007)

2.1.2 Roof loads

Four types of roof loads can be distinguished (figure 2.1.1). The dead load is the only permanently active force, caused by the weight of the roof itself. The imposed load is one of the live loads, which means it’s temporary, moving or has a short duration. Also the snow and ice load is a live load, caused by storm water that remains on the roof and temporarily causes extra load. Finally the wind load, that either pushes the roof surface or pulls under suction. This is therefore the only force with a variable working direction.

2.1.3 Flat roofs

Any roof with a pitch of max 5° can be called a flat roof. In case of flat roofs the wind load needs extra attention, regarding the low weight of most waterproofing materials that are placed on top. Potential lifting or movement of these materials needs to be prevented. The waterproofing in general is very different from pitched roofs that drain the water quite easily through their shape. Other moistures, like condensation, must be able to get out of the construction at all times. (Brotrück, 2007) In case of flat roofs the use of underlying rooms or functions needs to be considered, as well as the function on the roof itself.

2.2 FLAT ROOFS

This section describes the general anatomy of common flat roofs. Flat roofs can be constructed in different ways and deal different with storm water drainage. The structural requirements describe what needs to be taken into account when new rooftop architecture is made.

2.2.1 Flat roof construction

Every roof has a support structure to carry the roof membrane. Support structures can be made of stony materials, like concrete. In case of aerated concrete only prefab elements are used. To flatten this surface a concrete topping is poured over, which can be the water slope at the same time. Timber support structures are used for smaller buildings and often have an additional, secondary beam structure to carry the roof membrane. In case of profiled metal decking, the steel plates are mostly used in combination with a steel skeleton. Profiled steel plates vary in thickness and size and need protection from erosion. Other roof elements are prefab sandwich elements, which are a combination of load bearing structure and thermal insulation. The sandwich construction provides stiffness and the elements can be supplied with a watertight layer for example. The roof membrane on top of the support structure consists of a vapour barrier/watertight layer, thermal insulation and a roof topping including a ballast layer. Three types of roofing should be distinguished: the traditional non-ventilated roof, reversed roof and non-insulated roof. A non-ventilated roof is the most common roof type. The support structure remains ‘warm’ because the insulation layer is placed on top of the vapour barrier and roof construction (figure 2.1.1). With a reversed roof the insulation layer is placed on top of the water tight layer, instead of underneath it (figure 2.2.2). In this case the specific insulation material is used that handles pressures and doesn’t absorb water. Choosing for this system requires good detailing in insulation. A non-insulated roof is the same, but without an insulation layer. This is related to the (lack of) need for insulation by the expected functions beneath that roof. The vapour barrier is applied underneath the thermal insulation to prevent water vapour from infiltrating the insulation.
2.2.2 Structural requirements

Depending on the intended load on the roof, four different load levels can be distinguished describing the degree in which a roof is accessible for people: low, limited, normal and high load. Walking on flat roofs with a low load level is impossible, mostly because of the delicate, soft insulation on top. Roofs with a normal load level are accessible for people and high load level roofs can handle vehicles or other heavy pieces. When roofs are walkable extra facilities should be incorporated, like safety fences and stepping stones at least.

Wind load is elaborately described in building permit acts, since wind causes the most damage to roofs. This often has to do with defective connections or support structures. This permit also provides calculation rules for the wind load on roofs. For this calculation the roof surface is divided in zones that are differently affected by the wind: corners (c), edges (r) and normal zones (t). When calculating the wind load for roofs with toppings or added structures like elevator shafts, other rules apply. Also green roofs are sensitive to wind in a different way (see section 2.3). (Hout et al., 2005)

2.2.3 Flat roof drainage system (Kessel, n.d.)

Green roofs can absorb and evaporate rain water, which is convenient for the city sewer system in particular. Depending on the thickness of the substrate layer up to 80% of the rain water can be buffered. Chapter 3 will further elaborate on the capacities of green roofs. When it comes to fire safety most flat roofs largely conform to the fire prevention rules for roofs. These rules prescribe no fire can originate when so called flying sparks hit the roof, which won’t happen with gravel or concrete toppings. Exceptional roof openings need extra attention, just like glass roof parts and green roofs. New built roofs are required to have an RC-value of 2,5 m² * K/W. The RC-value of existing roofs needs to be at least preserved and can never be lower than 1,33. When the relative humidity of air becomes 100% condensation can occur. This happening within a building construction is called internal condensation. Rectifying moisture inside the construction can be done through ventilation with the open air, but this needs to be avoided to minimize heat losses. If the construction can dry up yearly condensation doesn’t have to be bad. If not, accumulated moist will eventually cause problems. (Hout et al., 2005)

