URBAN SOIL ASSESSMENT: LIMITING NEGATIVE ENVIRONMENTAL IMPACTS AND OPTIMISING ECOLOGICAL BENEFITS OF URBAN SOIL TRANSFORMATIONS.

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Track 6 : The resilient city

ABSTRACT

Keywords : *soil, pollution, environmental impacts, urban transformation*

In the context of the rehabilitation of former industrial districts into mixed-use neighbourhoods to meet the city’s current needs and to avoid urban sprawl, building typology changing, soil unsealing and revegetation are displayed as goals by the public authorities. These soil transformations aim to improve quality of life and city resilience (reducing heat island effects, decreasing flood risks, …). However, these transformations are also facing challenges, like soil pollution, high division of private ownership and densification pressure.

This paper presents a methodology to analyse and estimate, both at large scale and at small scale, the positive and negative impacts of soil transformations and the links between authorities' objectives and on-field operationalisation. This methodology calls upon different disciplines, such as urbanism, hydrogeology and pedology, to allow a decompartmentalised analysis of soils in the urban system. The case of the Heyvaert District in Brussels, Belgium, is studied, as this district is facing issues that can be found in many European cities: pollution coming from its industrial past, increasing flood risks and heat waves due to climate change.

At larger scale, this paper proposes a systemic perspective highlighting the interrelations and interconnections between the built environment, the soil and the underlying subsoil. This three-dimensional approach enables the reconceptualisation of urban soils based on these interrelations, highlighting the ecological opportunities or the critical impacts of soil transformations.

At the scale of the parcel/block, the integration of detailed data concerning soil contamination, mixed use of the buildings, protection of heritage buildings and infiltration potential allows the expression of global objectives into applied mechanisms leading to the achievement of those objectives. This analysis highlights levers and obstacles to an environmentally friendly urban soil transformation.

In Heyvaert case, the articulation of the visions based on these two scales enlightens authorities' decisions up to their application.

INTRODUCTION

In the context of the ecological transition, the issue of urban soil is of prime importance. The current urban model leads to a significant soil consumption. In Europe, even if it tends to slightly decrease, the artificialisation of soil still reached 711km^2 per year on average between 2012 and 2018 (European Environment Agency, 2019). This annual soil consumption represents more than four times the size of the whole Brussels Region (Institut Bruxellois de Statistique et d'Analyse, 2019).

Why is soil so important?

The increasing concern about this trend stems from the nonrenewable nature of soil (Mantziaras & Viganò, 2016, p. 23; Cavalieri, 2019, p. 105; Groupement d'intérêt scientifique sur les sols, 2011) and the many ecosystem functions performed by the soil (Mantziaras & Viganò, 2016, p. 23; Cavalieri, 2019, p. 105; Groupement d'intérêt scientifique sur les sols, 2011). These functions are indeed essential for humans and non-humans living in urban environment and will be even more crucial to face climate change.

European and global policies

In response to this challenge, global and European initiatives have emerged. The year 2015 has been declared the "international year of soil" by the United Nations (World Soil Day and International Year of Soils, 2013) and the EU Soil Strategy for 2030 aims to enforce by this year (2023) measurable and monitored national and local targets for reducing land take by 2030 in the EU member states (European Commission, 2021). This strategy also confirms the goal of "no net land take" by 2050, previously set by the "Roadmap to a Resource Efficient Europe"(European Commission, 2011).

Soil strategies in Belgium

Belgium is no exception to this renewed awareness of the crucial role of soil and the need to preserve and restore it. The slogans 'Stop Béton' and 'Bouwshift' represent this trend (Labo XX+I, 2021, p. 98), which is reflected in various regional policies, which will be detailed further.

A methodology to assess urban soils

However, the goals of these policies are facing various obstacles. The first one is the condition of the soil in a city with a strong industrial history. Soil pollution is significant in Brussels, which makes it necessary to carry out major soil remediation before any transformation or soil unsealing. These remediation operations are far from having a neutral environmental impact (Grifoni et al., 2022; Hou & Al-Tabbaa, 2014; Song et al., 2019).

The implementation of soil (and water) remediation – as well as the transformation of the city in a soil protection and restoration perspective more generally – also faces many other obstacles, the main ones being:

- The current use (and/or the future one) of the parcels which impacts directly on the objectives of the treatment, depending on the affectation's sensibility : housing is a very sensitive affectation needing a high treatment of the contamination but industry is a less sensitive one tolerating a low treatment;
- The heterogeneity of parcels' shapes and of private land ownership which prevents the treatment of pollution spots that are located on several cadastral parcels;
- The high density of buildings and their morphology which impacts the accessibility to the totality of the contaminated soil or water;
- The discrepancy between urbanistic and environmental laws;

- *The unknown underground of the city: old underground buildings and pipes, other overlaid contamination, …;*
- *The power of the real estate market that allows the full treatment of well-placed districts but also makes contaminated less-attractive parcels unsaleable.*

This paper focuses on the 4 first obstacles listed above and therefore proposes a methodology to better assess the environmental benefits of soil unsealing as well as the constraints related to soil remediation and its operational limitations.

UNDERSTANDING THE COMPLEXITY OF THE SOIL QUESTION

The awareness of the necessity to take soil into consideration is developing in the field of urbanism (Barcelloni Corte & Boivin, 2022; Vialle, 2021; Viganò & Guenat, 2022). However, current public policies often struggle to consider soil as a living and complex space, limiting their outlook on soil to a technical support function. In this section, we will describe the concepts used in this article, as well as the different disciplinary knowledge related to the urban soil and underground.

Soil and soil sealing

Soil is defined by the thin layer – from a few centimetres to a few metres – which lies beneath our feet. It is characterised by the interaction of the earth, the atmosphere and the living (Peleman et al., 2022, p. 9) and is in fact shaped by this interaction and by the living organisms that compose it (Darwin, 1881; Protasoni, 2022, p. 23). Soil is therefore a dynamic element, in constant transformation (Vialle, 2022, p. 117), whose genesis is very slow (Mantziaras & Viganò, 2016, p. 23), which makes it a non-renewable resource on a human timescale (Cavalieri, 2019, p. 105; Groupement d'intérêt scientifique sur les sols, 2011).

