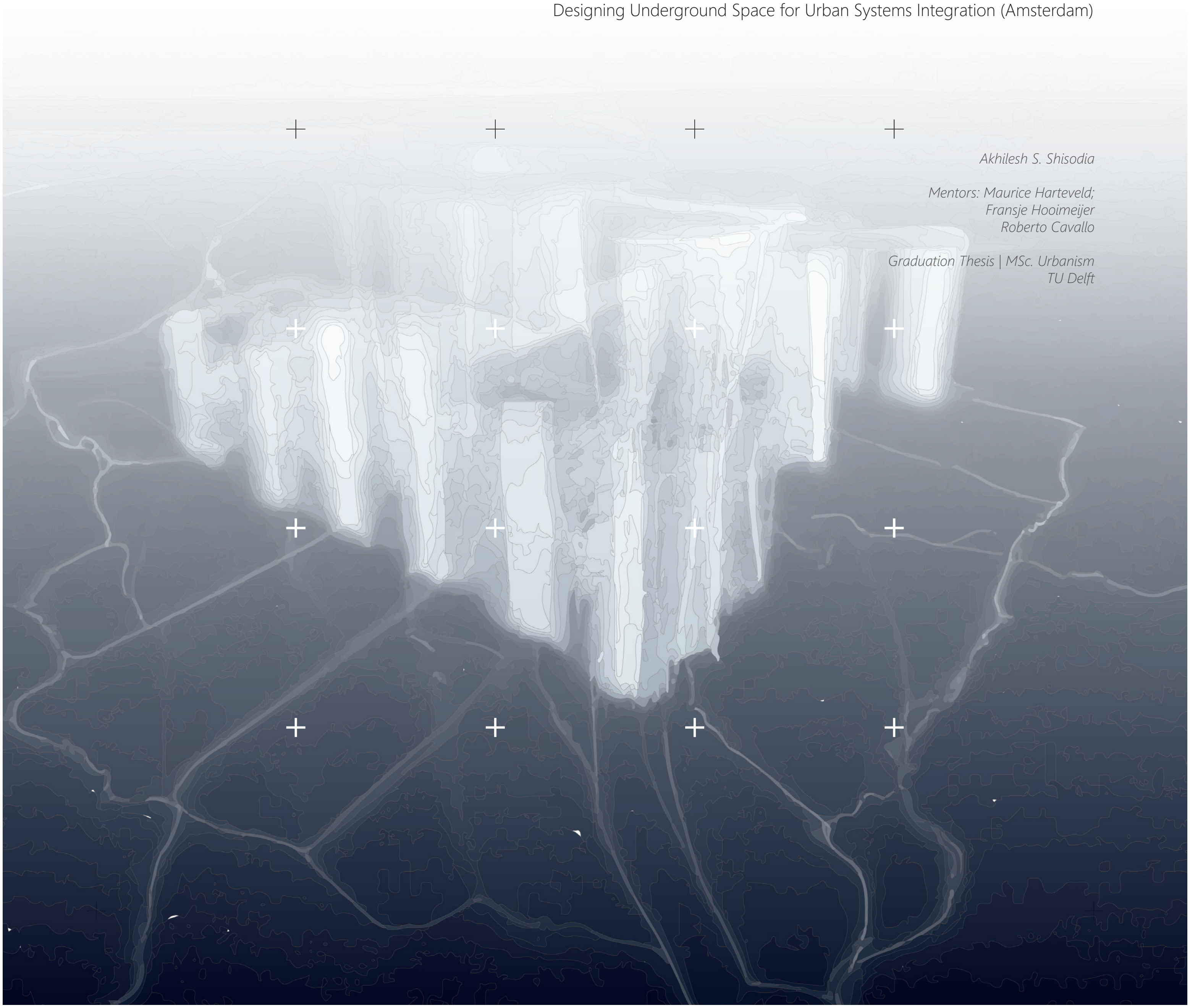
The **Subsurface**
A **Collective** Geography

Designing Underground Space for Urban Systems Integration (Amsterdam)



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Graduation Thesis | MSc. Urbanism
TU Delft

Title:
The Subsurface: A Collective Geography

Subtitle:
Designing Underground Space for Urban Systems Integration

Location:
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We had an expansive run in the 60s and the 70s exploring the cosmos. Eventually, we pulled inwards, subjected to the fragility of our planet.

These days, there seems no expanse left to traverse beyond the thin crust of the planet we call home. We sent out ships named after gods to look for worlds to reside in, to inject life into, and soon realized that Earth is all we have. Such future oriented projects bear a reminder of society's potential to realize Fiction, exploring dimensions of the urban realm beyond the surface of planet Earth.

- Carl Sagan (Age Exploration)

Where will we live when we run out of space?

Abstract

Urban areas project high demand for urban spaces to accommodate a wider range of functions associated with social, economic and physical development, given the rising rate of urbanization and over two-thirds of the human population projected to be urban dwellers by the year 2050. Consequently, cities are rapidly developing into complex and sprawling infrastructure reservoirs, limiting the capacity of vital natural ecosystem services. Development projects face several time-based constraints to find space for public access. In recent decades, brownfield development has directed its focus towards the subsurface, with the onset of initiatives like "net zero land take by 2050" set by the European Union. Expanding the public realm in cities through brownfield underground development can help close the gap between demand and supply of habitable land within cities, especially in urban areas housing contextual heritage.

There are various socio-cultural agents to be accounted for, which influence the experience of the subsurface. With appropriate structuring of documentation and design methods, underground built environments can potentially link diverse uses like transit, work, recreation, and more. The lack of development strategy inclusive of underground spaces poses risk of exploitation by private sector eventually resulting in super-basements that are value-centric. Underground spaces need a strategic spatial vision where the subsurface ecology is taken into account and developed in coherence with public life, integrating it with existing infrastructure networks.

The Thesis explores the subsurface uses and their potential to supplement demand of public/mobility space from surface in the city of Amsterdam. The applicability of urban underground functions in a delicate Dutch Landscape presents an opportunity to test and benchmark the suitability of subsurface realm for a range of functions. This is done by generating a guiding methodology for context-specific design interventions, followed by their integration with existing underground resources to form a holistic subsurface network that supplements the surface. The research takes into account the current technological and urban transitions to utilize them tools for developing underground spaces as collective, feasible and transformative spaces. Research-by-design approach is used to investigate essential parameters of subsurface design at different scales to contextualize prototypical interventions for Amsterdam.

TU Delft

Content

1. Preface

After decades of development initiatives, the initial mass transformation of infrastructure revolution has already taken place. The timeline of operation for these infrastructure systems extends across various urban and global transitions in the future. Incorporating the shifts brought forth by digitalization and alternative resources for energy, the physical space occupied by these networks is at risk of being rendered futile. Development of compact urban environments demands reduction in sprawled mobility and infrastructure networks. However, the volume of service demand remains at consistent acceleration. Densified urban environment need to account for volumetric spaces for dwellers, public spaces as well as utilities. Balancing these allocations is time-sensitive with rising real-estate pressure and restrictions posed by existing built environments. Developers move to subsurface utilization for generating more space. However, the subsoil is already populated with existing hidden networks, environmental assets and resources like minerals and energy. With this context, the potential for developing public space underground diminishes with each urban transition. How can we use these shifts as opportunities for unlocking the hidden 'underground' to enable collective subsurface systems integration.

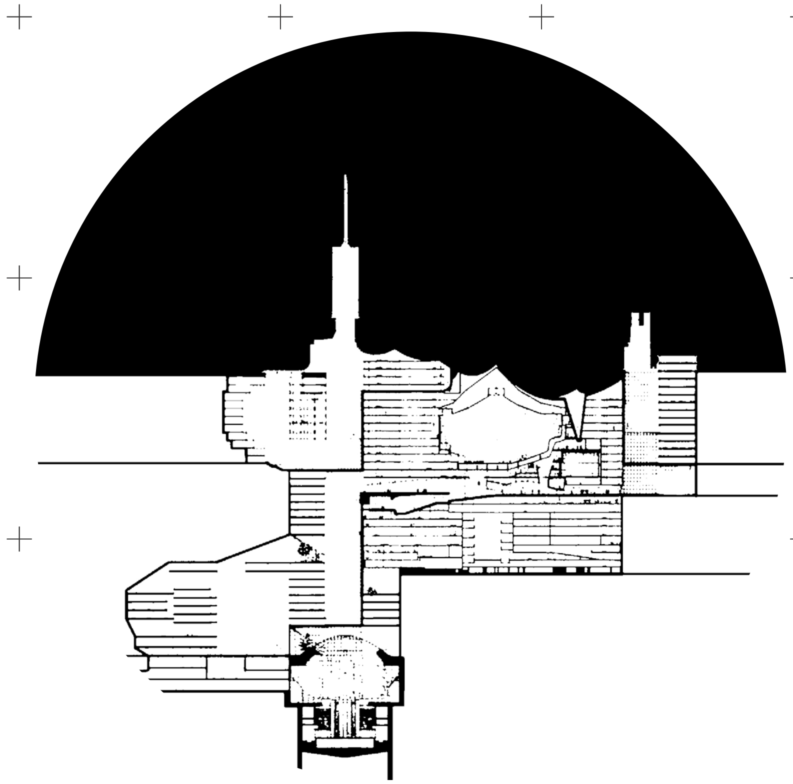
2. Problem Field

Overview

With the onset of 2030, the projected global demographic shifts are expected to commence an unprecendented global urban expansion, the extent of which may succeed the collective urban land cover so far. Cities worldwide host approximately 74 million new residents each year, spatially translating into urban sprawl (WSP Global, 2018). Cities sharing such global city character are working towards developing compact city models and innovative modes of densification.

This chapter illustrates this crisis and introduces how the Subsurface can assist this transition by offering supplementary space to reorganize and reimagine densification of functions and vertical urbanism. The chapter also briefly describes the current notions regarding urban underground spaces and their role in future-proof urban visions.

Chapter Structure:



a. Urbanisation and Underground Urbanism

By the end of the 20th century, urbanization posed considerable threats and concerns for forms of city growth. Most of this growth translates into sprawl, which further leads to spatial, economic, and infrastructural challenges. Globalized cities like London, Shenzhen, and Hong Kong have implemented various constraints to prevent outwards growth. However, these urban areas demand active access to the city center as a result of being driven by global economic models. (Reynolds, 2020) A context of regulation that allows vertical growth above the surface only has propelled urban expansion in these centers to a large degree, leaving the subsurface with monofunctional and independent construction projects (Lan, 2016).

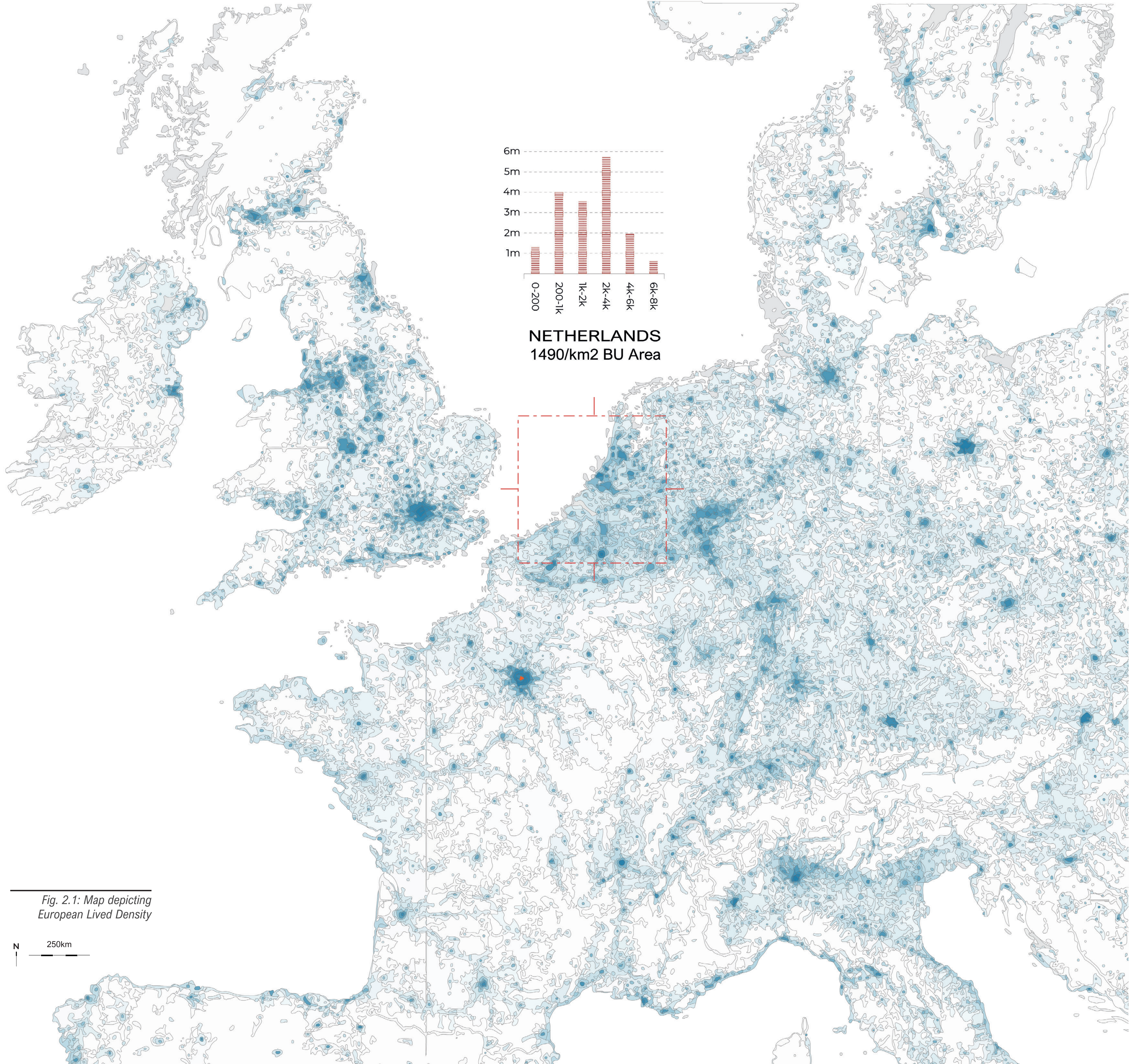


Fig. 2.1: Map depicting European Lived Density

Cities are compositions of elements subject to the dimension of time and, hence, constitute juxtaposed layers (Vigano, 1999). Each wave of vertical urbanization compounds an additional layer of pressure over the pre-existing fabric, i.e., city heritage, which cannot be demolished or redeveloped. This substantially elevates the competition for land in cities, making it economically unfeasible to recycle it. It is thus imperative to turn to alternative approaches for supplying space within urban areas. Land scarcity and increased land prices have compelled recent advancements in excavation technologies, bringing forth underground construction as an alternative approach to address these issues sustainably (WSP, 2018). Urban underground space (UUS) holds a variety of potentials, ranging from the generation of cohesive spaces, subsiding motorized transport, data storage, and supplementing surface use (Bobylev, 2015). However, implementing plans for Urban Underground Space (UUS) is subject to opportunities based on the primacy of location, collective use of resource area, and connectivity (Kinn, 2016).

It has become imperative for planners internationally to strive for UN Sustainable Development Goal 11 (SDG-11) to achieve a sustainable ratio of land consumption and population growth. The current subsurface in growing cities has been used for connectivity, transit, and utilitarian uses. Recent underground developments in Asian cities like Shenzhen, Beijing, and Tianjin have gained pace because of favorable regulatory context underground and shortage of central land on the surface. These developments are based on a 'point and line' mode of disjoint spaces, like metro stations (Lan, 2016).

Brownfield augmentation of new surface transit systems often poses physical and economic limitations due to the presence of existing built-up and spatial anchors. Since urban underground spaces are in their initial stages of acquisition, they provide a volumetric void that enables convenient linear expansion and hence, makes the placement of complex rail networks for passenger and freight movement practical. This ease of accessibility lends primacy and locational advantage to the nodes above these networks. However, the current scale of such underground construction has been project-based and restricted to the architectural scale, resulting in an archipelago beneath the surface (Zhu, 2014). To allow these fragments to function in a coordinated urban system, it is essential to observe and establish potential linkages and an integrated framework for a wider range of uses that can supplement the surface- use and free up space for new typologies of uses above ground.

There exists a dichotomy of infrastructure vs life that separates the Groundscape into two different realms. If expansion stays dominated by such functions, the window of opportunity for utilizing the untapped subsurface for public use would eventually close. The lack of development strategy inclusive of underground spaces poses risk of exploitation by private sector eventually resulting in super-basements that are value-centric.

Underground spaces need a strategic spatial vision where the subsurface ecology is taken into account and developed in coherence with public life, integrating it with existing infrastructure networks.

Fig. 2.2: SDG Goals impacted by Underground Urbanism

Growing Cities

In cities, tangible space is an essential resource. There exists a constant competition between urban aspects such as housing, manufacturing, utilities and services, transit, waste management, economic development and cultural exploration. As a result physical growth is important for metro cities like Hong Kong. However, it is often restricted by natural barriers, causing an increase in urban density to tackle population growth. Some cities like London use green belts to curb urban expansion as an administrative and policy-based approach. In recent decades, London has seen urban growth leap over the assigned barriers, expanding over a much larger region due to demand for access to the city's center resulting in a patchwork of several micro-cities.

Hence, competition for space in our cities is challenging while values are high and limitations to urban growth are policy-based and physical on surface.

Development in the vertical spectrum can reduce the size of an urban footprint, but it layers additional pressure over services an utilities catering to the built environment, leading to spatial problems on the ground level. When tall buildings are grouped together in crowded metropolises, it may result in lack of space on the street level for safe and feasible movement of people and products across the city. The interconnectedness of people and products is essential in developing urban environments. Growth depends on transit infrastructure both above and below the surface, from complex and intricate train networks to specially planned logistics networks and pedestrian routes.

b. Spatial Demand in the Netherlands

In the Netherlands, approximately 90 percent of the population has been residing in cities since 2018. The lived density figure for the Netherlands is 546 people per km². Netherlands is a dense and compact country. Majority of space is already dedicated to use for and by urban systems. The current demographic projections indicate a population density between 7500-12500 per sqkm for major cities such as Amsterdam, The Hague, Rotterdam and Utrecht, depicting a high demand for urban space within South Holland.

But is it so dense?

The development of subsurface assets has had a potentially positive effect since the beginning of 2000s. It is, however, imperative to evaluate the current need, receptivity and perception of underground development for uses apart form transit and utility or the need of integration measures for this new land market with existing subsurface infrastructure landscape. The current subsurface development primarily leans towards public uses and urban utility. However, the rising rate of land crisis in the Dutch context calls for tier-1 cities to recognize the urgency to capture rising real estate prices and supply the deficit of office and retail spaces by reorganizing and augmenting subsurface functions. The low vacancy rates and rising demand in cities like Amsterdam and Rotterdam (Fig. 2.3) should be accounted for by considering a newer base-land market that incorporates underground real estate.

Netherlands National Policy Strategy for Infrastructure and Spatial Planning (NNPSISP) recognizes efficient use of subsurface as a goal to maintain resource competitiveness taking into account groundwater, energy supply, minerals, infrastructure and utilities and public spaces. The current urban underground use has been reserved for densification of infrastructure networks like transportation, parking, energy resource. Urgenda 2007 states that within 15 years, intensive use of subsurface would be common in Netherlands. Visions to develop on use of underground have been taken up my various municipalities like Rotterdam and Zwolle.

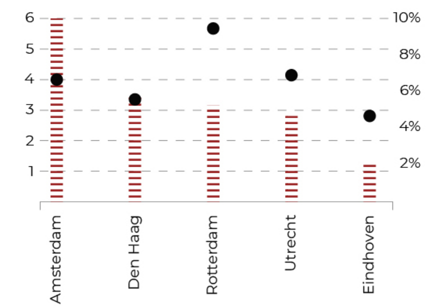


Fig. 2.3: Rising demand for Space and Low Vacancy (Source: Cushman and Wakefield Report 2021, Demand for Office Space)

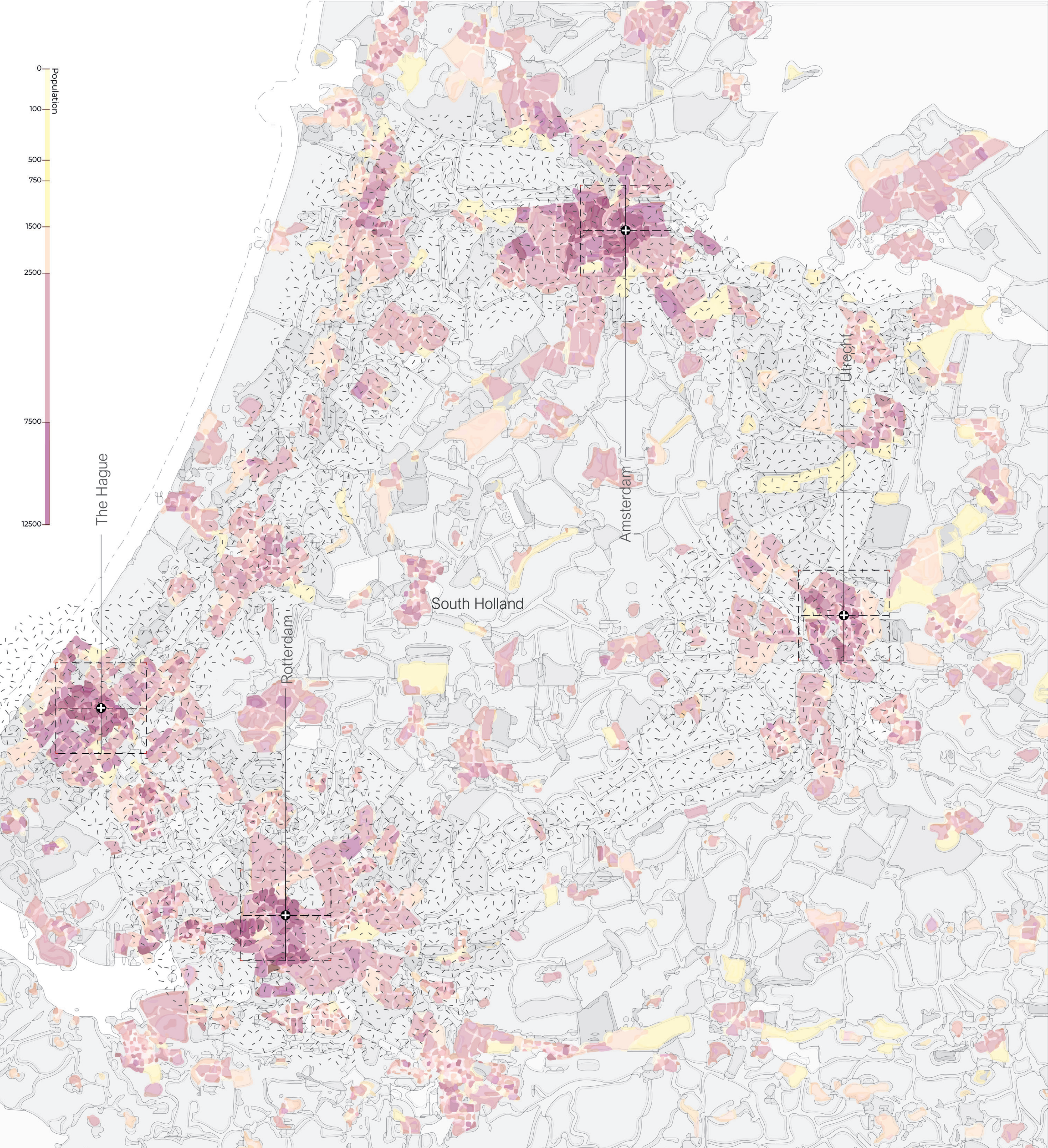


Fig. 2.3: Map showing Population Density of Netherlands

Ecological Risks to Urban Sprawl

Gradual concretization of urban areas reduces the permeability for regional natural networks. The imbalance of inorganic and organic surfaces depicted in the map indicates that dense on-ground development in Netherlands has pocketed soft and green surfaces within expanding cities, leading to poor vegetation health and potential risk of heat islands in metropolitan areas. European Union's decision for No-net land take by 2050 is influenced by similar phenomena to limit urban footprints of cities.

Densification in compact built-environments may give rise to a parallel set of issues such as concentrated emission nodes above ground, risk of flooding and water seepage for subsoil nutrition. Underground construction in such circumstances needs an in-depth study of its subsequent ecological benefits and risks, bargaining regional ecological advantages with local environmental degradation. The interventions for such construction should be informed by long-term urban and local-scale ecological challenges in order to ensure sustainable udnerground urbanism practices.

Fig: 2.4: Map showing Inorganic vs organic surfaces of Netherlands (Source: Author)

Urban Connectivity

Underground passenger transit networks provide long-distance high-speed connectivity without obstructing ground-level vehicular thoroughfare. But as cities sprawl outwards, so do the infrastructure networks that support them. The renowned subterranean system in London has grown to include a total of 270 stations and a large portion of the subsurface realm, and still continues to grow. It also links with additional stations and tracks on the surface as well. Crossrail, one of Europe's greatest construction projects, will add 40 more stations to the existing pool, and an additional 10% of infrastructural capacity. Growing population and lower willingness to own private vehicles today indicate further urgency of denser transit networks.

Long-distrance travel to city centers are frequently required for both people and products. The Cargo Sous train is an innovative approach to promote commercial efficiency, lowering vehicular congestion, and reducing carbon footprints. More compact, and continuously wagons lessen the time that big trucks require to be full before delivery. The initiative has broad industrial and government backing, despite the enormous capital investment required for execution. Cities around the world have expressed similar interests in using cutting-edge models to relieve traffic in their own centers. While projections for space required to lay down such an infrastructure landscape show promise to reduce permanent road infrastructure on surface, it adds to the pressure for excavation and subsoil maneuvering.

Land Values

Sometimes, no matter how far a city grows or what level of complexity the transit connectivity achieves, the desire for access to active centers can drive up real estate prices drastically to the point where subsurface development is economically feasible. For cities with highest property rates in the world, including Hong Kong and Singapore, the creation of underground assets may even be advantageous due to their particular economic circumstances.

In sharp contrast to the massive super-basements of London, more and more residents in Beijing move towards social housing in the city's underground basements. More than a million people live in underground flats in the city due to the legislation necessitating the construction of basements as safe havens during times of conflicts but allowing for personal and commercial use in the other times. Similar contexts have resulted in sizable quantity of underground space inventory in Chinese cities like Shenzen and Tianjin.

Indeed, it was discovered that physical vicinity to workplaces was a crucial motivator, allowing inhabitants to save expenses by promoting habits of cycling and walking. In conclusion, the underground housing market is driven by the superimposed demand of being located close to active centers instead of the urban periphery. The subsurface is not meant for permanent habitation but these trends show potential in reversing the location of functions by shifting workplaces and public spaces, requiring temporary habitation underground while making space on surface for housing.

Heritage Constraints

Low and deep constructions instead of vertical towers may occasionally be more feasible to protect the surroundings of historic exploration areas in cities. Since urban centers sprawl out from old city centers, development constraints increase for subsurface construction. The design of Amsterdam's central station needed to take into account its location in close vicinity to the heritage market and residential spaces and protected views/facades housed by local planning legislations. The final plan resulted in construction over the harbour in the form of a floating island complex consisting of transit station, institutions and office buildings. The depth of the complex has allowed the F.S.I. and property value to be maximized.

Another 10-story skyscraper with a 5 levels of basement volumes is being built in Singapore, but for totally different functions. On the location of a former parking lot, the building is tucked between the city's airport terminals. The underutilized area will be renovated to offer 150,000 sqm of transportation, hospitality, FnB spaces and amenities. Even though the structure is 60 m tall, there are no issues posed on existing flight patterns because more than half of the levels are built underground

The air above cities is jointly constraint by preservation of built-environment and intangible infrastructure networks overground. In such a context, moving public functions underground is a much viable option than reconfiguring existing systems.

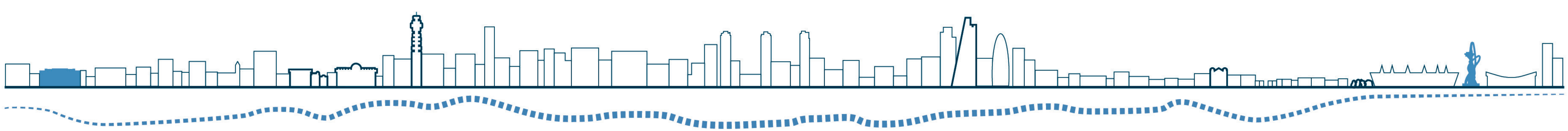
Resilience

The capacity of cities to withstand natural disasters is also an essential driver of exploring terrain beneath them. Seasonal calamities have devastated Hong Kong for decades, and even in contemporary structures are designed to endure strong winds, controlling heavy rains in a congested urban region is still extremely challenging. The subsurface in this context may emerge as a shelter. The government ordered the construction of a massive subsurface flood storage facility in 2001 rather than starting a protracted program to repair the current drainage systems in heavily occupied areas.

It is possible to put measures of mitigation in place to make urban environments as resilient and prepared as possible for future climate changes by employing simulations to test city's capacity to deal with potential disasters. Netherlands faces a potential rise in +3m sea-level by the end of this century. Where population growth is anticipated, pedestrian networks may be compacted and provide better walking experience by keeping utilities, traffic, waste management below the current ground level. The Bahnhof data center in Sweden serves as examples of how subsurface areas may be able to help meet the needs of technological landscape by converting underutilized places into spaces for future warehousing and logistics within cities, potentially reducing the risk of rising sea-levels.

Fig. 2.5: Connected overground and underground

Why Underground?



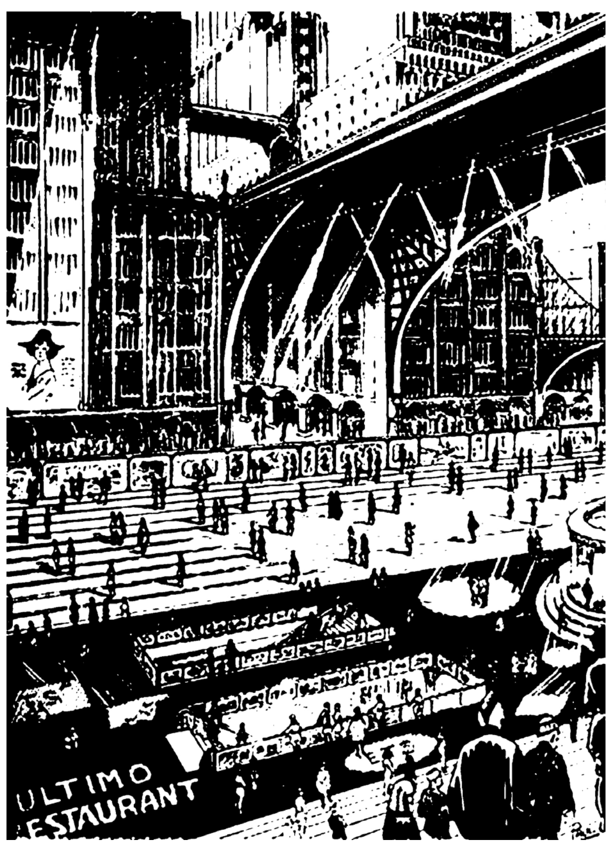
c. Subsurface: Fiction and Space

Urban underground spaces, when dealt with under a civil engineering regime, tend to overleap architectural significance and collective use of space as a resource and connective tissue (Perrault, Ground Scapes: Other Topographies, 2016). The ideal subsurface, though constraint on cost and technological thresholds, can contribute to the creation of a continuous landscape where the surface is penetrated by strategic incision to offer space for parallel layers of events that are no longer a part of separated economies. Beyond the technical aspects, it is also essential to account for the living and working experience in underground spaces.

Fictions have been used as key tools in the past to envision these experiences and enhance the spatial use of voids underground. Historic implementations of parallel subterranean composites in cities like Naples and Athens inspired Engineers and Urbanists to put forth images of underground cities as a system of inverted 'towers'.

The Japanese 'Depthscraper' from 1931 was an interesting manifestation of such a tower contesting the feeling of confinement to induce a sense of safety from earthquakes ("Depthscrapers Defy Earthquakes, 1931). Similar imaginations in recent times like Rosalind Williams' 'Notes on the Underground' present pioneering subsurface environmental imaginations (Hawkins, 2019). These images question the human tendency to move along the axis-mundi (earth's axis between the celestial poles) and use vertical means to escape the surface. The uncertainties of subsurface as a new reality question its existence in a context that fractures the conventional urban image (Perrault & Lee, Sublab: A Groundscape Story , 2017).

While such images reveal some key parameters and challenges attached to underground exploration, they tend to disengage from reality the moment they discard the persistent need of human subconscious to stay associated with the surface or a platform enunciating their connection to Earth.



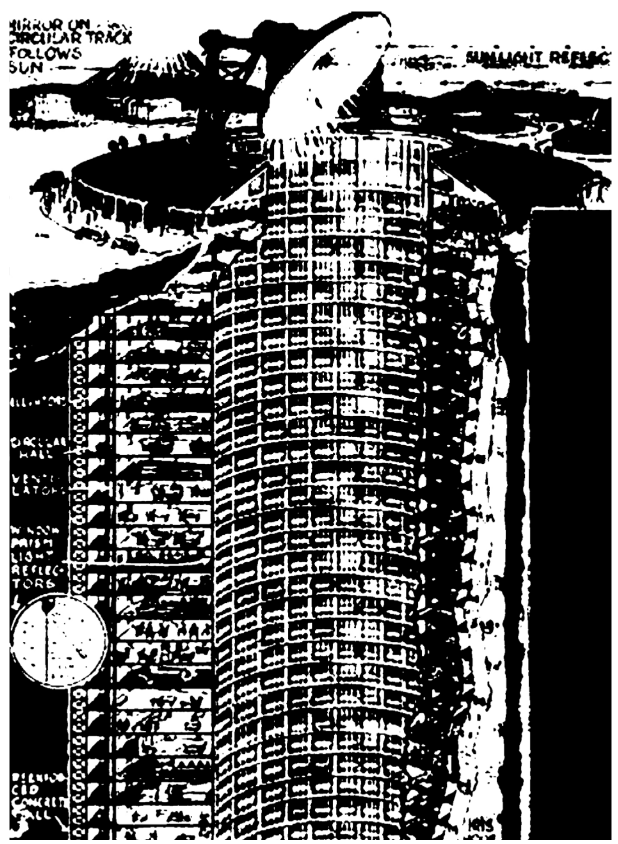


Fig. 2.6: Underground City Fictions (Source: Francisco Mujica)

d. The Subsurface as an Urban Frontier

The idea of subsurface as an 'untapped' resource opens up functional possibilities as well as risk of exploitation, depending on the players utilizing this asset. While public bodies focus on generating opportunities based on collective use of resource area, connectivity, and primacy of location, private sector may treat the ungoverned extension of space to super basements primarily for storage and data-based utilities, further risking attached ecosystems. The competition leaves the current subsurface in growing cities limited to transit and utilitarian uses to facilitate storage and movement. The subsurface is growing denser by the day with infrastructure networks to an extent that imagining public functions and habitation in the coming decades would be unlikely. Before the window closes on this territory, it is imperative to generate a platform for integrating infrastructure and life underground.

The lack of strategic spatial visions recognizing efficient use of underground as a goal to maintain resource competitiveness leaves the territory unchecked. In several European countries, you can practically own the space below your surface parcels, stretching till the core of the earth.

The preceding notion of planning for subsurface with natural and urban spaces has been that of a preservation agent for heritage. However, it can also act as an industrial enabler of new geographies and limit the city to its smallest potential surface area. Picture a Sphere, with one hemisphere underground while the other half above surface laced with harmonious functions at equidistant extents from the Groundscape, a haven for vitality and entropy. This city would be an exhibition of thickening urban substance, consequently reinstating heritage on surface back into the urban life of the city. Urban planners and Architects should lend special focus to the reconstruction and appropriation of transition interface between the surface heritage and underground. This interface links masses of similar characteristics to form unified spaces. Programs in these help spaces steer a narrative for the user and connect different timelines of growing city heritage in the same space.

Urban underground space holds latent possibilities to serve as a true alternative to horizontal urban growth, given it transcribes and merges with present geography. UUS offers various terra benefits, including protection from wind, acoustic insulation, and temperature stability due to increased inertial mass. It generates a realm of liaison by efficiently allocating programs concerning shared space. Parameters like volumetric hierarchy, depth, and existing functions above the surface govern the typologies of these programs. Based on such parameters, we can classify the subsurface into public spaces (collective), services (co-working; retail; offices), and technical (data stock; distribution center). Considering the time spent underground, perception studies have found UUS to be unfit for residential habitation (Perrault & Lee, Sublab: A Groundscape Story , 2017).

The existing practice of planning cities has been restricted to ground plans with juxtaposed yet parallel urban layers. The 'shared' nature, scalability and growing viability of the subsurface directs important concerns towards the dimensions of systems approach and spatial design while planning for underground development. While the window of injecting public functions in already densifying infrastructure networks slowly diminishes, Underground urbanism may provide an alternative skeleton to support such a landscape as an integrated supplement to the surface. Since underground expansion remains a relatively unchartered territory, it brings many experimental opportunities to produce denser, cohesive and unique city models which account for public experience, co-habitation and co-working. UUS potentially acts as a medium to revitalize and thicken urban substance, consequently reinstating heritage on surface back into the urban life of the city. The economic sustainability of subsurface real estate assets depends upon including underground spatial planning within the framework of development control regulations. Underground spaces need to be planned and visualized as a part of urban metabolism. Its current project-to-project basis of execution can be extended to district-level development by introducing specialized geographies in urban centers and governance bye-laws (Isocarp; ITACUS, 2015).

e. Psychological Perception of UUS

The current scale of underground construction has been project-based and restricted to the architectural scale without platform, resulting in an archipelago of volumetric voids beneath the surface (Zhu, 2014). These developments are based on a 'point and line' mode of disjoint spaces, like metro stations linked with linear retail (Lan, 2016). Such an orientation is prone to insinuate a sense of enclosure psychologically associated with loss of orientation and claustrophobia. Realized UUS (Urban Underground Space) projects in the past few decades have faced considerable public criticism concerning qualitative factors and psychological conventions.

The withdrawal of the perceived sense of control and safety in hidden/hiding spaces from the user often pick remarks of neglect, darkness and isolation lacking 'eyes on the street'. To allow these fragments to function in a coordinated urban system, it is essential to observe and establish potential linkages and an integrated framework for a wider range of uses that can supplement the surface in collective volumes instead of narrow networks. The uncertainties of subsurface as a new reality question its existence in a context that fractures the conventional urban image (Perrault & Lee, 2017). However, the primary challenge for the future subsurface realm is to tackle its susceptibility to generate a negative perception. Several architectural cases ranging from the Calatrava (Toronto) to the French National Library (Paris), and Berlin Velodrome, have explored underground spaces by employing light as a tool to expand idea of geography, induce orientation and establish a visual connection to surface (Miess & Radu, 2004).