2.2.4 Roof use

Adding a function on top of the roof (making it accessible), is rarely problematic from a technical point of view. However, the water tightness of the roof needs to be safeguarded during the roof renovation. Interventions on the roof usually include roof perforations in order to connect to the load bearing structure. Making the roof watertight again needs extra attention. More about this is discussed in section 2.4. (Hout et al., 2005)

2.3 GREEN ROOF SYSTEM

This section describes the consequences of building a green roof in practical terms like the installation. Chapter
3 will elaborate on the anatomy of green roofs furthermore and explaining what green roofs can do for the city and the user for example.

Green roofs are built for numerous reasons. Two types can be distinguished: intensive green roofs have a relatively thin substrate layer with low-maintenance vegetation. Intensive green roofs on the other hand need to be regularly maintained.

**2.3.1 Installation of green roofs**

Green roofs can be applied on an existing building or be part of the initial building design. Since most existing roof structures aren’t designed to carry the extra load, this makes a big difference in possibilities.

Green roof packs are delicately connected to the roof structure, which is why interruptions of the package are not desirable. Roof openings like roof lights, the elevator shaft or chimneys can best be clustered and, if possible, lifted from the roof surface a little bit, so the green roof pack can be installed around it.

![Option A](image)

![Option B](image)

2.3.1 Option B is the best option: island of roof perforations (Hout et al., 2005)

The roof membrane needs protection from the vegetation roots, which is why a root proof layer is necessary. Next a drainage layer is installed, in the first place to get rid of the excess water, but this layer can also contain a water buffer function. To drain the excess water successfully the earlier mentioned roof slope of 1.6% is crucial. This slope has to be built properly in order to drain the water towards the drains. These excess drains (figure 2.2.3) need to be cleaned every season. Next is the filter layer, filtering the smaller parts that otherwise would have clogged the drainage system. This layer too needs to be installed meticulously with an overlap of 100mm and extended up to the top of the substrate layers at the roof edges. On top comes the substrate layer, or growing medium, providing nutrition for the plants and other vegetation. This substrate differs from ordinary soil, which has proven to degenerate over time when exposed to roof conditions. This is why the soil needs to be pre-treated with organic and mineral matter. Some substrates can’t be walked over when they’re wet, because irreversible compression can be the result.

When planting trees a thick substrate layer (about 1000mm) is required. Obviously this leads to extreme extra loads, which can mean an increase in costs both if it’s even technically possible. Another aspect is the needed anchoring in thinner substrate layers, to make sure high vegetation won’t suffer too much from the wind. At last the humidification of the garden that can be important to achieve the desired growing quality. The watering can be done manually and automatic. (SBR, 2007)

### 2.3.2 Structural consequences

Application of a green roof structure means the imposed load will increase, in the first place the growing medium and the green itself. When calculating the total roof load this needs to be taken into account. Depending on the kind of substrate and green, the following rough classification can be made for different (fully saturated) green roofs:

<table>
<thead>
<tr>
<th>Green roof system</th>
<th>Thickness (cm)</th>
<th>Weight (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedum</td>
<td>2 – 6</td>
<td>10 – 60</td>
</tr>
<tr>
<td>Extensive</td>
<td>6 – 20</td>
<td>60 – 150</td>
</tr>
<tr>
<td>Semi-intensive</td>
<td>12 – 25</td>
<td>120 – 200</td>
</tr>
<tr>
<td>Intensive/rooftop garden</td>
<td>15 – 40</td>
<td>180 – 500</td>
</tr>
</tbody>
</table>

Table 3.4.1 Comparison of different green roof systems (British Flora, n.d.)

### 2.3.3 Maintenance of green roofs

The intensity of maintenance can differ strongly per green roof. It not only depends on the type of roof or the way it has been installed, but also the type of vegetation that is chosen for the design. For big roof gardens (without a lawn) the maintenance differs between 8 till 26 days per year. (SBR, 2007)

### 2.3.4 Sustainable system

In order to create a sustainable green roof system the materials that are used for the system need to be taken into account. This requires a concise study on the lifecycle of different materials used for green roof systems. (Bianchini & Hewage, 2011)

#### 2.4 CONNECTIONS

In order to investigate how rooftop architecture can be made, this section will concisely describe several reference projects. Multiple roof topping projects has been done for housing projects in the past, especially to make more efficient use of the ground. The biggest difficulty is the limited extra capacity of most existing foundations.