Soil sealing represents a dramatic degradation of the soil functions (Tobias et al., 2018). The dysfunction of the water cycle regulation role of the soil can cause flooding, droughts, heat island effects and pollution of ground and surface water (European Environment Agency, 2021; Mantziaras & Viganò, 2016; Poelmans et al., 2010; Tobias et al., 2018). It also endangered the groundwater recharge capacity and the underground role of drinking water reservoir (De Bondt, 2017). The functions of soil threatened by soil sealing are not limited to the water cycle: productive functions (food or biomass), capacity to host biodiversity and greenhouse gas regulation functions are, among others, also compromised (European Commission & European Soil Bureau, 2005; Groupement d'intérêt scientifique sur les sols, 2011; Hazelton et al., 2009; Pataki et al., 2006; Poelmans et al., 2010; Vialle, 2021).

Unsealing constraints

Soil unsealing (and regeneration) is therefore a key transformation to achieve more resilient cities able to face climate change consequences. However, side effects of soil unsealing in cities with a strong industrial past and large amounts of polluted soil can be significant. The risks of contaminants dispersion increase the more the soil is permeable and the more the geological strata allows infiltration (Foster et al., 2013; Machiwal et al., 2018; Palmer & Lewis, 1998). Soil remediation is therefore fundamental when unsealing contaminated soils. However, soil remediation can generate important greenhouse gas emissions, massive energy consumption and waste production, and represent huge costs (Grifoni et al., 2022; Hou & Al-Tabbaa, 2014; Song et al., 2019).

These issues have led to the emergence of 'risk-based land management' or 'green remediation' movements that advocate a better balance between the impacts of remediation and its environmental and social benefits (Grifoni et al., 2022; Hou & Al-Tabbaa, 2014; Pedron & Petruzzelli, 2011; Song et al., 2019). This perspective results in a deeper understanding of the risks generated by contamination and the behaviour of these contaminants, as the dispersion of contaminants is highly influenced many factors, as soil cover and geological strata permeability (Foster et al., 2013; Palmer & Lewis, 1998).

Unsealing benefits

On the other hand, the benefits of soil unsealing also vary according to the geological structures. The water infiltration potential depends on the underlying geological composition, thus impacting the groundwater recharge capacity as well as the flood risk (De Bondt, 2017). These geological strata are classified by hydrogeologists according to their permeability, ranging from permeable aquifers to impermeable aquicludes (Bruxelles Environnement, 2020b). The hydrogeological properties are also defined by the vertical location of the geological strata : for example, an unconfined groundwater system can be recharged by rainwater, unlike a confined aquifer that can't be reached by rainwater, due to an overlying impermeable stratum (Peeters, 2010).

Underground constructions

In urban context, hydrogeology is also greatly affected by the numerous underground infrastructures. These constructions modify the flow of groundwater, its quality, and its temperature (Attard et al., 2017). Their impact on groundwater flows can cause drops or rises in water table levels near these underground infrastructures, which can cause pressure on these constructions or even their flooding (Attard et al., 2017). To deal with these groundwater issues, underground constructions rely on different techniques, such as ballasting and waterproofing or groundwater drainage (Attard et al., 2016).

The groundwater disruption caused by underground infrastructures also increases the risk of contaminants dispersion. Impermeable underground structures lead to the diversion of water flows and can result in the dissemination of contaminants near the structure, while drainage installations of underground structures can result in the dispersion of contaminants on a large scale (Attard et al., 2017). In addition to these indirect effects, there is also the risk of pollution by the materials used in these underground constructions themselves, which can dissolve over time and lead to contamination (Chae et al., 2008).

Operationalisation obstacles

We are therefore looking at a complex system, made of interactions between soil cover, soil contamination, geological strata and underground constructions. Furthermore, obstacles of operationalisation also need to be tackled. Indeed, multiple factors have to be considered to effectively enable urban soil transformation, including the parcel size and shape, the accessibility to a soil needing remediation, the different possibilities of remediation technology (ADEME & BRGM, 2013), but also the treatment objective (total cancellation or risk handling), the soil's characteristics (permeability, structure, density, organic matter) and the contamination characteristics (type of contaminant, concentration, depth, degradation byproducts,…).

BRUSSELS' SOIL STRATEGY AND THE CASE OF THE HEYVAERT DISTRICT

The methodology presented in this paper is based on the case study of the Brussels-Capital Region. In a multiscalar approach, the district of Heyvaert is selected as a smaller-scale case study, and some urban blocks of this district are also studied in more detail.

Brussels' soil strategies and tools

The case study of the Brussels-Capital Region is particularly interesting given the renewed interest in the question of soils in the Region. A strategy specific to the soil is being implemented, the 'Good Soil' strategy (Centre d'Ecologie Urbaine et al., 2020), which aims to preserve, improve and gather knowledge on urban soils. It led, among other things, to the implementation of soil quality monitoring tools (Bruxelles Environnement, 2021c, 2021b). Other tools relative to the soil have also been implemented by the Brussels Region environmental agency, Bruxelles Environnement. The InfiltraSoil tool (Bruxelles Environnement, 2022b) allows citizens and professionals to visualise water infiltration rules, flood risk, water table depth and other data related to water infiltration at the parcel level. To better understand the geological structure of Brussels – and therefore its geothermal potential – BruGeoTool (Bruxelles Environnement, 2022a) displays three-dimensional views and virtual drillings of the underground structures.

The regional regulations are also evolving by imposing a greater proportion of unbuilt and unsealed soil in new projects or in projects of building transformation (*Projet de Règlement Régional d'Urbanisme (RRU)*, 2022). This new regulation imposes a minimum of 30% of unbuilt surface, and at least 75% of this unbuilt surface should be unsealed and vegetalised. This regulation also provides for differentiated soil permeability goals within the urban blocks. The built-up street front is preserved, and stricter rules are applied to the inner part of the blocks, where unsealed and vegetated spaces should be the norm[1].

Heyvaert district and its master plan (PAD)

The master plans (Plans d'Aménagement Directeurs, PAD) also give an important place to green spaces and seek to preserve and restore soils (perspective.Brussels, 2019). The Heyvaert master plan aims to transform this old industrial neighbourhood in the west of the centre of Brussels, along its canal. In the course of the 19th and 20th centuries, the extension of the canal and the modernisation and relocation of the Slaughterhouse in the marshy valley of the Senne reinforced the industrial specialisation of the area. During this period, the high number of diverse industries and the importance of the working-class population generate a very high density of mixed-used buildings. The area was known as "the little Manchester".

The Heyvaert district master plan (PAD) aims to accompany the transformation of the Heyvaert district by reaffirming the anchoring of the productive function in a mixed district while improving the quality of life of its inhabitants. Its primary objective is therefore to encourage and support the creation and maintenance of productive activities that are better integrated into the urban context, while controlling the impact on the other functions of the district.