From the above examples, it is clear that qualitative factors attached to urban underground corridors and entrances play a crucial role in influencing the demand of subsurface anchors. Their perception is primarily influenced by level of safety, maintenance, presence of light and lineation. Existing notions for subsurface habitation can act as parameters to cater to by large-scale engineering projects concerning underground commercial and public spaces.

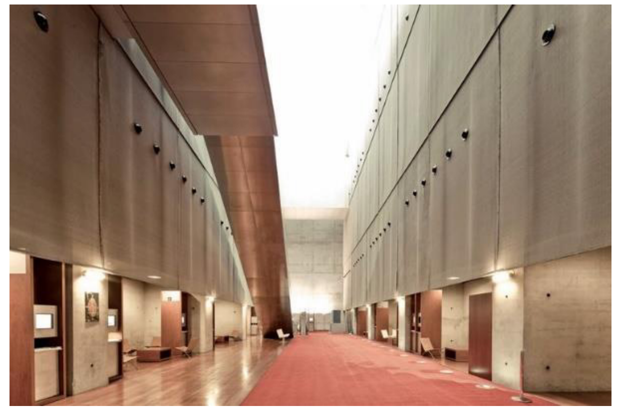


Fig. 2.7: French National Library (Source: Dominique Perrault Architecture)

Fig. 2.8: Berlin Velodrom (Source: Dominique Perrault Architecture)

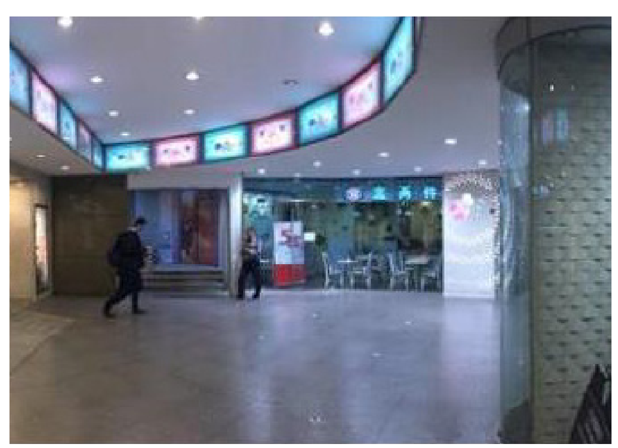
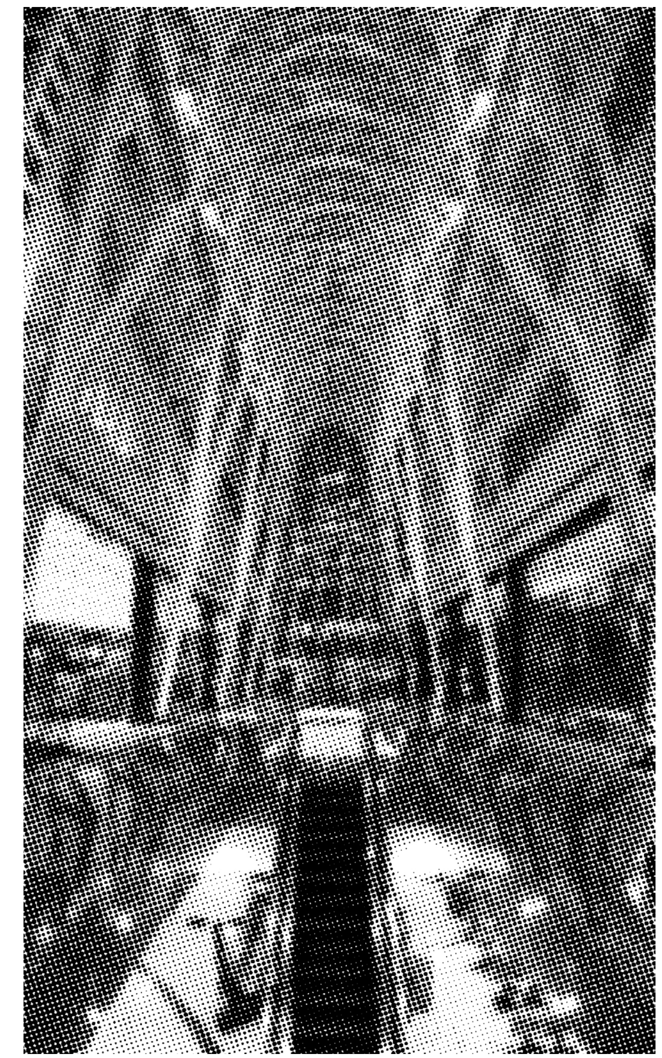


Fig. 2.9: Tinajin's Yingkoudao Station (Source: Anna Lan, Don State Technical University)



3. Problem Focus

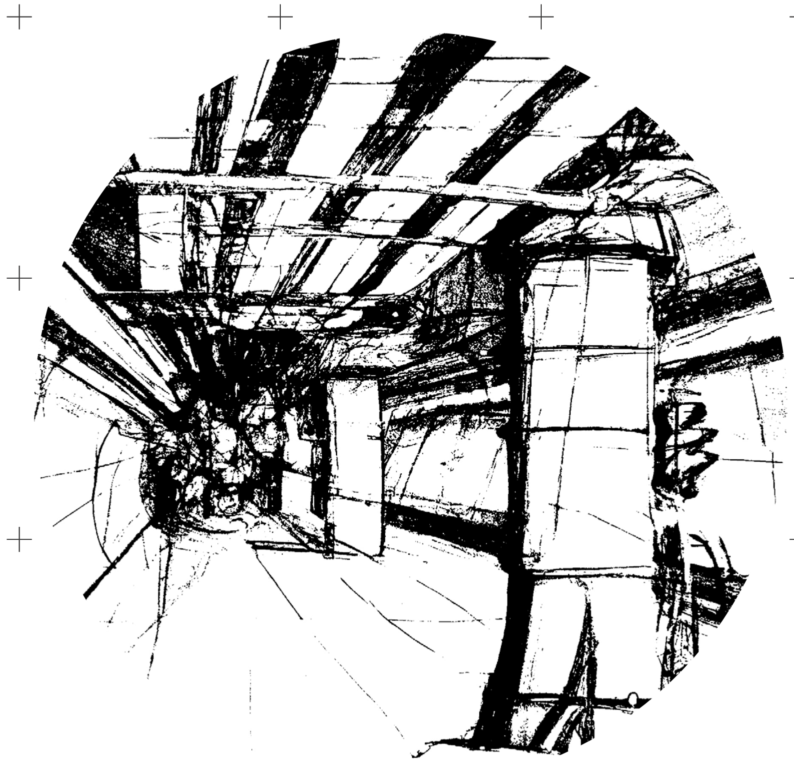
Overview

In a Global environment, the role of subsurface development varies with change in landscape, political structure, actor-domains and availability of infrastructure networks. The Dutch context offers an interesting mix of geological, economic and design parameters of modifying space to incorporate underground spaces. The city chosen to test and evaluate these parameters of subsurface development is Amsterdam, where existing case-based challenges and constraints are illustrated at a macro-scape.

This chapter briefly describes the transition from global to local subsurface visions and potentials. It identifies the role of underground spaces in building future-proof cities and challenges faced in doing so.

Chapter Structure:

a. Subsurface: Global vs Dutch
b. Parameters of space augmentation
c. Role of the subsurface realm



Global Subsurface Inventory

Underground structures around the world are born out of contextual necessities posed by development challenges on surface. The inventory is a pool of learnings in terms to of form typologies, contextual environmental risks, construction techniques with respect to the local soil condition, and programs implemented in subsurface structures. Contrary to popular notions regarding existing underground functions, though parcellated, majority of these spaces are occupied by housing. The remaining uses however, are far from public access, limited to storage, agriculture, infrastructure and utility networks.

The complexity of form decreases with increase in scale of underground spaces subject to construction challenges. The current form does pronounce the need of daylight for orientation and sense of safety in these complexes. The lowest concentration of these spaces is seen in areas with Maritime temperate and oceanic regions due to environmental risk, Netherlands being a part of this context. Subsurface use is essentially irreversible with limited possibility of redevelopment. Any expansion that impacts the formations below the existing water tables can negatively influence resource flows in the surrounding geology, permanently altering the ecological networks. Hence, the implementation and scale of functions of undergorund spaces should be critically informed by in-depth environmental impact assessments on an urban and regional scale.

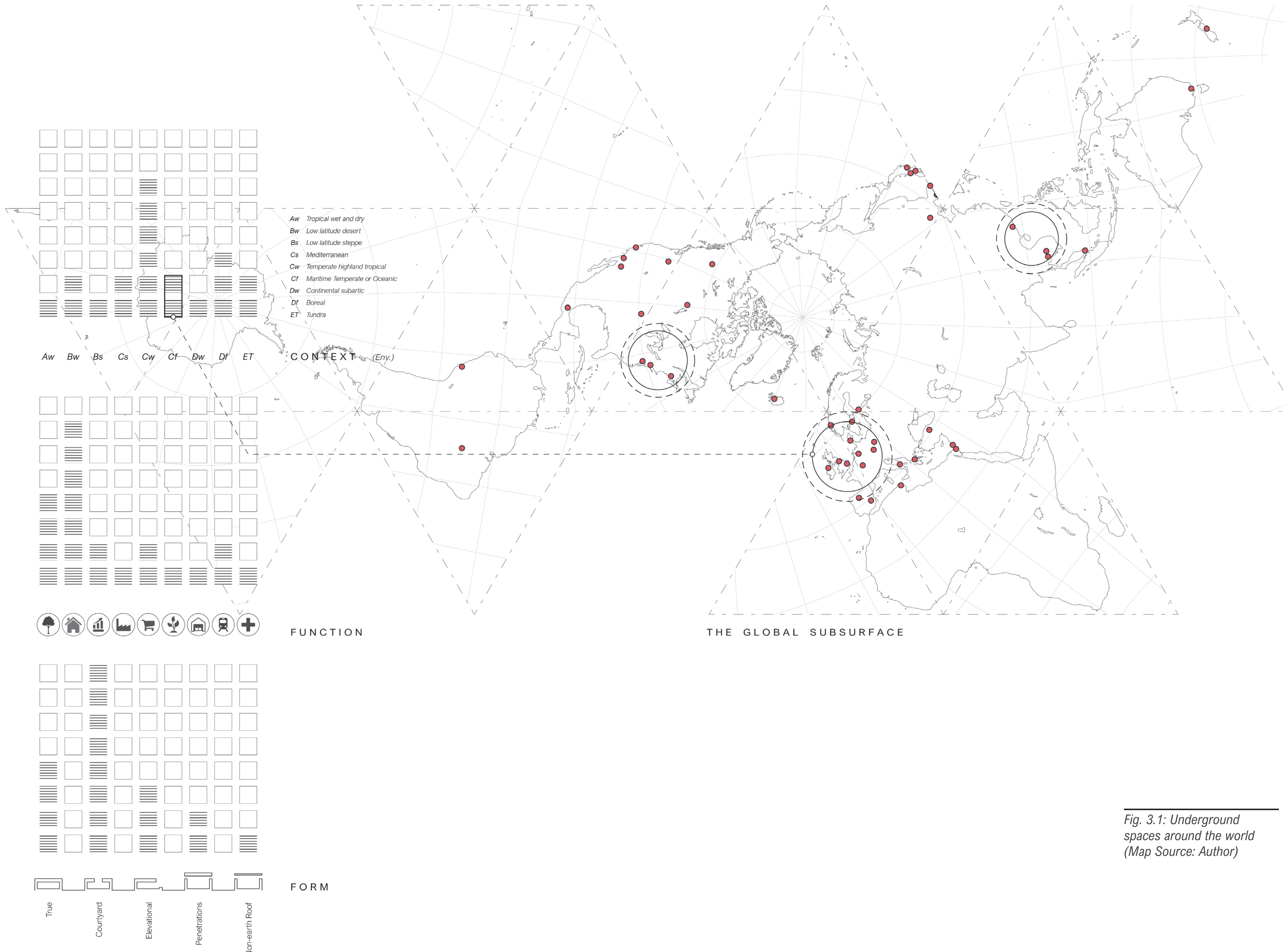


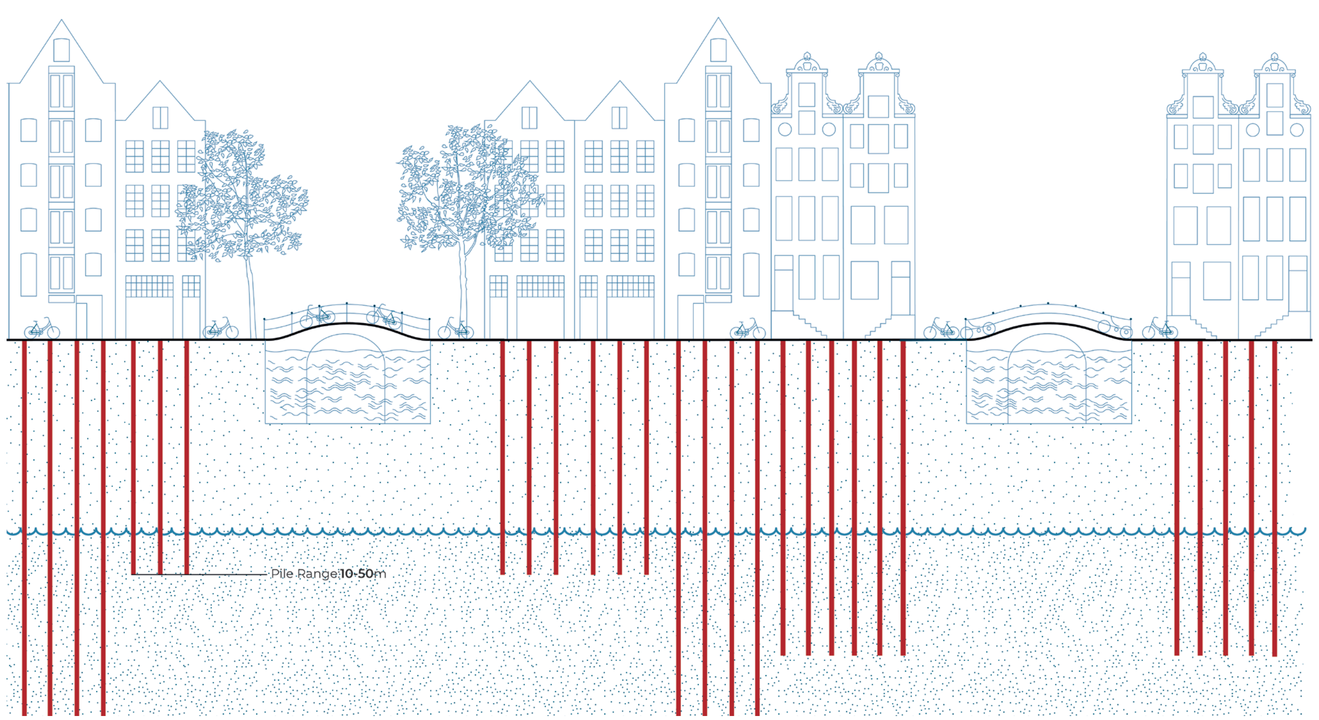
Fig. 3.1: Underground spaces around the world (Map Source: Author)

a. Subsurface: Global vs Dutch

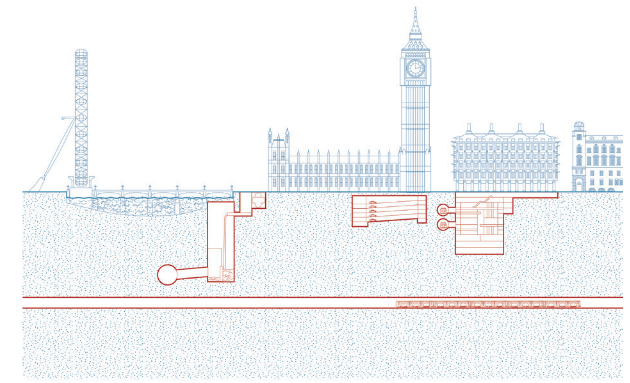
Major cities globally have utilized subsurface for uses like logistics, transit, public space, urban corridors connecting heritage and more. The Dutch landscape is especially delicate to respond to subsurface use at such scale, given risk of subsidence, risk to water table and existing pile foundations.

In Netherlands, municipallities of Zwolle and Arnhem have opted for a 3D approach and volumetric planning with layers including functions, networks and subsurface use like resource storage. The functions layer includes residential areas, commercial nodes, and transit infrastructure. Amsterdam would be well to keep expanding on similar initiatives and national policies. The primary land use planning document for the city and 2040's structural vision carefully outlines six key objectives where underground construction could assist long-term city commitments to building smarter urban environments. Accounting for this context, underground space planning can also contribute to the rising sea-level risks and future climate change.

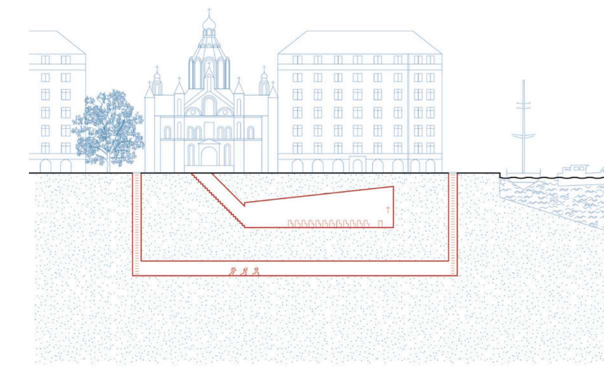
Fig. 3.2: Dutch vs Global use of Subsurface Spaces (Source: Underground Urbanism by Elizabeth Reynolds)



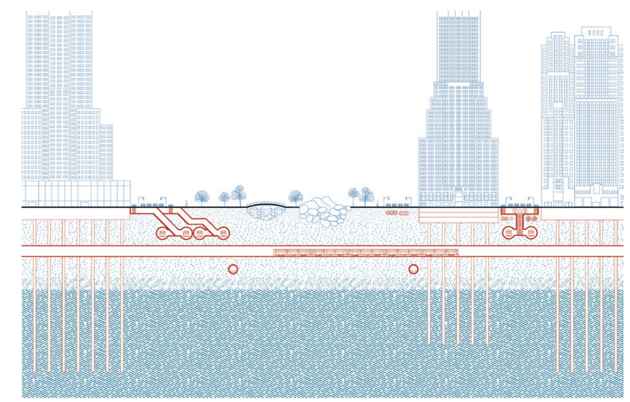
Amsterdam



London



Helsinki



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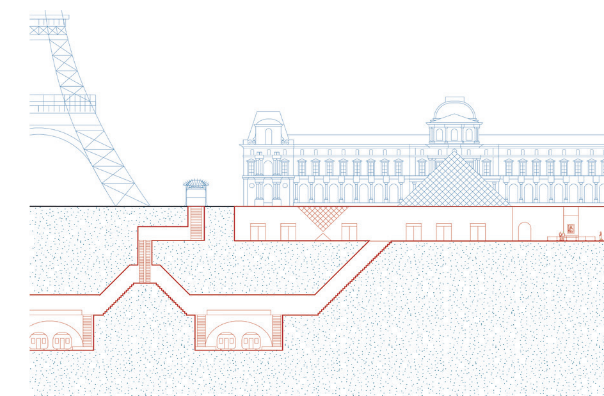
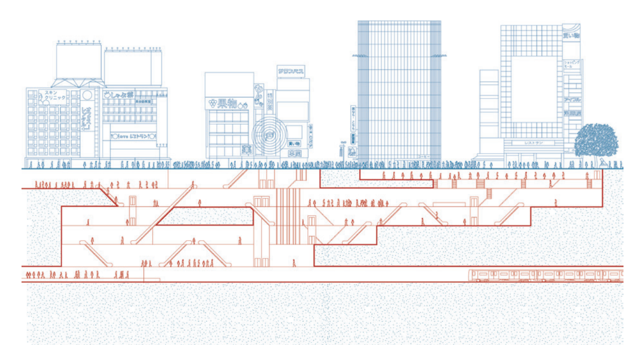


Paris



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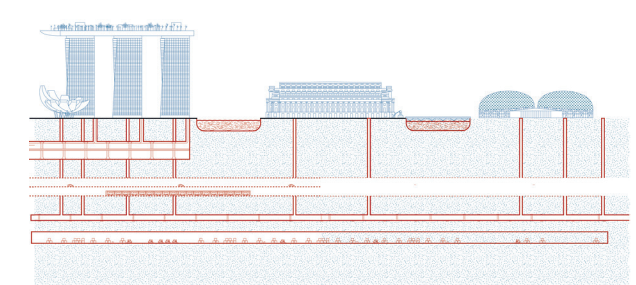
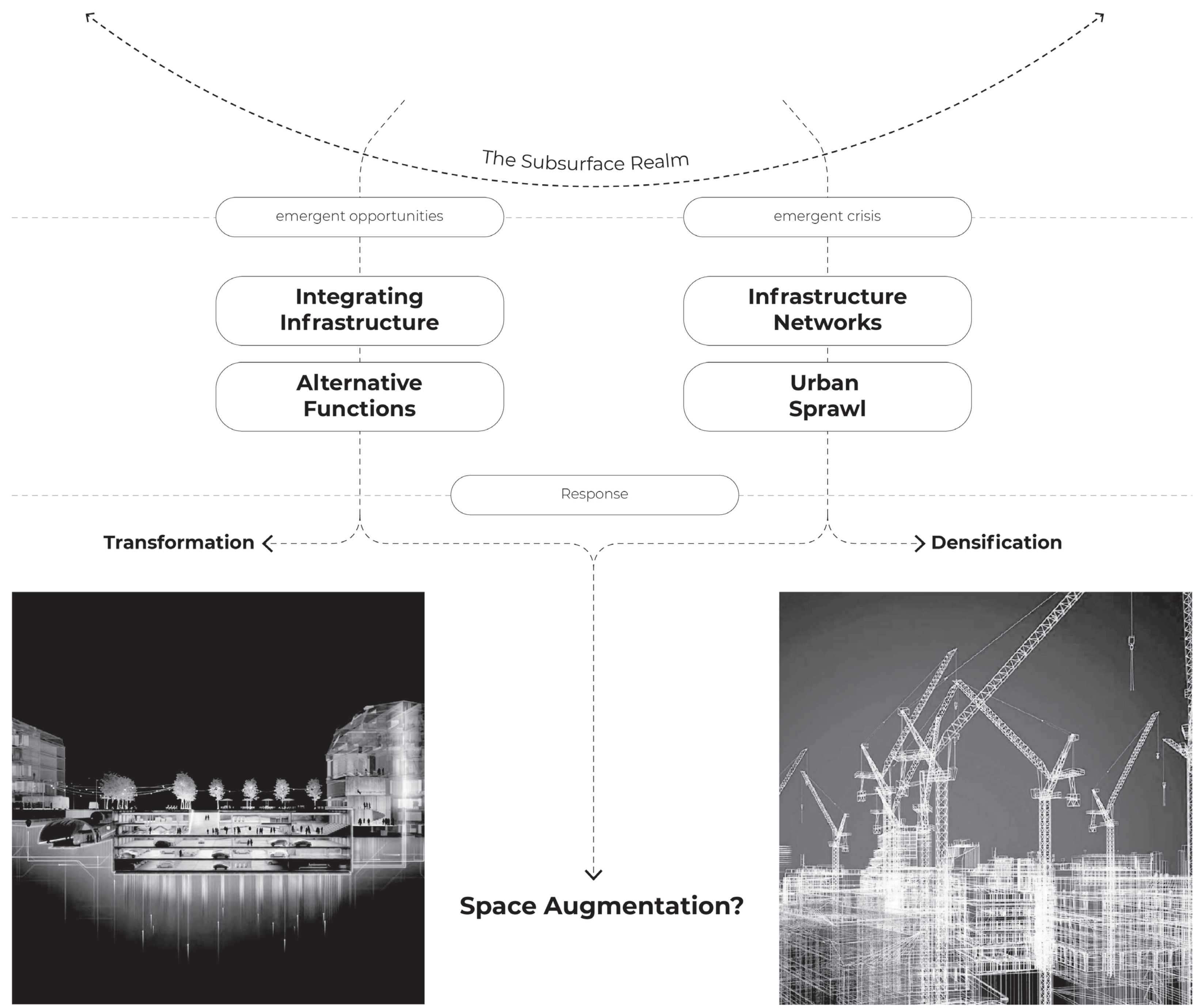
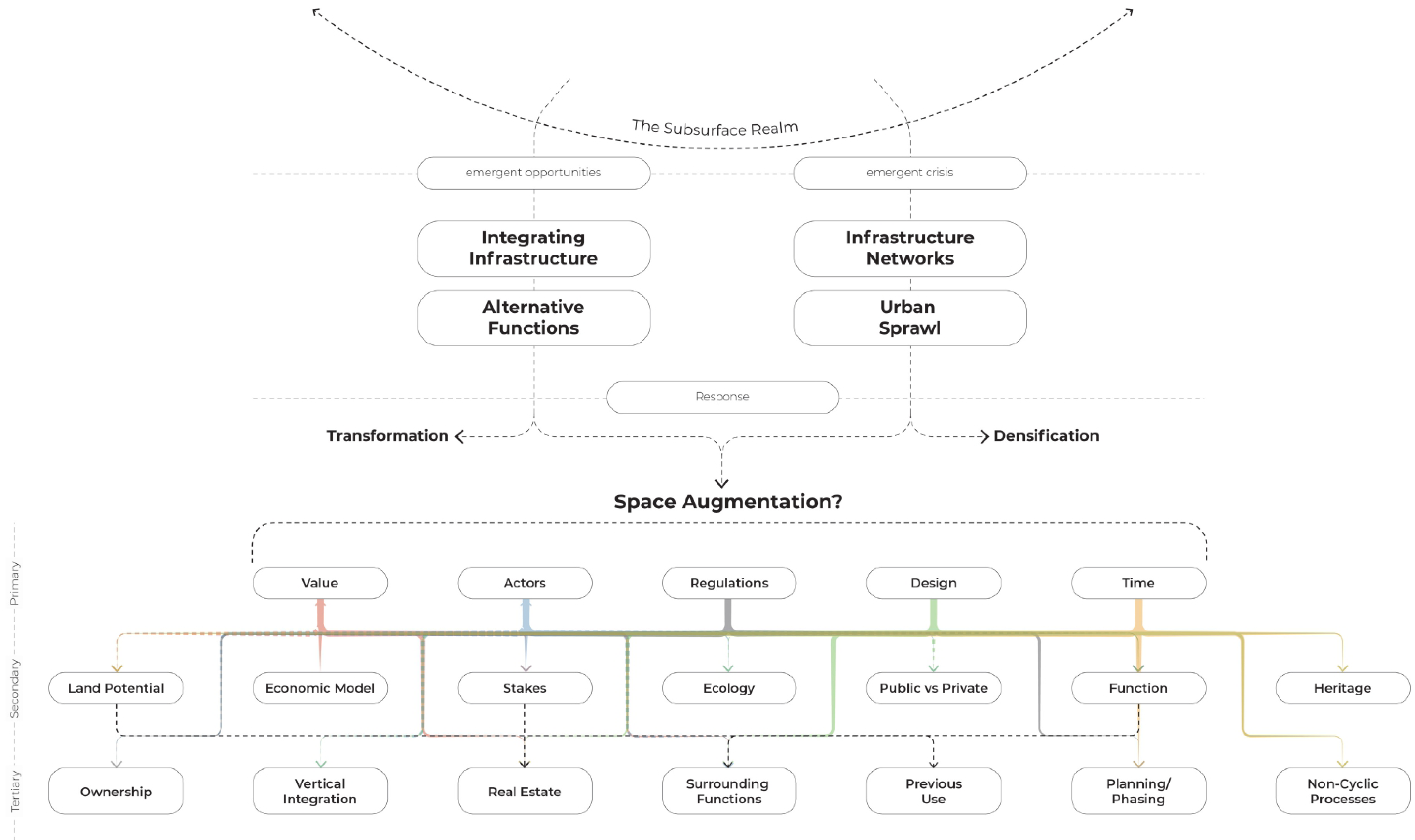


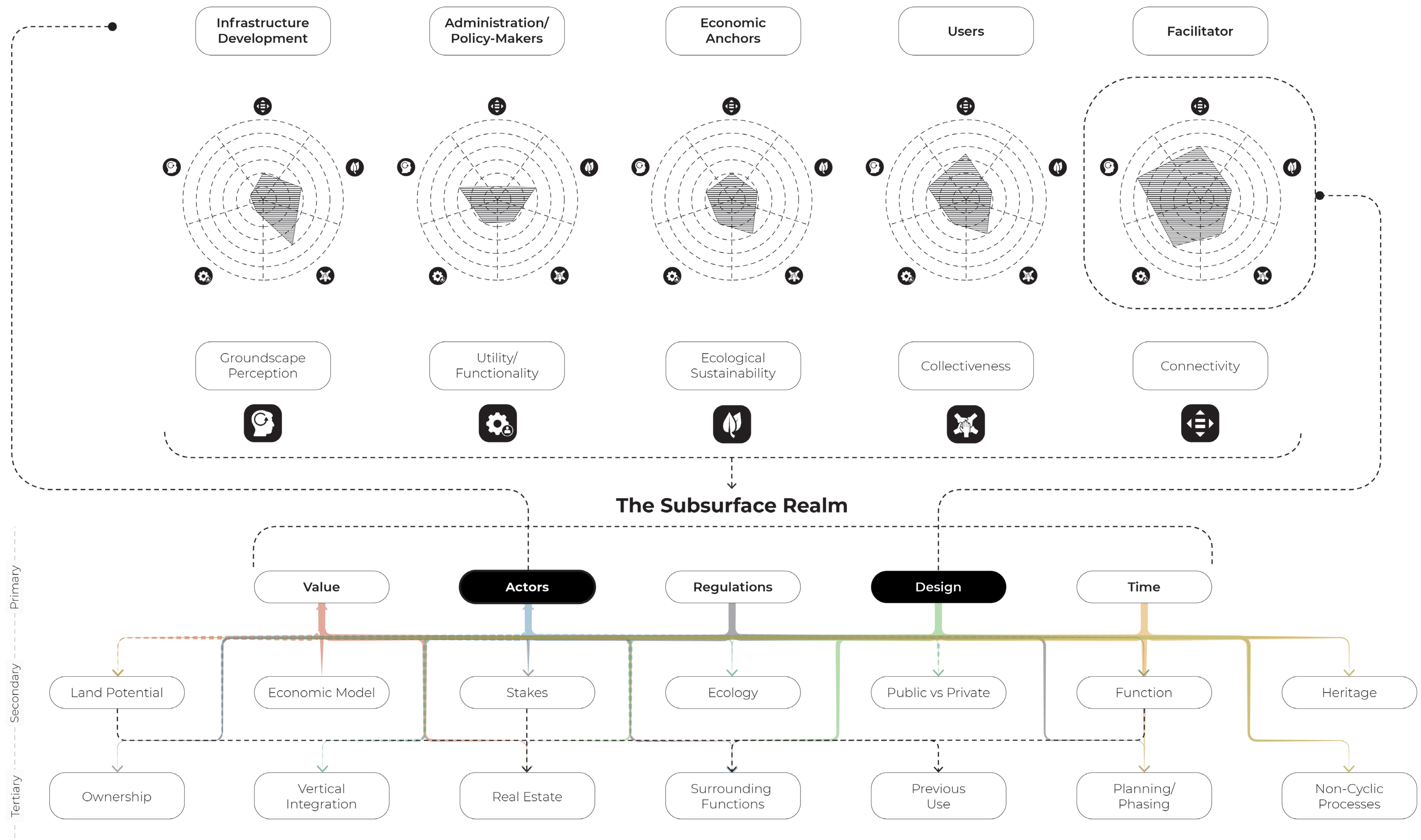
Singapore

b. Parameters of Space Augmentation




The Subsurface Realm
emergent opportunities
emergent crisis
Integrating Infrastructure
Infrastructure Networks
Alternative Functions
Urban Sprawl
Response
Transformation
Densification
Space Augmentation?
Primary
Secondary
Tertiary
Value
Actors
Regulations
Design
Time
Land Potential
Economic Model
Stakes
Ecology
Public vs Private
Function
Heritage
Ownership
Vertical Integration
Real Estate
Surrounding Functions
Previous Use
Planning/ Phasing
Non-Cyclic Processes

c. Role of the Subsurface Realm



4. Research Approach

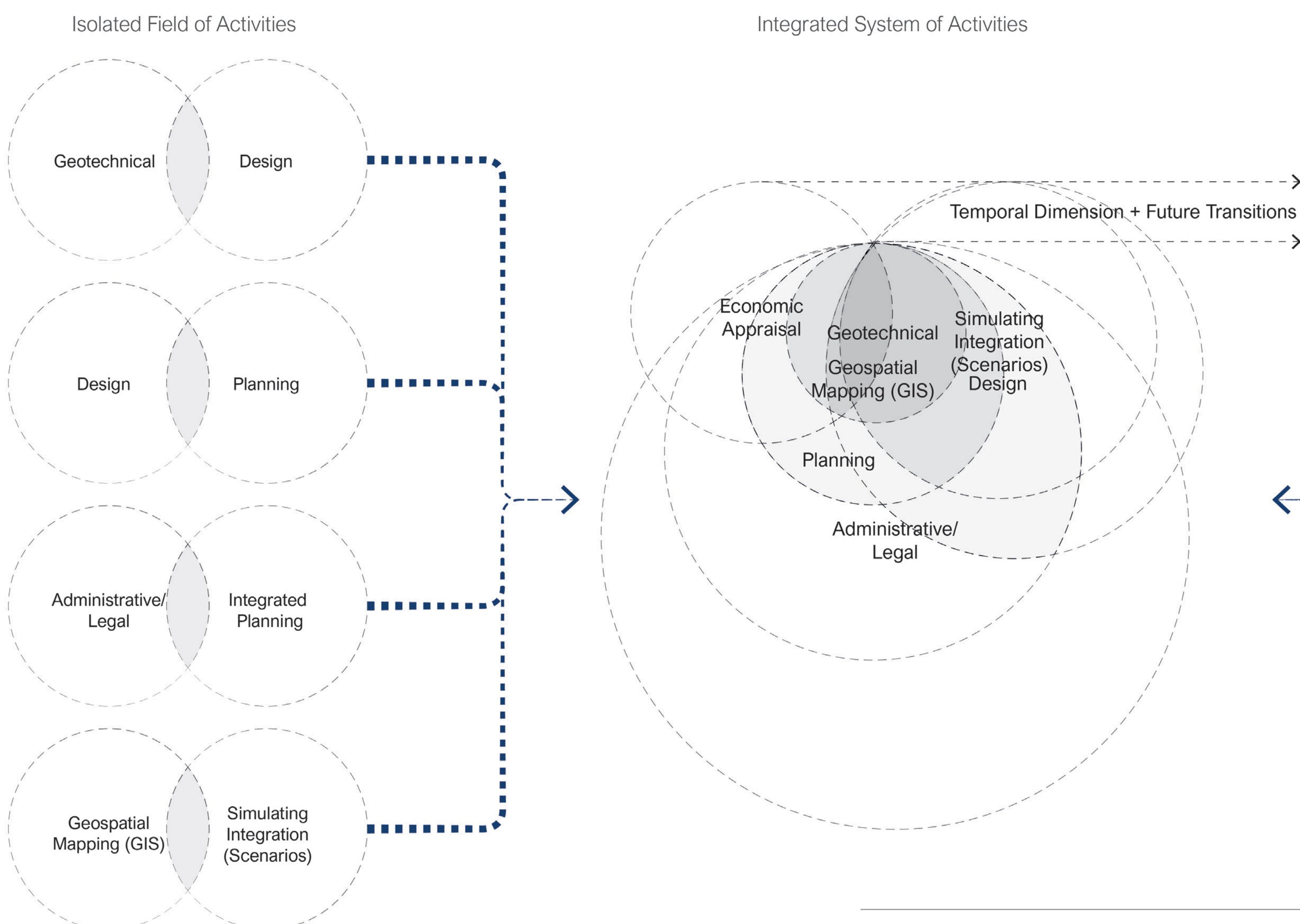
Overview

The following chapter will illustrate the process of developing areas of investigation and proposed research approach. It will describe the problem statement, research objectives and research questions derived from identifying challenges to underground development and evaluating critical subsurface planning approaches in the city of Amsterdam.

Chapter Structure:

a. The Posed Problem
b. Research Aim and Objectives
c. Research Questions

Identifying Areas of Investigation



Research Gaps	Research Aims
Development Projects undertaken at point-scale without considering wider urban impacts and opportunities.	Platform Generation: Interdisciplinarity in designing and planning for underground spaces.
Risk of exploitation: Subsurface regulations are still a relatively unchartered field.	**Volumetric Planning**: Urban development projects should consider 3D phasing and design.
Who are the Users? Existing notions of subsurface yield an unstable mix of public vs private users	**Perception Study**: Identifying needs of different typologies of users to be served by subsurface functions.
U.G. construction is a permanent change in geography. Current functions neglect the need of transition.	Designing U.G. spaces and functions that are conscious of future transitions and transformability.

How can the existing isolated subsurface uses be integrated to form a collective functional geography composed of integrated urban underground systems through design interventions?

- What is the extent of current Underground space inventory in the city of Amsterdam?
- How to map and visualize the existing underground assets in a participatory manner?
- How to integrate isolated project-based underground development into a collective subsurface network?
- How to phase and design the Groundscape according to the needs of public life and infrastructure development?
- How to strategize balanced use of underground space at a city-scale?

a. The Posed Problem

Assessing the potential and planning for zone-based underground space development as a collective functional geography in the city of Amsterdam.

b. Research Aims and Objectives

1. *Platform Generation:* Interdisciplinarity in designing and planning for underground spaces

2. *Volumetric Planning:* Urban development projects should consider 3D phasing and design.

3. *Perception Study:* Identifying needs of different typologies of users to be served by subsurface functions.

4. *Designing:* Underground spaces and functions that are conscious of future transitions and transformability.

c. Research Questions

Primary Research Question:

How can the existing isolated subsurface uses be integrated to form a collective functional geography composed of integrated urban underground systems through design interventions?

Sub-Research Questions:

1. What is the extent of current underground space inventory in the city of Amsterdam?
2. How to map and visualize the existing underground assets in the city of Amsterdam in a participatory manner?
3. How to integrate isolated project-based underground development into a holistic subsurface network?
4. How to phase and design the Groundscape according to the needs of public life and infrastructure development?
5. How to strategize balanced use of underground space at a city-scale?