### 4.2.1 Connecting old and new

For toppings, small support feet can be placed on the load bearing walls of the underlying building. Beams on top of this feet span the dwelling units at once. This approach spares the existing roof structure for the bigger part, since the new topping is lifted from it. However, the support feet still need to penetrate the roof membrane to be placed on the construction walls. Figure 2.4.1 gives a detail for a topping for the Elementumflats in Maassluis where the same strategy is used. In the bottom the existing building part is shown, including the load bearing wall and the roof pack (support structure, slope shape, insulation and topping). The dotted line indicates the support foot on which a steel beam is placed that carries the new construction. In this particular case concrete
hollow-core slabs could be used, however in most cases lighter materials are used. (Debets, 2003)

2.4.2 Light weight construction
Within the specific project in Maassluis quite heavy hollowcore slabs could be used as construction material, because the foundation of the building allowed some extra weight. However, in most cases lighter materials need to be used, like timber frame or steel frame structures. Another option is aerated concrete: prefab concrete elements with a relative low weight and fair insulation properties. Prefab is favourable for a quick assembly of the topping. This was applied with the topping of an apartment building on Melis Stokelaan in The Hague (figure 2.4.2). This block built in 1958 escaped demolition; because of its royal floor plans it was worth keeping the complex, after which it was extensively renovated with an addition of 36 new dwellings. (Crone, 2001)

Another example is the apartment block for the elderly (Eikenhorst te Lisse). The building foundation and structure was sufficient to carry an extra layer with 32 new senior dwellings, provided that the topping would be performed in lightweight material. A timber frame construction was chosen, except for the ends of the building where the brick walls were prolonged to the (new) rooftop. Adjustment rails of 12x12cm were put on the existing roofs, on which the new lightweight, prefabricated building units were positioned. (figure 2.4.3) (Gordijn, 1996)

2.4.3 Topping structure
The substructure connecting the existing building to the new rooftop provides freedom of design, for example to create a crawling space. This space makes it possible to do maintenance on the existing roof afterwards, but also provide room for pipes and tubes and outlet of the building below. When the span range of the existing structure doesn’t match the desired span for the topping a substructure is a solution as well. With a secondary structure a new, smaller subgrid can be created, which leaves the construction weight as the only real uncertain variable.

A way to provide complete freedom is to build an autonomous topping structure that is build over the existing building. Maritime Hotel (used to be Zeemanshuis) in Rotterdam expanded this way in 2001 and three years later once again, executed by BIAS architects, Rotterdam. Both the foundation and building structure wouldn’t allow extra load, so the toppings required an autonomous support system. In both cases a steel box with stiff connections (simulated slabs) on supporting legs was placed tightly over the existing building (figure 2.4.4). The beams are dimensioned quite usefully because of the need for a stiff connection in the entire construction. For the second topping a table construction was impossible, because the adjacent building is against the Maritime Hotel building on the
opposite side. The plan was to use this concrete wall as the opposite stiff slab and incorporate this in the construction. It turned out this wall wasn’t made out of concrete as was assumed, which asked for a substitute solution. Another steel ‘slab’ was made and placed against that wall, of which only one column was prolonged penetrating the entire building to the foundation. (Wind, 2004)

extra elevator shaft next to the building. This however, is a more expensive solution that will only be feasible if existing users in the building can use it as well, or it can be covered in new renting prices.

CHAPTER 3 GREEN ROOFS

3.1 GREEN ROOFS TERMINOLOGY
Green roofs are applied for various reasons and are designed in different ways. Green roofs can be subdivided into extensive and intensive green roofs. Technical definitions for these two kinds are lacking, but an extensive green roof can be described as quite simple, light weighted and thinner in profile. As mentioned before this type doesn’t require a lot of maintenance. Mostly the maximum depth is about 15 centimetres, filled with a mineral-based growing medium that grows simple sedums or other drought-resistant plants. In Germany, the pioneering country for green roofs, 80 percent of the green roofs are extensive. Intensive roofs are deeper, filled with more organic material and grow all kinds of plants and even trees. Roof gardens for example are intensive. Extensive green roof seem less helpful, but are a good choice. Compared to their costs in both production and maintenance, they usually have the greatest return on investment in both economic and ecological terms. Especially built on a bigger scale in the city these green roofs can achieve significant energy savings, storm water management and contribute to the quality of urban life. (Snodgrass & McIntyre, 2010) Intensive roofs are usually built to fulfil a bigger variety of functions, like roof gardens, public spaces and growing vegetables. It’s therefore quite hard to compare the two. The focus of this design project on the extension of urban space and urban green, implies an accessible roof garden rather than an extensive green roof.