A second objective is to requalify and extend the existing public space while enhancing the remarkable character of its industrial buildings and the presence of the Canal. This is reflected in the

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[1] According to the regulation (*Projet de Règlement Régional d'Urbanisme (RRU)*, 2022), the inner part of urban blocks start beyond 37 metres from the street front. A minimum of 70% of unbuilt is fixed and 90% of the unbuild should be unsealed and vegetalised.

creation of a network of permeable public spaces that emphasise the identified landscape features. This development aims at a more balanced sharing of the space between all users (perspective.Brussels, 2019).

Linked to these 2 major objectives, a list of 9 "principles of quality" has been defined to analyse the real-estate projects. Among those 9 principles:

- Contribution to the circular economy : maintenance and renovation of buildings, re-use of materials, renewable resources;
- Sustainability of the project : water management, energy production, flexible structures;
- Specific qualities of the unsealed areas : vegetation, paving,…
- Contextual morphologies : industrial typology, fine urban fabric or emergence with connection to the neighbour.

Given these often conflicting objectives, a methodology to assess impacts, benefits and obstacles to soil transformation seems necessary. The ambition of this paper is to fill this gap between the available soil data and knowledge, and the planification and transformation process.

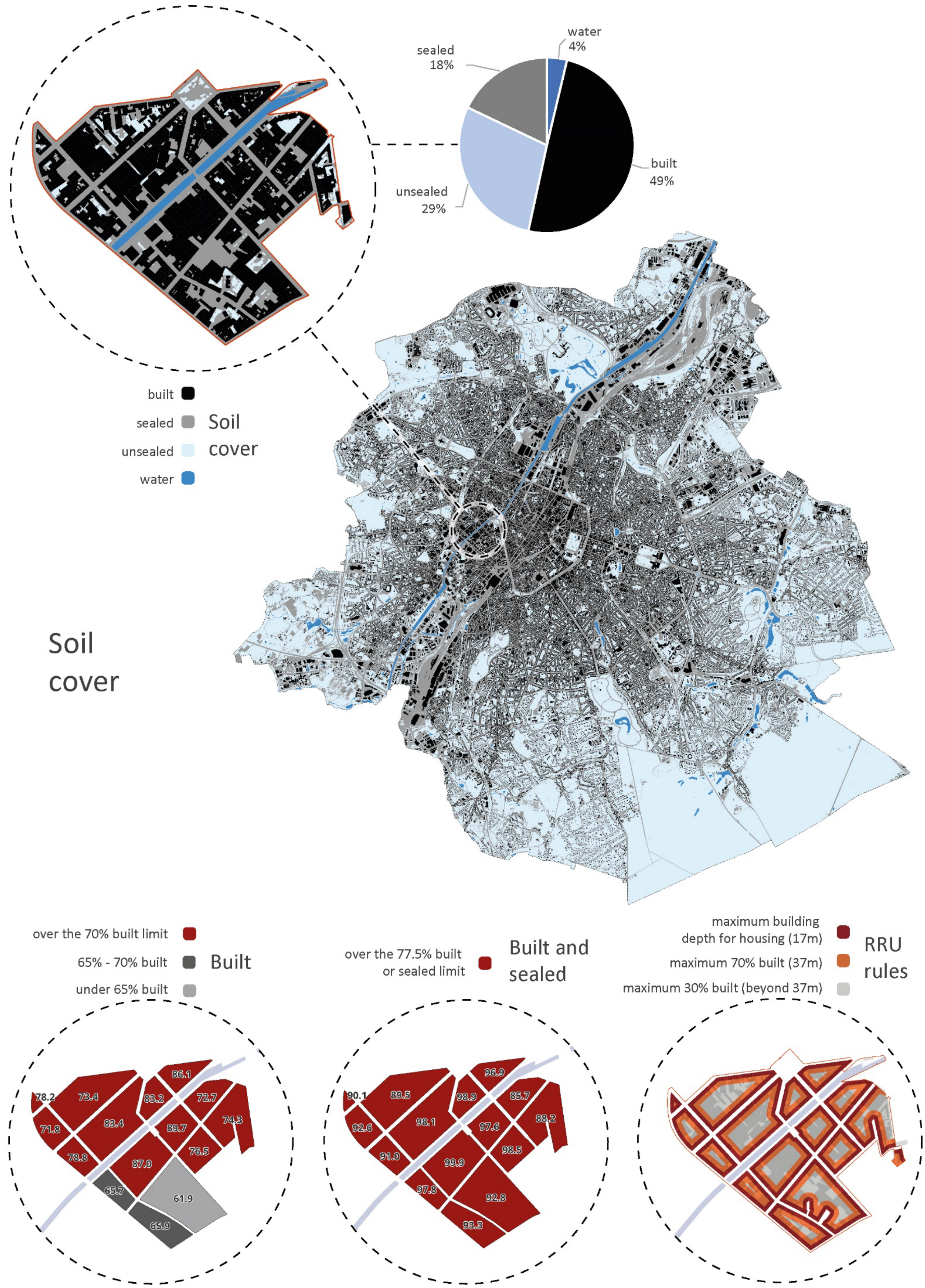
ASSESSMENT OF URBAN SOIL TRANSFORMATION

A. Soil transformation evaluation at macro scale

Soil cover and the goals of soil permeability and revegetation

European goals and the following objectives fixed by the Brussels-Capital Region presented previously are ambitious and aim at a drastic reduction of soil consumption as well as the requalification of soil in urban environments. A first analysis therefore evaluates the Heyvaert District according to its soil cover (Bossard & Cavalieri, 2023).

As in many dense areas of large cities, the proportion of soil covered by buildings is very high in Heyvaert District [fig. 1]. Most of the urban blocks exceed the 70% limit for built-up areas set by the new regulations in Brussels (*Projet de Règlement Régional d'Urbanisme (RRU)*, 2022). Concerning unsealed soil, the district condition is even further away from the objectives : most urban blocks are under 10% of unsealed soil. On the whole district area – thus taking into account the roads and the public domain - 91% of the soil is sealed or built-up and only 5% is permeable, the remaining 4% being the water of the canal.



[fig. 1] Soil cover

Soil and the constraints on soil transformation

Reaching the stated regional goals aiming to improve the city's resilience therefore implies a major transformation of dense urban districts such as the Heyvaert District.