5. Theoretical Framework

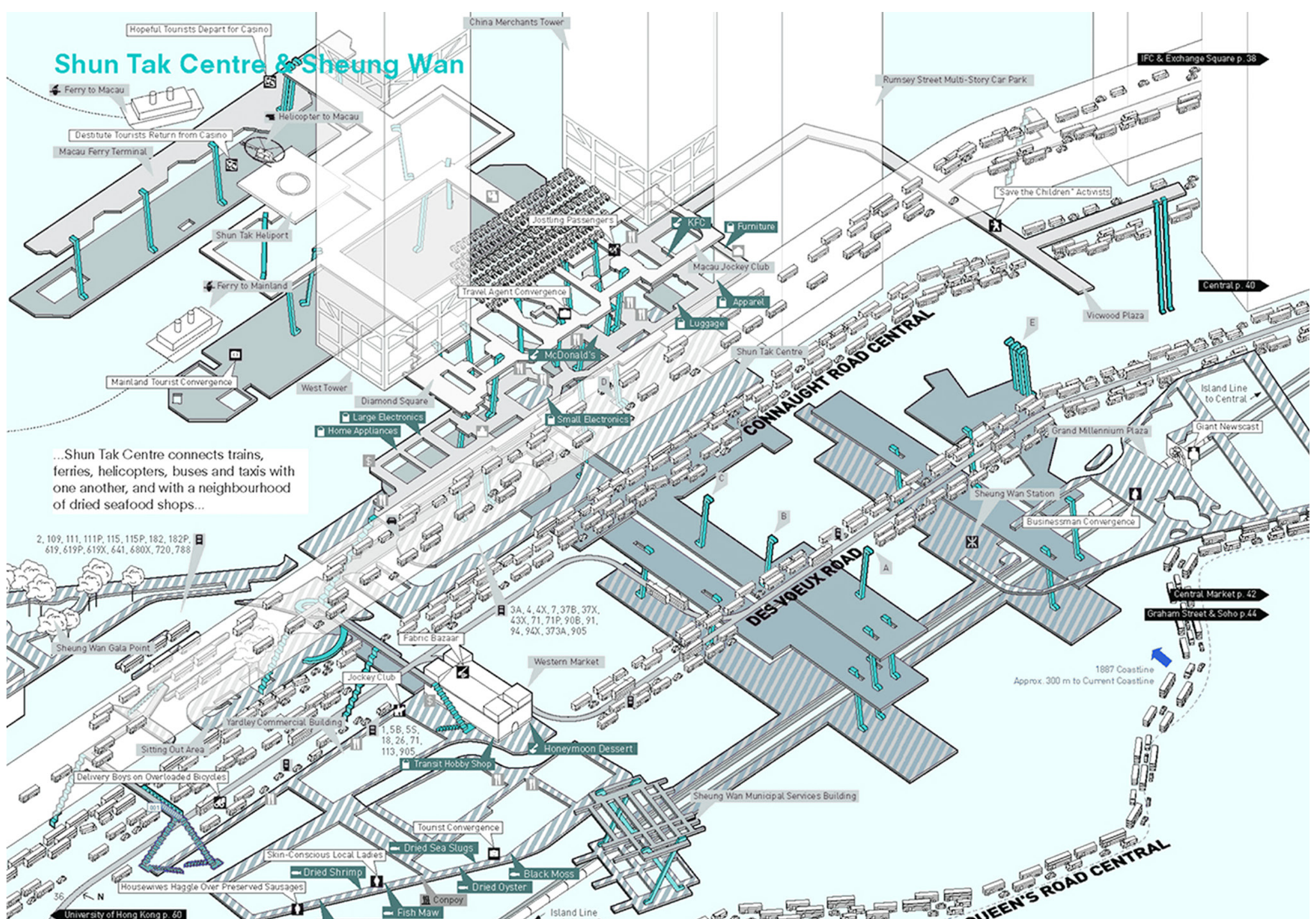
Chapter Structure:

a. The Groundscape

The term groundscape has gone through several derivations and explications over the past few decades from geological separator to a transitional plane between vertical programmatic relationships. Initially associated with exercises to imagine or visualize public-private spatial relationships, groundscape lent connections to density of functions and the percieved distance between them through underlying infrastructure landscape. The idea of visualizing the surface as a separate element instead of a traditional constant while analysing figure-ground of urban areas revealed complex 3-dimensional networks of circulation flowing through various functions. These networks shape a continuous volume of assorted environments serving as a spectacle as well as a resource for cities. Here, the groundscape emerges as a void-enclosing lid instead of an opaque volume that reconceptualizes the idea of surface and its importance.

Jonathan Solomon in his book '*Cities Without Ground*' discusses the verticality of the surface itself, including the networks of movement, solids, and shell-based voids inhabited by it. The concept is useful in rethinking structure of constantly densifying urban systems. Since the primary aim of underground space development is time-sensitive opportunity-capturing of public space between dense infrastructure landscapes, Groundscape can be used as a tool to reveal the subsurface as a system of activites connected to the surface as opposed to a parallel realm of functions. This helps in establishing the mutually influential relationship between overground and underground.

Fig. 5.1: Shun Tak Center visualized as a vertical system of functions(Source: Cities without Ground: A Hong Kong Guidebook)



The use of groundscape in revealing the subsurface is not particularly centered around doing away with the surface layer in its entirety. Rather, it is aimed at lending transparency to the surface to view it as a connective tissue at its interface with the cultural life of tube-mapping for complex systems such as London's subsurface infrastructure. The gradual obliviation of these systems form memory with time makes it challenging to plan new infrastructures with the vertical understanding of figure-ground in dense metro cities. It helps reveal value beyond 'space', venturing into resource value, socio-economic understanding and user's perception. The concept assists documentation as well as designing of stable entrances into these exsiting tube-systems accounting for risks and impacts to their attachments to built environment. Building walls are treated as connective paths, surfaces of engagement, delineating roads from unique construction mechanisms.

The governing ethics of planning a city and it morphology is affected primarily by function and void. Their scale, density and multiplicity of linkages defines future urban solutions while holding a historic narrative of city evolution in context. The loss of traditional street with the introduciton of the groundscape drives focus of vision development towards city blocks as indexes of the future city. Harteveld's exploration of typological relations between subways and skyways in '*Interior Public Space*' (2014) rids the consideration of planes beyond these volumes to focus on the quality and understanding of interior systems as urban corridors. Though lending the same purpose of movement of entities, the location of these volumes above or below the groundscape often differentiates the functions occupied by them, segregating citizens and infrastructure.

Rowe Colin and Koetter Fred unearthed the connections of vertical volumes with their work in Collage City in 1984, documenting typologies of accessibility of built environment taking shape of Nolli maps. This research intends to use these methods of documentation to enhance the understanding of infrastructural figure ground in 3 dimensions instead of points-and-lines networks. Here, the groundscape is used as a tool to reveal existing inventory of space for subsurface transformation. Assisted by mapping technologies of current digital transition i.e. scanning the subsurface can be an essential outcome for municipalities to prepare platforms for co-creation with respective actors linked to subsurface construction. The documented volumes can be an exhibition for users to percieve the projected environments and reconfigure their existing notions of social safety and orientations attached to underground spaces.

Visualizing the vertical city in terms of accessible volumes questions the materiality of the inaccessible volumes for both skyways and subways. They can be considered as reserves of spatial resource for the public in the future, be it the fillers between toronto's subway system, the air over grand central station or the subsoil beneath Connaught place. At present, the networks existing between these urban corridors in the vertical realm are the priority nodes for urban transformation, acting as spines for sprawling functions, the foundations of growth for collective overground and subsurface cities.

Fig. 5.2: Subway System, Toronto (Source: Interior Public Space by Maurice Harteveld)

The Groundscape Method
Concept by Dominique Perrault

Groundscape, a neologism product of combining two components of a geography i.e., ground and landscape, is a recent field of research functioning primarily at an architectural scale. It deals with construction, understanding and innovation in the field of subterranean architecture, exploring generation of visionary atmospheres at the conjoint membranes of surface and underground, paving way for urbanists and architects to explores tools and strategies to expand scope of what lies beneath the surface. The concepts is intended at extending nature into the soil, extending light to the subsurface resulting in a continuous landscape on surface by bringing the roof down.

Groundscape is the architectural use of civil engineering, collectivizing the use of resource and connecting existing functions to create a well-integrated vibrant geography. It can house superstructures like train lines, power plants, storage facilities and urban streets. Manifesting the groundscape involves a process of working backwards from developing fictions to realizing it as a project by overlaying physcial restrictions and constraints. The groundscape is supported by three pillars for this research, to be translated into categories for the design parameters in further discussion :

- Form
- Ecology
- Socio-Economic Aspects

Keeping the deepest end of an underground space opens it to the sky. Groundscape, as a membrane functions in this way to extend the surface to great depths while helping users to percieve underground similar to the street levels. The process enables densifying the city without raising its height profile with multi-level neighborhoods, complementing the existing surface. The new ground does not exist as a place for closure, but allows users to have an architectural walk within the ground, making them feel more connected to the geography.

Fig. 5.3: Designing the Groundscape within Arc d'triomphe
Source: Dominique Perrault Architects

b. Methods of Groundscape Design

The primary concept of morphing the groundscape is not guided by permanently residing underground. It is aimed at revealing and locating places for active surfaces and materials within the earth itself. Designing this membrane should bring forth innovative catalysts for network integration, respect for geological resources, appreciation of existing heritage and providing incisions to 'enter the subsoil'.

The design of groundscape can be categorized on the basis of the types and multiplicity of surfaces it engages with i.e., the lower ground, roof, surrounding walls, approach and the volume it generates. Different types of surface enable different movements, visual connections, orientations and sense of volume to the users. These contributions include:

- Protrusions: reconfiguring the form of engaged surfaces to provide new uses to the void.
- Exhibition: monumentalization of unique construction techniques and ecological elements to establish visual connection.
- Experience: modifying the nature of and time of user's movement to generate a range of experiences.
- Habitation: treating the surfaces involved as individual volumes instead of planes, housing unique functions.

Experimenting with the surfaces used and their functional contributions provides us with a matrix of typologies of groundscape entry design that can be used to reconfigure the vertical transitional experience during the research by design exercise for this project.

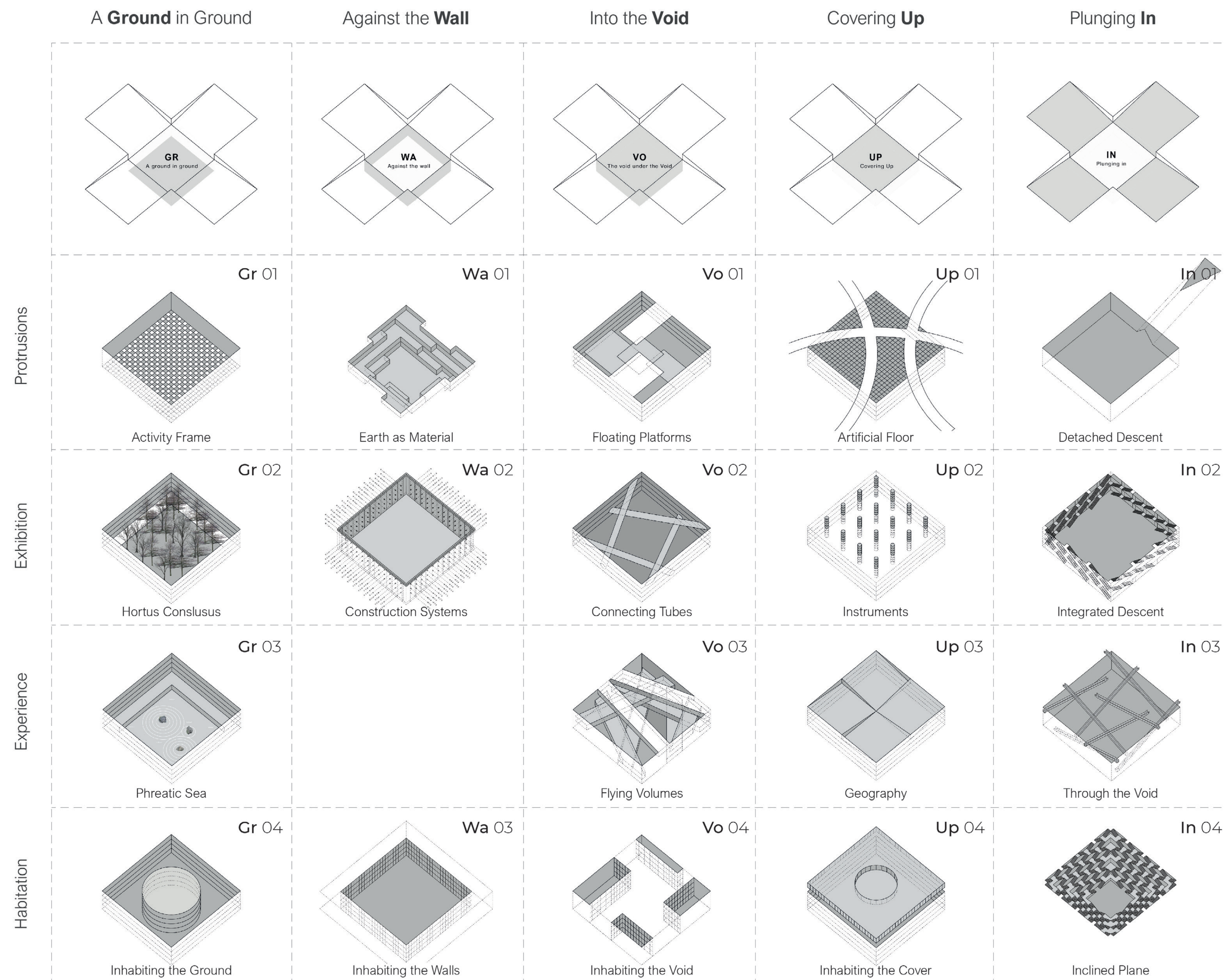
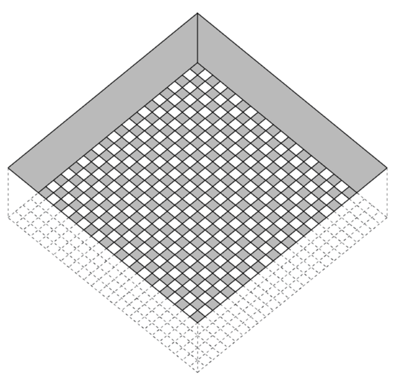


Fig. 5.4: Groundscape design methods(Source: DPA-X)

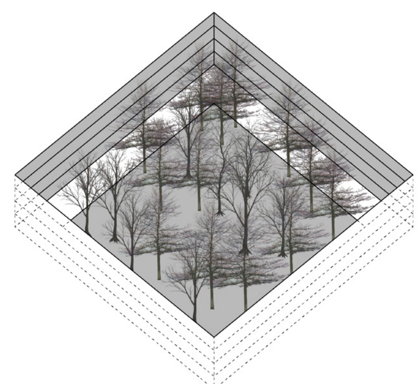
A **Ground** in Ground **(GR)**

A platform or usable surface can be found at the bottom of the well, the bottom of the vacuum that has been formed. The activity center that needs to be colonized is then this open surface. This foundation can be utilized as a gathering place for events or meetings, similar to a public square surrounded by buildings. This base will be able to draw attention to itself like an amphitheater or a stadium surrounded by bleachers.

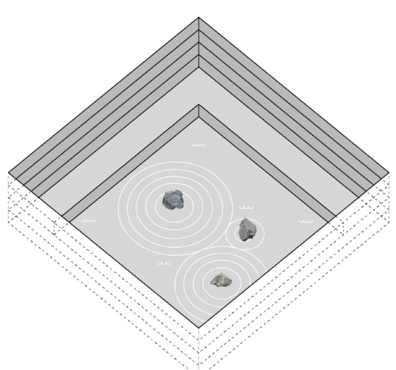
1. The base of the void is an empty available surface
2. The Naturalization of the void through the production of vegetation. The use of the base as a fertile surface.
3. The naturalization of the underground through one of its fundamental components: the water
4. The use of the base of the void as a foundation surface upon which to build new available volumes.



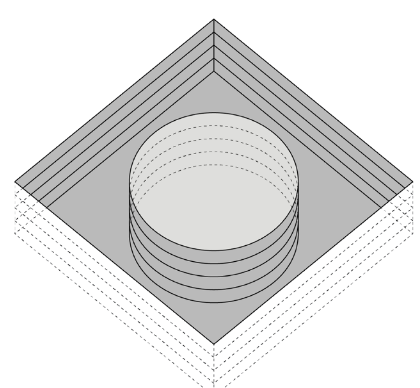
The bottom of the created vacuum, the bottom of the well, constitutes a platform, an available surface. By nature, this base is framed by partitions, walls. Like a public square surrounded by buildings, This base can be used as a meeting points, for gatherings or events. Like an amphitheatre or a stadium surrounded by bleachers, base will be able to attract all eyes to it.



To invent under the surface shared public spaces, urban domains of a new kind, it is necessary to somehow naturalize the underground, create an environment, i.e. all conditions that allow the extension of above-ground life into a space that is not abstract, a space that resonates physiologically where the body feels protected by what surrounds it.



This groundwater table is a layer that can be found at shallow depths. It traditionally supplies wells and springs with drinking water. On the other hand, let us take again the example of the well, the void base naturally becomes the perfect place to collect rainwater like a glass that fills up in the same way as the impluvium in the Roman domus.

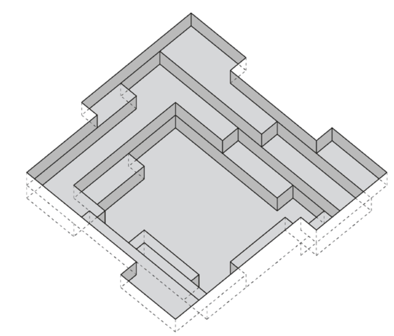


This descent system is detached from the main volume, creating a walk at the end of which is found the main volume . The disappearance of architecture in order to leave stronger and more present the remains and ruins of a camp that saw the disappearance of many populations. It is a tribute by the absence to omissions.

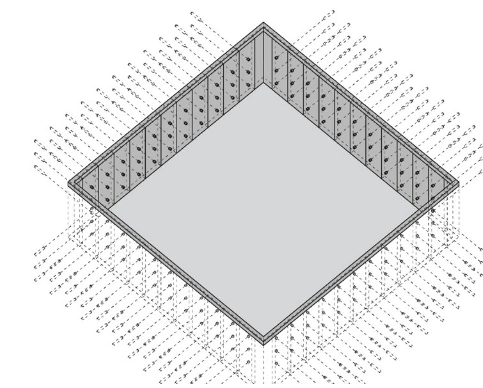
Against the **Wall (Wa)**

In order to construct a basement, one must obviously dig the ground. Afterward, this exposed dirt serves as the main component of underground construction. It will cover us, enclose us, and shelter us. Thus, a distinct interaction with this element is suggested by The Groundscape. Instead of concealing them, it is important to concentrate on the excavation techniques that have been employed,.

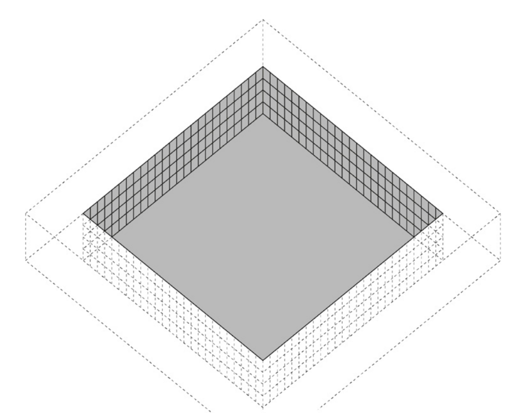
1. The showcase of the specific geophysical nature of a certain site
2. The showcase of the different engineering techniques that allow to dig into the earth.
3. Thickecning of the walls of the void to accomodate programs. The wall as a facade.



Formal negotiation has no control over the geographical context of a location. This constraint will create an irreducible specificity on which the architectural project can be developed. It is necessary to requalify the interventions on the sites, to take into account the complex materiality of each situation, to respect the material specificity of contexts.



To create verticality by resisting soil pressure, we use mostly civil engineering techniques. These construction methods isolate from the geophysical environment. These elements of infrastructure, usually meant to be concealed, to be burried, have an existence of their own and give a specific meaning to the places that will be built.

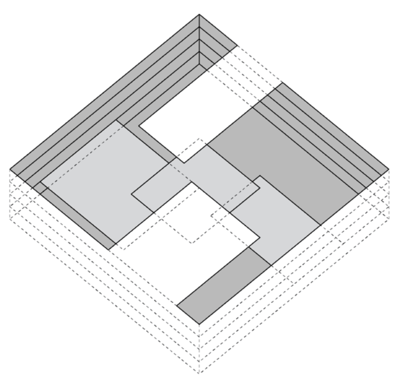


Inhabiting the surface in depth and use it as a new facade. In all this work of intervention on soil surfaces, there are open areas outside, accessible to natural light and other areas are in the back, hidden. It's a new morphological situation. The facade in this case will be in relation with light while the back will be in relation with the depths of the soil.

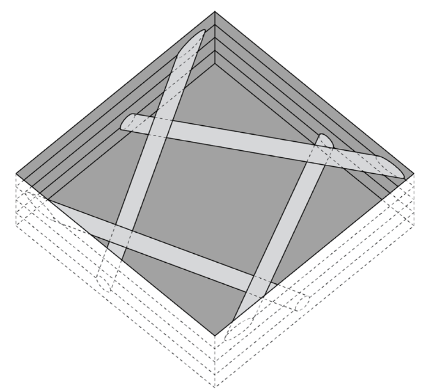
Into the **Void (Vo)**

It is possible to colonize or depart the vacuum once it has been established. Through tubes, connection platforms, ethereal volumes, or inhabited volumes in all of their depth, it can be colonized. Then, it becomes conceivable to consider other tactics. Vacuum could end up being a gadget component that is programmed.

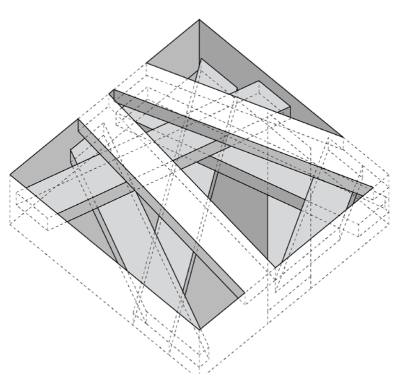
1. The decomposition of the ground surface in to layers.
2. The creation of links between the walls through connecting tubes.
3. Subsurface archaeological assets should be accounted for as constraints to underground construction.
4. Devising regulations to extent of land owned underground leads to efficient zone-based spatial planning of subsurface.



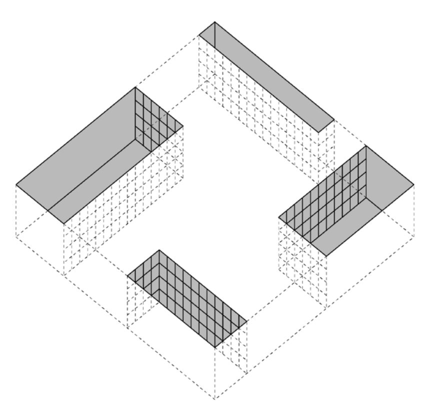
Here, it is a plating, a constitutive detachment of a succession of levels, first the surface of this first leaf of soil, then of the second then of the third and so on, thus multiplying the resources in terms of living space. At the scale of a few centimeters, each plate creates a succession of spaces which follow one another by multiplying the uses and potentialities.



A concentric composition that is to say a heart around which different satellites revolve, each serving different platforms. A series of escalators are implanted into this void which connect the different levels of access to the platforms. These gateways are used to reach the different satellites which can be accessed through an underground gallery.



s part of the Danish National Maritime Museum, the architect Bjarke Ingels has chosen to preserve the dry dock proposed as the site's intervention site instead of filling it up as the other competitors did. He chose to preserve this void and build the museum around this dock and, at points, to occupy this void by installing passages, footbridges and amphitheatres.

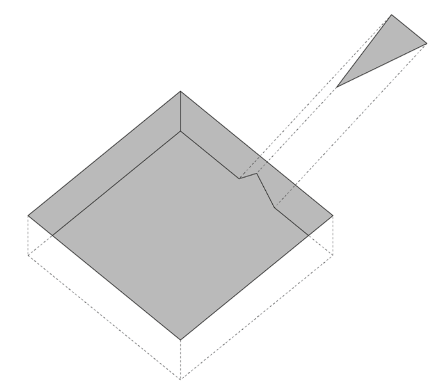


In Graz, Austria, architects Nieto and Sobejano invest in depth the space inside the courtyard of a museum in order to extend the available surfaces while creating patios that provide light or access to this new floor. In short, vacuum can become a programmed element of the device.

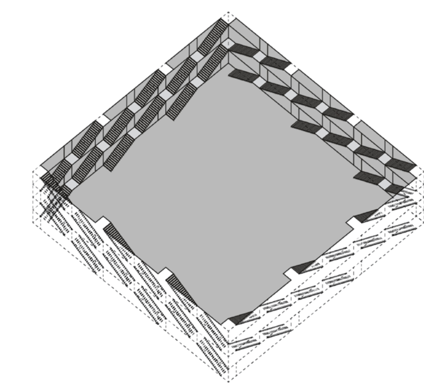
Plunging **In**

The issue of access to this new ground, this new territory at these underground or semi-buried levels is crucial in the context of underground architecture, Groundscape, as we have defined it, in order to ensure both the quality of these spaces as well as the success of the development of these new territories in the city. Different technologies and installations of these descent systems are conceivable.

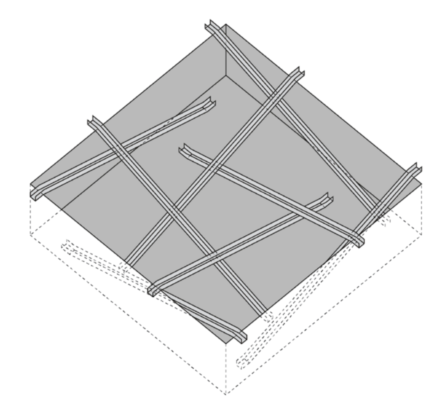
1. Remote descent. Separation of the descent strategy from the main void.
2. The thickening of the walls of the void to accommodate the descent.
3. The descent to the groundscape across the interior of the void.
4. The transformation of the walls of the void into a sloping public space.



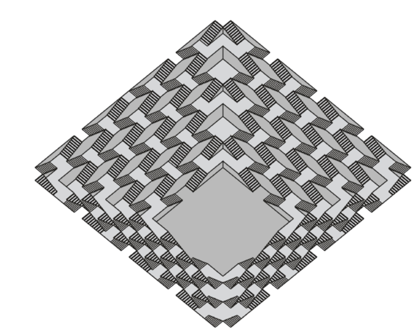
The ramp leading to the site is located a few dozen meters away and thus recalls the steps at the front of a site. This inverted system of descent allows to keep the principle of procession to the heart of the building. The detached descent mechanism only reveals the space of the church at the end of a long, narrow and dark procession.



It is possible to go down through the walls encasing the void themselves. This is the typology that has been adopted in Italy in the well of Saint Patrice in Orvieto. This incorporates a spiral staircase, parallel to the well walls. Direct contact with the void creates openings that will illuminate the steps down to the deepest part of the well.



This system brings an almost physical relationship with the void that surrounds us. At the London Zoo, the architect Berthold Lubetkin created an icon of modernism and an emblematic example of underground architecture. In the 1934 penguin pool, two intertwined white ramps go through the space and descend down to the pool.

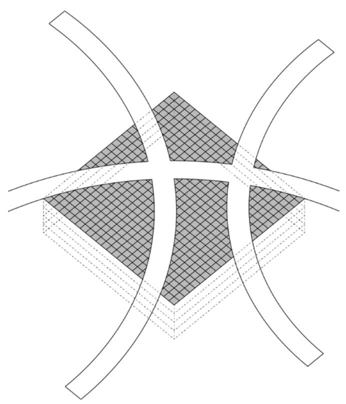


The Indian wells have propagating step systems, multiple or single, which can be occupied like a multi-level public space and can accommodate informal uses. A similar descent mechanism has been put in place at the Ewha women's university. A large ramp on one side and a monumental staircase on the other side provide access in the deepest part of the valley.

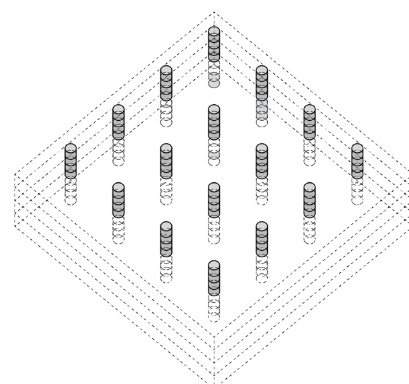
Covering **Up**

For certain applications, it might be practical or required to fill the produced void for thermal, climatic, or functional reasons. Here, we'll go over a number of various methods for colonizing the void's upper surface. It can therefore be employed as an optical device to increase the amount of light entering the void; a simple roof covering from the outside enables the invention of new landscapes.

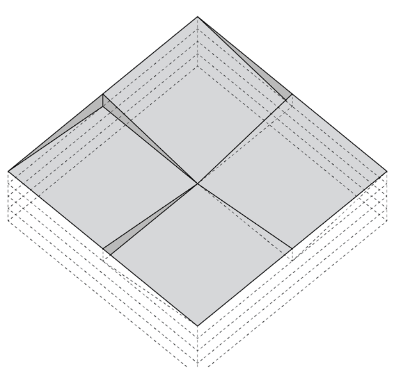
1. The transformation of the ground surface into a horizontal facade.
2. The transformation of the ground surface through the use of scientific knowledge of optics technology.
3. The creation of a new topography through the physical manipulation of the territory.
4. The thickening of the cover of the void to accommodate volumes and programs.



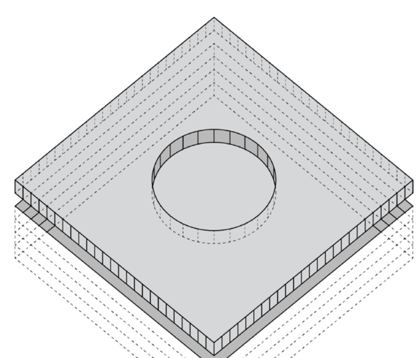
This cover can become the identity of the building. It will then be necessary to preserve it and to study its expressiveness, its materiality and also its urban coherence. The naturally lit extension of the groundscape can be located in the basement. The composition of the glass floor should be adapted to the needs in light, ventilation.



One of the challenges for the Groundscape is to respond to prejudices according to which the underground is a dark, somber universe, technical, even criminal. The use of optical instruments and of new technologies that are available today for light capture is becoming an increasingly relevant new research axis.



Drawing on the freedom of intervention on topography, it is not a question of constructing buildings but of creating devices, the set of mechanisms that transform one place into another. The Groundscape thus defines potentially a geography, a thickness of the soil that will replace the flatness of the urban fabric to put this relief into perspective.



This volume of opaque appearance from the outside is actually made of translucent marble slabs that filter the light inside the library. The Hilversum Media Center, built by Dutch architects Neutelings Riedijk, proposes to organize the various programs in three volumes separated by a large atrium. In the basement, there are five levels of archives.

c. Socio-Economic Parameters

The research delves into several parameters influencing the socio-economic constraints to groundscape design centered around value, complexity and network of actors with respect to temporality and contribution towards quality and experience of underground space. The field of parameters are described by respective actor domains. These constraints are aimed at bringing stakeholders together and helping generate a platform that enables co-creation. The process of shortlisting the parameters involves critical analysis of modes and terminologies used during participatory exercises taking into account common expertise, cultural backgrounds and insights of respective actors.

Although the parameter field for spatial quality and integration stretches wider than the scope of this research, the ones chosen have siginficant impact on functionality, ecological sustainability and perception of the subsurface.

Fig. 5.5: Activity field of actors attached to subsurface construction (Source: Author)

Actor Domains					Activity Field	Outcome
User-Ended	Future User	Visitors			Design | Planning	How to Navigate Groundscape?
Administrators	Municipality	Landowners	PPP	Heritage	Planning | Economic Appraisal	How to Govern Underground?
Facilitators	Urbanist	Architect	Engineer		Planning | Administrative	
Infrastructure Co.	Power/Energy	Logistics	Parking		Geospatial | Simulation	
Commercial Inhabitants	Shoppers	Offices	Shopkeepers		Design | Economic Appraisal	How to Design the Underground?

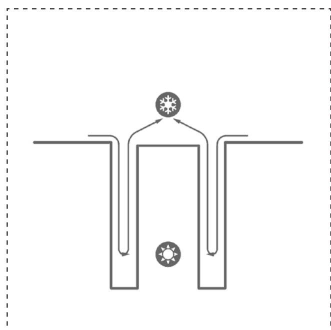
Impact Typology

Perception	Collectiveness
Ecological Sustainability	Connectivity
Utility/ Functionality	

Infrastructure

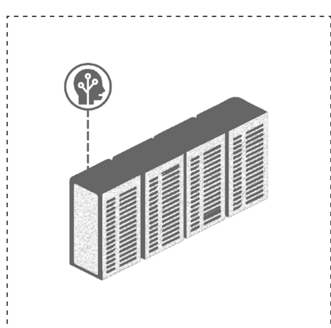
Infrastructure networks act as connections between subsurface nodes through ensuring flow of services and resources, essentially the spine of underground spatial network. The stakeholders involved in supply of these networks require careful consideration of long-term urban viability and economic feasibility of infrastructure before construction.

I1



A step towards CO_2 neutrality for underground spaces, heat exchangers help with dehumidification through transition of water from walls to air. In this manner, temperature of the underground space can be maintained in all seasons. In summer, there is an abundance of cool water, which can be offered as city cooling, for the replacement of air-conditioning in buildings above-ground.

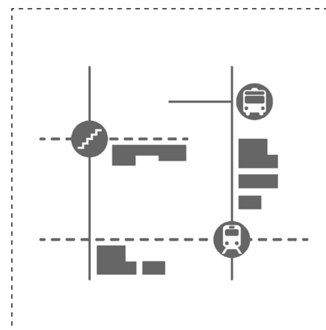
I2



Locating data storage and servers directly beneath host centers provides regulatory and economic convenience to manage operations while occupying least surface area. This raises the value of the real estate and at the same time moderates the use of city outskirts as data terminals by consolidating technical infrastructure within deep underground spaces.

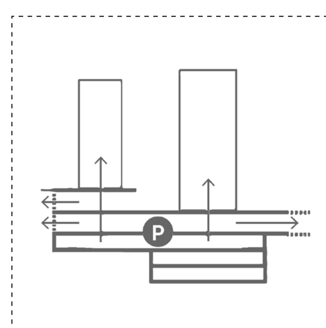
1. Application of diaphragm walls reduces additional energy to cool or heat underground spaces
2. Integrating underground MRT and access roads lends an efficient traffic structure
3. Deep underground spaces provide opportunity to locate servers.
4. Underused underground Carparks will evolve into local service providers to new mobilities.

I1



Underground integrated transit creates more space in the inner city for squares and public green spaces on surface that were previously dominated by car traffic. Via existing network of shafts and underground pavillions, a fine-meshed network of entrances can be developed to offer a series of accessible functions by both car-traffic and public transport like MRTS.

I3

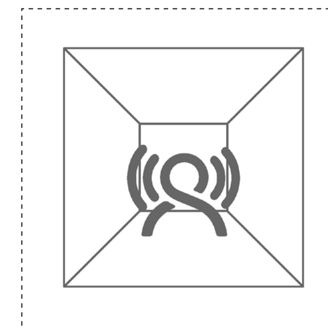


The sustainable trends in mobility are part of the broader optimisation of space in high-density high-value urban areas in paraller with the search for sustainable solutions. In this case, underground infrastructures are particularly relevant, especially when they are already built and ready to be converted. Future carparks will cease to be a closed concrete box to become a site of connections to multiple transport lines.

Users

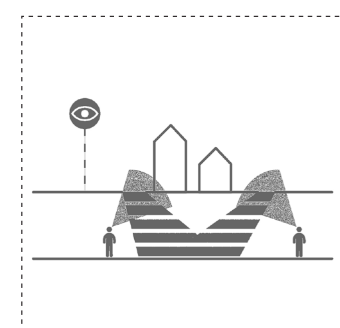
The typologies of users vary according to the programs and functions constituted by subsurface spaces. Their perception of such spaces changes according to these functions, physical design, and amount of time spent underground. Users may include shoppers, pedestrians, employees, owners etc.

U1



Realized UUS (Urban Underground Space) projects in the past few decades have faced considerable public criticism concerning qualitative factors and psychological conventions. The withdrawal of the perceived sense of control and safety in hidden/hiding spaces from the user often pick remarks of neglect, darkness and isolation lacking 'eyes on the street'.

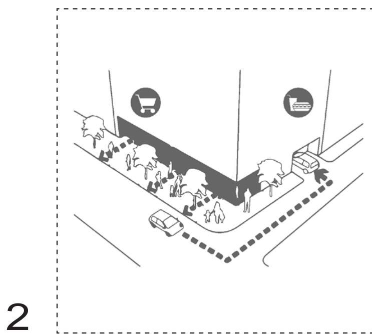
U3



The uncertainties of subsurface as a new reality question its existence in a context that fractures the conventional urban image. However, the primary challenge for the future subsurface realm is to tackle its susceptibility to generate a negative perception. To eliminate the feeling of uncertainty, connection to surface helps users to orient themselves with memory.

1. Subsurface is prone to insinuate a sense of enclosure psychologically associated with loss of orientation and claustrophobia
2. Functions like shopfronts and food and beverage centers invite flow of people to activate underground spaces.
3. Visual or Virtual link to surface instills sense of orientation among users.

U2



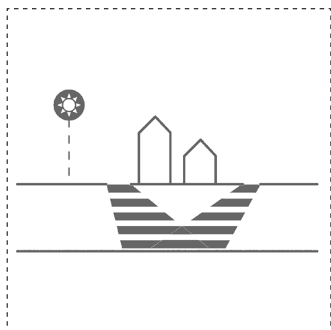
Allocation of seamless walkable retail frontages and food and beverage spaces activate linear underground spaces and higher flow of people prevents voids that feel unsafe to users. The highstreet character also maintains a sense of orientation for users through intuitive street knowledge as users psychologically depend on active frontages for assigning landmarks.

Facilitator

Facilitators constitute the maximum impact of quality and experience of underground spaces since their expertise is attached to design, allocation and structural integrity of subsurface nodes. Their sub-domains are closely interlinked and hence, require consistent collaboration and communication to ensure spatial coherence. These involve designers, engineers, developers etc.

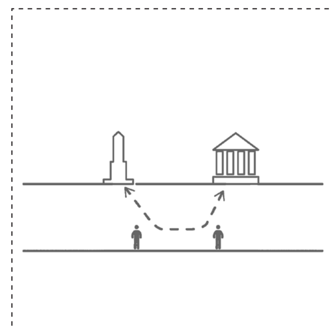
1. Daylight can be manipulated underground, inducing a sense of volume, orientation & connection.
2. The fabrication of monumentality not through physical presence.
3. Extent of placing public functions below ground is inversely proportional to depth of subsurface construction.
4. Soil as a material around Subsurface construction offers increased wind protection and acoustics insulation.

F1



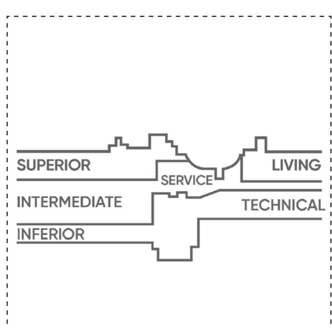
People are used to living aboveground. Underground spaces misses two important qualities of the surface: orientation and light. Daylight can be used as an instrument - one could even call it a network - where the easily grasped reorganization of the interior and its streamlined interfaces facilitate and humanize the processing of voluminous flows. The spaces autonomy is strengthened without eliminating direct access.