3.2 URBAN BENEFITS
Green roofs have a lot of benefits for the city in terms of energy, water, biodiversity and human health. In this section the most important ones will be concisely described (taken into account that the application of green roofs is not done in an atmosphere with extreme weather conditions like the desert or very cold places). Next to the climatic benefits of green, also the positive effects of green roofs on social cohesion, human health and economy are discussed.

3.2.1 Storm water management
In rainy periods storm water runs off buildings and roads, carrying pollutants like fertilizers, oil and grease, or salts and acid drainage. This runoff water contaminates surface waters like rivers or canals, what especially will affect aquatic life, reducing the fish population or insect diversity. The increased amount of runoff water during heavy storms causes an overloaded sewer system, that will then discharge the surplus of water into the surface waters. Runoff water is only problematic if it’s unable to infiltrate the land. This is why rough earth or land slows down the water flow into surface waters. In that case the water is absorbed by the land, which rebalances groundwater levels, the rest of the water will evaporate.
during dryer periods. Due to an increased paved surface the runoff water exceeds the control system’s capacity. Water treatment systems get overloaded which results in a discharge of mixed sewage and storm water into local surface waters. Green roofs can play a significant role in preventing these problems, by providing soil platforms that are capable of both water absorption as well as evaporation. Depending on the thickness of the absorbing layer, the climate of the specific roof location and the average amount of rainfall, green roofs can easily capture about 50% of the annual rain fall. Furthermore, the water that does come off a green roof is cleaner, due to the filtering effect of plants and medium. Managing storm water in cities through green roofs is quite proven and therefore the main driver of green roof construction worldwide. (Snodgrass & McIntyre, 2010)

### 3.2.2 Lifespan roof membrane
Conventional flat roofs have been covered with bitumen as long as flat roofs exist. It’s distilled from raw petroleum, just like gasoline and diesel and show similarities with tar. It’s popular for its usefulness, in the first place its watertight properties. It gets liquid when its heated which is why it can adapt to unorthodox roof shapes and sticks easily to itself and other materials (Eurobitume, n.d.). When not protected by a layer of gravel or external roof insulation, the roof bitumen is directly exposed to the sun. UV light will make the bitumen brittle over time, which makes that roof layers need replacement every 15 to 20 years, though most buildings are designed to last for two till three times longer. The dark colour of the bitumen will enhance this decreasing effect and will also makes a bitumen roof an unpleasant spot to stay on a hot summer day. Green roofs don’t have these problems. Membranes protected by a green layer are expected to last twice as long, about thirty to forty years.

### 3.2.3 Mitigation urban heat island effect
Referring to the previous paragraph the increased roof temperatures also affects the city temperature. The heated paved surfaces on buildings slowly release solar radiation, which will heat up the city. This is called the urban heat island effect, which can cause a temperature raise of 4 to 8°C in urban areas, compared to rural areas. A linear relationship was found between the percentage of green roof surface and reduced sound pressure, with a maximum reduction of 10 decibel. Increasing the substrate depth would increase the sound reduction effect too, but after 10-15 centimetres a further deepening is useless. (Rowe, 2010)

### 3.2.4 Noise reduction
Being exposed to noise in cities, mostly produced by traffic streams, can cause serious health problems like hearing issues that lead to isolation, or hypertension. In 2008 the effect of extensive and intensive green roofs on noise reduction was studied by Van Renterghem and Van Botteldooren. A linear relationship was found between the percentage of grown roof surface and reduced sound pressure.