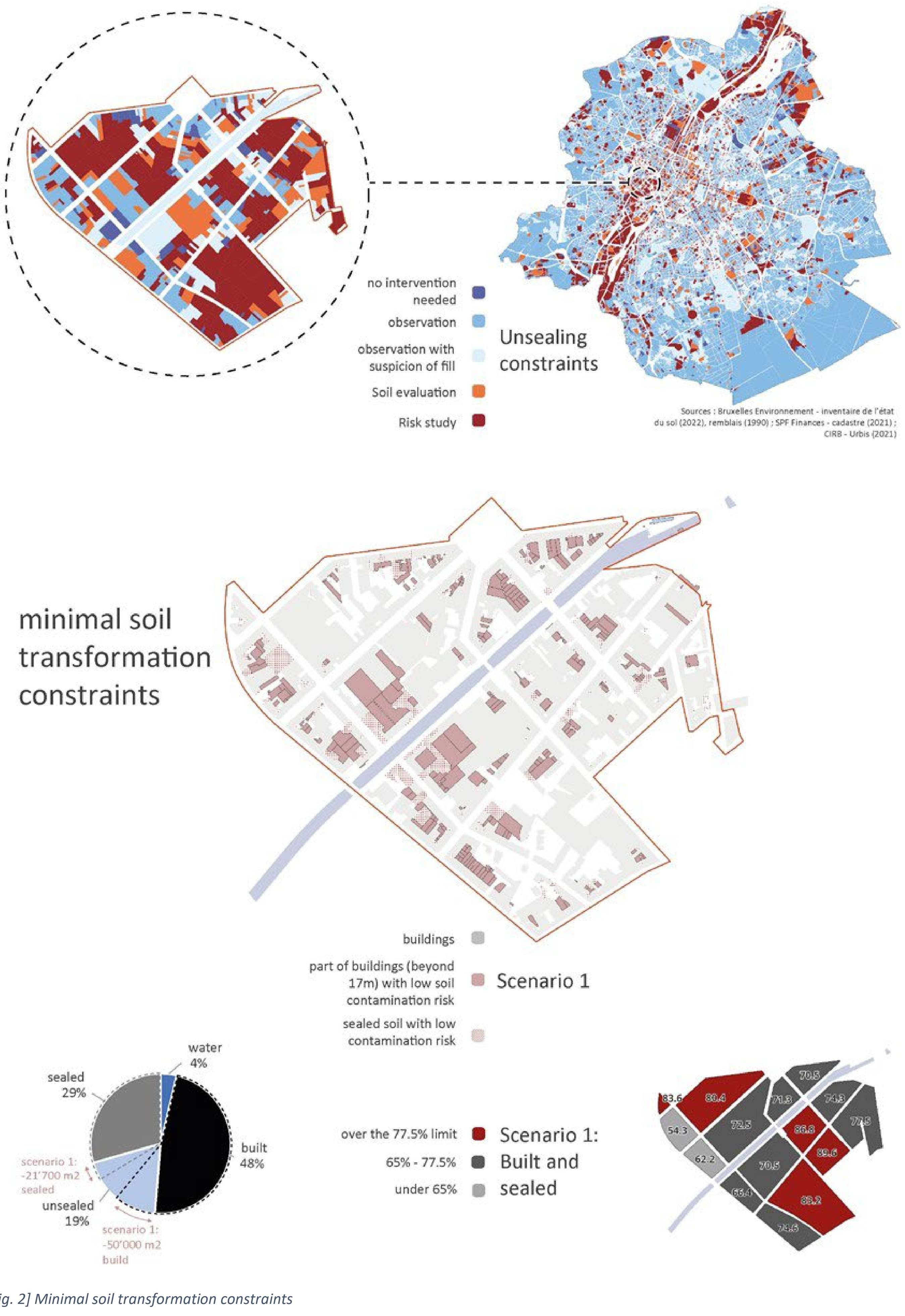
A mapping of the unsealing constraints related to soil contamination has been carried out [fig. 2, top] (Bossard & Cavalieri, 2023). This map is based on the required process related to soil contamination (Bruxelles Environnement, 2010, 2021a) for each parcel and on the probability of discovering contamination on parcels that are not yet documented. The first category (1) includes parcels that have been studied where no contamination has been detected or which have already been remediated. No intervention is therefore necessary for these parcels. The next two categories (2-3) contain parcels where no pollution evaluation has been carried out and where only an observation of the terrain for potential sources of pollution - for example an oil tank or buried construction wastes - is required. The difference between these two categories is the presence of artificial backfill in the second case – the topography has been changed by earthworks and construction wastes could have been used for these modifications – which increases the probability of pollution. The penultimate category (4) includes parcels where potentially polluting activities have taken place - for example a chemical warehouse or a vehicle maintenance workshop (Bruxelles Environnement, 2023) - and where the probability of pollution is consequently high. Parcels where contaminants have been discovered fall into the last category (5). This pollution may present a risk and require remediation, or may not present a risk as long as restrictions are applied, such as maintaining a sealed soil or prohibiting vegetable gardens (Bruxelles Environnement, 2021a; Région Bruxelles-Capitale, 2018).

A first scenario: increasing unbuilt and unsealed soil with minimal soil constraints

Based on these data, what would happen if soil contamination was considered in the transformation of the Heyvaert district? In order to answer this question, a first scenario was built: a transformation of the district aiming to increase the unsealed soils while presenting as few soil-related constraints as possible, thus limit the side effects of remediation (CO2 emissions, waste exports, import of good quality soils…). This scenario also has the advantage of unsealing the 'best' soils in the district, the least polluted ones.

This first scenario therefore proposes to increase the amount of unbuilt and unsealed soils in priority in parcels where the risk of pollution is low, i.e. parcels in the first three categories presented above. The goal of this scenario is to decrease the built and sealed soil under the limits fixed by the Brussels urban planning regulations of 77.5% (*Projet de Règlement Régional d'Urbanisme (RRU)*, 2022).

The following plan [fig. 2, centre] shows in red all the parts of buildings located on parcels with a low pollution risk and beyond 17 metres from the street front, which is the maximum depth for residential buildings set by Brussels' regulation. The red dotted surfaces represent the unbuilt but sealed soils located within parcels with low pollution risks. If all the buildings shown in red were demolished and all the sealed soil in doted red was unsealed, the proportion of built-up and sealed soil would fall below the limits of the Brussels urban planning. Over the whole district, the built surface would represent 48% instead of 57%, and the permeable area would reach 19%, which is almost four times more than in the current situation. This could be achieved with a very limited negative environmental impact related to soil remediation.