F2



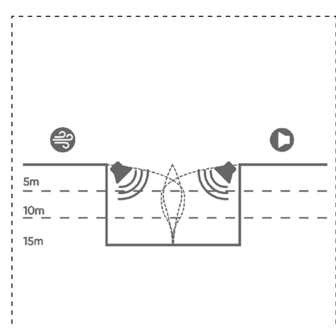
The Groundscape offers opportunities to contain very large programs and permeable public spaces in places of impenetrable constructions like heritage where building on surface might pose restrictions acocrding to bylaws and may also hinder visual connections to monumentality of surface anchors. The value of sursurface voids here lies in establishing valuable urban connections.

F3



The development of overground strategy, surface interface and descent mechanism should adhere to the subconscious need of attachment to surface for public functions. Hence, the vertical zoning of functions should place public uses closer to surface while deeper regions can be used for technical and service uses like infrastructure networks and data storage.

F4



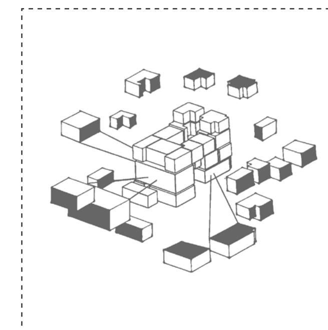
Soil's epidermis i.e., the space of transition possesses higher intertial mass and atmospheric stability that decreases the need of external energy input underground. This eliminates superficial and cosmetic interventions in favour of circulatory and volumetric transformations. Building techniques should be coherent to these geophysical conditions.

Administration

Regulating and maintaining balance of ownership of underground space falls under the domain of public and private organizations whose goals and demands respectively shape the maximum and achievable underground spaces on the basis of feasibility, spatial demand, environmental risks, social risks, economic opportunities and so on.

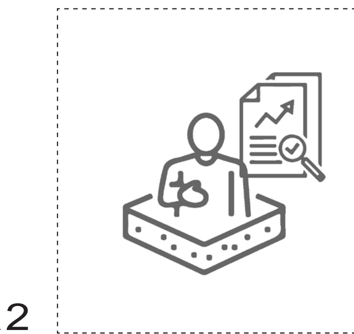
1. Subsurface volumes can be integrated with spatial planning by making four-dimensional space workable.
2. Devising regulations to extent of land owned underground leads to efficient zone-based spatial planning of subsurface.
3. Subsurface archaeological assets should be accounted for as constraints to underground construction.

A1



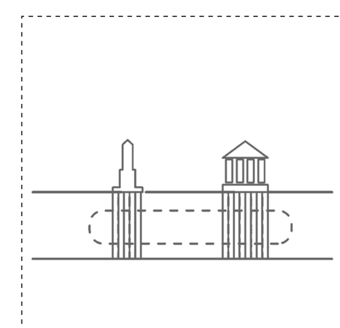
Spatial planning is a complicated puzzle that becomes even more complex due to major system transitions. Due to the scarcity of space, the possibilities in the subsurface are gaining ground. In order to make the values of smarter land use readable, we must learn to think, plan and design differently. From 2D to 3D and then to 4D. Adding the dimension time increases the spatial efficiency even more.

A2



In a city where space is becoming increasingly scarce and the demand for space is increasing, the urgency of better underground use of space is growing. Lack of appropriate regulations regarding ownership of underground spaces poses risk of exploitation by private sector by building superbasements below office spaces that effect the natural ecosystems underground.

A3



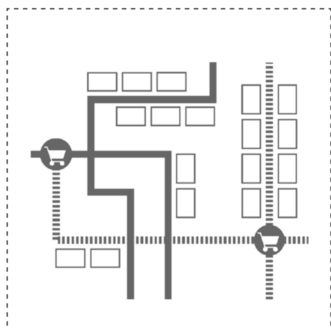
City centres consist of spaces with heritage significance as well as congestion in terms of residences, offices, transit networks and commerce. Urban redevelopment cost in these spaces spike high with irregular trends. In order to address the feasibility issues to utilize underground space, a study of size forecasting, municipal and transport facilities, spatial distribution is essential.

Commercial Anchors

Since construction and maintenance of underground spaces is considerably more capital-intensive than overground functions, allocation of space for retail and commerce is an important propeller of activity in the subsurface. The willingness to shift for these anchors describes the projection of functional supply within nodes and corridors.

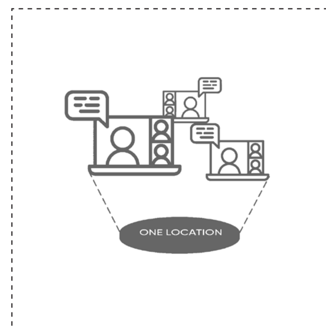
1. Linear shopping lanes help percieve volume and seamless transition between surface and underground.
2. Similar to coworking spaces, these have been upcoming as an efficient choice for small business establishments.
3. Subsurface optimizes logistics services by facilitating last-mile delivery and warehousing.

C1



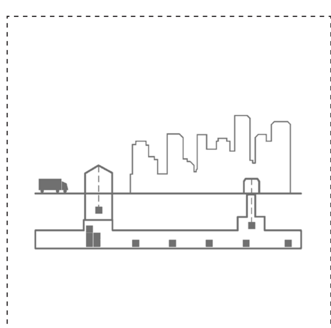
Linear shopping resembles the characteristics of a high streets and hence, induces perception of conventional shopping similar to surface streets. It also generates flow of people making underground spaces appealing for commercial anchors that in-turn activate the surface with wider functions. This also prevents inductive social segregation with seamless transitions to the surface.

C2



Underground real estate in commercial sector shows a majority preference in small-sized offices working in coworking spaces linked to fretail stores, which is an up and coming typology for office spaces. The potential rise in demand may also make way for even newer typologies like Virtual offices which essentially provide locational advantage to new business establishments which cannot afford high rentals like that of the city centres.

C3



Large-scale warehouses are conventionally placed on city periphery laying considerable pressure on road infrastructure to incorporate large vehicular traffic. Subsurface superhighways provide networks for last-mile delivery, especially for commercial and retail purposes. They can also make use of existing underground public transportation to substiture freight traffic.

d. Methods to map the Subsurface

The current debate around the sense of in-betweenness induced by digitalization is dichotomous, with some postulates considering the detrimental impacts of network cities concerning detachment and delocalization, while others support the creation of space for local empowerment and collective action. Increasing ubiquitous interfaces are gradually softening the combined experience of 'here' (physical environment) and 'there' (virtual environment) (Floridi, 2014). One of the essential products of this rapid transition has been the generation of a superset enabling simulation, reception, and enhancement of the real urban environment i.e., Digital Twin (Hassani, Huang, & MacFeely, 2022).

Current urban Digital Twins only account for surface assets to be interacted with and simulated for projecting impacts of development projects. However, with the recent shifts in construction trends with the onset of compact cities and a high rate of urbanization, subsurface construction has been gaining appeal among developers, city planners, and utility companies. The subsurface in cities is layered with a dense infrastructure landscape. An increase in infrastructure construction and the potential of designing public spaces underground makes it imperative for the subsurface spaces to be visualized and incorporated in the existing Digital Twins for cities. This research involves a literature review to devise a suitable methodology to use LiDAR technology to visualize underground spaces and analyze their potential to be used in 3D Digital Twins by different stakeholders depending on several parameters of technological suitability.

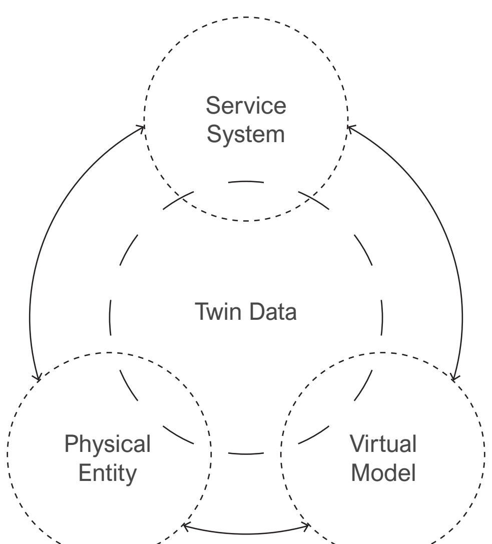


Fig. 5.6: Dimensions virtual city models

Volumetric Planning

The current debate around the sense of in-betweenness induced by digitalization is dichotomous, with some postulates considering the detrimental impacts of network cities concerning detachment and delocalization, while others support the creation of space for local empowerment and collective action. Increasing ubiquitous interfaces are gradually softening the combined experience of 'here' (physical environment) and 'there' (virtual environment) (Floridi, 2014). One of the essential products of this rapid transition has been the generation of a superset enabling simulation, reception, and enhancement of the real urban environment i.e., Digital Twin (Hassani, Huang, & MacFeely, 2022).

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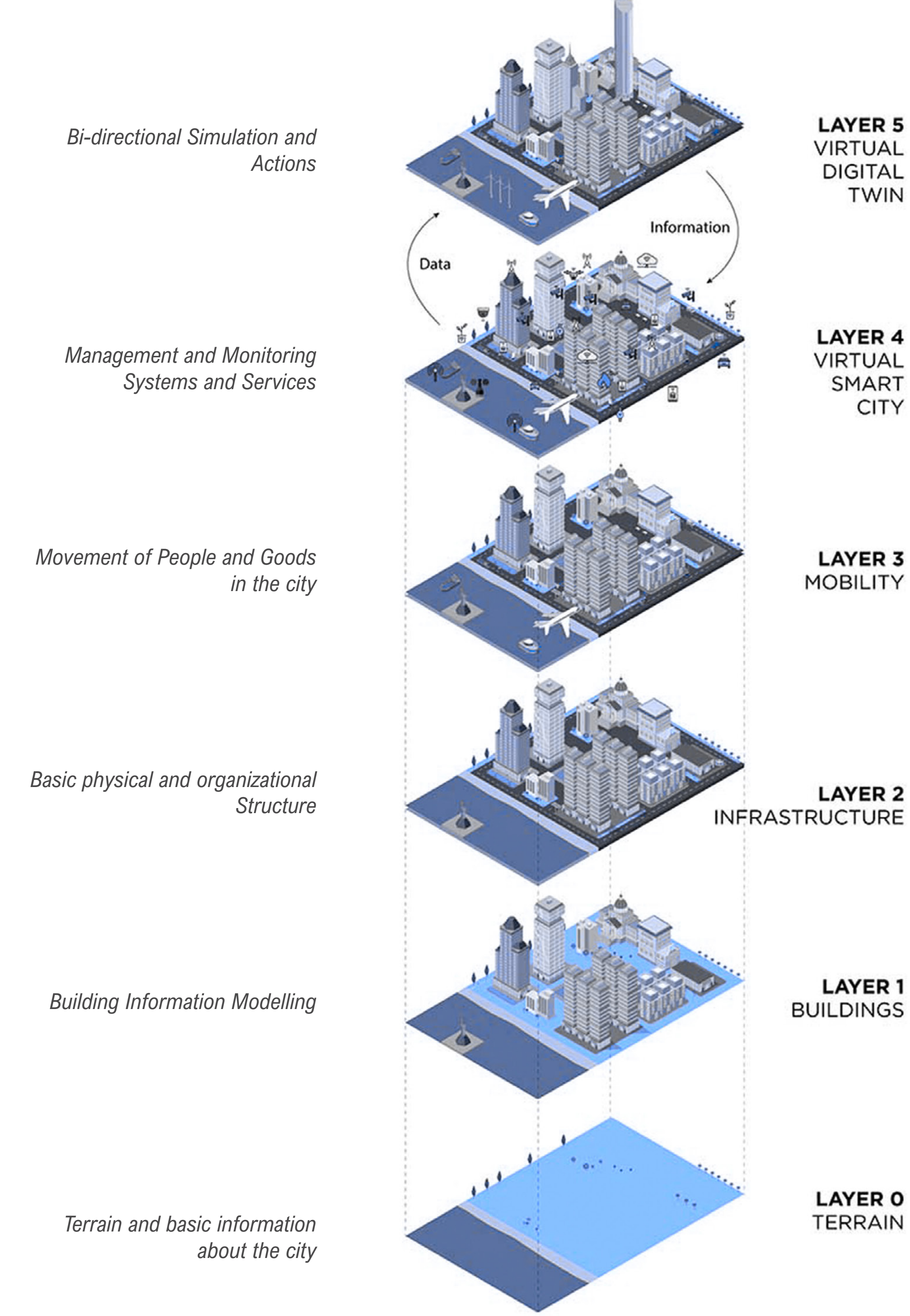
Against the context of rapid digitalization and emerging technologies, the nature and rate of urban development have substantially increased within the last three decades. Ubiquitous technology has played a major role in propelling planning practices with intelligence. Consequently, the perception and management of urban resources, primarily land have progressed beyond two-dimensional allocation frameworks. Digital Twin technology is equipped to assist 3-D volumetric planning processes in terms of visualizing space, alleviating perception, real-estate appraisal, sustainable design, and risk assessment (Shao & Wang, 2022). The integrated platform generation provided by this tool presents opportunities to consolidate a wide spectrum of spatial layers beyond the surface. While Big data and cloud computing help approach accurate real-time planning and mitigation for urban areas, the ability to visualize underground spaces and infrastructure is still limited to a point-and-line system consisting of pipelines, subways, parking spaces, and commercial facilities. Global initiatives like 'No Net Land-Take by 2050' proposed by the European Commission place pressure on the existing underground space to augment spatial and functional reserves for compact city planning (European Commission , 2016).

Fig. 5.7: Mapping and Simulating Layers of Cities(Source: American Planning Association)



Visualizing the city in 3-Dimensions

The municipality of Amsterdam partnered with several institutions including the University of Amsterdam and The Amsterdam Institute of Humanities Research in 2019 to develop a temporal 3D urban model of Amsterdam. The model known as 3D Amsterdam (Figure 2) enables the mapping of semi-automated pipelines/workflows, socio-historical data, and green-blue networks within the city using the semi-automatic generation of buildings and rule-based parametric modeling strategy. The approach ensures time-efficient mapping and query generation assisted by GIS (University of Amsterdam, 2019). 3D Amsterdam is an open-source interactive platform offering a digital copy of the city to run simulations and project potential impacts of urban strategies before implementation (Openresearch. Amsterdam, 2021). The platform also facilitated several innovative research initiatives such as:

- Simulation of Tree Root Growth
- Individual step detection and segmentation in Urban point clouds
- Living with Water in Amsterdam

The platform is currently growing in terms of accessibility and participatory planning, the flow of information being unidirectional at this stage. However, the municipality of Amsterdam intends to augment the platform's spatial elements and functionalities to allow bi-directional interaction, color, materialization, traffic simulation, and improved geometric quality. Among these functional demands, one of the major ones is the addition of underground infrastructure, sewer systems, pipes, and cables. The municipality managed to update the subsurface point-and-line networks by December 2020. However, spatializing subsurface urban corridors is still limited by data availability, satellite-mapping constraints, and point-cloud data generation by CityEngine software.

Mapping the Subsurface using LiDAR

When combined, Underground LiDAR (Light Detection and Ranging) scanning and Digital Twin technology can provide valuable insights into underground infrastructure. This can help city planners and engineers to identify potential issues and optimize the design of underground infrastructure to improve its efficiency, safety, and sustainability. For instance, a detailed 3D model of an underground utility network can be used to identify areas where the network is at capacity and plan for expansion.

Digital twin technology can also be used for monitoring and maintenance of underground infrastructure, which can help to reduce downtime and improve overall performance. In addition, Digital twin technology can provide an interactive visualization of underground infrastructure, making it easier for stakeholders and decision-makers to understand and analyze the data. This can facilitate communication between different departments and organizations, and help to ensure that the best decisions are made for the community. Spatially documenting the subsurface presents several constraints and specifications dealing with typology and availability of resources. With recent technological developments, various LiDAR scanning devices show the potential to document urban underground systems to create detailed 3D environments. The range of scanners each has its own unique applications, features, and capabilities.

It is essential to ensure that underground project objectives are properly aligned with the needs and concerns of the citizens of Amsterdam and that the formulated urban strategies are effective and well-informed. With the range of possibilities and availability constraints of LiDAR technology, documentation of subsurface assets to incorporate the spatial underground environment in the current Digital Twin of Amsterdam i.e., 3D Amsterdam, there exists an opportunity for platform generation, participation, and stakeholder engagement (Vollmer, 2022).

1. *Terrestrial Scanners:* typically mounted on a vehicle, these are used to closely scan the terrain and relief features. These can be used to create detailed subsurface models of tunnels, mines, and caves. It is also possible to document networks attached to exposed underground surfaces such as water and sewer lines. They require a clear line of sight to the surfaces and their mounting mechanism might make them difficult to use in compact spaces given low mobility.

2. *Airborne Scanners:* typically mounted on airborne devices including drones and near-surface probes. These can be used to cover areas of a larger scale to create broad terrain analysis, including subsurface assets, geological formations, and appraising areas for construction safety. While they can be used for large exposed subsurface entrances such as mines and quarries, usually located far off or at the periphery of urban areas.

3. *Mobile LiDAR Scanners:* mounted on smaller vehicles, these scanners can be used to document large urban environments including transportation systems and utility tunnels. They have been used by Google maps to create detailed point-cloud-based 3D models of cities. Availability of clearance and appropriate transit infrastructure including roadways and railway lines is a prerequisite for operating these scanners. The cost of operations and portability usually limit their local availability.

4. *Handheld LiDAR Scanners:* a relatively smaller and portable version, these are widely available for documentation purposes and enable surveyors to access difficult-to-reach areas. They offer higher flexibility in mapping and can be locally used to survey underground urban corridors, subways, and transit terminals. The process of scanning is more time-consuming than higher-grade scanners and requires larger survey crews for mapping in urban areas.

5. *Tablets and Phone scanners:* These offer mapping for augmented and mixed reality applications with promising surveying tasks using miniaturized low-cost sensors. However, their positional accuracy and point-cloud precision have not yet been fully substantiated (Lose, Spreafico, & Chiabrando, 2022). For instance, Apple devices launched in 2020 included the LiDAR system and TrueDepth Camera for the possibility of use for industrial 3D scanning (Vogt, Rips, & Emmelmann, 2021).

Suitable Mapping Techniques

LiDAR scanning is a relatively new technology and undergoes consistent innovation to be compatible with existing digital twin platforms in terms of georeferenced scans, visualization type, and simplified poly-surfaces. Consequently, the initial incorporation of the scans may be low in accuracy and reliability as compared to other methods of collecting 3D data. The primary limitations in surveying urban areas are associated with equipment cost and skill development for operation. Different types of stakeholders can map subsurface data using different versions of this technology depending on their specific capabilities, affordability, the scale of mapped areas, location of the project, equipment required, and workforce size:

- Environmental Researchers and Scientists can use airborne scanners to map large covers of nature reserves and analyze the composition of subsurface materials. Airborne scanners enable monitoring capabilities to develop and simulate long-term regional visions based on geological changes.

- Terrestrial scanners can be used by policymakers, city planners, and engineers involved in urban development projects to survey, optimize and design underground infrastructure in a sustainable manner. These scanners can also study urban soil composition at different depths to define respective realms of underground functions.

- Handheld LiDAR scanners, given their efficiency and portability for small-scale sites, can be equipped by utility companies to optimize and augment existing utility infrastructure underground. They offer higher flexibility and accessibility in a city like Amsterdam where subsurface expansion is restricted to a great extent by heritage buildings and delicate subsoil.

- Mobile LiDAR scanners are suitable for construction companies, private developers, and miners for appraising land potential in terms of safe construction and excavation. These scanners can also be used to monitor and evaluate the stability and structural integrity of neighborhood-scale construction projects.

- Tablets and Phones can localize methods of the survey while instating data empowerment among citizens by offering them opportunities to collaborate with municipalities. They can provide crowd-sourced spatial data for subsurface urban corridors and report any needs for maintenance making the creation of 3D Amsterdam a participatory process.

A holistic data collection using LiDAR technology to incorporate urban underground spaces within 3D Amsterdam requires a framework to segregate survey devices according to respective stakeholders while ensuring a homogenous data reception that can be interacted with bi-directionally by all types of users. The laser-scanned and compiled metadata require z-axis-based reconstruction to be visualized and exposed to users. Software like GIS and ESRI CityEngine provide semi-automated methods to combine polygon-based and cloud-point-based data to form a unified 3D Digital Twin that can be 3D-referenced with the surface model.

To make the methodology progressional in nature, several steps need to be ensured, beginning with the definition of the scope and interest of concerned projects such as surveying, appraisal, maintenance, or design of subsurface assets. An inventory of stakeholders and their roles in different stages of data collection can be prepared to visualize the underground spaces from a regional to a hyperlocal scale. The stakeholders can conduct focus-group discussions and workshops to redefine project objectives according to respective needs and accessibility, followed by processing and analyzing the obtained imagery/ models. The georeferenced models can then be linked with existing Digital Twin, augmenting and restructuring its attributes for symbiotic functioning of surface and underground spaces. The platform will provide opportunities for feedback and local project simulations as a means for citizens to communicate their design visions for the city of Amsterdam. Being an open-access platform, making the underground spaces visible to the citizens can improve the perception of subsurface spaces and help community-based organizations to monitor the implementation of urban underground projects as collective geographies and soften the surface line.

Parameters of Suitability of LiDAR Scanners						
S. No.	Type of Scanner	Cost of Operation	Scale of Project	Suitable Location	Cost of Equipment	Workforce Size
1	Terrestrial Scanners	High	Territorial; City	Urban Peripheries; Mines & Quarries	High	Moderate
2	Airborne Scanners	Moderate	Regional; Territorial	Regional Nature and Terraneous reserves	High	Low
3	Mobile LiDAR Scanners	High	Sub-City	City Centers; Transit Terminals	Moderate	High
4	Handheld LiDAR Scanners	Moderate	Sub-City/ Local	Transit Terminals; Neighborhoods; Warehouses	Moderate	High
5	Tablets and Phone Scanners	Low	Local/ Building	Neighborhoods; Subways; Warehouses; Markets	Low	High

Fig. 5.8: Table consisting of parameters of suitability for LiDAR Scanning(Source: Author)

e. Learning from Cases: *AMFORA Project (2009)*

Vision for Amsterdam Canal Subsurface

Alternate Multifunctional Subterranean Development Amsterdam. Solving spatial, infrastructural and environmental problems in the city. Zwarts and Jansma proposed an ambitious plan to solve the spatial, infrastructural and environmental problems of Amsterdam: AMFORA proposed close to 50km of tunnels to be built underneath the famous canals in the heart of the city of Amsterdam.

Primary Challenges:
The project's lack of impact projections at an urban scale and speculative applications of technology combined with adverse ecological implications limited the design to engineering and geotechnical fields of expertise.

Opportunities:
The design promotes alternative modes of densification by unique use of space as a solution to rising rate of urbanisation in Amsterdam. Proposing public programs below the tunnels established a symbiotic relationship of surface and subsurface. The techniques of construction were innovative and cost-effectative, generating benchmarks for cost and technological thresholds for shifting underground to compose collective public subsurface use.

Fig. 2.5: AMFORA vision sections 2009
Source: ZJA Archives

Provisions for Traffic and Environment

The opposite of a livable environment and environment seems to be traffic. Parking lots along the quays in Amsterdam, and air pollution is caused by particulate matter. AMFORA is a proposal that creates a network of areas beneath the existing canals to improve the living environment without compromising accessibility. a strategy that eliminates environmental buffer zones and creates a win-win situation between traffic, the environment, and livability. Additionally, the subsurface areas make room aboveground for commercial activity and a livelier street environment. This plan's scope mostly encompasses the area inside the ring. The canals and the Amstel, which are currently used as waterways, are the greatest places to locate the underground areas and the supply highways to those spaces.

Drivers can enter the system of underground spaces right away from the ring A10 highway. The city center continues to be shielded from heavy traffic and transportation, yet accessibility will only grow. A carefully woven web of ramps connects the system of underground areas to the city above ground.

Sustainable technology and feasibility

Technical and financial feasibility studies have demonstrated the viability of the proposal, which calls for 1 million m2 of floor space per underground stratum. AMFORA is thus unquestionably not a utopian scheme. Two nodes on the city ring (S110) may be joined at the initial stage. The idea can then be expanded by a number of connections using the additional canals after that. The cost of construction will fall off swiftly as more layers are realized. Six layers would result in building costs per square meter falling below 1500 euros, or less than 30,000 euros per parking space. AMFORA is a solution with enormous promise because it is both new and sustainable, significantly improves the quality of life, and is both technically and financially practical.

Technical and economic feasibility studies have demonstrated the plan's viability. The strategy was created with Amsterdam in mind, but it can also be used in other cities for the same objectives. Groenmarkt and Amstel site studies are now in way. The Amstel Hotel, Carré Theatre, and the recently inaugurated Hermitage will all be connected by these locations.

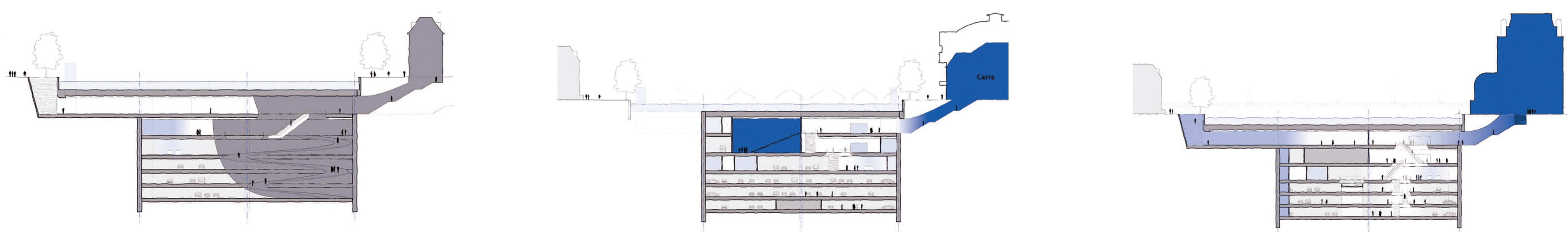


Fig. 5.9: Sections depicting Multistorey UG tunnels in AMFORA (Source: ZJA Archives)

Disadvantages and Opportunities

On the basis of an in-depth study of cases similar to AMFORA around the world depicted in Chapter 3, drawbacks and benefits of underground construction were compiled. Carrying out construction in the subsoil is not limited to any fixed design strategies. Several contextual conditions and balance of opportunities need to be considered to move beyond technological and economic thresholds of underground construction.

Fig. 5.10: Advantages andn Disadvantages of Underground construction

ISSUES	CATEGORY	POTENTIAL BENEFITS	POTENTIAL DRAWBACKS
PSYCHOLOGICAL & PHYSIOLOGICAL	PSYCHOLOGICAL	Relief from severe climate (coolness in hot - climates)	Lack of spatial orientation Negative psychological reactions association death and burial, claustrophobia, fear of collapse/entrapment Lack of public acceptance
	PHYSIOLOGICAL	Isolation from surface noise and vibration Stable indoor temperatures	Excessive noise or lack of noise Lack of fresh air/indoor air pollution High humidity/condensation Lack of natural daylight and view Higher radon concentration Requirement for openings
ENERGY	ENERGY USE	Reduction conduction Heat storage capacity Stability ground temperatures Control on air infiltration Reduction of heat gain	Impact ventilation rate Slow response Lack of useful ground temperatures Heating/cooling compromises Lack of available data on the energy performance
LAND USE AND LOCATION	PROTECTION	Provide security limited access Fire protection Protection from s ever e climate Protection from n atural disasters	Degradation underground environment
	LOCATION	Visual impact Preservation of surface space Lack of surface space Preservation of natural vegetation scenery/ecology Efficient use of scarce land	Aesthetics skillful design, building services Uncertain geology Unfavorable geology
	LAYOUT	Topographic freedom	Access limitations Sewage removal Water problems Adaptability
LIFE CYCLE COSTS	INITIAL COST	No need of external cladding Land cost savings N o structural support, W eather independent	Increased structural cost requirements Ground excavation Cost uncertainty Confined work conditions Ground support
	OPERATING COST	Reduced maintenance Building and building material durability Energy use Insurance	Personnel access Ventilation and lighting

f. Theoretical Framework

On consolidating the learning from literature on groundscape, stakeholders goals and methods to map and transform the existing subsurface assets, a framework was drawn to investigate the linkages of parameters attached to each of these domain. These domains function at urban and micro-scale built environment to identify and document challenges with subsurface construction, and further devise localized technological and design-based interventions for integrating urban underground systems that include infrastructure, functional nodes and connective corridors. The inferences from actor networks, subways and skyways, and LiDAR scanning lead to formation of a comprehensive methodology for public sector organizations to plan for holistic underground resources. These are explained as follows:

1. Mapping the existing subsurface inventory: converting line-based infrastructure networks to volumes and understanding their intra-relationships can be achieved by generating a digital platform where different actors can percieve and engage with subsurface assets of their interests. This platform can be assisted by scanning techniques like LiDAR and physical documentation to feed into Amsterdam's three-dimensional model. The resulting products can assist with identifying ecological risks at a city scale, volumetric network optimization through urban design, and quantify the demand of underground resources.

2. Identifying User Goals: Since the ownership of subsurface needs to be balanced by feasibility, public access and capital invested in its construction and maintenance, the spatial demands and perceptions of users should be accounted for. After helping the users visualize underground spaces, their requirements in terms of dimensions, resource allocation and transportation can be quantified. These goals inform subsurface design at micro-scale with technological interventions and spatial quality.

3. Designing the Groundscape: By establishing the ecological and socio-economic understanding of the existing subsurface, their relationship with surface networks can be studied to guide the design of transition nodes between overground and underground spaces i.e., entrances within the groundscape. These entrances act as connective elements to maintain a cyclic quality and feature transfer between both vertical realms for gradually lowering the perception of surface as a boundary, extending it above and below.

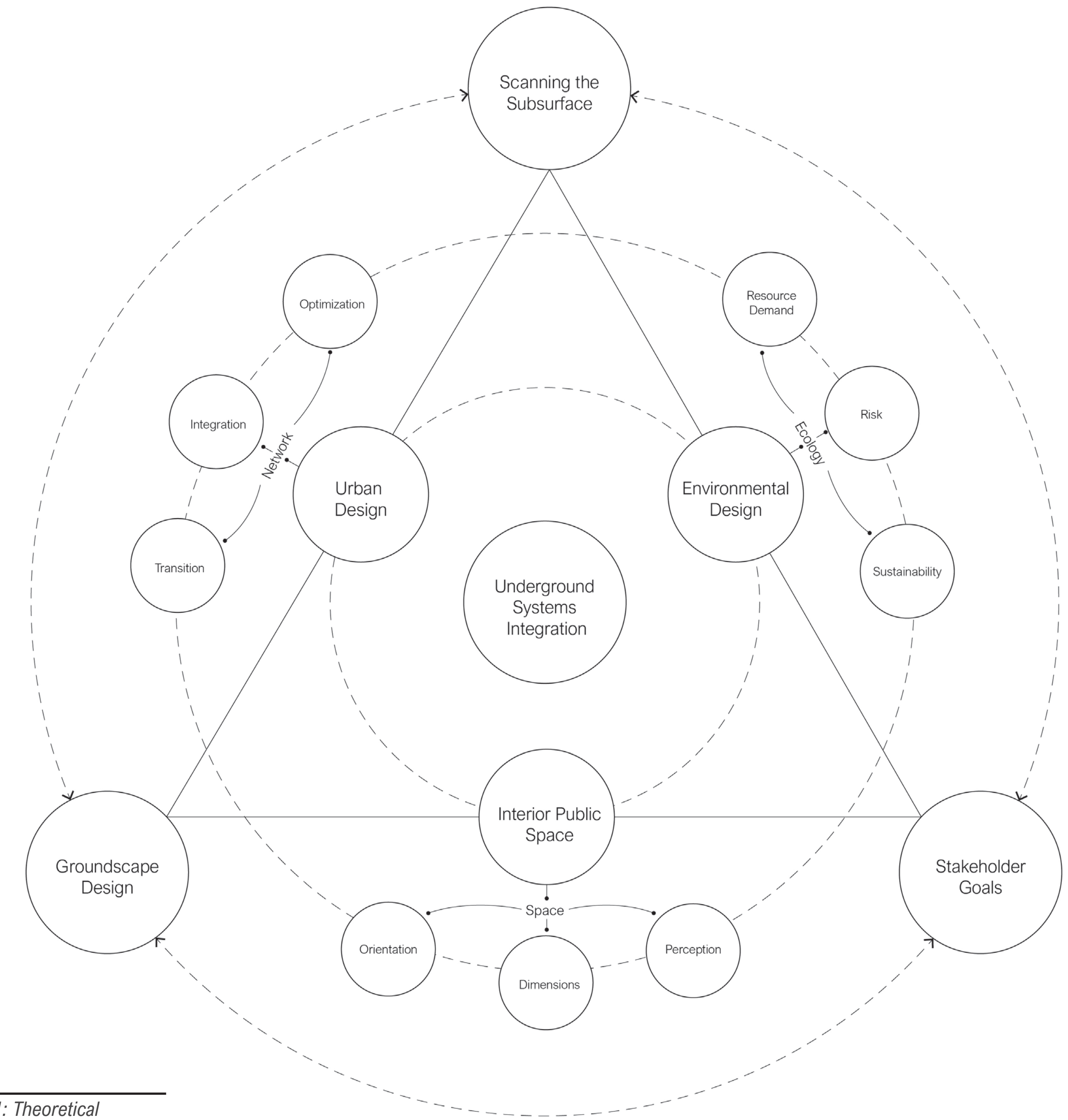


Fig. 5.11: Theoretical Framework (Source: Author)

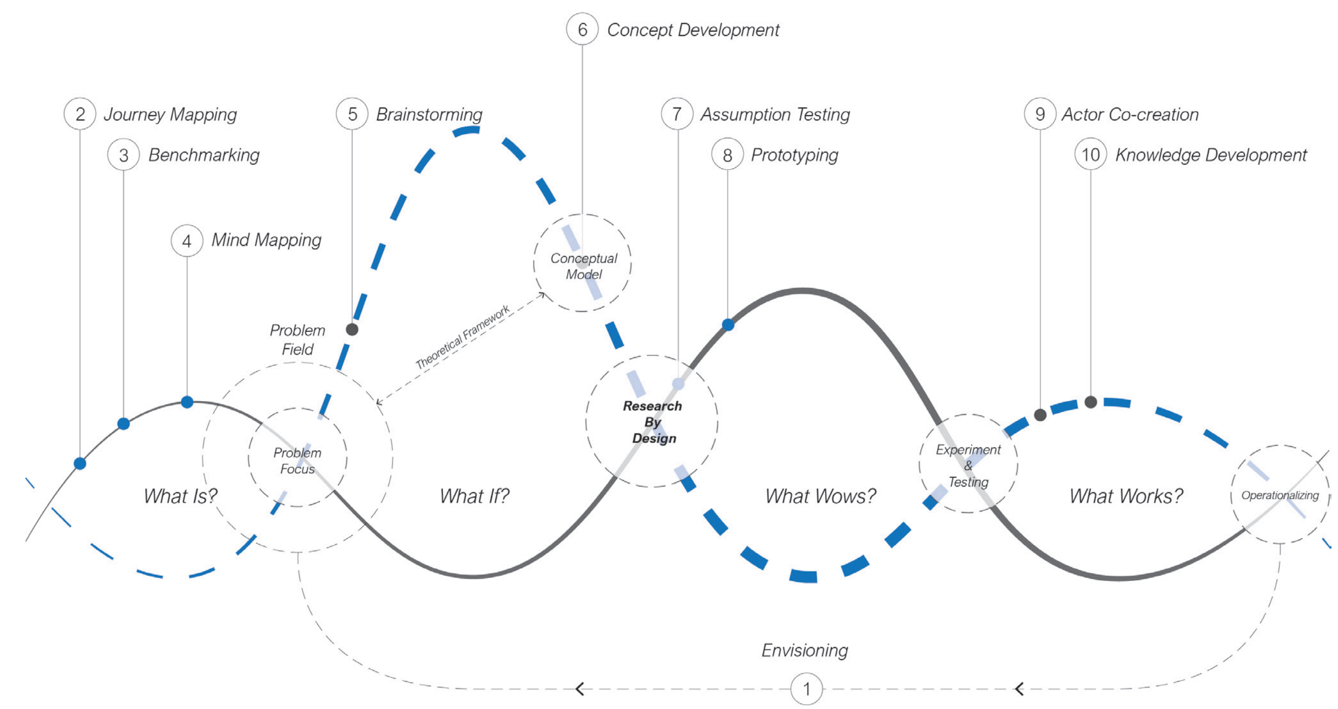
6. Methodological Framework

Overview

As stated in the previous sections, the conceptual model was derived from parameters of understanding space and its relation with identified opportunities and crisis. The model illustrates the essential sectors of theory required to integrate the realms of surface, groundscape and the subsurface. The Methodological framework draws a roadmap towards analyzing the existing subsurface uses and their potential transformation to incorporate future transitions.

Chapter Structure:

Fig. 6.1: Methodological Process (Source: Author)



1. Problem Field and Problem Focus

With the intent of tackling rapid rate of urbanisation by exploring potential of alternative spaces and challenging verticality in the Dutch context, subsurface expansion emerged as the primary focus for the present timeline to safeguard public functions within the growing infrastructure landscape.

2. Conceptual Model and Theoritical Structure

The parameters consisting of contextualized solutions will be primarily derived from the 'Groundscape' concept to bridge functional and perception-based gaps between the current surface and isolated subsurface uses.

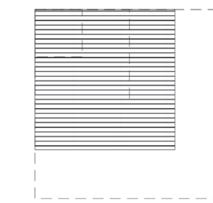
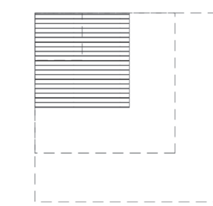
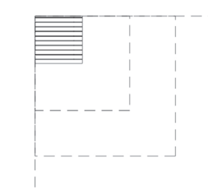
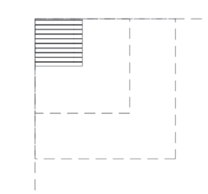
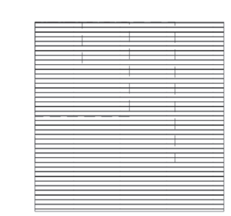
3. Research by Experimental Design

Through a research by design approach, the parameter inventory is expanded with theory, experimental design and observations from a micro-scale urban design case study to obtain a set of solutions tailored specifically for Dutch cities.