### 3.2.5 Stimulating biodiversity
Although it’s likely to say that an increase of green roofs will have a positive effect on biodiversity, a lack of data on this complex subject makes it impossible to provide concrete figures information. There is no question about the ability of plants to attract certain insects, bees or birds. However, it’s not always clear whether these specific plants are capable of growing on a roof medium for example. What a green roof tends to do is in fact restoring the original biodiversity, since the grown city took this present piece of nature away. This connects to the idea of applying native plants on green roofs, to attract local urban wildlife. However, since successful examples in different regions aren’t relevant anymore, this can be even more time consuming and difficult than with a wider plant range. Mimicking the natural environment for urban wildlife is like building a complex nature system. This needs to be done well-considered and with care, based on differing knowledge. (Snodgrass & McIntyre, 2010)

### 3.2.6 Human health
In prehistoric times our bodies reacted to stressful situations only occasionally when dangerous, life threatening events occurred for example. The stress we were experiencing as part of our survival mode is a natural, healthy feature. It temporarily increases our adrenaline level and therefore our alertness, which help us to survive (figure 3.2.2). When things went back to normal our stress level would drop back to the basic,
healthy level (between the green lines), so our body would have time to restore. Nowadays we deal with so-called modern stress. Stress occurs on a lower level, though it’s there constantly. The things on our mind concerning work, relationships, money and expectations are more complex than back in the days and occupy our mind all day. Our current stress levels are therefore constantly on a higher level than what’s considered healthy, without finding the time or environment to recover. This continuous stress has proven to be harmful for all vital organs. Being under stress for an unacceptable period of time without having the chance to recover, makes the reactions the human body shows dysfunctional. Sometimes with the result of deleterious effects on the body causing type II diabetes, depression and infections. Also mental disorders like schizophrenia, anxiety, exhaustion and fatigue syndromes can be directly related to an excess of stress (Grahn & Stigsdotter, 2009).

It appears that the urban environment as ‘concrete jungle’ enhances this negative effects for two reasons. In the first place there’s overstimulation. Depending on the specific city a certain visual complexity, amount of noise, movement and intensity will burden our system. Second is that urban environments don’t provide the possibility to restore our attention. According to the Attention Restoration Theory (ART) people can concentrate better after spending time in nature. Research shows that green urban spaces in the urban environment should in the first place provide nature, richness in species and refuge or shelter. This indicates the urge of city inhabitants to look for the most restorative environments. (Grahn & Stigsdotter, 2009) (Voeten, 2013)

3.2.7 Social green

Green urban spaces like parks, green lanes and community gardens brings people together. These leisure spots provide the opportunity to relax and meet friends for example. People prefer to live in a green area, flourishing neighbourhoods are to be found more attractive for establishment of enterprises and therefore, as discussed in the following paragraph, the value of with green surrounded real estate is generally higher. As Germann-Chiari and Seeland describe, social structures in dense cities are often based on the differences between minorities. Social segregation is often responsible for tensions, what is is also what creates ghettos for example. Recreation, wellbeing and intercultural activities can enhance mutual understanding and therefore resolve conflicts and offer the opportunity for various ethnic groups to come to terms with each other. They plead for a new development in which green areas will be mobilised by urban planners to create a platform for social encounter. (Germann-Chiari & Seeland, 2002)

3.2.8 Use, aesthetics and marketing

As mentioned in the paragraphs above green roofs provide a cooler space in summer, compared to paved city surfaces. Therefore green roofs are valuable as amenity spaces, for example for the people that live or work in the same building, or nearby. Depending on the load capacities even an extensive green roof can sometimes contain a simple roof spot with a patio for example, to be reached by stepping stones. (Snodgrass & McIntyre, 2010)

Since 2012 an outside space for every new-built dwelling was reintroduced as an obligated feature for Dutch buildings after the Building Regulations Program of 2003 cancelled it. An outside space was reconsidered as indispensable space for people to connect with their environment. (BRIS Bouwbesluit Online, 2012) However, most buildings arose in times when this wasn’t mandatory yet, which is why different rules go for renovated buildings. Numerous buildings remain without outside space, despite its proven function. The roof may provide a solution afterwards in these cases, so older buildings will be equipped with an outside space for its workers or inhabitants as well.

Next to this a lower positioned green roof will provide an attractive view for the inhabitants or workers in the higher floors of adjacent buildings. This green perspective can, as mentioned earlier, contribute to a better mental health. In that case green roofs will contribute in a positive way to the urban aesthetics. (Snodgrass & McIntyre, 2010)

All these contributing factors have already proven to cause a rise in value of the building below and to a lesser extend the buildings nearby. Property value will rise as soon as green facilities are available in the neighbourhood, the closer the better. In case of a private green roof a green facility will be provided only for the building user, not for the people that only have a view on this roof. This can be a reason for developers or owners to green their roofs. Next to this, more concrete yield can be recognized in growing food on roofs. This roof can either raise direct profit or save money for the owner of a private garden, that’ll spend less money on healthy food. Also earlier mentioned climatic benefits like retaining storm water and saving on air conditioning costs will lead directly to money savings. (Tomalty & Komorowski, 2010)

3.3 ANATOMY OF INTENSIVE GREEN ROOFS

Green roofs have a comparable set-up, as shown in figure 3.3.1, concisely described below.