[fig. 2] Minimal soil transformation constraints

Infiltration potential and benefits of soil unsealing

Until now, only the soil transformation constrains where explored, but the benefits of soil unsealing also need to be assessed.

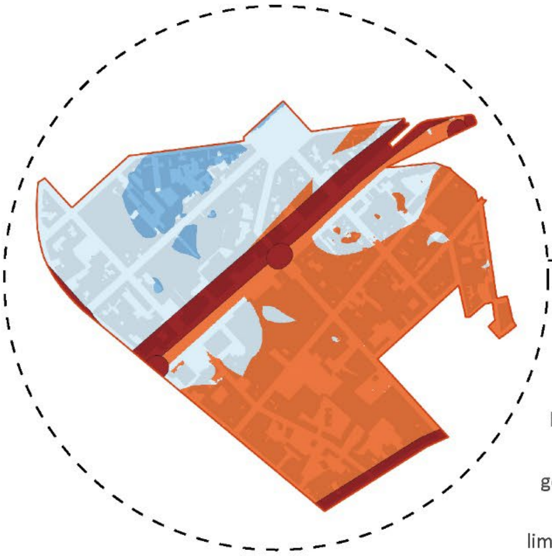
The rainwater infiltration potential of soil does not only depend on soil cover, but is also influenced by the geological structure underneath the soil and the water table level. Indeed, shallow impermeable geological strata limit infiltration. Similarly, a shallow water table also limits infiltration, as the soil and supporting strata are already waterlogged.

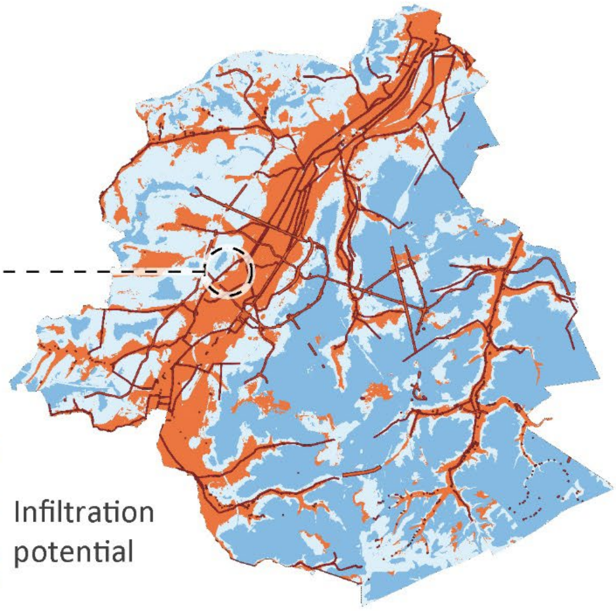
A map summarising the geological infiltration potential has therefore been constructed (Bossard & Cavalieri, 2023). It is based firstly on geological data (Bruxelles Environnement, 2020a) : a shallow impermeable geological layer limits the infiltration potential, but a deep permeable layer increase this infiltration potential. The proximity of the water table (Agniel, 2019) was also added to the model. Finally, the proximity of major underground infrastructure is also studied, given the disruption of the water cycle caused by these constructions.

A second scenario: optimizing infiltration

Based on the infiltration potential, a second scenario [fig. 3, centre] was constructed. Given the impacts of water cycle dysfunctions in Brussels - such as flooding and water pollution - the objective of this scenario is to test how far the optimisation of infiltration can go without exaggeratedly impacting the existing building stock. This scenario therefore goes beyond the unsealed soil proportion fixed by the Brussels urban planning regulations.

The scenario prioritises unsealing where the infiltration potential is the highest. In these areas, the unsealing is generalised beyond 17 metres from the street front – according to the limit fixed by the regional regulation for residential buildings (*Projet de Règlement Régional d'Urbanisme (RRU)*, 2022) – even if these surfaces are built. The benefits of restoring the water cycle where infiltration potential is the highest is considered here to outweigh the impacts of demolition. Where infiltration potential is still good, unsealing is taking place in the inner part of the urban blocks, defined by the regional regulation as the area beyond 37 metres from street front. Finally, unsealing of the unbuilt but sealed soil is generalised across the district. This scenario results in a 6-fold increase in unsealed surfaces, mainly where infiltration potential is high, while maintaining 86% of the current built surface.



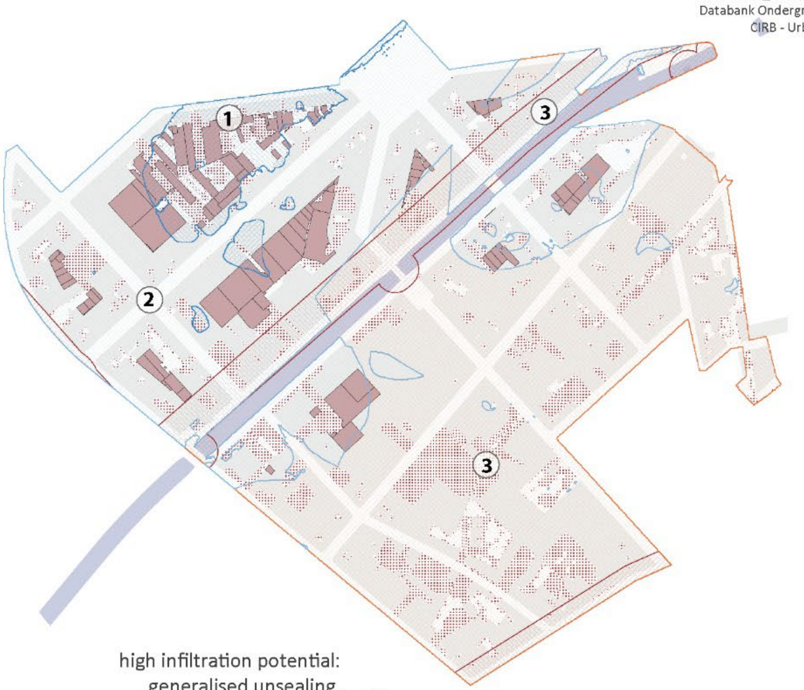


high infiltration potential
good infiltration potential
limited infiltration potential
close to an underground infrastructure (25m)

Infiltration potential

Sources : Bruxelles Environnement - BruStrati3D (2018), Brussels Phreatic System Model (2019), remblais (1990), Exploitations souterraines (1990), River_cover (2022), Collectoren_AED (2020) ; BruFlow - Bassins d'orage (2020) ; Databank Onderground Vlaanderen - Geology stratigraphy ; CIRB - Urbis (2021) ; SPF Finances - cadastre (2021)

optimising infiltration



high infiltration potential: generalised unsealing, max. 17m built depth (1)