4. Collaborative Operationalization

The development of guiding principles is intended at a medium for cross-domain collaboration to test and evaluate design interventions and their impacts on chosen sites in a participatory manner taking into account respective actor goals.

a. Methodological Structure

Primary Research Question	Sub-Research Question	Scope of Study	Methods	Expected Outcomes	Scale
How can the existing isolated subsurface uses can be integrated to form a **Collective Functional Geography** composed of **Integrated Urban Underground Systems** through Design Interventions?	What is the extent of current Underground space inventory in the city of Amsterdam?	Analyzing current surface vs underground supply scenario Establishing dimensions of Underground space Planning Developing prototypical methods to spatialize existing underground spaces Mapping usable underground space within identified areas of interest	Literature Review, LiDAR Scanning and Digital Twins (GIS), Expert interviews, Secondary Data	Sizeable underground workable area with respect to opportunity and constraints Methods to reveal underground spaces for perception study	
	How to map and visualize the existing underground assets in a participatory manner?	Identifying gaps and potential nodes for connections with respect to function Identifying symbiotic current and future functions to be connected Designing typologies of urban underground corridors	Suitability Analysis (GIS), Expert interviews and Collaboration, Case Studies	Types of underground spaces suitable to influence demand including MRTS Time-based potential use for delineated space within site	
	How to integrate isolated project-based underground development into a collective subsurface network?	Testing existing parameters to design chosen case Analyzing context based constraints with respect to chosen geography Augmenting the existing inventory of patterns by micro-scale design and atmosphere definition	Technical Profile Analysis, Research by Design	Micro-scale Urban Design project to produce revised parameters of design directed towards integrating system of activities	
	How to Phase and Design the Groundscape according to the needs of public life and infrastructure development?	Preparing a parameters of design for context-specific subsurface interventions Testing devised typologies and aligning functions with future transitions for remaining cases Allocating functions to promote collective surface and U.G. use	Learning from literature, Developing Scenarios, Collaboration Workshop, Actor interviews (Perception study)	Context-specific toolbox to design underground spaces Suitable Volumetric functions	
	How to strategize balanced use of underground space at the city scale?	Integrating zone-based surface and subsurface development strategy	Literature review, Research by Design, Stakeholder Consultation	Comprehensive Zone-based development strategies inclusive of subsurface functions	

b. Conceptual Framework

The conceptual framework shows the current understanding of relationship between surface and subsurface geography. There is a need to realize their supplementary nature instead of imagining them as two parallel layers functioning in isolation. The model explores the role of grounscape, a semipermeable membrane acting as a connective tissue to bring forth a new collective geography to form the foundation of future densification by transforming the accessibility of the current infrastructure landscape.

The Groundscape

The idea of Groundscape proposes an evolved way of perceiving underground spaces by addressing the layers connected to surface as an extension. Designing the entrance membrane offers a resilient, aesthetic and accountable responce to challenges posed by densification and urbanisation. The concept moves beyond making condensed and complex building surfaces by reimagining the geography they rest upon. The Groundscape offers a dynamic catalyst for networks prevailing in the urban realm that simultaneously respects the landscape and existing surface heritage.

Socio-economic Constraints

The existing subsurface use, being restricted to puzzling infrastructure networks, parking spaces and utilities gradually secludes the possibility of public use while private entities utilize the space for developing reserved superstructures. Underground spaces can be a solution to moderate the rising real estate prices in urban centers while ensuring public accessibility if envisioned as an extension of public uses on the surface.

Ecological Constraints

A prerequisite of underground construction is a permanent change in geography. For it to be a fluid void to cater urban growth, the landscape it is morphed around, emerges as an essential element and an initial parameter to generate the paramters intended within the project. Hence, groundscape design should be conscious of preserving and sustainably transforming the ecological elements attached to it, especially in the Dutch context for instance, risk posed by subsidence, water table, soil conditions and natural anchors on the surface.

Form Constraints

The form traced by underground spaces in urban environments share codependent relationship with the previously discussed constraints. The mode of entrances , vollume, and functions implemented impact the perception and needs of the users and economic resources required for construction. Hence, form emerges is an important limiter as well as enabler of features that complement the urban strain on surface instead of amplifying it.

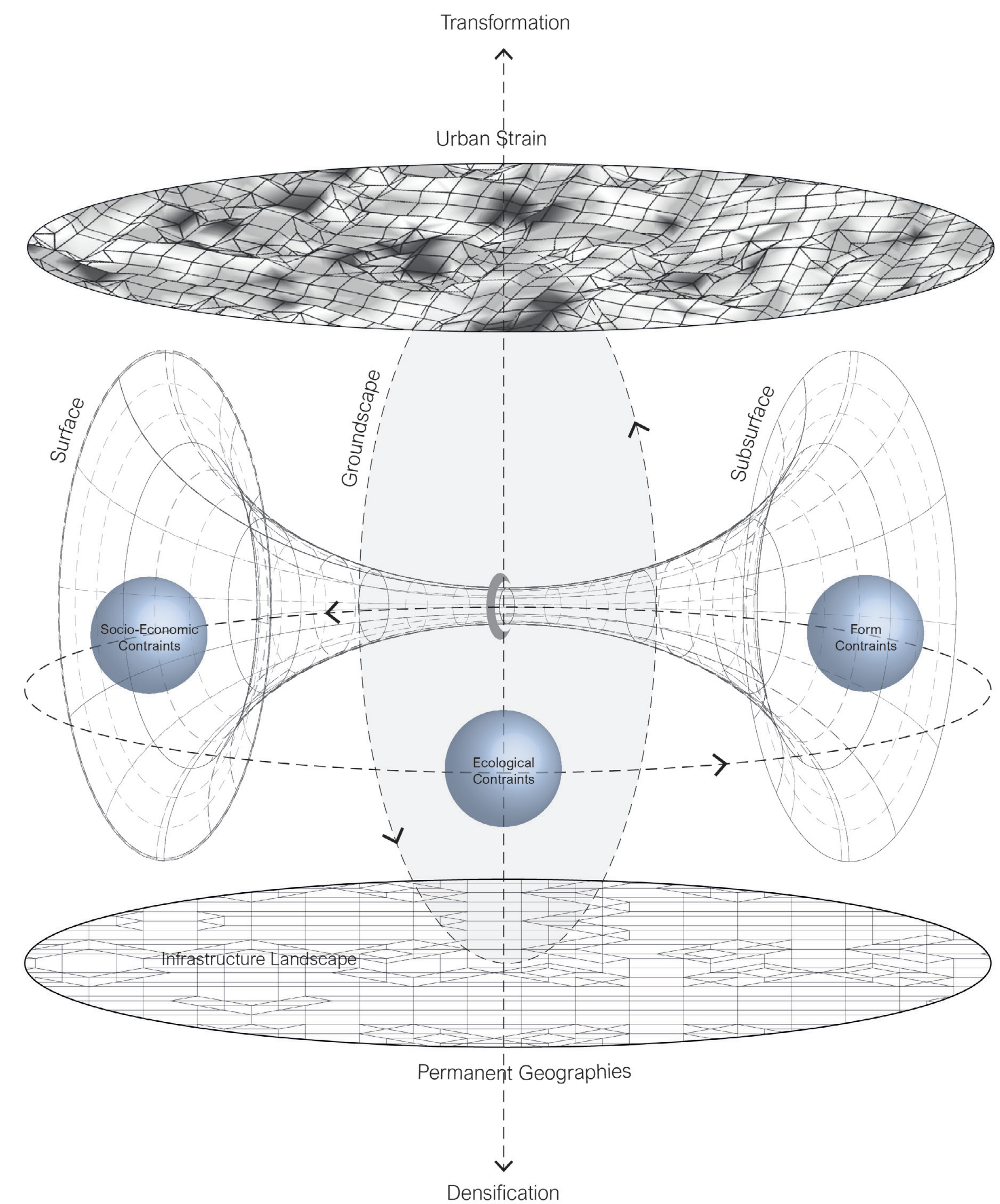


Fig. 6.2: Diagram illustrating Conceptual Framework Source: Author

c. Analytical Framework

The analytical framework expands upon the concept model of using the Groundscape as a tool to link surface and subsurface geographies. It illustrates the features needed for this membrane to answer the posed sub-research questions based around collective and integrated nature of space nature of space. The framework explores the most crucial secondary and tertiary elements attached to the role of designers to balance the connectivity, sustainability and utility offered by the subsurface.

Densification

Analysis of the base urban form and existing infrastructure networks in Amsterdam was carried out to identify the potential nodes where future densification is focused or envisioned in the development plans for 2040. These superimposed with exsiting inventory of infrastructural assets and projected direction of expansion provides us with current socio-economic and development trends and delineation of viable redevelopment zones.

Inclusivity

Analyzing the current public vs private accessibility and functional inclusivity is important to lead the nature and scale of subsurface expansion possible. Micro-scale nolli maps, figure ground and level of current integration of transportation infrastructure helps identify gaps for future transformation, resulting in a workable catalogue of underground space. It is also important to identify the types of users for spaces to be design that cater their requirements related to spatial quality, utility, orientation and perception of underground space.

Integration

Integration of existing surface functions with isolated underground infrastructural nodes adds to the connectivity and cyclic nature of these layers, lending the current subsurface a wider range of uses and new functional nodes. Case-based benchmarking and joining these nodes will generate an integrated point-and-line system to the subsurface of Amsterdam which is currenty restricted to utility and transport. Integration taps into the projected urban flux and introduces it to the subsurface as a new entropy to demand a wider range of functions.

Livability and Adaptability

After identifying the potential integration of functions, analysis of perception of existing underground nodes is conducted to focus on the quality-based needs of chosen micro-sites with respect to their surrounding context. Here, the idea of plugging the public realm into the groundscape is realized as a vision-based opportunity to prevent the subsurface from being claimed by actors belonging to private and infrastructure sector.

The 'Just' nature of this new territory is realized by reinstating its right to the city of Amsterdam by proposing livable and ecologically adaptable solutions. From existing literature analysis, it is clear that the subsurface is not suitable for permanent habitation. Hence, the functions to be introduces should be conscious of spaces resulting in dynamic uses.

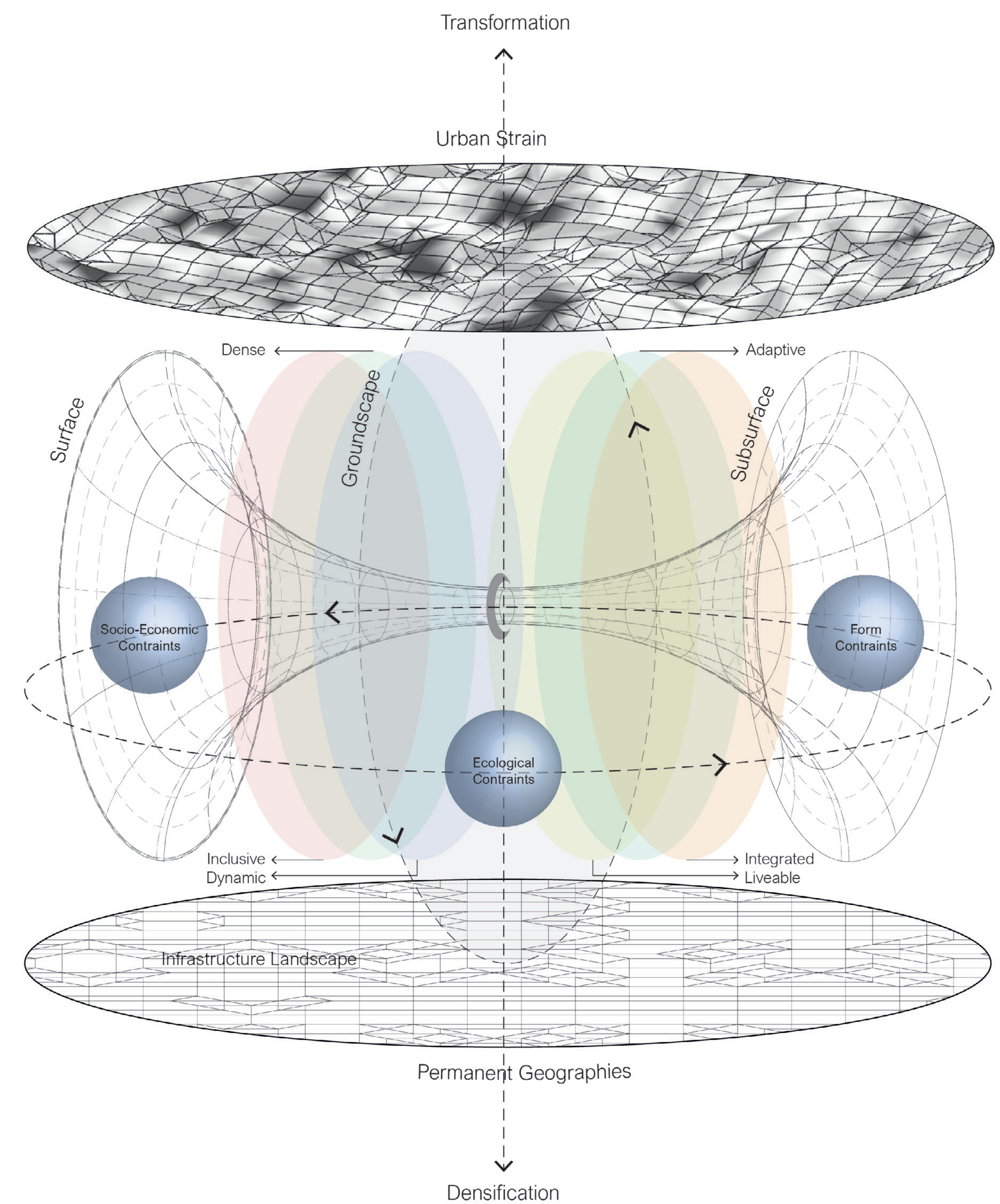


Fig. 6.3: Diagram illustrating Analytical Framework
Source: Author

d. Methods

Literature Review

The literature review involves an in-depth review of documents, research papers, articles, reports, case studies and book publications to generate an initial theoretical knowledge bank surrounding the problem field. This involves theories derived from the Groundscape concept by Dominique Perrault and EPFL sublab for designing collective surface and subsurface environments for public use suggesting design tools to improve their current perception, forming the initial code inventory of parameters. The problem field is contextualized by gathering information and opinions attached to the Dutch landscape at a national and city scale, specifically for Amsterdam.

Since the methodology rests on a research by design approach, the collection of literature also includes research regarding development plans and visions related to the future of amsterdam and its rate of urbanization. It is important to consider the design testing and experimentation as an extension of the theories as a constantly evolving framwork with changing temporal, spatial, and social context of Amsterdam.

Secondary Data and Policies

Reviewing documents and policies is an essential part of scope development, providing spatial, economic and political restrictions to underground construction in urban centers. Vision based documents help strengthen the need of subsurface as a sustainable resource while documents describing building regulations, cultural heritage, and infrastrcuture projects in Amsterdam lay down the technical and cost thresholds of moving underground. This adds another filtration layer to delineate a workable underground space in chosen sites.

Public and private organisations functioning at various scales in Netherlands have created a range of policy frameworks, socio-economic visions, local area plans , long-term visions, and upcoming development projects. A critical analysis of these documents is conducted to identify gaps and opportunities to integrate the role of subsurface functions to design comprehensive and feasible zone-based masterplans.

Statistical Benchmarking

Statistical information available at national and municipal scale contributes to the development of a preliminary local demographic, economic and ecological profile. These trends depict the potential direction of growth and rate of urbanisation to be tackled. The data is derived from multiple institutional and academic repositories, visualized and inferred to validate the concepts discussed within the Theoretical framework.

Fieldwork

Fieldwork primarily involves intial reconnaissance by site visits, office visits to collect data on previously envsioned projects related to the chosen micro-sites by architecture and urban design offices. The exercise of user interactions, photography and on-ground accessibility study helps derive the current atmosphere of the sites while laying a base image over which fictions can be tested and envisioned to enable retracing and backtracking future transitions.

Documentation, initial urban sketches and observations made during the reconnaissance lend an urbanist the perspectives of different types of users of the site.

Stakeholder Analysis

The potential of sufficient subsurface planning and management of Groundscape to enhance allocation of functions requires an understanding of several parameters influenced by a network of actors involved. The actors share respective sets of goals, limitations and ambitions from underground spaces that constitute parts of holistic output of collective, connective, economically and ecologically sustainable spaces.

Stakeholder analysis involves identification of key operating stakeholders at different scales and phases of research with their respective power dynamics in influencing the resultant underground typologies.

Mapping

Mapping at various scales contributes towards understanding the demographic, spatial, economic, and ecological relations shared across borders and scales. Since underground expansion is a relatively recent research phenomena, its spatial scope is limited to urban and local scale. Initial mapping and visualization of data is conducted at a national scale to identify a vision-based need of study for subsurface use and its value as a resource for Netherlands.

Mapping involved in the design process accounts 3 primary scales, the municipality of Amsterdam as the city scale, chosen study areas along the N-S metro line as the meso-scale i.e., Amsterdam Zuid, Amsterdam Centraal, and Noorderpark, and volumetric and micro-scale mapping for localized design interventions.

Research by Design

The approach has been used as the research within the project follows temporal evolution of spaces accounting for transitions. The subsurface is imagined as a future-proof shell so it needs to be tested against future opportunities and crisis to stay functionally fluid and dynamic. Research by design is an experimental approach where design constitutes a substantial part of the research process, generating critical perspectives through design interventions and forming a feedback loop of enhancements and constraints related to possible fictions and realities. Since the project undertakes a network of actors, the design process helps validate a wide cross-disciplinary spectrum.

Testing

Testing the additional knowledge developed through designing one of the chosen cases in Amsterdam is intended to develop systematic and expressive tools forming new codes of the design parameters by establishing a cylic relationship between analysis and contextualized interventions. Experimental design helps validate and challenge existing theories to result in comprehensive project development through concrete on-ground contemplation of experience and perception of proposed solutions by respective users.

Interviews and Workshops

A panel of experts connected to various disciplines around underground construction was developed to provide an expert peer review of contextualized interventions. Workshops are an extension of the testing exercise to understand the integrated system of activities related to construction and design of urban underground systems, mapping and appropriate feasibility. The experts belonged to institutions and organizations such as ITACUS, Municipality of Amsterdam, Think Deep, Center for Underground Buildings, Senseable City Lap, independent researchers and engineers.

e. Intended Outcomes

The research process is aimed at exploring four research gaps associated with subsurface development:

The current project development involving underground construction is undertaken at a point-scale isolated actor bubbles without considering wider urban impacts and opportunities. The role of an urbanist is thus realized as a mediator enabling platform generation that promotes interdisciplinary designing and planning for underground spaces. The point-scale projects being capital-intensive face a high risk of exploitation by private developers since the current regulations are still a relatively unchartered field. Integration of functions and volumetric planning is hence important for such projects to scale beyond two dimensional phasing and design.

Volumetric design involves a gradient of users with respective notions of subsurface yield, currently existing as an unstable mix of public vs private. Identifying the needs of different user typologies demands an in-depth understanding of spatial perception parameters and sense of orientation. With the identified research gaps, the tools described within the methodological framework are intended at achieving the following outcomes:

1. Practicable Subsurface figure-ground

The phenomena of underground as an unchartered territory is drawn from its existing perception and lack of visibility. Mapping the existing structure of subsurface functions transitions into an exercise of 'exposing' the underground and providing urbanists with a figure-ground and limited expanse of space suitable for construction. This acts as a volumetric inventory of exploration possible withing the scope of the project. Using tools like digital twins and 3D modelling by public institutions helps users to discover and engage with this new territory and develop a game-board for experimental opportunities. Research related to LiDAR scanning and field mapping as a part of theoretical framework offers an open-ended roadmap to municipality of Amsterdam in developing projects conscious of geographies beneath the built-environment.

2. Point-and-Lines to a System of Planes

Subsequent steps after establishing Amsterdam's subsurface figure-ground involve realizing the structure of isolated underground functions. Their current form illustrates a system of point-and-lines restricting their potential uses to utility and connected corridors of movement. For the groundscape to emerge as a geography collectivising wider public functions, there is a need to reconfigure its current form to a system of planes working in synchronization with surface use to prevent separation of spatial realms as users transition through different vertical levels. Hence, the exercise of integrating isolated nodes across different scales lends the subsurface an opportunity to exist as a holistic part of a cyclic urban environment.

3. Contextualized Strategic Framework

The guidelines of integration derived from Groundscape literature present a general methodology to design socially and ecologically conscious form of underground incisions. Similar to how a language changes with shift in region and dialect across different scales, the parametersto be used for testing design intervention needs to be contextualized to the shift in dialect of suitable design language specifically for the Dutch context. The locations of chosen project sites with respect to surrounding built environment, proximity to infrastructure and scale of public and private functions dictates the nature of geography they trace. Hence, research by design is used to contextualize the theories into a holistic phase-based strategy.

4. Knowledge Development

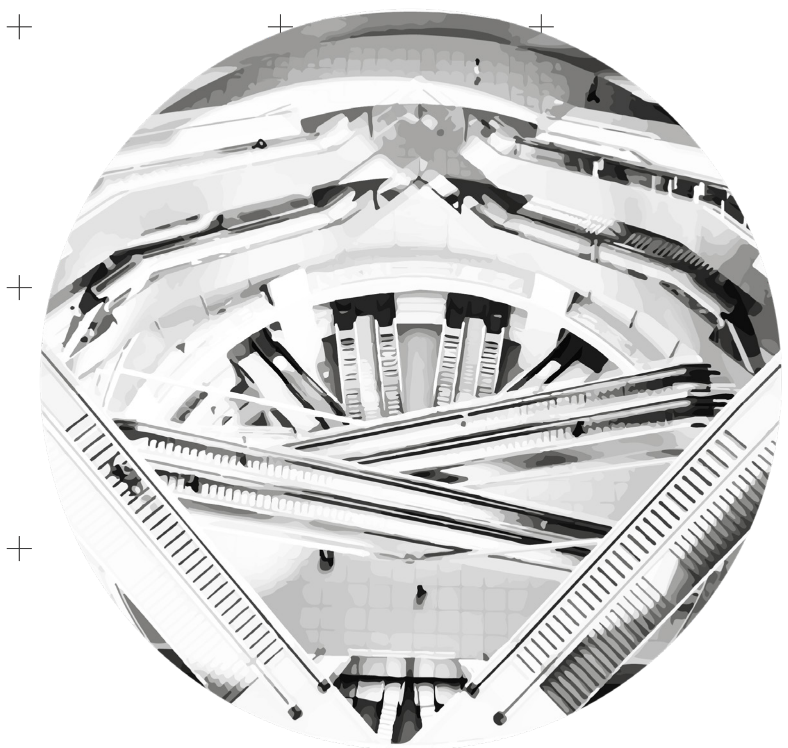
The policy-based operation and maintenance of proposed underground typologies is dependent on long-term transitions, urban flux, changing user needs with spatial and ecological transitions. Regulating the balanced use of underground space with respect to actor-based power dynamics and transformability requires an open-ended experimental framework that feeds new parameters and knowledge generation back into the design process enabling the subsurface to maintain a fluid identity.

7. Analytical Framework

Overview

The analytical frameworks draws from the parameters of site analysis in theoretical framework to study potentials of groundscape construction and delineate workable subsurface spaces based on existing ecological, spatial and economic constraint. It involves studying the chosen sites at three different scales, categorizing their features for selection and defining context parameters. The research further uses research by design to bring forth an updated design parameters to test upon remaining sites.

a. Site Selection and Analysis: Macro-Scale
b. Site Analysis: Chosen Transformative spaces
c. Europaplein, Vivaldi and Zuidas



a. Site Selection & Analysis: Macro Scale

System of Point and Lines

The city of Amsterdam exists in complex state of presevation and flux given the sensitive landscape combined with globalized urban spaces. Recent design projects have explored alternative locations for construction beyond the surface i.e., in the form of urban islands on water bodies and underground. The strain placed by existing heritage and development restrictions has directed infrastructure development to the subsoil, including the North-South Metro line. Previously, underground spaces in the city have only existed as isolated local basements or parking spaces for business centers. This translated the subsurface use as a system of point and lines where the distances between the nodes is not walkable.

In comparison to the underground, the superground has seen rapid vertical growth in west and south of Amsterdam with business districts of Sloterdijk and Zuidas. While the demand for space in the city keeps increasing, pressure over existing foundations would limit the future vertical growth over the surface. The groundscape can emerge as a medium to widen the 'lines' of underground system and introduce new nodes to generate public life.

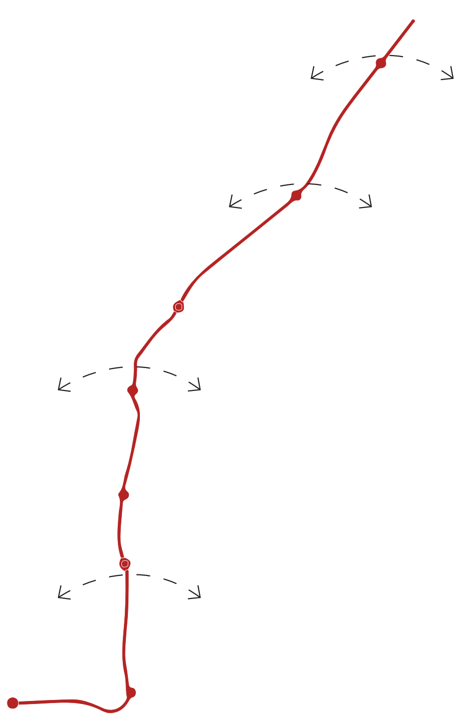


Fig. 7.1: Map showing Amsterdam's Superground vs Underground profile Source: Author

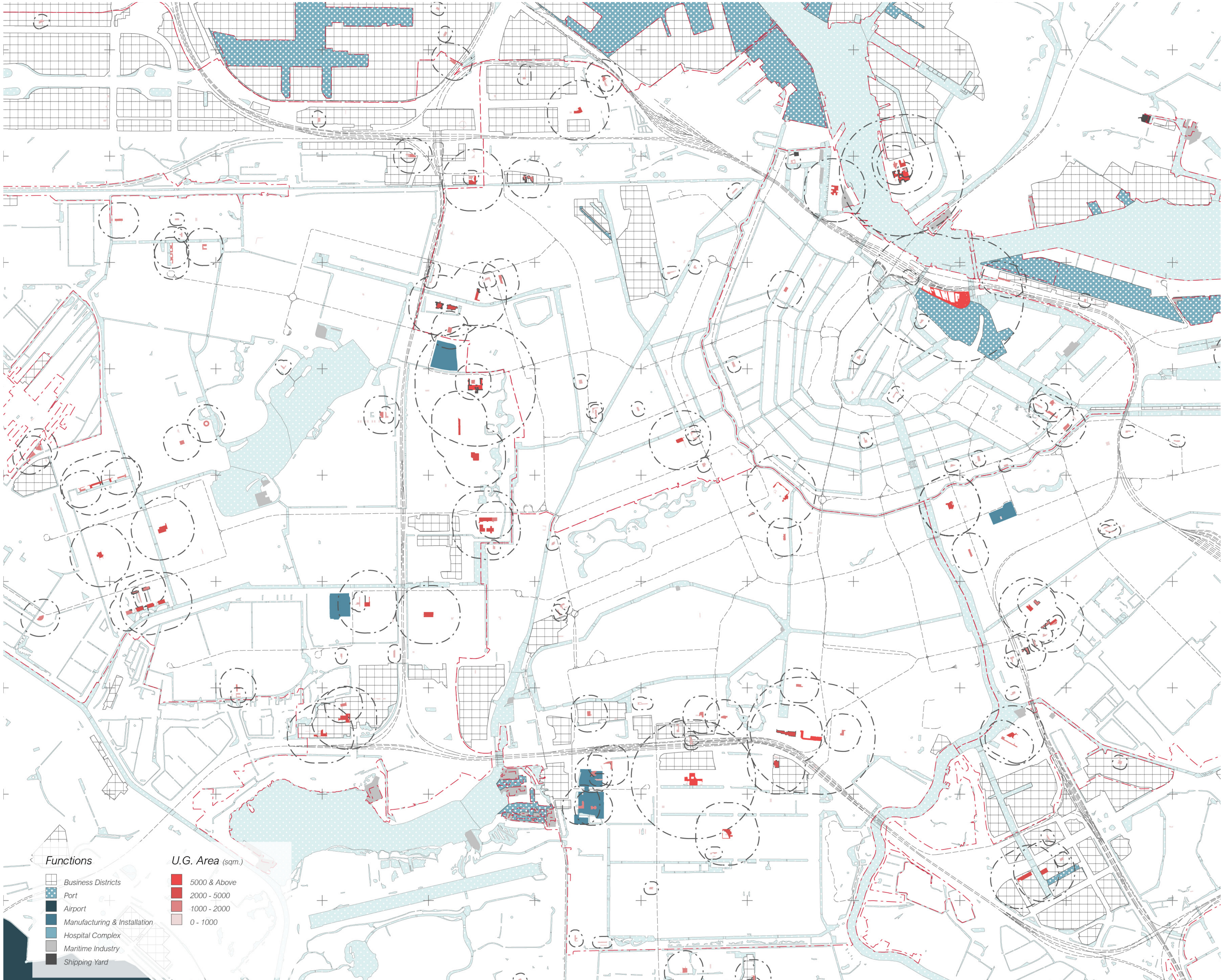


Fig. 7.2: Map showing Amsterdam's Underground space inventory
Source: Author

City-Scale Subsurface Inventory

The currently documented underground spaces in the city vary in size according to surrounding landuse, development regulations and infrastructure networks in the vicinity. Mapping the existing inventory reveals areas above 2000 sqm to be located near non-residential functions such as business districts, port facilities, maritime yards, and manufacturing industries. Although the current depository does not account for their specific uses, it can be assumed that these sizable spaces are primarily dedicated to formal uses such as storage, archives, data centers, parking and network of basement amenities. They can be categorized into clusters according to size that can act as possible nodes of integration while designing and transformation initiatives for subsurface expansion.

The location trends of underground parcels depict higher concentration around areas of economic propulsion and in close proximity to major metro interchanges along the ring road. Underground spaces in the center are clustered near the central station, serving supplementary functions to institutions, offices and the station itself. Since the complex was essentially a greenfield development project on the harbour, such a scale of construction was possible.

Fig. 7.3: Map showing Amsterdam's Subsidence risk profile (Source: Author)

Risk of Subsidence

Data retrieved from the national climate effects projected till the end of the century predict an average subsidence risk of 0.5-1.2 m, reaching a little of 5m in extreme cases. These conditions significantly impact the typology of construction and achievable depth of construction underground. Apart from areas close to water bodies, very high risk of subsidence is seen along the southern ring road and Metro line 50. These areas have to be treated with safety buffers which carrying out subsurface development to prevent risk to existing buildings in the vicinity. The composition of water table and nature of existing pile foundations beneath the buildings also significantly impact the level of subsidence of soil.

When planning for zone-based underground development, maps for city-scale subsidence can act as primary ecological constraints to depth and workable parcels of space. A combination of clusters of existing underground inventory and risk mapping reveals neighborhoods of interest where potential of underground construction is promising, consequently limiting the regions to near districts with dominant non-residential functions.

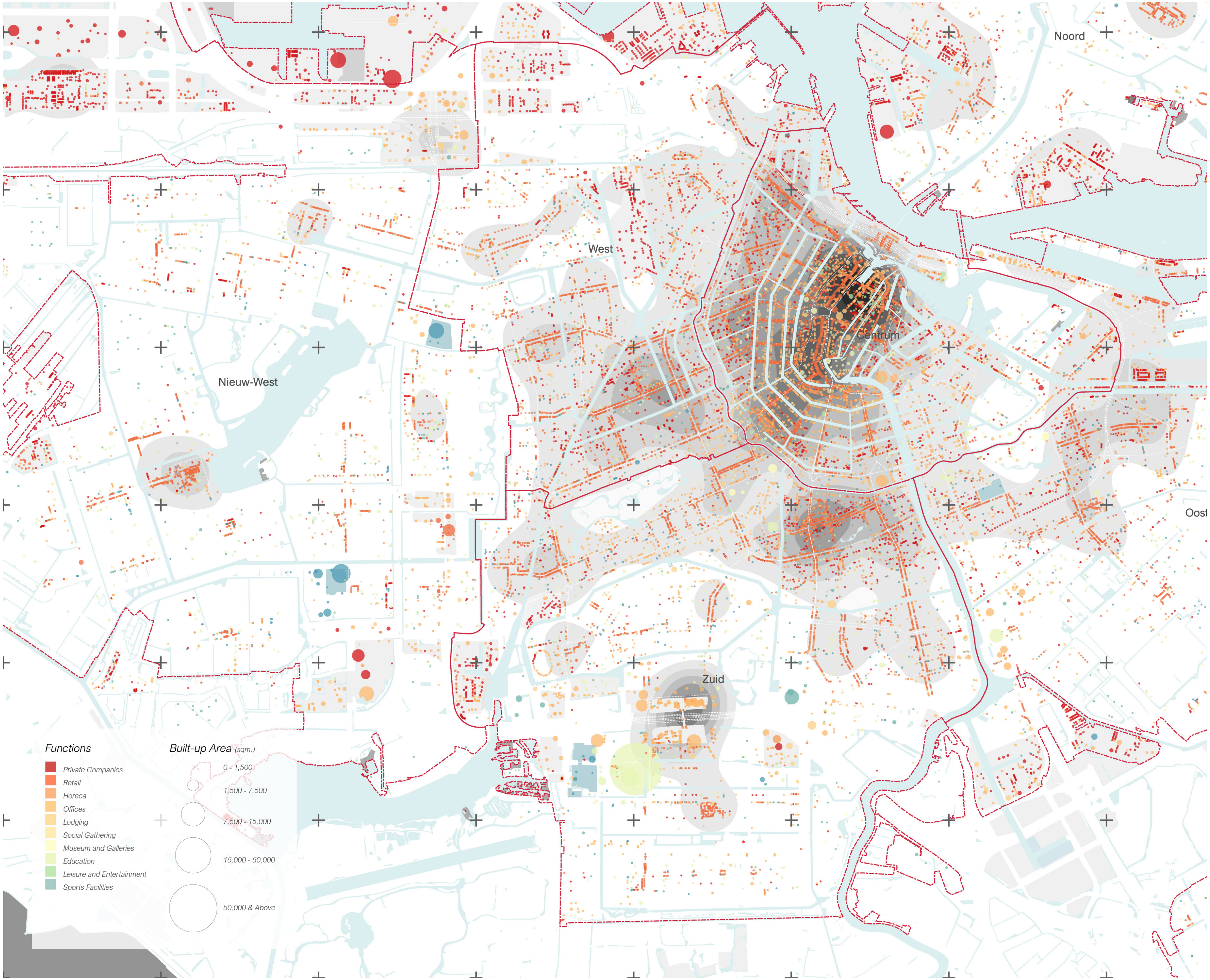


Fig. 7.4: Map showing Amsterdam's non-residential functions (Source: Author)

Non-Residential Nodes

Since potential areas for subsurface development require significant footfall and active maintenance to ensure safe temporary habitation, areas with non-residential clusters attracting movement are likely sites of interests. The relation between built-up area and occupied function combined with development restrictions guides the type of underground construction possible. Larger parcels show possibility of both greenfield and brownfield expansion while clusters of small-size non-residential functions bear the capacity of connections and transformations.

The suitable form of underground construction is that of a shell with minimal parcellations and collective functions. Sites with monofunctional surface use make it easier to construct such volumes without stakeholder conflicts. Hence the areas of priority for city-scale subsurface vision would be located near hotspots of large-scale monofunctional non-residential uses including businessparks, local urban centers, cultural nodes and institutional hubs. With this consideration, several districts show immediate potential including Zuidas, Sloterdijk, Centraal, Lelylaan, and Amstel.

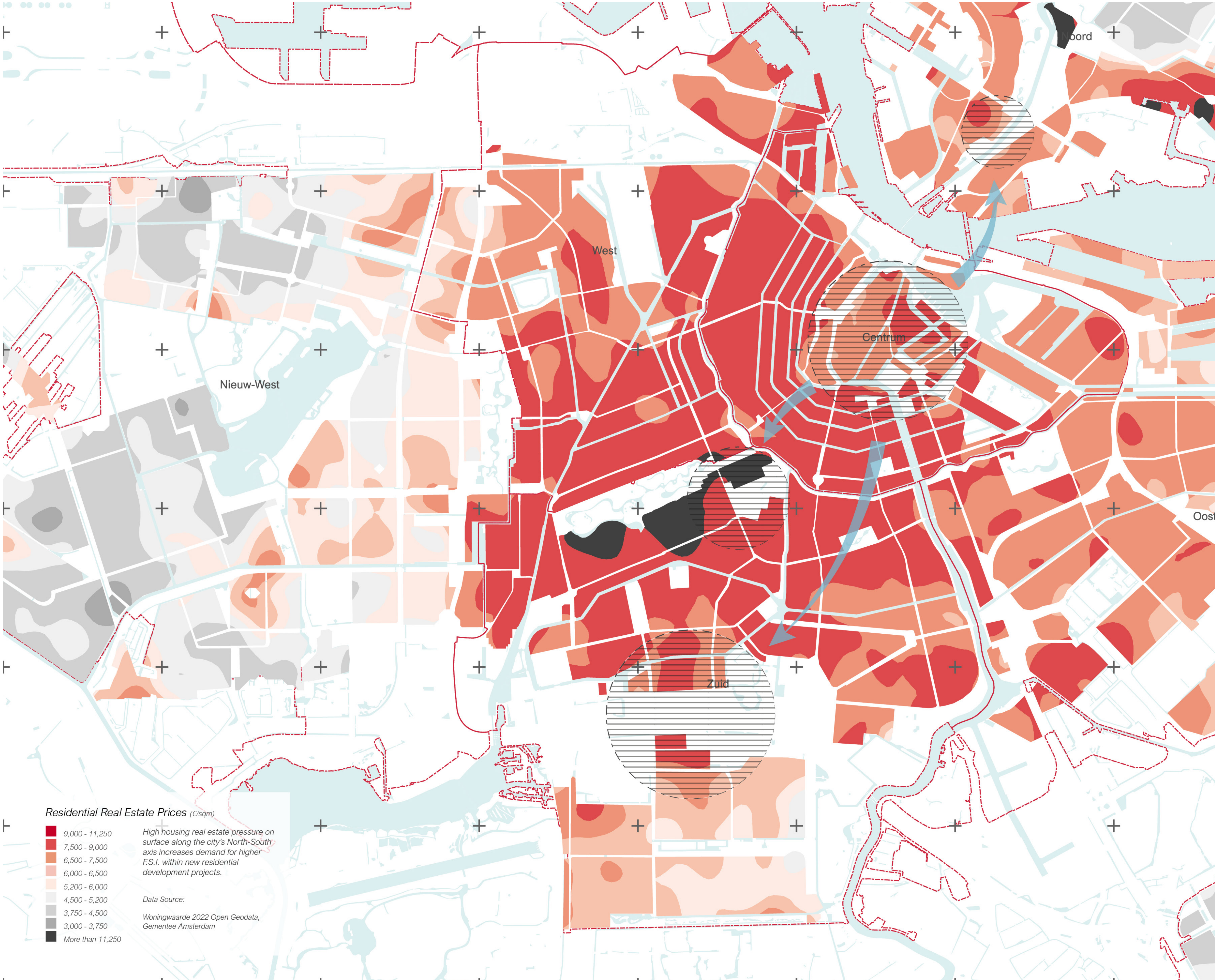
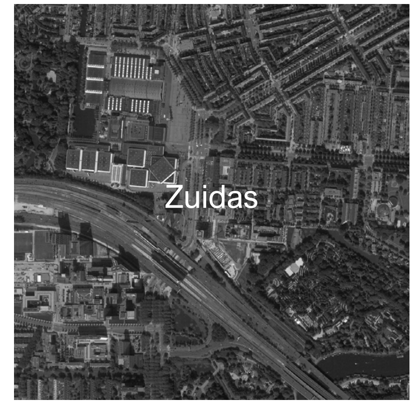


Fig. 7.5: Map showing Amsterdam's Residential real estate profile (Source: Author)

Residential Potential on Surface

Recent development plans across several districts in Amsterdam and its structural vision for 2040 have incorporated residential development iniatives to account for 700,000 new houses. With highly dense brownfield areas, space for new projects is scarce while the demand for housing keeps exceeding the vision projections each decade. In this case, underground spaces can help open up new areas for such projects on the surface while shifting non-residential functions underground in phases.