1. Plants and seed mix. Depending on the type of roof and expected function different seeds are planted.
2. Growing medium. The substrate layer contains matter
that differs from ordinary soil. It’s composed out of mineral aggregates and small amounts of organic material and gets less muddy when it gets wet.

3. Filter fabric. This fabric prevents small matter in the substrate from polluting or clogging the drainage system.

4. Drainage layer. This layer discharges the excess water coming through the substrate layer. This water can be collected in a rain water buffer that’s used to water the vegetated roof in dry periods.

5. Root protection layer. This layer prevents vegetation roots from damaging the roof membrane causing leakages.

6-9. Existing roof pack. This is (an example of) an existing roof structure of an existing building.

3.3.1 Anatomy of green roof (Goodman, n.d.)

Every of those layers can differ per case, depending on the allowed extra weight, the chosen vegetation for the designed roof and the desired functions of the drainage layer.

DISCUSSION

This paper handled a set of different topics that are all relevant for the design phase that comes next. Not only (the relevance of) urban stratification and rooftop architecture as a solution for that, but also the technical sides of both general roof technology and green roofs.

Important results

At first, there are different ways to construct rooftop architecture. As shown in section 2.4 not all topping renovations are technically possible, since the foundation isn’t always sufficient. In some cases an autonomous structure is built around the existing building, like with the Maritime Hotel in Rotterdam. This is more expensive, though it offers a lot of freedom in design. For the design phase this means two things. First, the boundary conditions of the chosen building are a leading factor for the feasibility of a roof topping. Depending on my resources this can be either sorted out by a professional structural engineer, or an assumption for the design phase can be made. Second, it also depends on the aimed design whether an autonomous structure is needed. A multiple storeys design will result in extra load, compared to a single topping layer. If the desired design result is more important, an autonomous structure might be the best solution.

Another thing, coming out of researching precedents, is the success of executed projects. It’s reasonable to say there are a fair number of obstructing factors as described in section 1.4, but those ideas that came through mostly give good examples of the added value coming from rooftop architecture. This confirms the idea that rooftop architecture in the city can be quite relevant. The High Line in New York shows, like several other successful roof parks, how much a dissociated green spots in cities are appreciated, not only for the scientific reasons described in section 3.2. Putting the benefits of urban green into order showed a certain desperation in the need for change. The lack of green jeopardizes the quality of life in cities, it’s relevant to highlight these findings.

At last, the collected body of knowledge on basic roof technology was essential in preparation of a roof design. The crucial elements of flat roofs are clear now and can be taken into account. Further research will be necessary as soon as I go deeper into the subject.

Sustainable development

Creating rooftop architecture means multiple ground use, which is a sustainable initiative in the first place. This goes for green roofs as well. However, also the fabrication of the structure in terms of materials and assembly needs to be done in a sustainable way. This includes at least a basic lifecycle analysis, that has to be done when design choices need to be made. This might be interesting, since the choice of material doesn’t seem to be the first requirement to live up to when it comes to rooftop architecture. Other aspects like designing a sufficient structure, are more difficult and thus leading. For the green roof part on the other hand, a sustainable, fast and affordable system can be designed, in answer to the research question. Sustainable design goes without saying and is quite an elaborate topic on itself. It’s therefore not treated in this paper, but can be expected to be influencing the design choices.

Design phase

For the specific design assignment one building on the Weesperstraat will be extended with a rooftop architecture design including an extension on the urban green of Amsterdam. This building and redesign will be part of a fictive master plan, prescribing for the Weesperstraat to become the green axis of Amsterdam. This roof design will be lifted from the existing building, to create designers freedom and will consist of a structure that can be filled with an exploitable user function. This idea is strongly based on the concepts by Yona Friedman, described in section 1.1, but to a lesser extent on the urban scale. To emphasize the power of this 3d concept, a multiple storey design would be more powerful. The new function will be designed in combination with green areas. This green can serve different goals, like growing vegetables, a mini park or private gardens, which will depend on the final user function.
LITERATURE


Leeuw, D. d. (2013, 12th of December). [Consult existing roof structure with De Dakdokters].