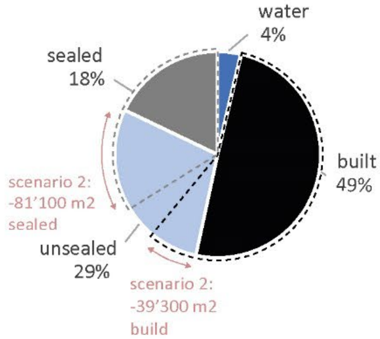
good infiltration potentiel: unsealing the inner part of blocks (beyond 37m) (2)

limited infiltration potential or underground infrastructure: unsealing only unbuilt sealed surfaces (3)

Scenario 2

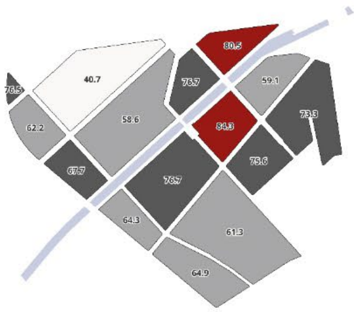
built : unsealing prioritised

sealed soil : unsealing prioritised



over the 77.5% limit
65% - 77.5%
under 65%

Scenario 2: Built and sealed



[fig. 3] Optimising infiltration

Superposing scenarios: optimising infiltration with minimal soil constraints

In order to integrate different scenarios and allow them to coexist (Vigano, 2014), the two scenarios presented above were superposed. The new scenario [fig. 4] resulting from this superposition takes into account both the unsealing constraints and the infiltration potential. Where infiltration potential is high, the benefits of soil unsealing could be considered as outweighing the constraints and thus the side effects of remediation. This second scenario therefore proposes a generalised unsealing of the inner part of urban blocks where the infiltration potential is high, regardless of soil contamination. Where infiltration potential is rather good, unsealing would also be important. The inner part of urban blocks would be unsealed, but this time except for parcels where there's a known contamination. Finally, where the infiltration potential is low or near a major underground infrastructure, unsealing would only take place on the 'best' soils, where the risk of pollution is low.

This scenario therefore optimises infiltration, giving priority to areas with the highest infiltration potential, while limiting soil transformation negative side effects. If all the built-up and sealed soils shown in red in this scenario were unsealed, the permeable surface would be multiplied by five in the district. However, this large increase would be largely at the expense of the built-up area, which ground surface area would decrease by more than 68,000 m2 (-23%).

Superposing scenarios	High infiltration potential	Good infiltration potential	Low infiltration potential or underground construction
Low risk of contamination (no intervention needed and observation)	Max. building depth of 17m, unsealing of sealed soils	Max. building depth of 17m, unsealing of sealed soils	Max. building depth of 17m, unsealing of sealed soils
Important risk of contamination (soil evaluation)	Max. building depth of 17m, unsealing of sealed soils	Max. building depth of 17m, unsealing of sealed soils	No unsealing
Contaminated soil (risk study)	Max. building depth of 17m, unsealing of sealed soils	No unsealing	No unsealing

high infiltration potential: generalised unsealing ①

good infiltration potentiel: unsealing except where contamination risk is high ②

limited infiltration potential or underground infrastructure: unsealing only where contamination risk is low ③

Scenario 3

built : unsealing prioritised

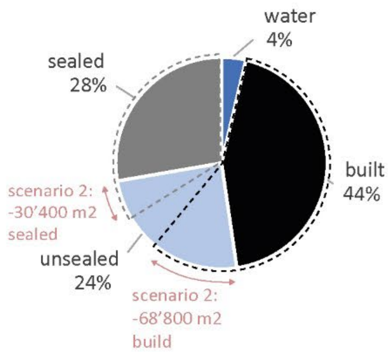
sealed soil : unsealing prioritised

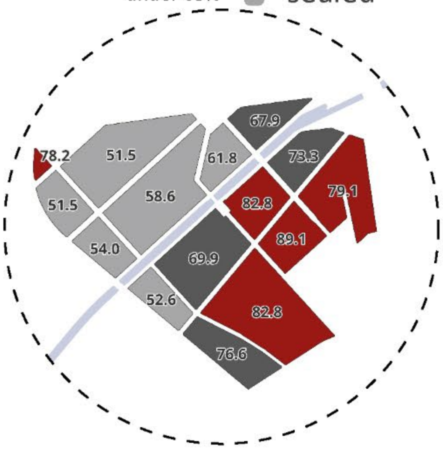
over the 77.5% limit

65% - 77.5%

under 65%

Scenario 3: Built and sealed





[fig. 4] Superposing scenarios

B. Soil transformation assessment at micro scale

Definition of a generic block

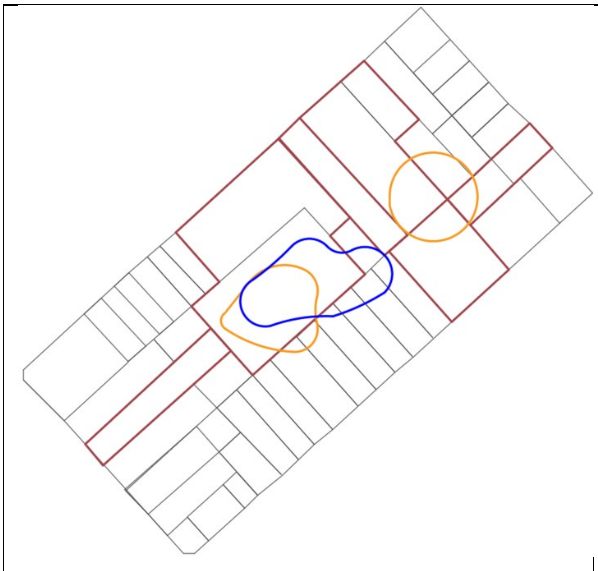
From the study of different blocks located into the PAD Heyvaert study case, a generic block has been designed, which includes the different urbanistic and environmental characteristics observed on the study case blocks:

- A mix of long and narrow mixed-use parcels, small residential or commercial parcels and broad-deep industrial parcels;
- High density of 3-4 floors buildings along the streets, 1-floor industrial back buildings;
- Heavy metal soil contaminations linked to the landfill material;
- Hydrocarbon soil and water contaminations linked to a punctual source