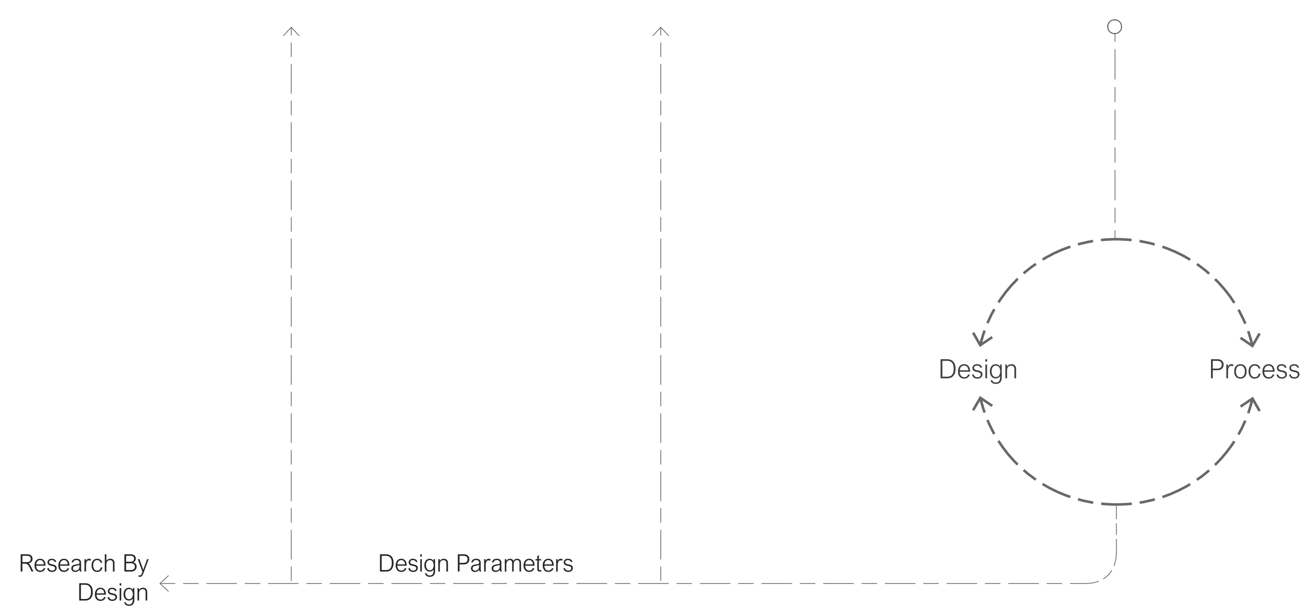
The current real restate trends depict rise in residential property rates spreading outwards from the old city towards north-east and south-west. Incidentally, the N-S metro line is located along this corridor, acting as an asset for subsurface expansion. Choosing a site along this stem would be appropriate to depict maximum contextual parameters and challenges to underground development. Superimposing this corridor over previously identified non-residential nodes safe for subsurface integration, the most prominent sites are found to be in vicinity of Amsterdam central station, Europaplein and Noorderpark.



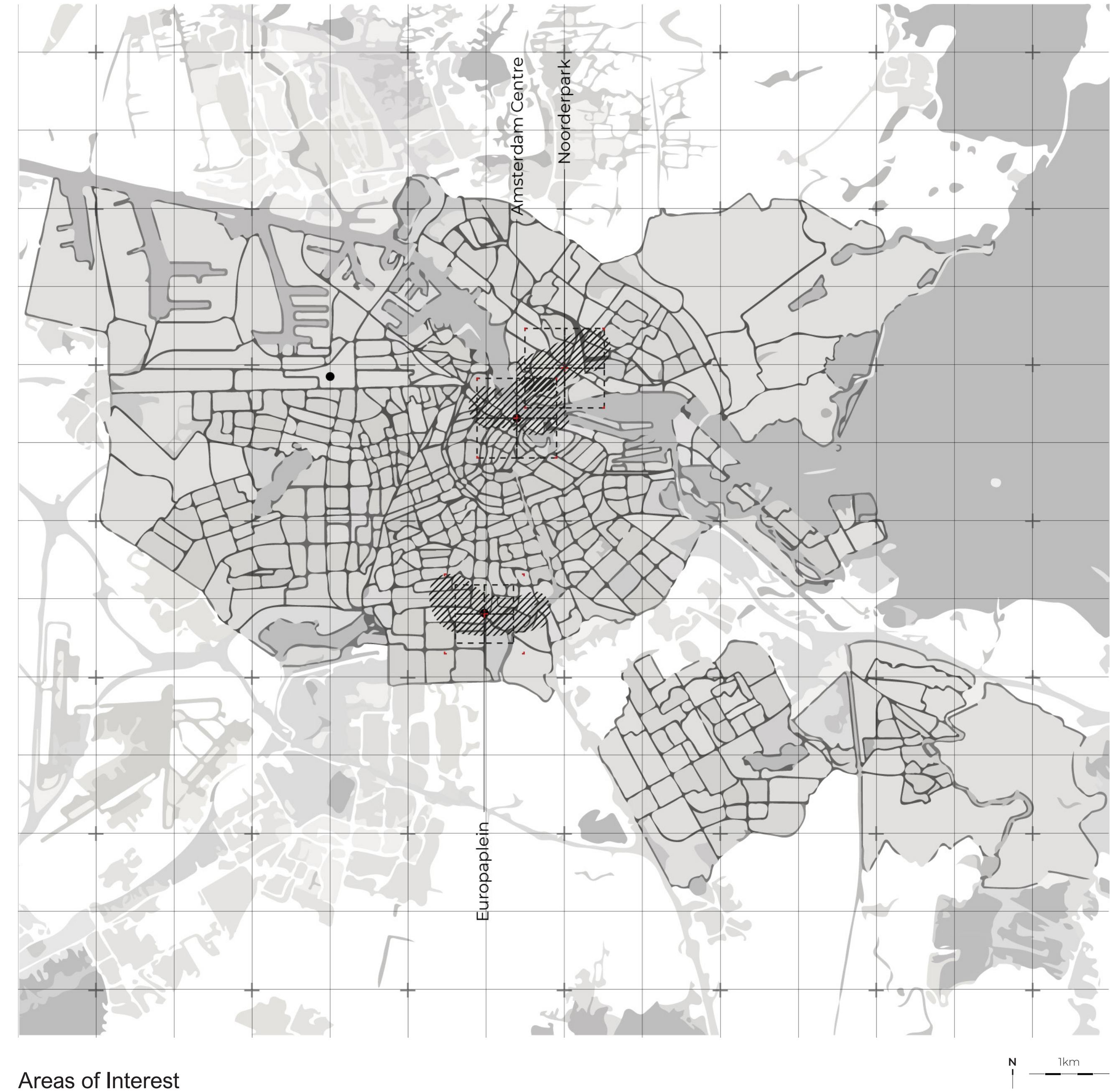
Located north of the harbour, the site describes predominantly residential land use with isolated small-scale commercial nodes in the vicinity. The current spatial growth trends in the city have been directed towards the west and south (globalized functions). To balance this growth in the future, there are projects planned northwards. Being the station closest to Amsterdam Central, the site is suitable for greenfield subsurface development to cater to future projects.

Amsterdam central is complex in terms of landuse and typed of constructions around the site. Sharing a heritage and institutional context, the site caters to a large footfall of tourists and commuters. As a result, it houses dense transportation infrastructure and underground parking spaces. The central station is an important national node for passengers as well as logistics. Since the subsurface is already densely occupied by infrastructure, transformation is the most suitable form of expansion.

Europaplein is located close to the Amsterdam South ring road connecting Utrecht and Schipol airport. The surrounding landuse is a dense mix of business centers, hotels, cultural and public spaces with numerous upcoming residential projects planned near the site. Given the location and opportunities of brownfield development and constraints placed by existing road infrastructure, the site shows an interesting potential of both transformation and new subsurface construction.



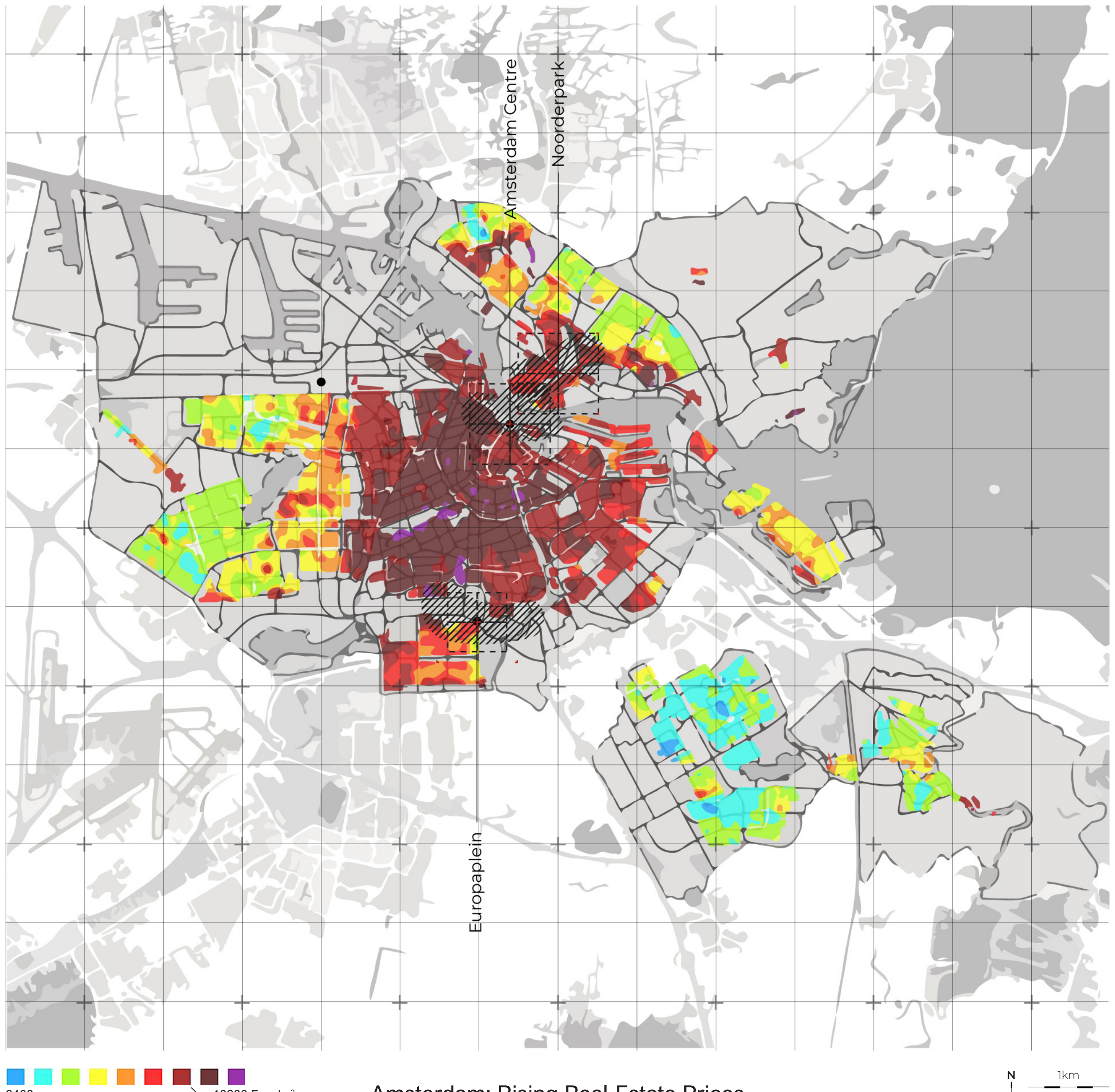
b. Site Analysis: Chosen Transformative Spaces



Areas of Interest

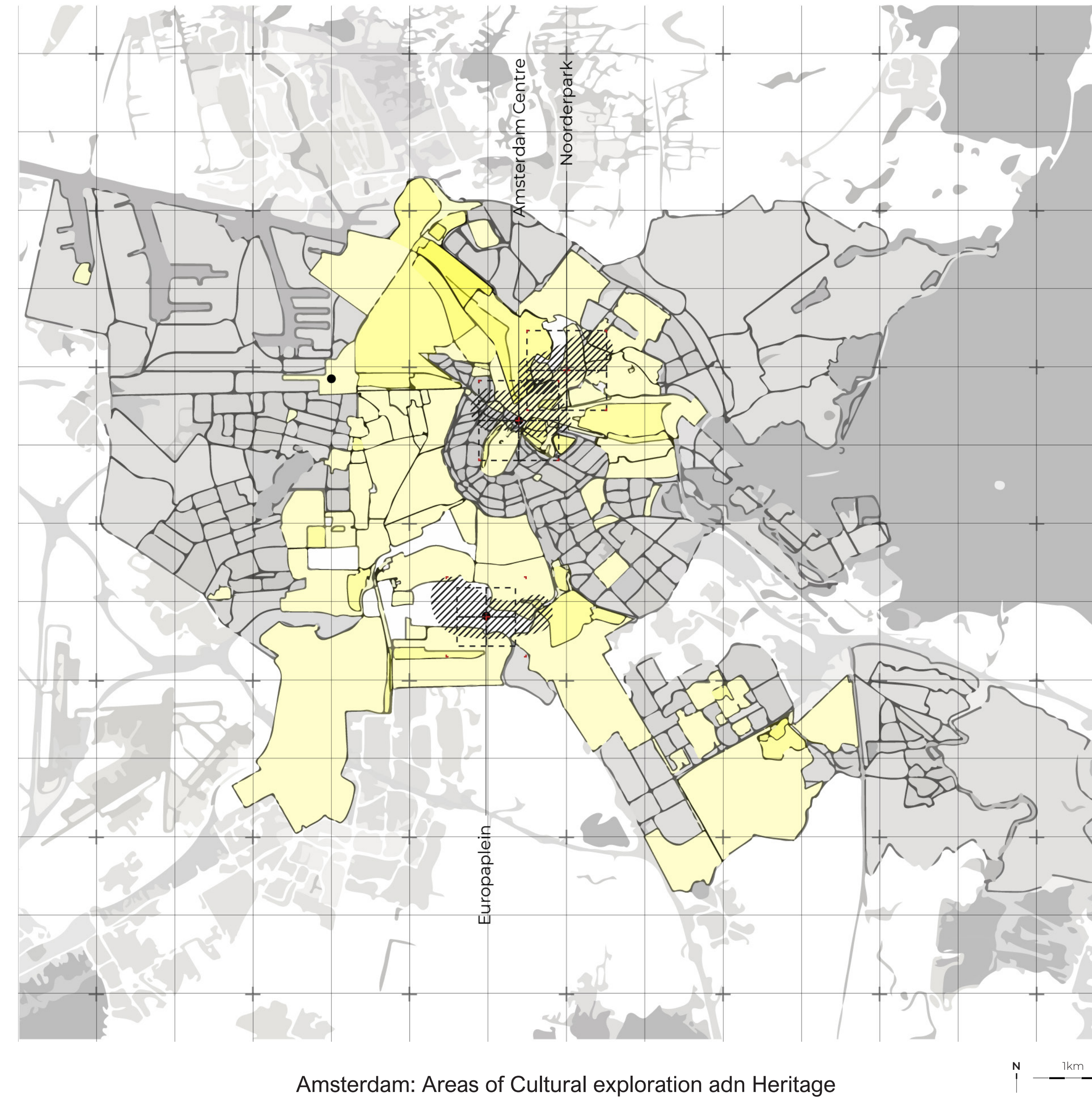
The North-South Metro line's construction spanned over 15 years through several hurdles and large capital investments. Instead of addressing it as a limitation, its infrastructure can be used as an asset, potentially acting as a spine for urban underground nodes. Hence, the chosen test sites for this study are located at three different stations along the metro line, catering to surrounding neighborhoods of distinct character and respective nature of possible underground construction.

Fig. 7.6: Map of Amsterdam locating chosen sites and areas of interest
Source: Author



Amsterdam: Rising Real-Estate Prices

Fig. 7.8: Map of Amsterdam's real-estate scenario
Source: Author



Amsterdam: Areas of Cultural exploration adn Heritage

Fig. 7.7: Map of Amsterdam's cultural exploration spaces
Source: Author

c. Europaplein and Vivaldi, Amsterdam Zuidas

The site lies outside the old city with large office spaces, cultural nodes, and parks in the vicinity. Hence the context is composed of high value real estate. Europaplein is well-connected by tram , metro and bicycle networks and located adjacent to the South Ring road which is a major thoroughfare producing physical barriers for pedestrians.

Described by abundant expanse of ecological context, parks and open spaces provide a suitable base for redevelopment, construction of urban underground spaces, augmentation and infrastructural integration. The existing underground N-S metro station links pedestrians with Amsterdam south and RAI station.

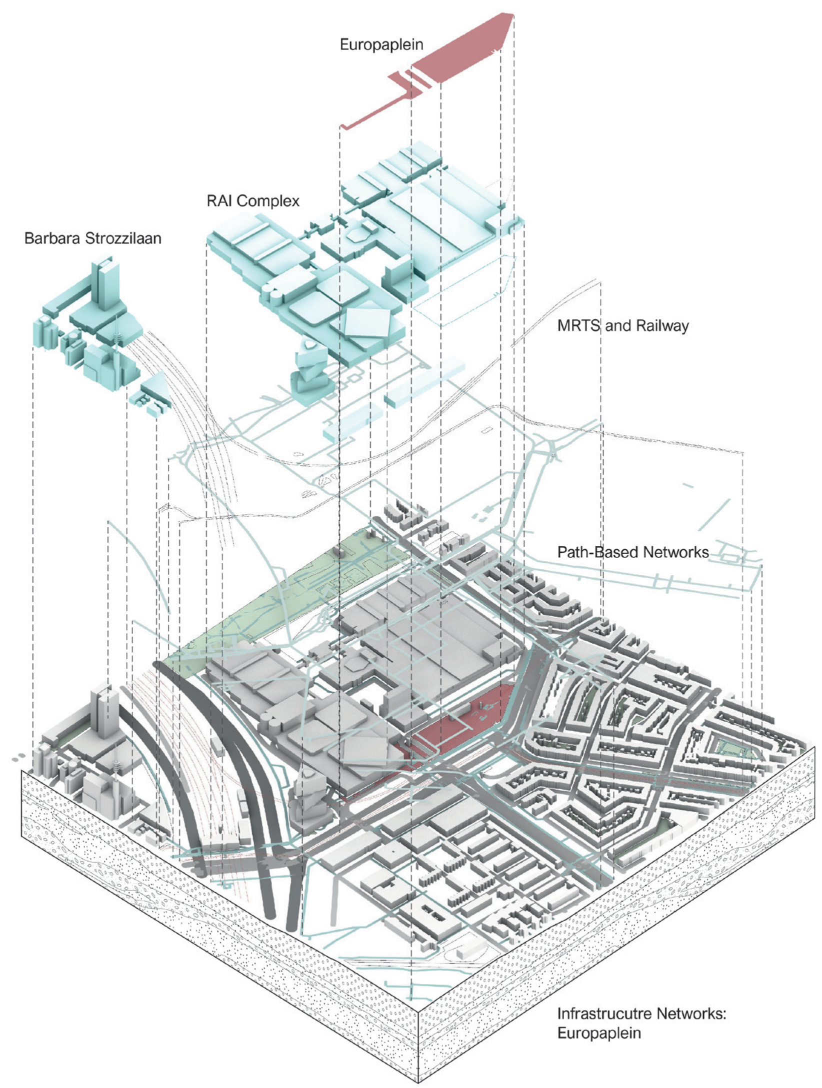


Fig. 7.9: Axonometric of micro-site Europaplein
Source: Author

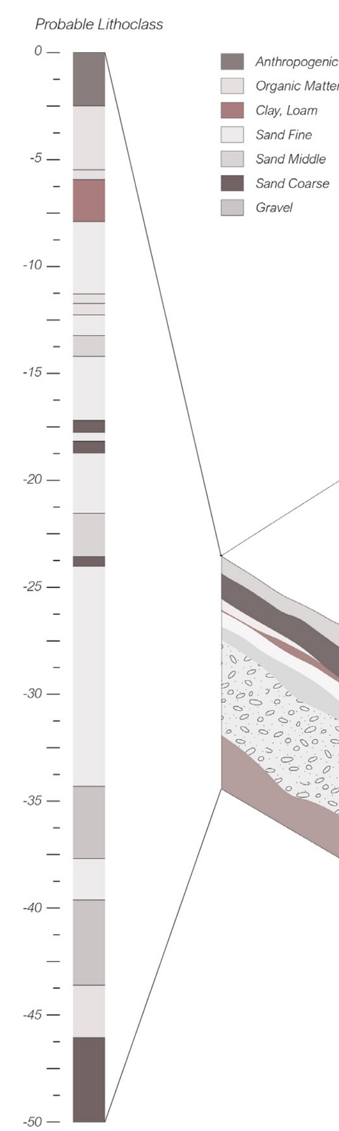
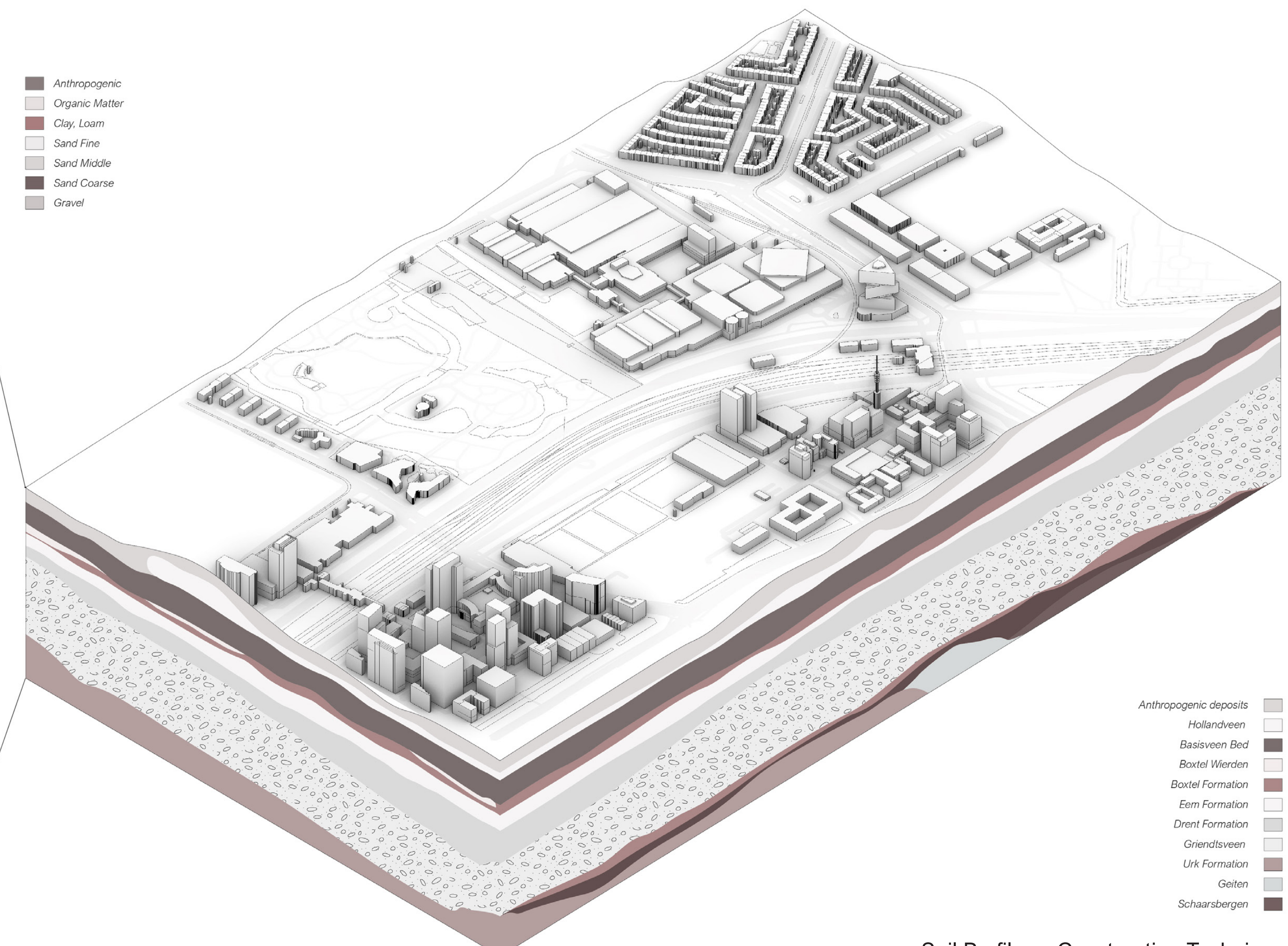


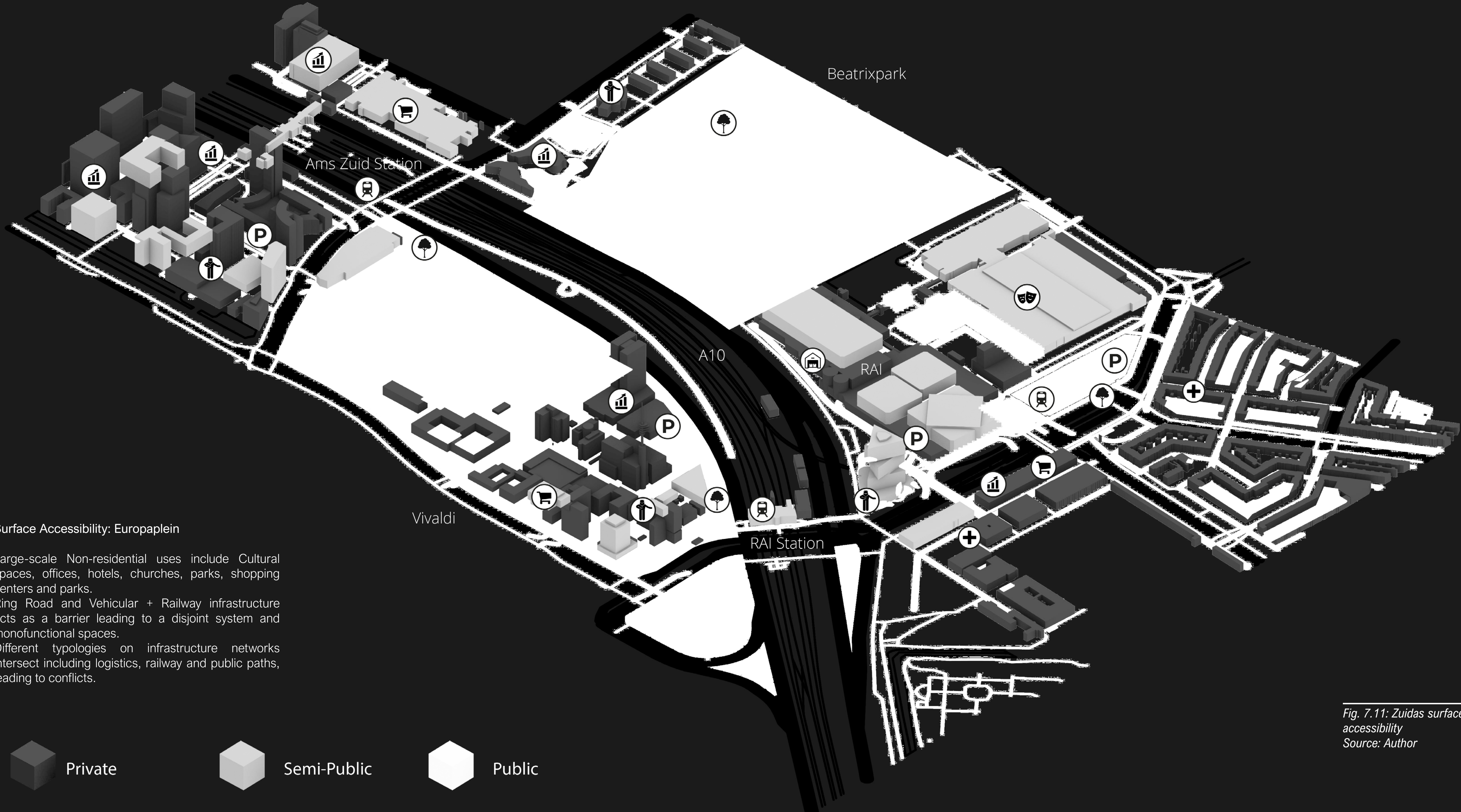
Fig. 7.10: Europaplein Subsoil Profile
Source: Author

Subsoil and Subsidence

The technical profile of the site descibes primary layers of sand, boxtel and clay at the depth of 0-12m. Underground construction in this soil profile is only possible till the extent of stronghold formation to prevent subsidence. Hence, the site can withstand construction at the maximum depth of -47.4m.



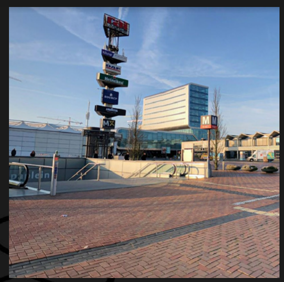
Soil Profile vs Construction Techniques



Surface Accessibility: Europaplein

- Large-scale Non-residential uses include Cultural spaces, offices, hotels, churches, parks, shopping centers and parks.
- Ring Road and Vehicular + Railway infrastructure acts as a barrier leading to a disjoint system and monofunctional spaces.
- Different typologies on infrastructure networks intersect including logistics, railway and public paths, leading to conflicts.

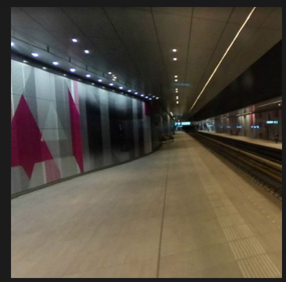
Fig. 7.11: Zuidas surface site accessibility
Source: Author



① North-Side Entrance

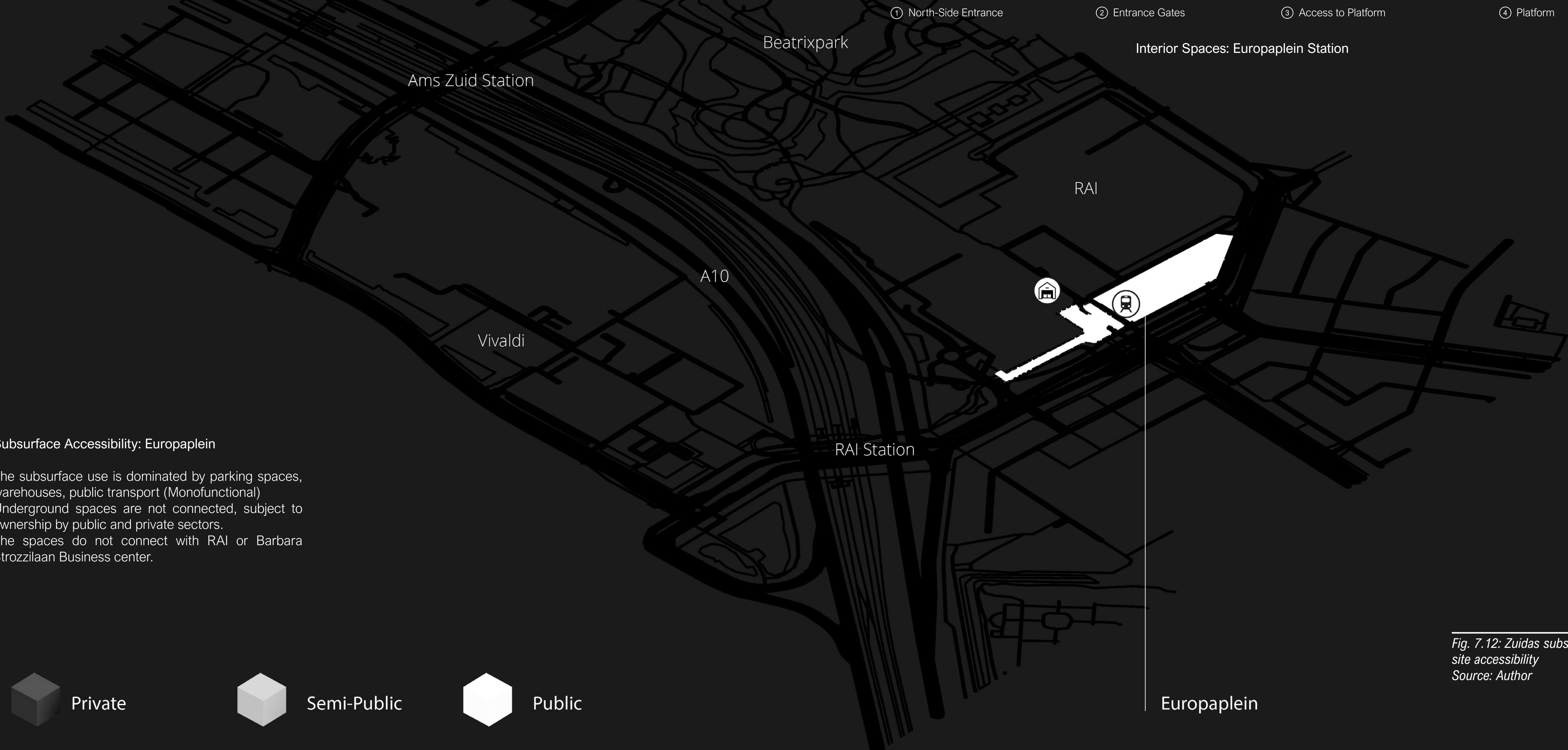
② Entrance Gates

③ Access to Platform



④ Platform

Interior Spaces: Europaplein Station



Subsurface Accessibility: Europaplein

- The subsurface use is dominated by parking spaces, warehouses, public transport (Monofunctional)
- Underground spaces are not connected, subject to ownership by public and private sectors.
- The spaces do not connect with RAI or Barbara Strozzilaan Business center.