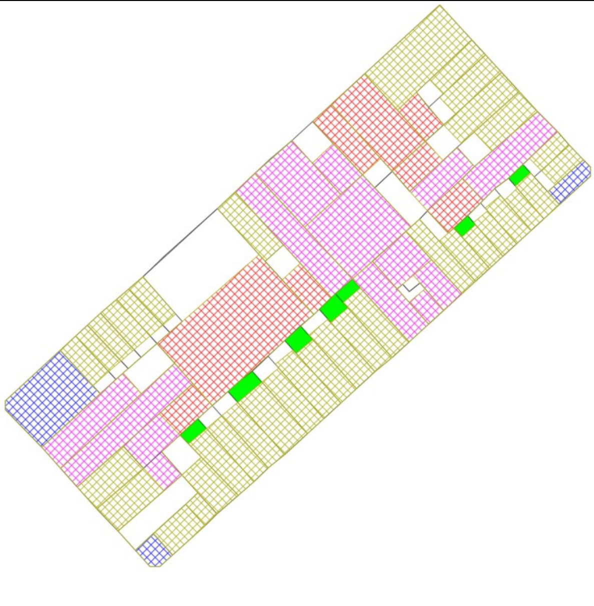
In the figure below [fig. 5], the left frame shows the limits of the different cadastral parcels (in light grey) and the different soil and water contamination. Soil contamination is of two types: pollution linked to the quality of the backfilling soil is in dark red and the entire cadastral parcel on which these backfillings were observed are considered contaminated. It consists of heavy metal pollution. Pollution in the form of stains, linked to a point source, is represented in orange. It consists of hydrocarbon pollution. The pollution of the water table (in blue) is of the hydrocarbon type.

The right frame shows the frame and the current allocations of the block:

- The hatched areas are built-up, the unhatched areas are unbuilt but covered by asphalt or concrete;
- Green areas are undeveloped and unsealed (greening) ;
- the blue hatched areas cover commercial/equipment type buildings;
- The beige hatched areas cover homogeneous housing type buildings;
- The pink hatched areas cover the heterogeneous production buildings. The heterogeneity comes from the fact that a multi-storey building gives access, via a carriage entrance on the ground floor, to a building at the back used for production (at least on the ground floor);
- The red hatched areas cover homogeneous productive buildings, consisting of one or more floors.



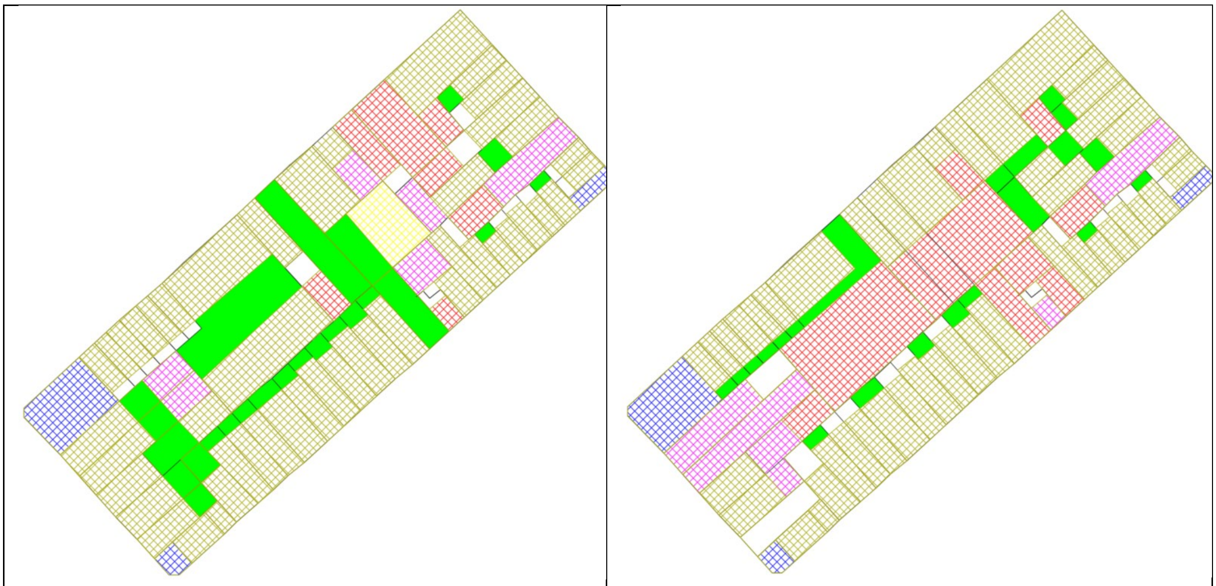
[fig. 5] Analysis at the micro scale



Urbanistic scenarios of the future developments of the generic block

Linked to the PAD objectives, several scenarios can be developed depending on the enhancement of the housing affectation, the maintaining of the productive affectation and the unsealing of the non-built areas to enhance the greening and the infiltration potential of the block.

From the generic block described above, 2 scenarios have been designed : on the left of the figure below [fig. 6], the residential hypothesis on which most of the previous industrial buildings at the front of the parcels have been converted to housing as well as some back buildings. On this hypothesis, following the PAD's rules, the outside areas between buildings have been unsealed. On the right of the figure, the industrial hypothesis on which productive activities has been maintained and a lower proportion of greening areas are present.



[fig. 6] Scenarios at the micro scale

Environmental analysis of soil contamination

In order to develop the treatment objectives, the first step consists in describing the different soil (and water) contamination present in the studied block.

The description takes into account the type of contaminants, his extension and depth, the soil quality (permeability, structure, organic matter, presence of anthropogenic materials, …) and the impacted matrix (soil, water and/or pure product).

The description also insists on the actual accessibility, localisation of the buildings and non-built areas of the block.

The current Brussels legislation has established a robust analyse for the comparison of the treatment techniques applicable to a specific contamination at a particular site. The BATNEEC analyse (best available technique not entailing excessive cost) consists of a comparison of different treatment variants on the basis of a calculation of their overall environmental performance. The first step is to define the treatment objective (suppression of the contamination or risk management). The possible treatment techniques are then compared with double criteria: the cost (direct and indirect) and the environmental assessment. This last criterion is evaluated by 2 sub-criteria : the removed contamination load and the environmental bonus : energy consumption and greenhouse gas emissions, inconveniences and uncertainties linked to the technique, related issues such as duration, residual contamination, security, waste and other emissions (Bruxelles Environnement, 2015).