Private Semi-Public Public

Fig. 7.12: Zuidas subsurface site accessibility
Source: Author

Potential Vertical integration of Functions

Other Soil Layers | Sand | Clay

North-South Corridor | Obstacles | Station

Fig. 7.13: Europaplein technical section
Source: Author

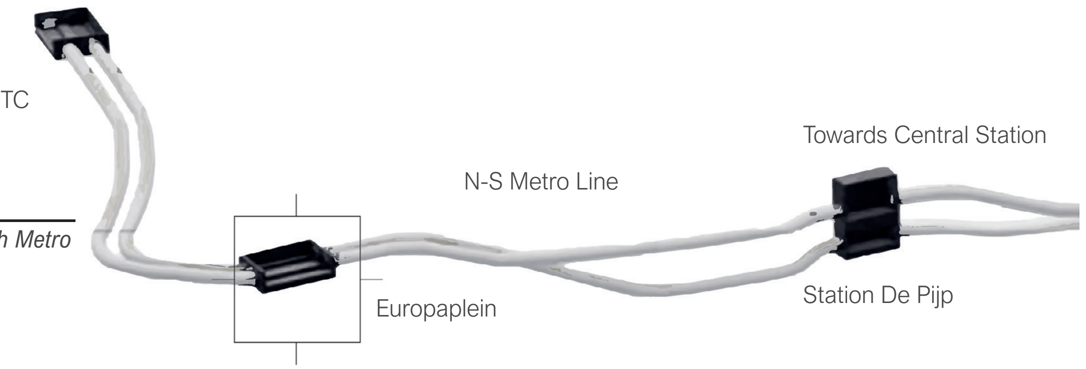
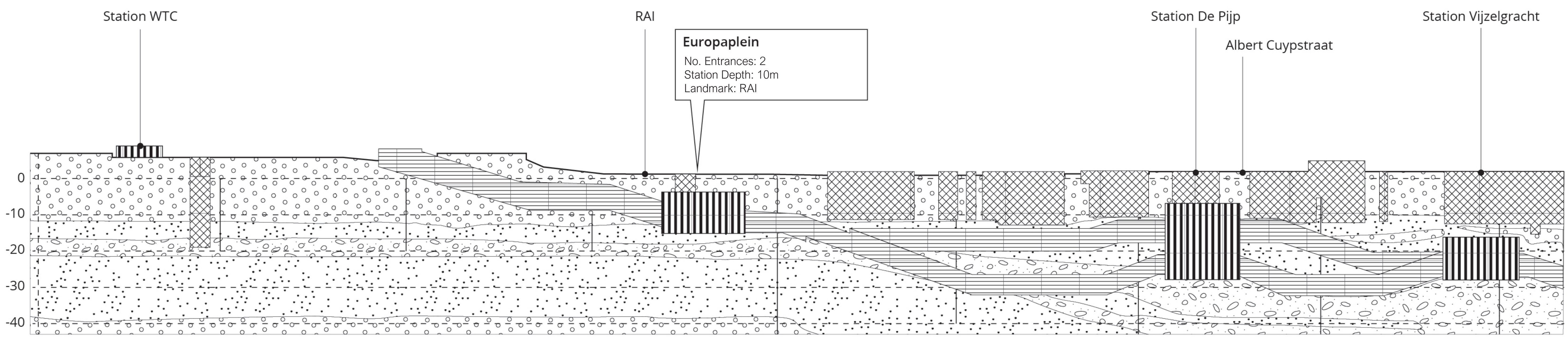
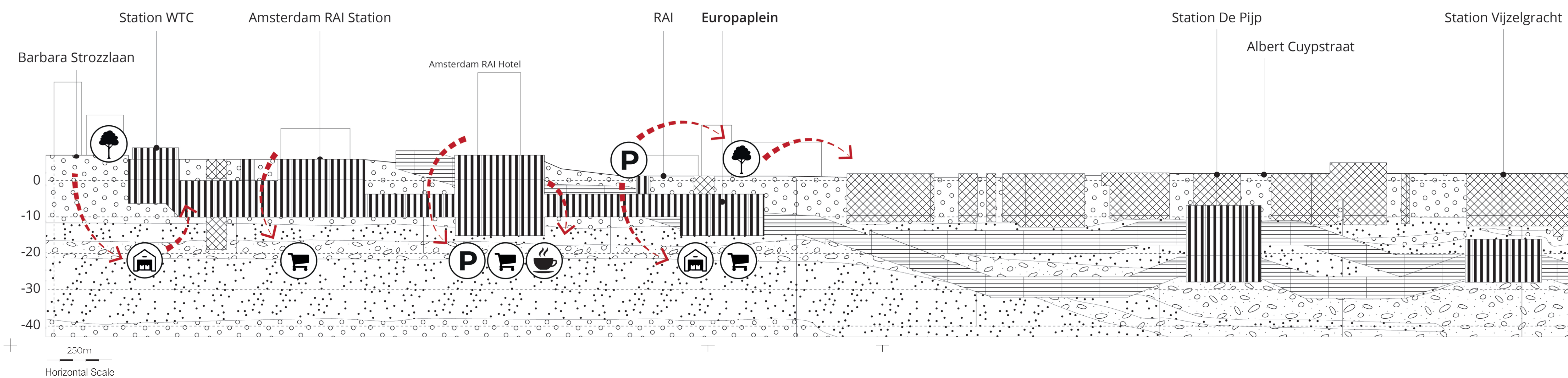


Fig. 7.14: North-South Metro line
Source: Author





Zuidas Urban Redevelopment Vision 2050

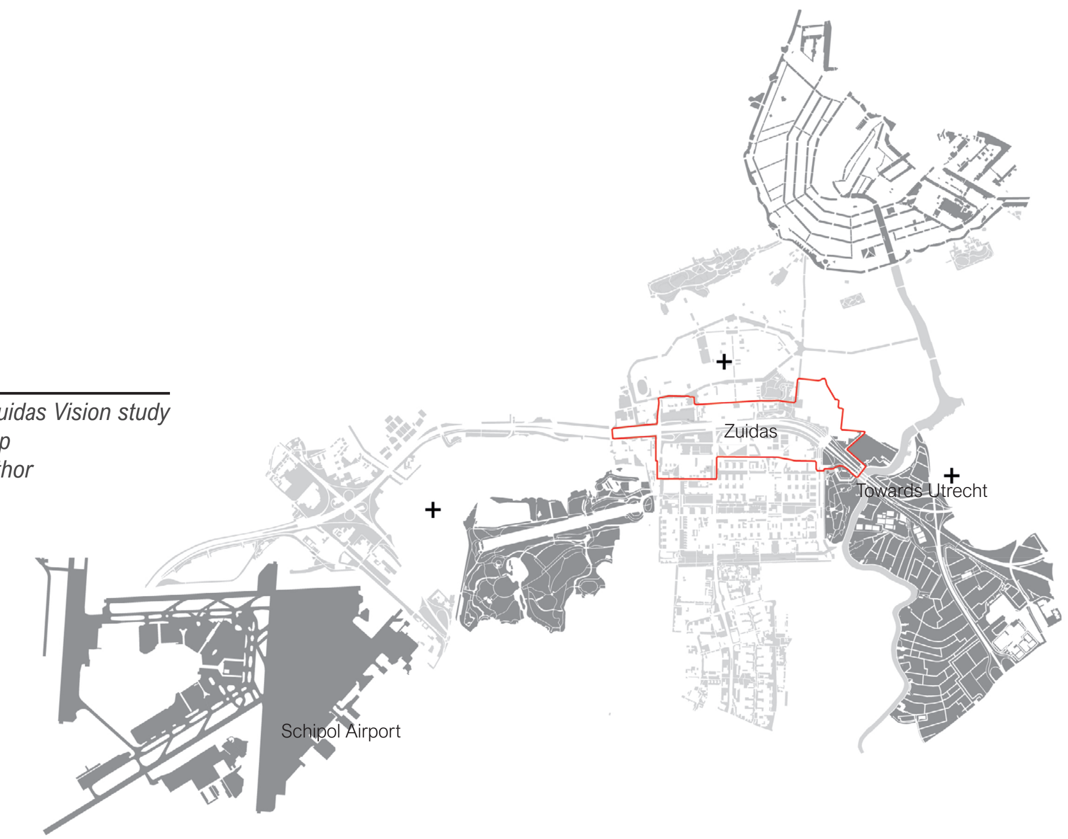
Since mid 2000s, consistent and rapid economic development in the southern business districts of Amsterdam saw the real estate prices and demand for space increased drastically given the increasing scale and spatial concentration of non-residential functions. Hence, the emerging metropolitan region was envisioned to be an essential node for global linkages, connecting Utrecht and Schipol airport. The plan addressed the office market slump and the need of new layered infrastructure networks, transforming the South ring road, maintaining an appropriate balance of working, amenities and livable spaces.

The strategic locational advantage of Zuidas offered green field developmentsite with an area of 270 ha, reducing construction cost for future underground spaces. Located between two major residential areas, the site was planned as a accessible strip to the Amsterdam Extension Plan of 1935. Currently, Zuidas is the city's 2nd most prime office and residential real estate hub with a range of business and knowledge centers, cultural hotspots and hotels. By the year 2008, the municipality made agreements to explore potential for densifying underground infrastructure within the site.

With constant investments and new residential projects proposed within the site for 2030, Zuidas still faces high demand for space on surface. The scale of infrastructure and built-environment, dominated by non-residential functions, tends to create hard borders between public spaces, roads and buildings. With utilities devoid of human-scale use, there exists an opportunity to plan for new subsurface functions that reduce the urban strain on surface where the groundscape may act as a soft border connecting public spaces with the rest of build environment.

Since multistorey tunnels have already been proposed over the current ring road, urban underground corridors can from Europaplein station can act as a pedestrian-scale attachment on both sides of the highway. Through the design exercise for the site, subsurface zones can be plugged-in as a part of a wider development vision for 2030. With further densification of transportation infrastructure connecting intercity trainlines with metro, the window for developing public spaces underground is limited and calls for transformation. Hence, a system of vertical nodes and corridors would be a suitable spatial form for future design.

Fig. 7.15: Zuidas Vision study area keymap
Source: Author



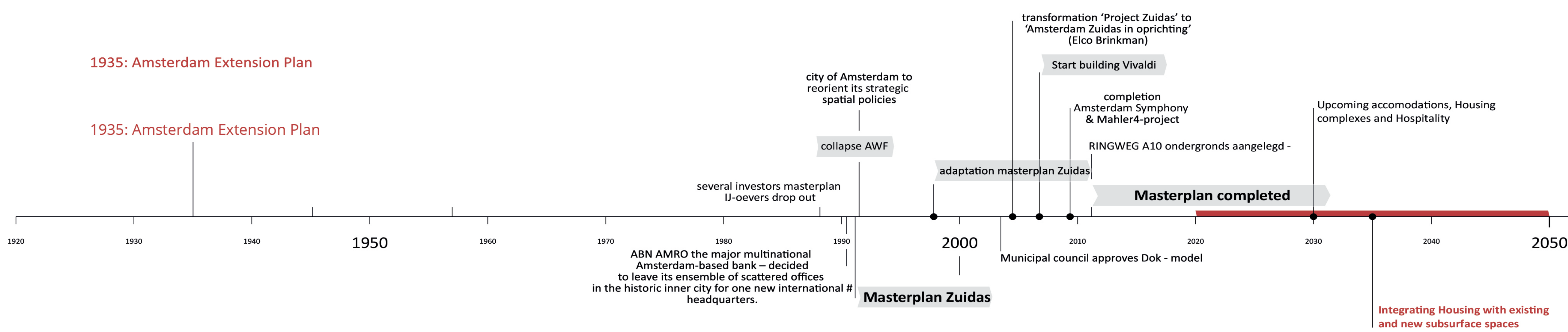
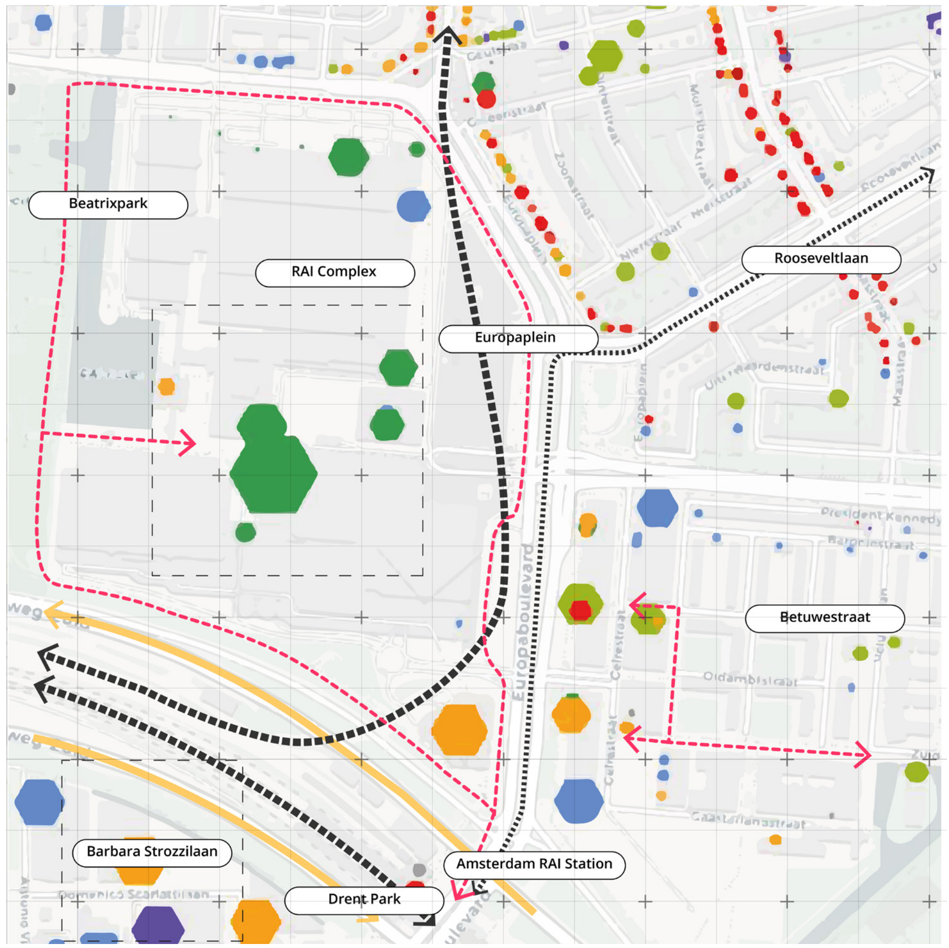


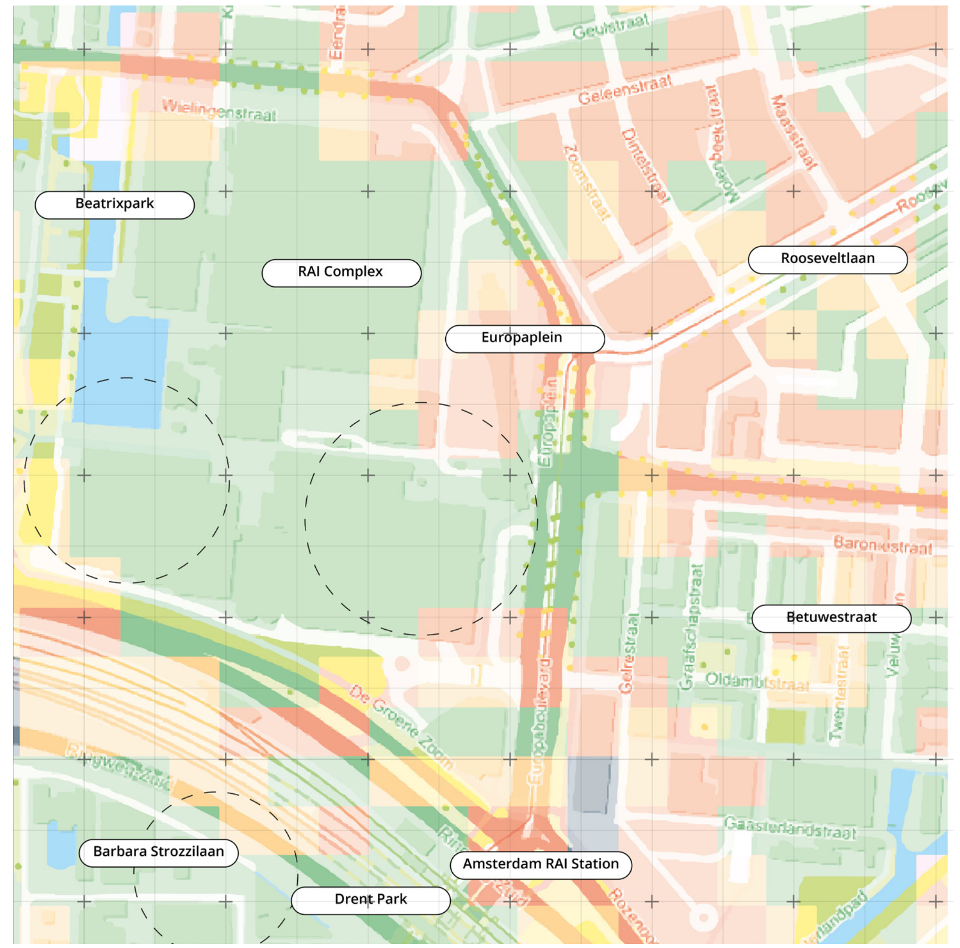
Fig. 7.16: Zuidas Vision timeline
Source: Author



Legend: Public Functions

- Retail
- FnB
- Offices
- Businesses
- Social Gathering
- Pedestrians
- Highway Traffic
- Railway/Metro
- Tram
- Museum/Leisure

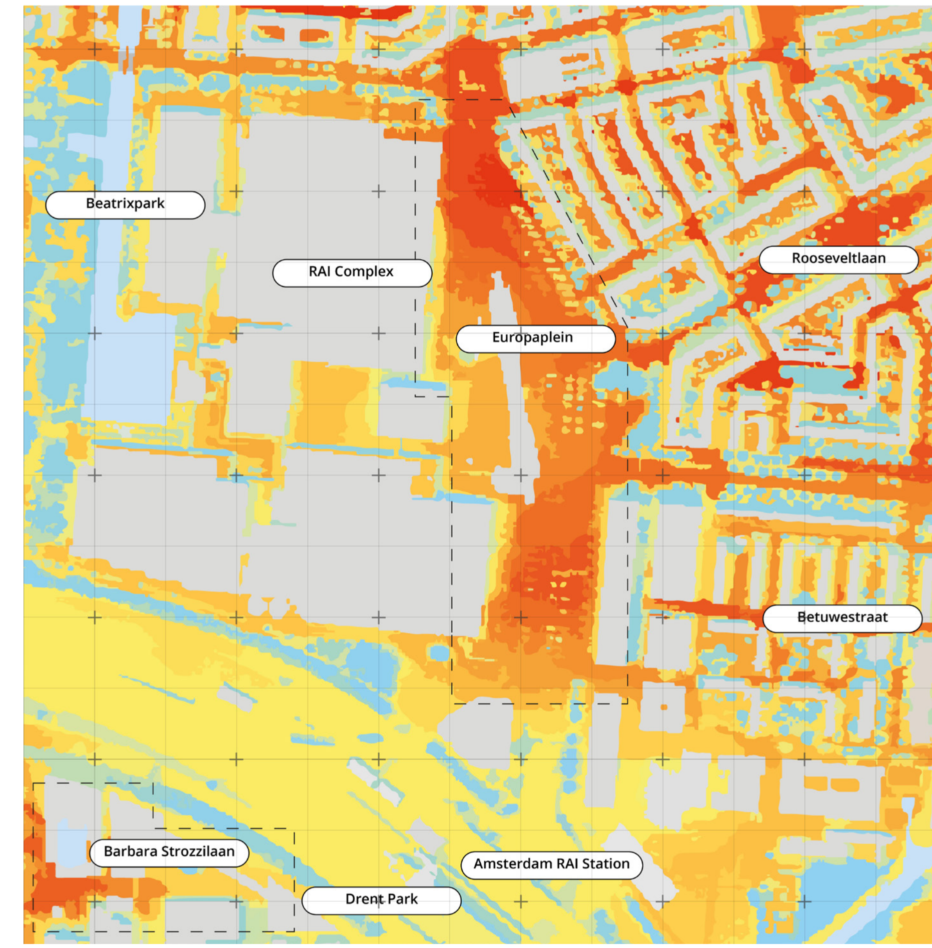
N 100m



Legend: Subsidence Risk

- Low risk
- Moderate Risk
- Significant Risk
- High Risk

N 100m



Legend: Heatstress

49°C 48°C 47°C 46°C 45°C 44°C 43°C 42°C 41°C 40°C 39°C 38°C 37°C 36°C 35°C 34°C 33°C 32°C 31°C 30°C 29°C 28°C 27°C 26°C of lager

N 100m

Opportunity: Linking Public Functions

- To bring the functions around Europaplein closer to human-scale while increasing range of functions, underground spaces can incorporate linear corridors for pedestrians, retail spaces and FnB outlets.
- To overcome physical barriers such as ring road on surface, subsurface augmentation can help in integrating isolated functions.

Subsidence and Redevelopment

- In the past 5 years, RAI and Barbara Strozzilaan show least risk of subsidence. Hence, suitable for underground urban corridors as connective tissue.
- Using public spaces in vicinity as sites for redevelopment to construct subsurface nodes reduces cost threshold.

Opportunity: Reduced Heatstress

- Subsurface spaces offer higher interstitial mass and atmospheric stability with low energy input.
- To reduce heat stress, several functions can be shifted underground to make space for green spaces on surface instead of paved.

8. Research by Design: Zuidas

Overview

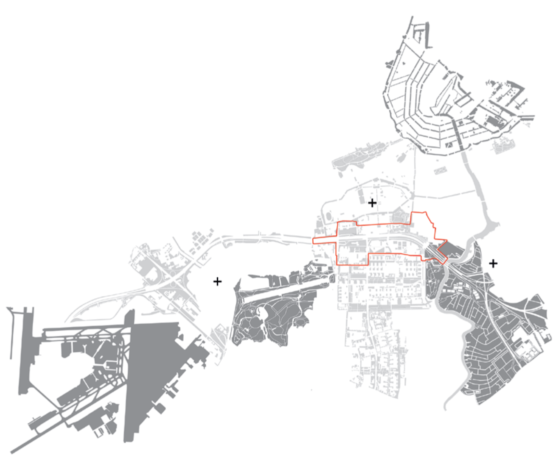
The exercise of research by design is intended for testing learnings from literature, experiment with analysis and design process to revise existing set of parameters and guidelines while planning for underground spaces. The approach is carried out for the extended site of Zuidas where the outcomes from theoretical and analytical framework are brought together to test methods of urban design, environmental planning and architectural design at different scales for the site.

a. Delineating workable underground space
b. Volumetric Planning
c. Vertical Program Integration
d. Design intervention

a. Delineating Workable Underground Spaces

Meso-Scale: Europaplein

The meso-scale accounts for Europaplein and its spatial links with Amsterdam Zuidas financial district. The stations proposed for the year 2030 would accommodate 325 thousand passengers within the south axis of the city. The vision document describes the western extent of the site to be a wide band of public spaces separated from the ringroad which will be shifted to multilevel tunnels in the future. The tunnels are composed of tramways, railway lines, and adjacent underground parking spaces catering to the business centers in the vicinity. Zuidas East is connected to this green band on surface with dynamic routes for slow-moving traffic alternating with several focal points for urban life.

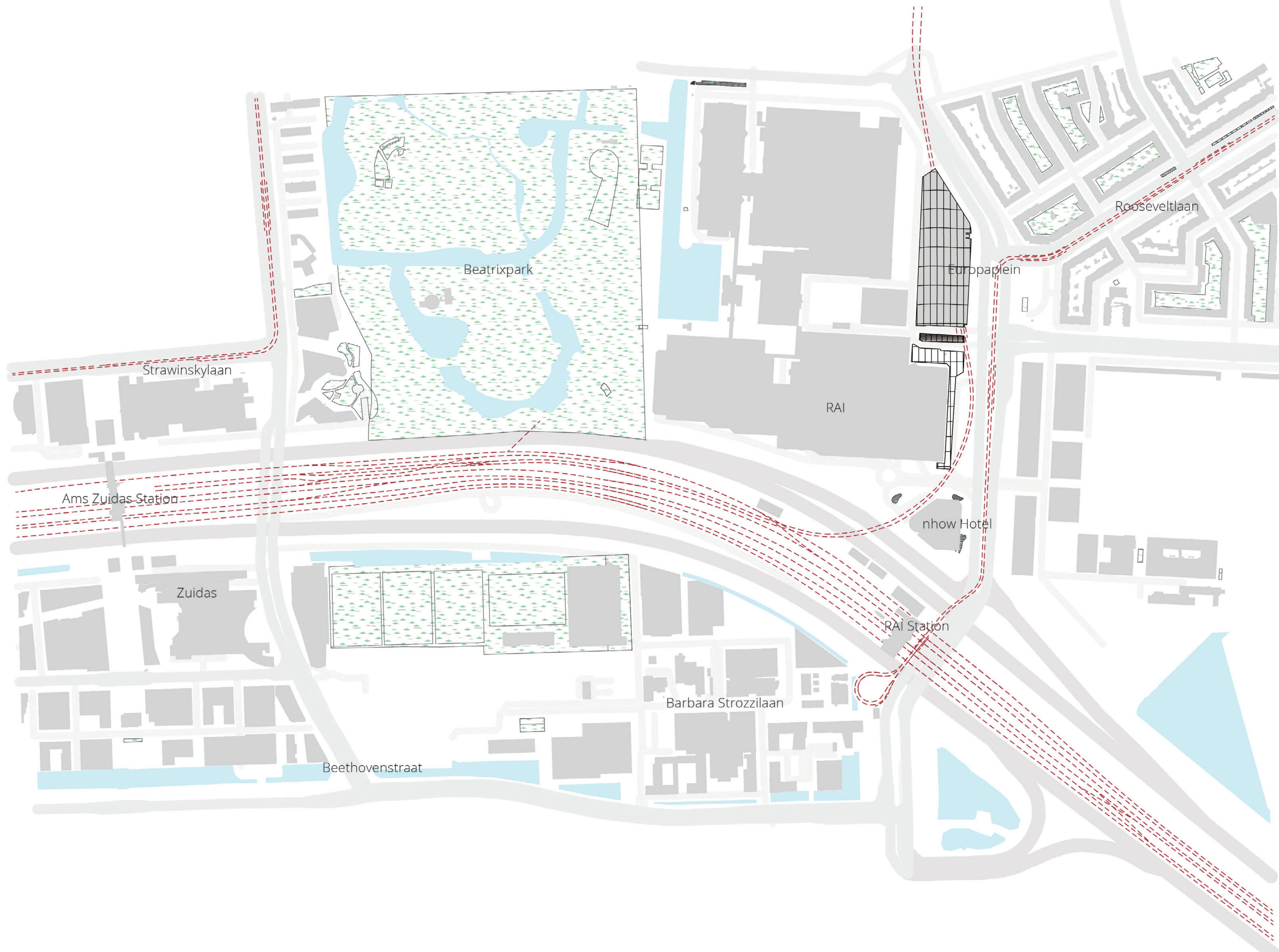


keymap

Legend

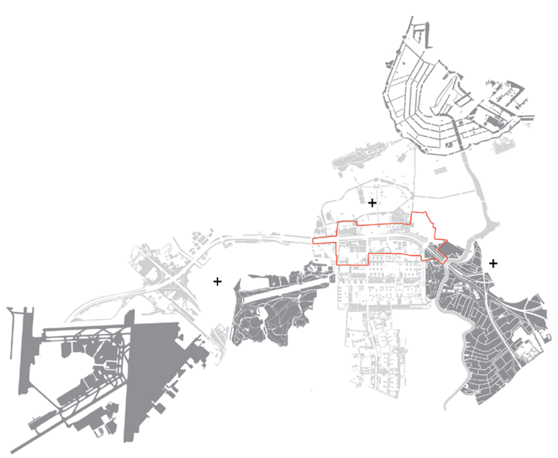
- Public Parks
- Buildings
- Highway
- Water Bodies
- Railway/Tram
- Underground Expansion
- U.G. to Surface Transition
- U.G. Movement

N 150m



Workable Underground: Subsidence Risk

The primary risk and limitations to delineation of workable underground spaces are placed by subsidence. The map highlights areas that have previously shown least subsidence since 2018. These areas can withstand deeper underground construction with minimal impact to the water table below. Regions with low subsidence risk can be used as spatial nodes with multiple gradients underground composed of lower-streets, entrances, pedestrian movement, resource storage and other activities. The remaining areas are suitable for urban underground corridors restricted to 0-12m of depth. These act linkages to the nodes and enable linear retail programs and walkable underground streets. The resultant workable area takes shape of a system of points and planes at a human-scale.

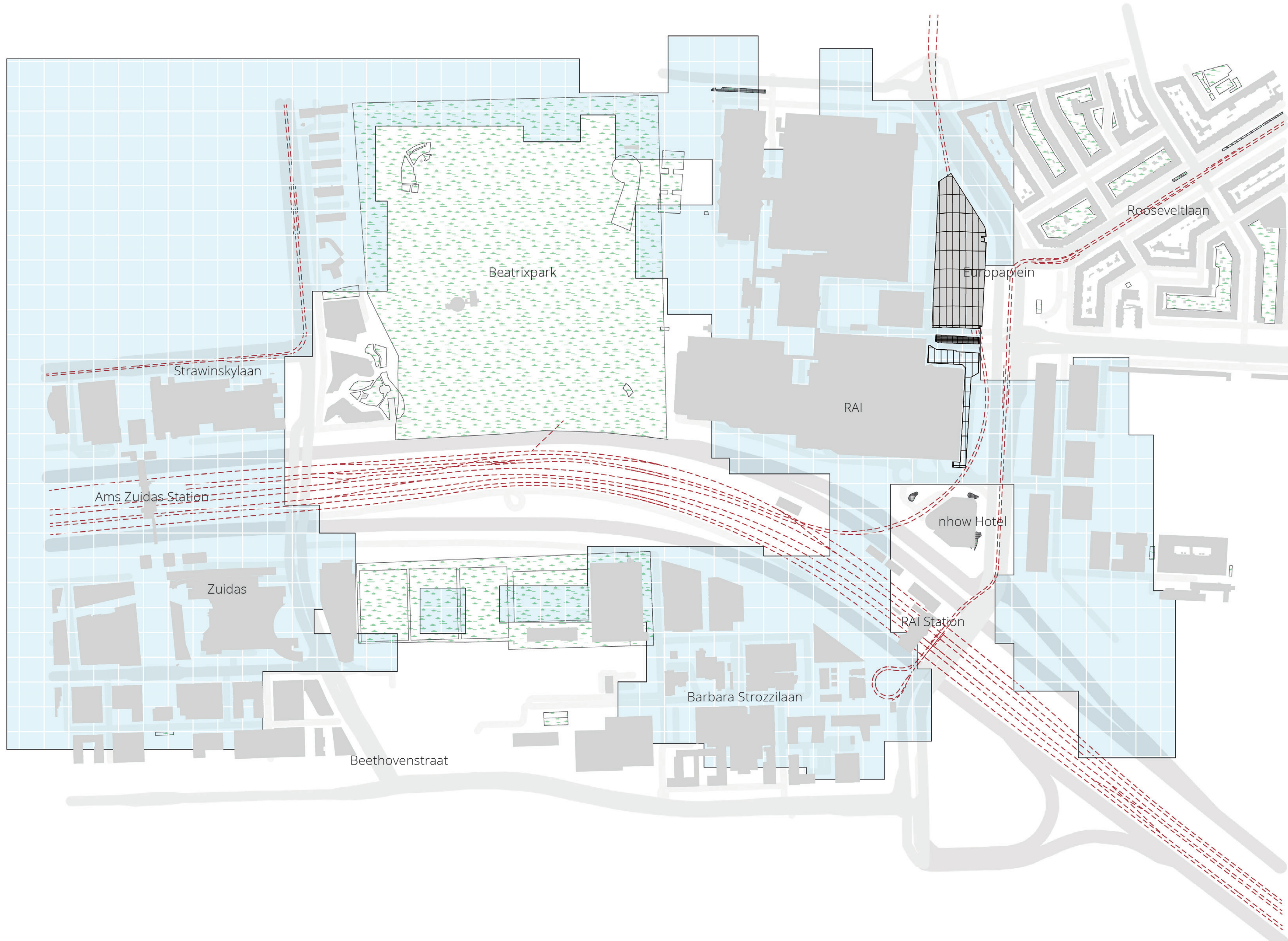


keymap

Legend

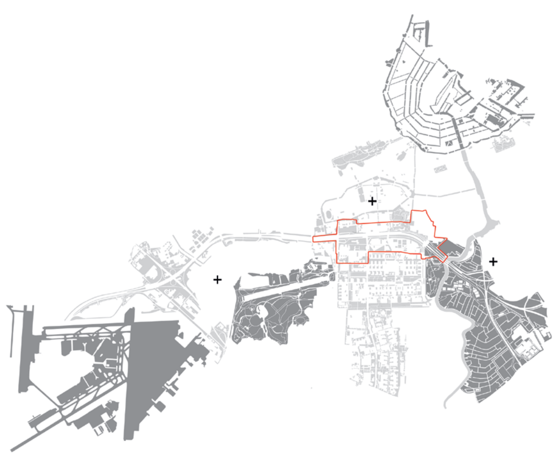
- Public Parks
- Buildings
- Highway
- Low Subsidence Risk
- Railway/Tram

N 150m



Expandable Corridors

While delineating the base workable region, it is important to consider limiting the distance between each node to be less than 300m to maintain walkability. The resultant expanse of base subsurface takes shape of a loop to link footfall between all three train stations away from physical barriers such as the ring road. The technological and cost thresholds also make it imperative to prioritize parcels with least redevelopment costs, hence point of entrances and groundscape development are most suitable around public spaces, sports facilities, road buffers and Beatrixpark for feasible excavation and construction.

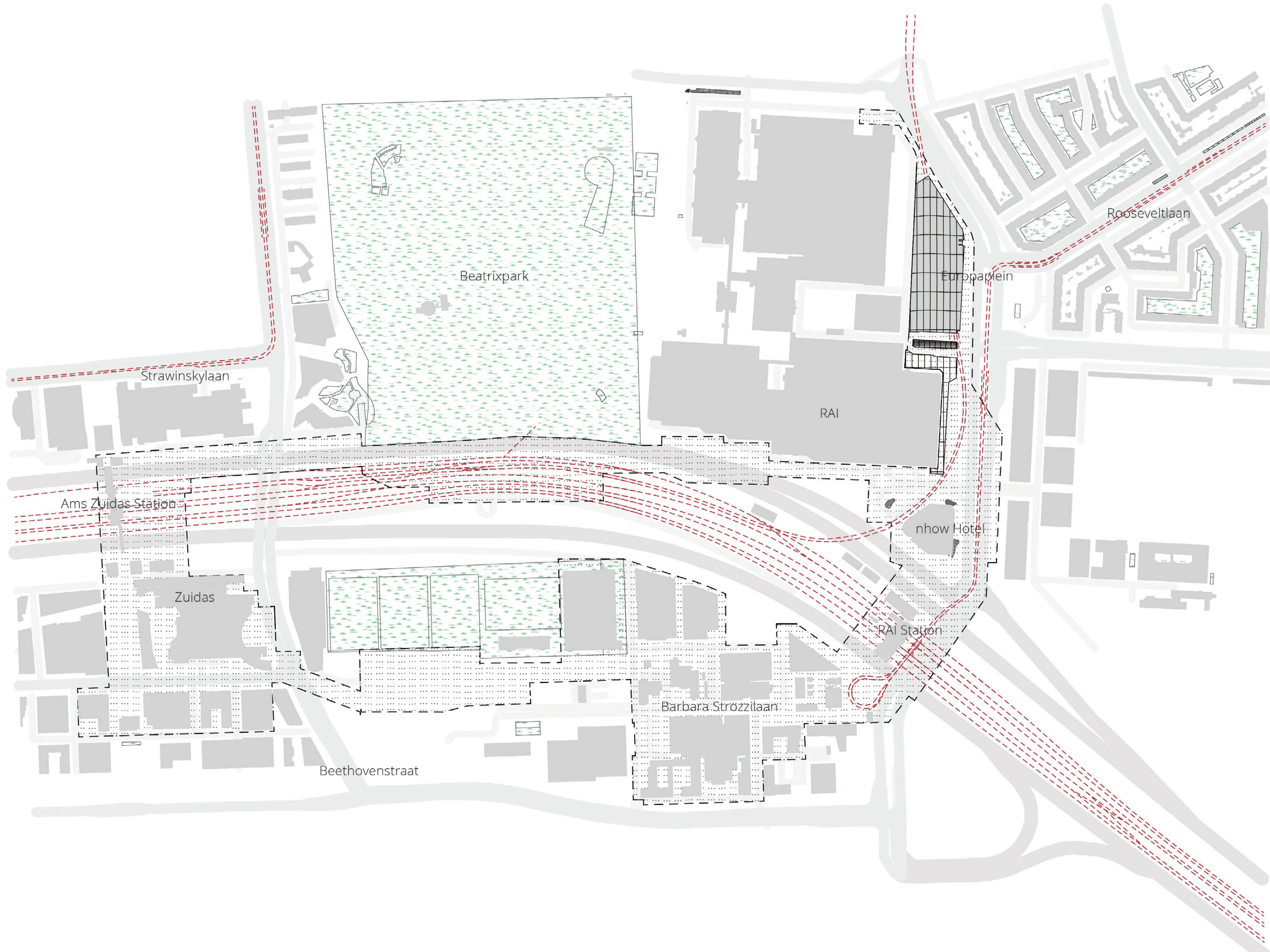


keymap

Legend

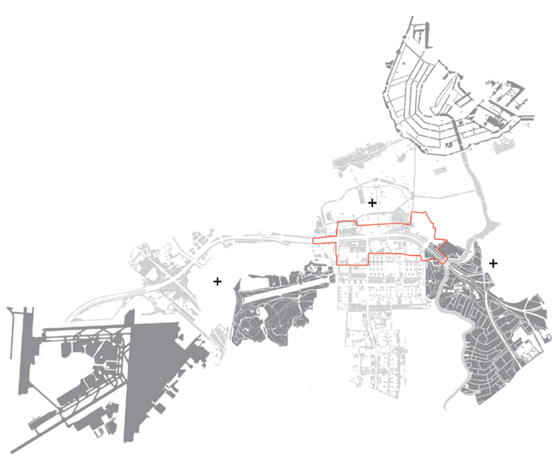
- Public Parks
- Buildings
- Highway
- Water Bodies
- Railway/Tram
- Underground Expansion

N 150m



Nodes and Corridors

The system of underground corridors and points is focused on generating new public streets instead of tunnels where the subsurface can be a substitute of public spaces with convenient transition between different vertical levels. The identified single-storey corridors enable constant moving footfall laced with linear retail, cultural spaces and commercials functions preferring street visibility. The nodes are envisioned as a system of double heighted volumes and complexes integrating commercial, hospitality and public spaces.

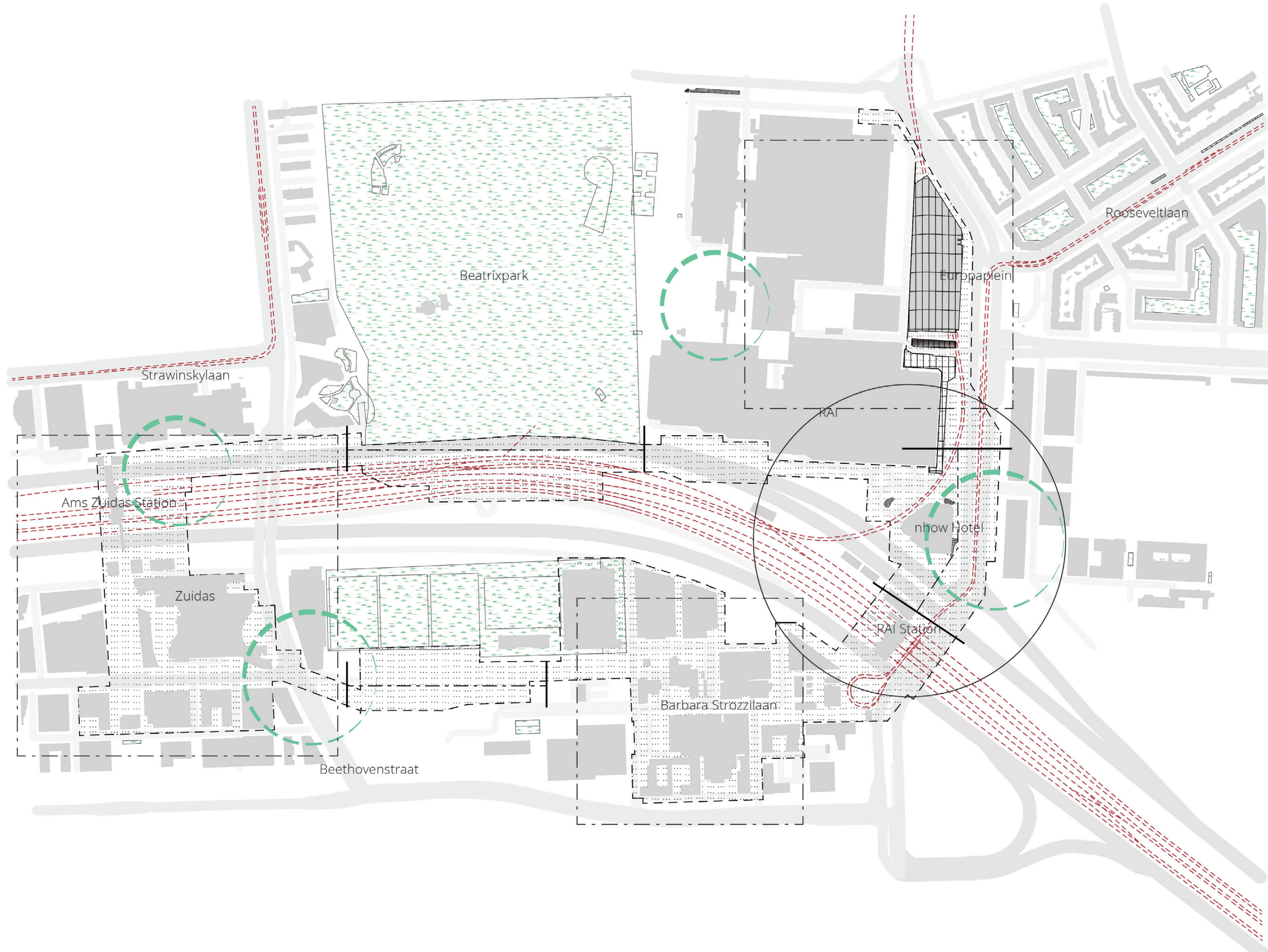


keymap

Legend

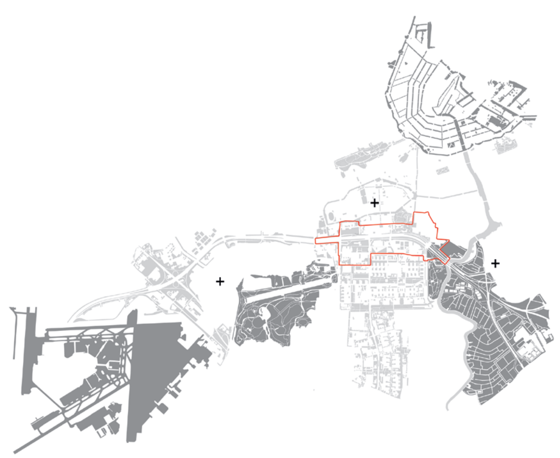
- Public Parks
- Buildings
- Highway
- Water Bodies
- Railway/Tram
- Underground Expansion

N 150m



Linking Surface and Subsurface

The study area includes a mix of business centers, public spaces, convention spaces and train stations. The vertical differenciation of these programs makes it essential for the subsurface loop to alternate overground to maintain a connected seamless experience for pedestrians and prevent disorientation. The alternation provides ecological elements on the surface to be infused into the groundscape making it more livable and softening the barriers between different programs. The resultant identity of future Europaplein is hence focused around maintaining well-integrated and walkable system of public space loops functioning at a human-scale.



keymap

Legend

- Public Parks
- Buildings
- Highway
- Water Bodies
- Railway/Tram
- Underground Expansion
- U.G. to Surface Transition
- U.G. Movement

N 150m

b. Volumetric Planning

Quantifying Volumetric Functions

Drawing inferences from ecological and geological risk, physical volumetric and spatial limitations can be established. The risk of subsidence limites the safe depth of underground construction to a depth of 47.5 m. However, to maintain the viability of functions allocated within this volume, it is important to quantify maximum achievable built-up area according to demand for space. The vision document for Zuidas indicates the need of an additional 350,000 sqm of base area based on the projections of space required for uses like offices, parking, amenities, cultural spaces and retail nodes. To determine the appropriate F.S.I. for underground development, a 60-40% composition of low-rise to mid-rise develoment was assumed bringing the average F.S.I. of 1.55. Assuming 25% of non-residential functions within the district are shifted underground, a total achievable built-up area of approximately 550,000 sqm was obtained.