On the studied generic block, after BATNEEC analyse, the applied treatments are the following ones, for each contamination, depending on the treatment objective (withdrawal or decrease of the contamination):

1. Heavy metal contamination of the soil matrix : these contaminants generate risks linked to the exposure “inhalation and ingestion of soil particles” and “ingestion of vegetables”. The treatment of those contamination is then directly linked to the future real estate project. Contaminations that are located under the buildings or under a sealed layer must not be removed. Contaminated future greening areas must be treated. The best applicable technique for the most concentrated contamination is the excavation and the physico-chemical treatment off-site ;
2. Hydrocarbons contamination of the soil matrix and of the water matrix : these contamination generate risks linked to the exposure “inhalation of indoor air” and “inhalation of outdoor air”. They must be mandatory treated . The following treatment techniques are applicable to the study site:
    a. Excavation and off-site treatment : if the contamination spot is available to the equipment, it is the easiest and cheapest technique;
    b. Chemical oxidation/reduction : injection of a chemical agent into the contaminated depth of the soil. The distance between injection points is short because the permeability of the studied soil is very low. This technique allows the decrease of the concentration to a level on which there is no remaining risk;
    c. Pump & treat: this is a hydrodynamic remediation: by pumping out the groundwater, the polluted soil is flushed with unpolluted groundwater, which is effective for the treatment of groundwater hydrocarbon contaminations and/or the light fractions of hydrocarbon soil contaminations.

Observations

The application of the classic BATNEEC analysis to the 2 scenarios highlighted 2 main observations that could limit the achievement of the objectives of the PAD:

1. The classic BATNEEC analysis favours mainly the transformation to housing. Indeed, as this use is more sensitive, the removed contamination load is much more important than in maintaining the industrial use, for which the pollution can often be maintained in place. However, this analysis does not take into account the impacts on C02 emissions and the very low use of the circular economy, two important pillars of the PAD;
2. The application of classical BATNEEC to individual parcels and, to a greater extent, the application of the PAD objectives to the owners, without coordination by block, will make it difficult to achieve the PAD's principles of sustainability, greening and circular economy. Indeed, the typology of the industrial parcels in the district is mostly narrow, with a building with a driveway at the front, with residential floors, and an industrial rear building. The legal difficulty of increasing the floors of the front building imposes significant pressure on the rear building, which will have to ensure the various objectives of the PAD: maintaining industrial activity, opening up the ground and improving the quality of the living space. This strong pressure will make it difficult for each of the parcels to ensure the principles of water management, greening and maintenance of industrial activities.

Furthermore, the treatment plot-by-plot, following the local private decision to treat the contamination located on each plot is less efficient than a treatment at wider scale, and don't follow the rules of circular economy, due to following reasons : technical limitations linked to individual access, residual contamination at the boundaries of parcels and above all huge soil carriages without the sorting and the re-use possibilities provided by a wider worksite ;

To address these observations, two methodologies have been developed specifically for the PAD.

Achievement of the PAD objectives at the block's scale

Three major steps allow the achievement of the PAD's global objectives on the block's scale:

1. The translation of those global objectives into local objectives, applied to the block situation. For example, one of the PAD key objective is the greening of the blocks to answer different sub-issues : enhancement of infiltration potential, improvement of the quality of life, creation of "freshness islands". The unsealing of non-built areas is not possible everywhere. Some blocks need to stay covered to maintain the productive affectation, one another key objective of the PAD. Nevertheless, the sub-issues can be solved locally without the unsealing of non-built areas, thanks to different solutions : infiltration by technical means underneath sealed surface (inside the block and on surrounding streets), greening can be added on those streets also, or on the built area of the block, even on a roof.

2. The consideration of the treatment of the different contaminations at the block's scale, instead of on the plot's scale. The coordination of the treatments block-by-block will enable the sorting and the re-use possibilities provided by a wider worksite.

3. The consideration of the achievement of the translated PAD's global objectives at the block's scale, instead of the plot's scale. The usual practice is to apply the global objectives at the plot's scale. For example, if the PAD's objective target 25% of the total area of green spaces, each plot of land will be assigned an individual proportion of 25% of green space, when applying for an urbanistic transformation.
   That strategy has been proven ineffective because many parcels could apply for a local derogation. However, if the global objective is targeted at the block's scale, even including the public space consisting of the surrounding streets, there are more possible adjustments.

Those 3 major steps allow the development of different projects that combines soil treatment and achievement of the PAD's objectives. Those projects are then compared with the "PAD adjusted BATNEEC methodology" (see below).

PAD Adjusted BATNEEC methodology

Thanks to the observation of different blocks and the translation of the PAD objectives at the local scale, we developed an enhanced version of the BATNEEC methodology that we called "PAD Adjusted BATNEEC methodology".

On this methodology, 2 criteria are added to the first 2 classical modules (cost and environmental criteria).

- Energy efficiency of the construction. The total demolition of the buildings earns 0 points, complete retention of the buildings in place earns a maximum of 100 points. Between these two extremes, the percentage of demolition is left to the discretion of the expert, taking into account:
    - The proportion of the volume of the demolished buildings;
    - The proportion of materials removed (in relation to the materials kept in place);
    - The proportion of the surface area of the buildings retained/demolished;
- Qualitative assessment of the buildings and their intended use:
    - Follow-up of the objectives of the PAD (maintenance of industrial activity = 50 points, reallocation to housing = 0 points);
    - Modularity of the buildings: possibility of easily transforming a current use into a different future use. This modularity earns 0 to 50 points and is left to the expert's discretion, taking into account different local principles, such as:
        - Ceiling heights (possibility of easy conversion to industrial use);
        - Accessibility to vehicles through the front building;
        - Access to sufficient natural light for housing (e.g. conversion of offices to housing);
        - Sufficient slab thickness for machinery.

CONCLUSION

The analysis at the macro scale presented previously enables a better assessment of soil and geological strata in urban projects. The deliberate abstraction of many other factors - such as mobility, social questions or economic issues - makes the direct implementation of these scenarios unrealistic or undesirable. However, the method developed in this paper results in the creation of a methodology for urban planners to integrate the questions of soil and geological strata into urban projects, enabling a transformation toward a more resilient city able to face the challenges of climate change.

Micro-scale analysis, on the other hand, allows for the implementation of local objectives within the model, as well as goals related to soil transformation methods. The parcel scale, to which existing policies for urban transformation and soil remediation refer, is also being questioned due to the limitations it entails.

Therefore, this multiscale methodology aims to provide more suitable tools for both urban planners and project developers to achieve low-impact soil transformation and enhance the resilience of the city of tomorrow.

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