The composition of functions underground were kept coherent with surface allocations for amenities, commercial spaces and parking. The calculation of a general volumetric split was done by studying the basic volumetric division of functions with 100 blocks divided along the meso-scale site. This method helps calculate the design split and specify dimension parameter at different scales. The blocks are placed on a grid with each block covering an approximate area of 6,000 sqm. The uses on surface can be categorized into 4 functional clusters: high-rise business district, mid-rise residential use, low-rise cultural spaces and transit nodes i.e., railway stations. The study identifies 3 primary areas of interest for detailed design further in this exercise.

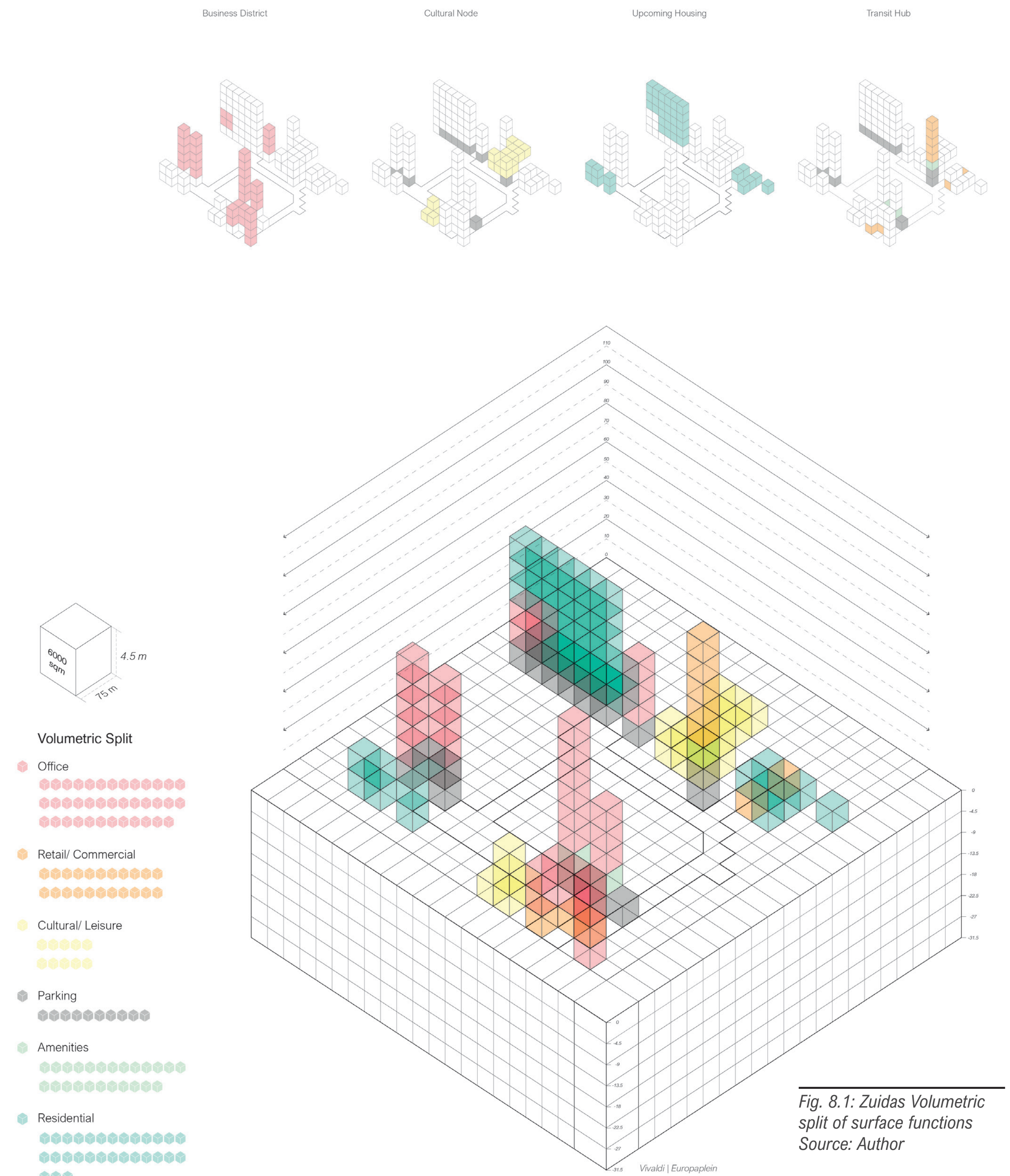


Fig. 8.1: Zuidas Volumetric split of surface functions
Source: Author

Allocation of Functions within Achievable Depth

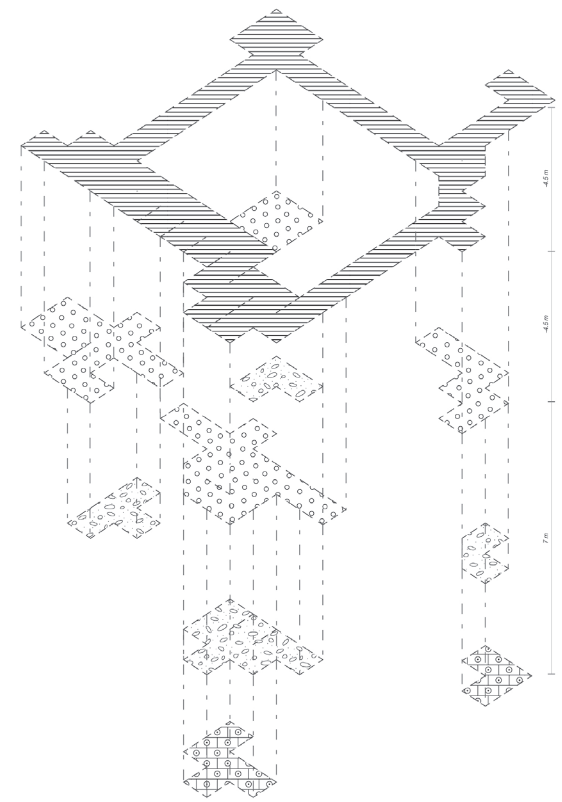
With the maximum vertical depth of 47m, a suitable division of levels was carried out. The current maximum volume allows a total of 7 levels underground assuming a standard block height of 4.5 meters per level, gradually increasing with depth. However, dividing the blocks within identified loop on the grid, a total of 4 levels are achieved. The composition of these volumes consists of 30% amenities, 5% parking, 32% public (retail and cultural/leisure spaces), and 33% office spaces. Dividing these spaces according to levels is done by ensuring the concentration of living spaces with inverse proportionality to depth i.e., the public nature of underground spaces reduces with increase in depth.

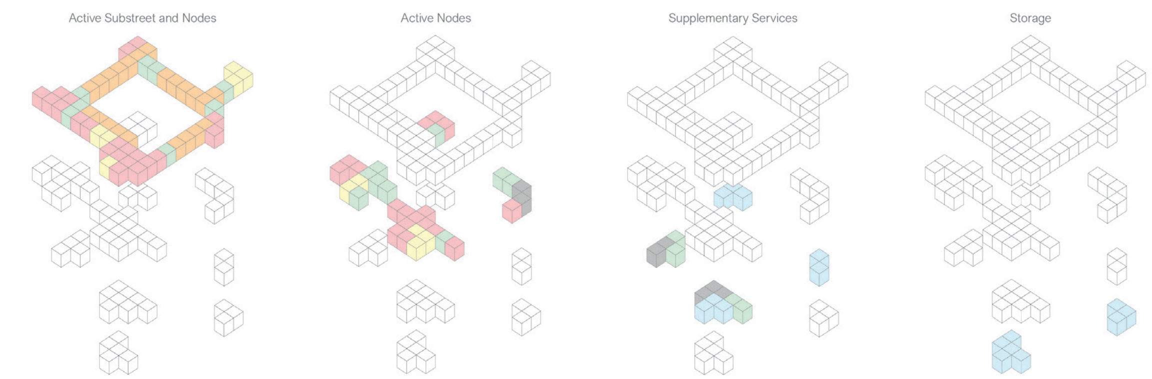
Level 1 to 3 are composed of blocks of 4.5m height each. The last level is reserved for spaces of storage, warehousing, data servers, and future logistics innovations. The clusters of engagement of surface use with these levels also varies according to depth. Since the first level is closest to the surface, majority of retail and cultural spaces are allocated along a loop of nodes and planes. As we head deeper, the loop at meso-scale transforms into a system of local hubs and streets in proximity to the nodes located on the level above. Level 3, requiring lower temporary habitation is supplied with spaces for utilities, services and parking spaces. These spaces serve the office clusters on the surface. The number of blocks allocated per level reduces with an exponential expression.

The quanitification of underground volumetric split results in levels of 4 different characters:

1. Active substreet and nodes
2. Active Nodes
3. Supplementary services
4. Storage

Observing the patterns of allocation, it was noticed that the division of volumes was carried out with similar principles as those required for surface landuse planning. However, the achieved system extends the groundscape to one subsequent level underground according to chosen functions. While the subsurface previously was only utilized utilities and storage, the current split shift these uses further down two levels, extending urban streets to the subsurface.





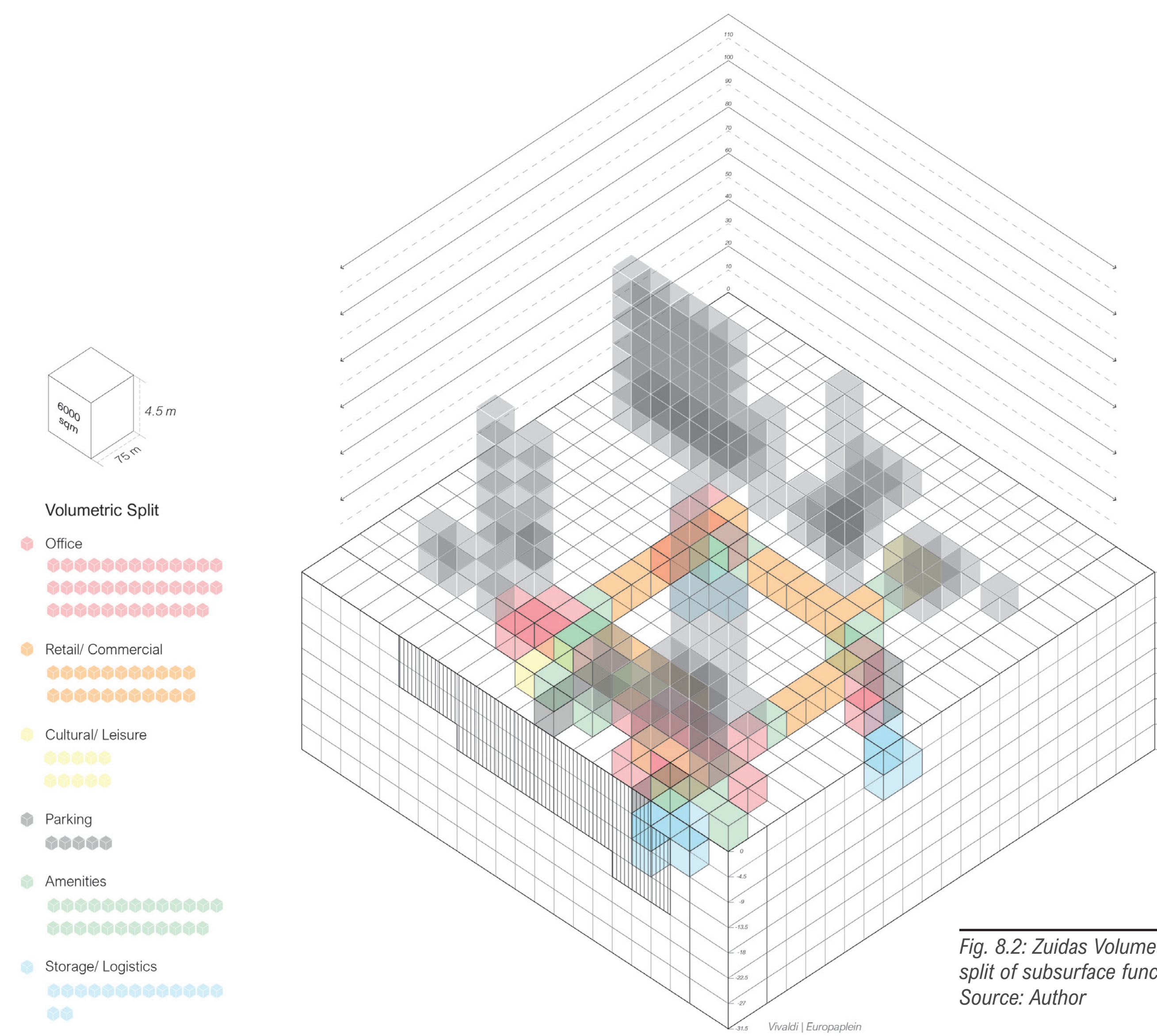
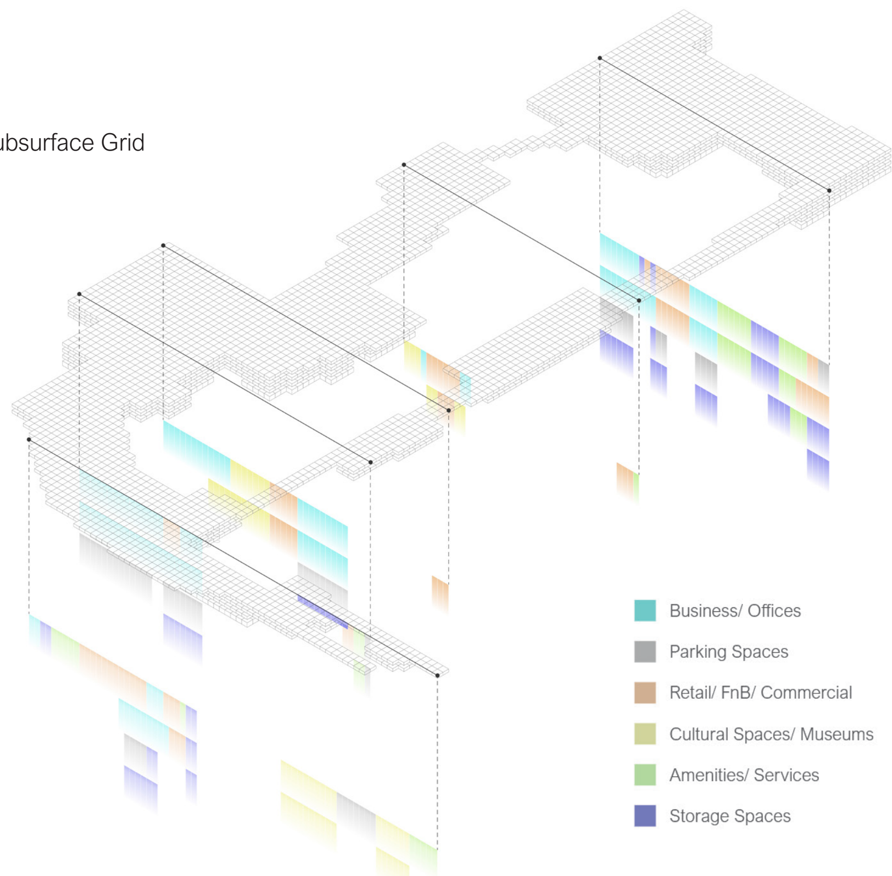


Fig. 8.2: Zuidas Volumetric split of subsurface functions Source: Author

Subsurface Grid



Enhancing the Subsurface Grid

The delineated workable subsurface loop is coverted into a grid of unitary blocks of size 100 sqm and an average volume of 450 cu.m in place of previously used blocks of 6000 sqm. This is done to enhance understanding of spatial requirements in terms of dimensions of corridors and respective nodal functions. The proportionally allocated with selected non-residential functions according to the specified 4 levels of nodes and streets. Sections across the grid indicate dominant functions of local nodes, dividing the site into 3 prominent areas: Cultural node, Shopping district and Business district. The concentration of allocated functions resonate with supplementary user requirements of respective nodes. The substreets consist of linear retail and leisure/ cultural spaces such as theatres, museums and exhibition halls while the nodes exist as double heighted volume converging office, cultural and commercial uses from surrounding streets.

Meso-scale Volumetric Allocation

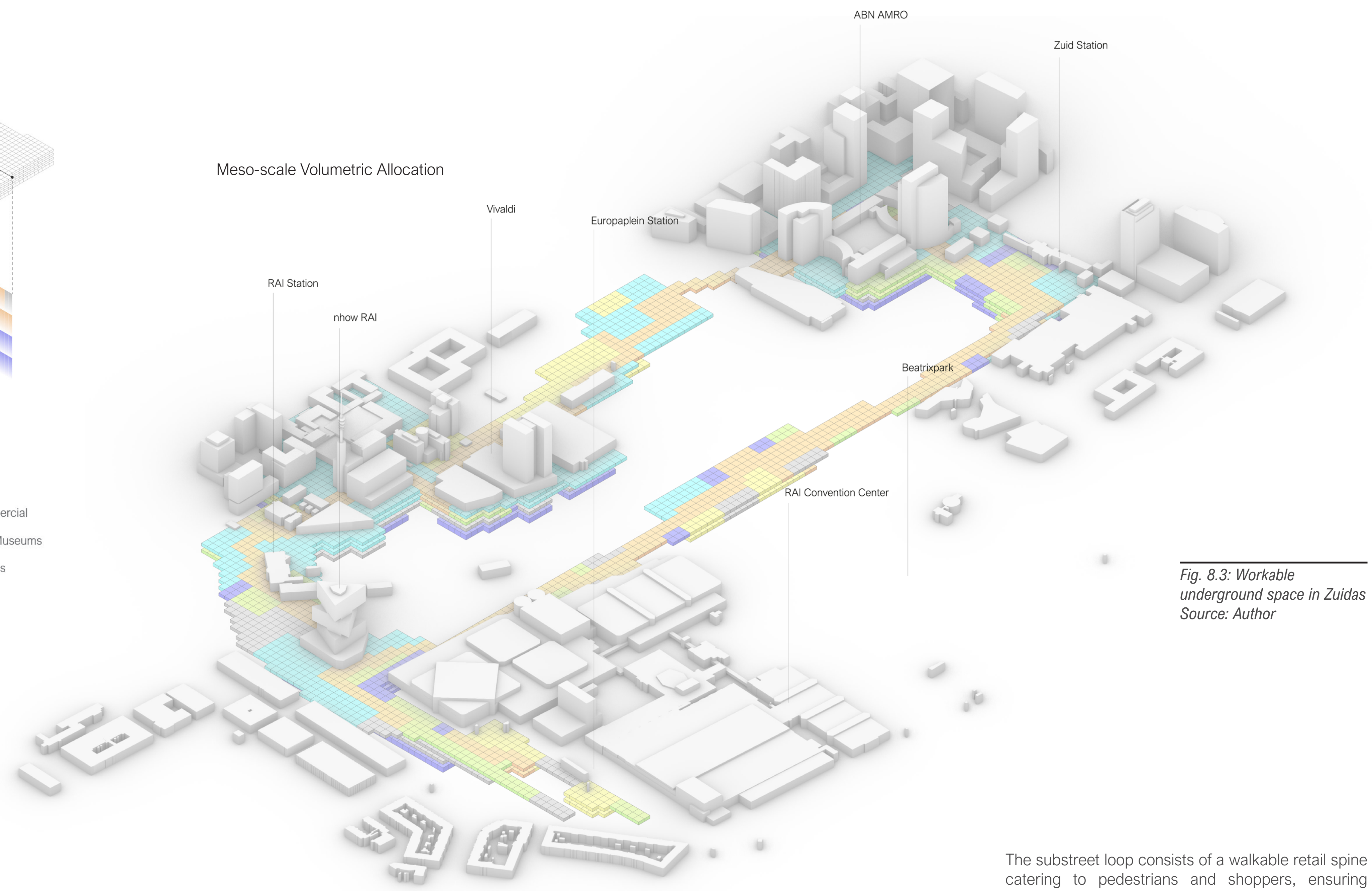


Fig. 8.3: Workable underground space in Zuidas
Source: Author

The substreet loop consists of a walkable retail spine catering to pedestrians and shoppers, ensuring constant movement and sense of orientation. Cultural spaces are located in close vicinity to the nHow Hotel and RAI complex to extend the existing cultural functions on surface within the groundscape. Spaces for utilities and services are assigned at regular intervals along retail and business nodes while parking spaces cater to the spatial requirements of private offices and railway stations.

Substreet and Nodes

The form and depth of underground levels are directly dependent on the subsidence risk faced by the underlying soil parcels. With respect to recent subsidence faced till 2018, the section of U.G. levels depicts the risk. Areas with high or significant risk hold the capacity of only one level of subsurface construction. This levels contains the walkable loop spanning the site and is hence, categorized as the urban underground street composed of linear retail, active frontages and pedestrian walkways. One the other hand, areas with low risk can withstand construction beyond 4 levels of depth, in this case, a depth of 20.5 m. Clusters of these parcels emerge as nodes composed of converging functions, intersections and concentration of activity spectrum. The volumes of non-residential functions are distributed accordingly. A system of these streets and nodes guides the form and orientation of users along the loop from RAI to Zuidas station.

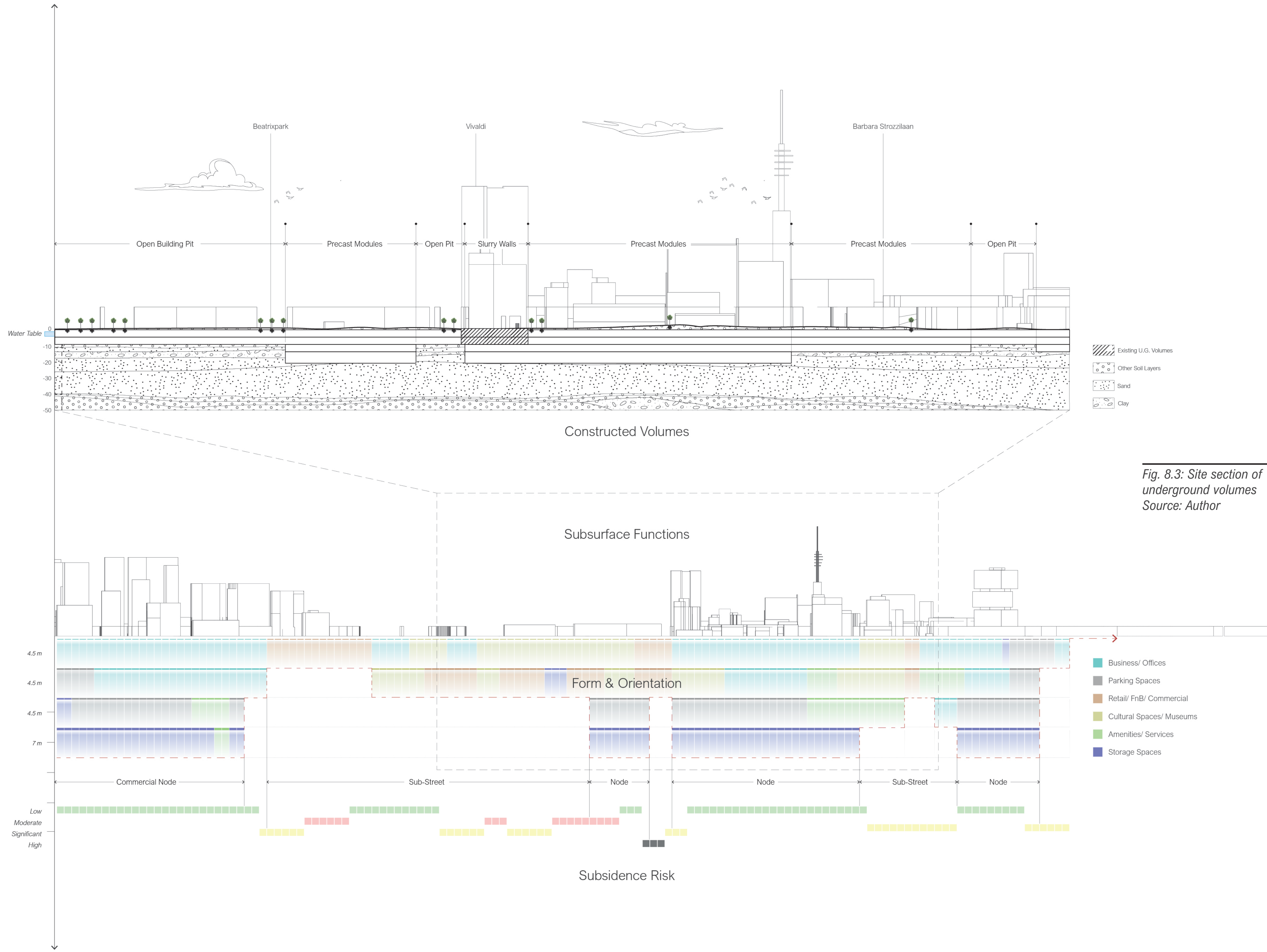


Fig. 8.3: Site section of underground volumes
Source: Author

Construction Techniques: Basements

Amsterdam's soil profile consist of sealing layers where clay layer is easily accessible for constructing diaphragm walls below underground volumes. These structures need to withstand pressure from surrounding sand as well as water. To prevent floating volumes, two types of construction techniques are used to stabilize diaphragm walls: underwater concrete with tension piles and placing composite wall in impervious layer. The use of each type is dependent upon the depth of immersion of composite wall in sand layer. The section shows the depths suitable for each type of construction. For desiging the basement structures, depth of levels guides the construction type i.e., open building pit for shallow construction similar to a subsurface valley, precast modules for deeper levels and the use of slurry walls in places of pre-existing underground spaces. Precast modules are most suitable for basement structures of tall buildings and hence appropriate for the built character of the site.

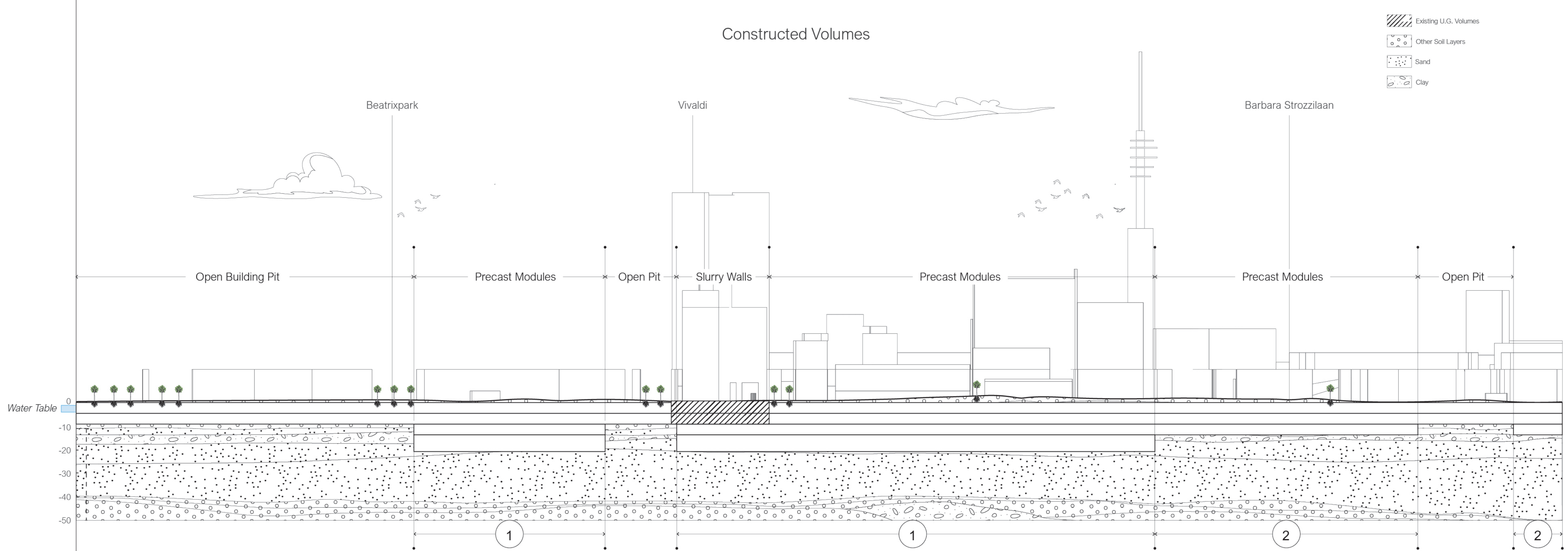
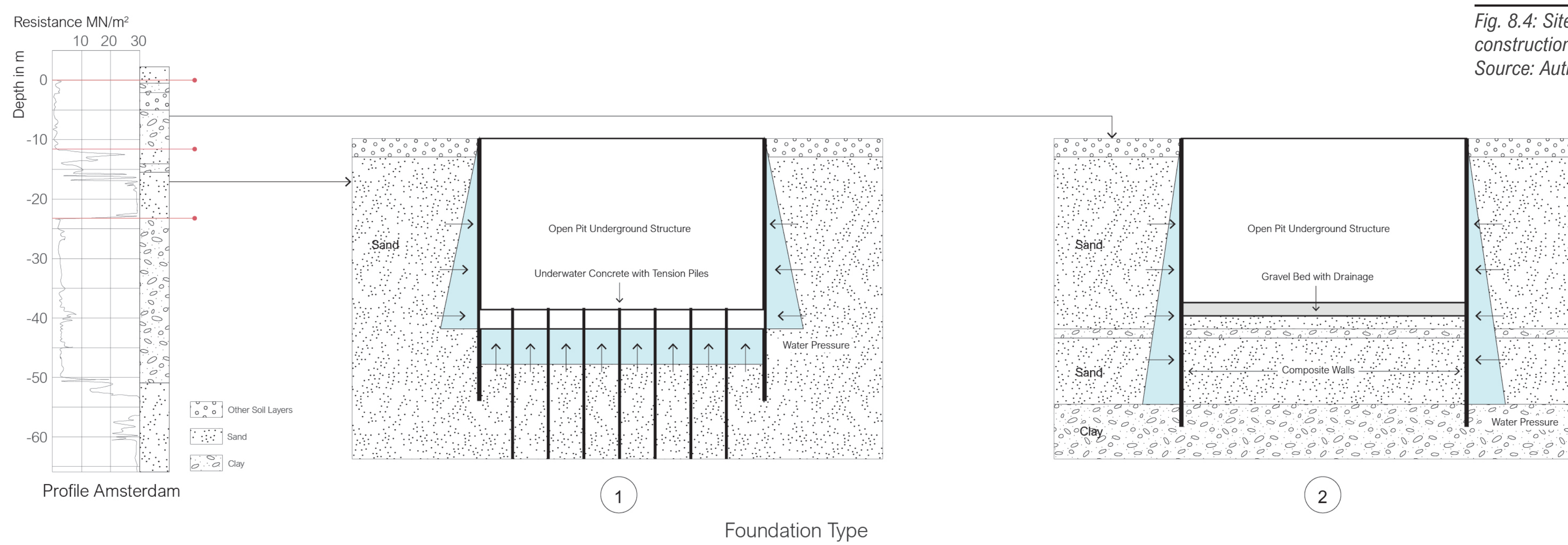
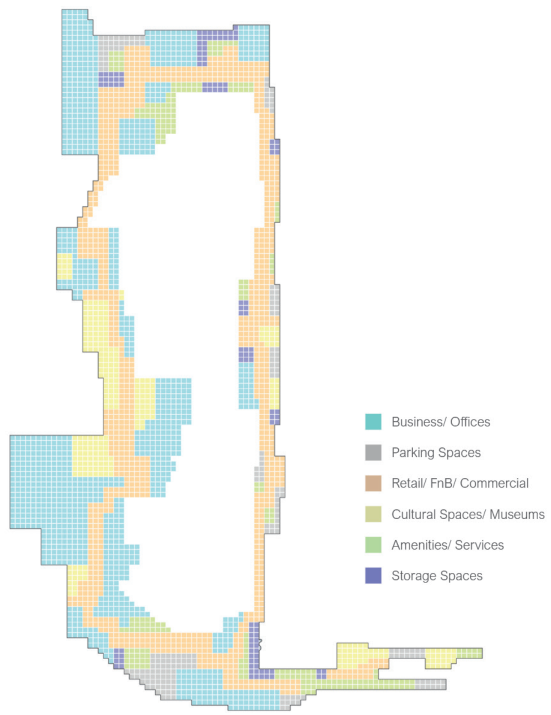
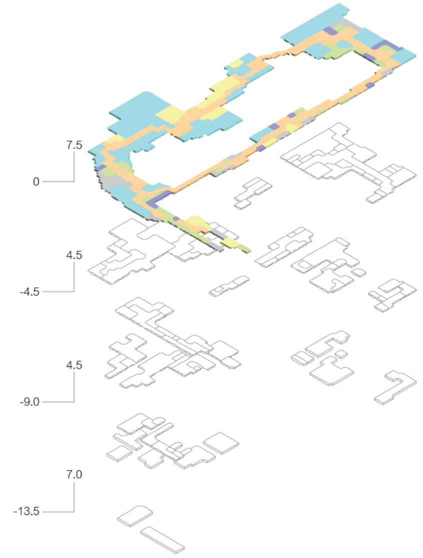


Fig. 8.4: Site section showing construction methods
Source: Author







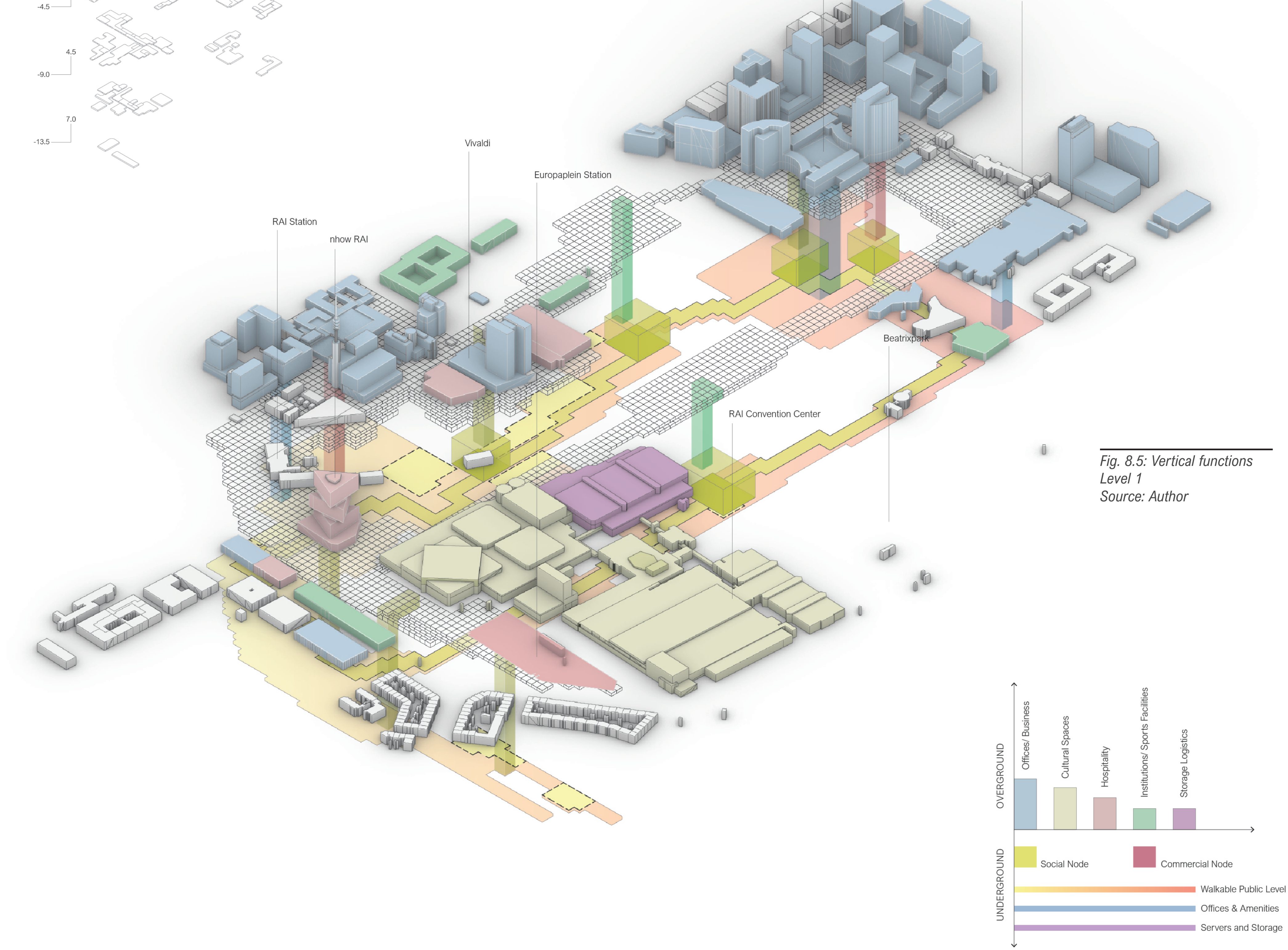
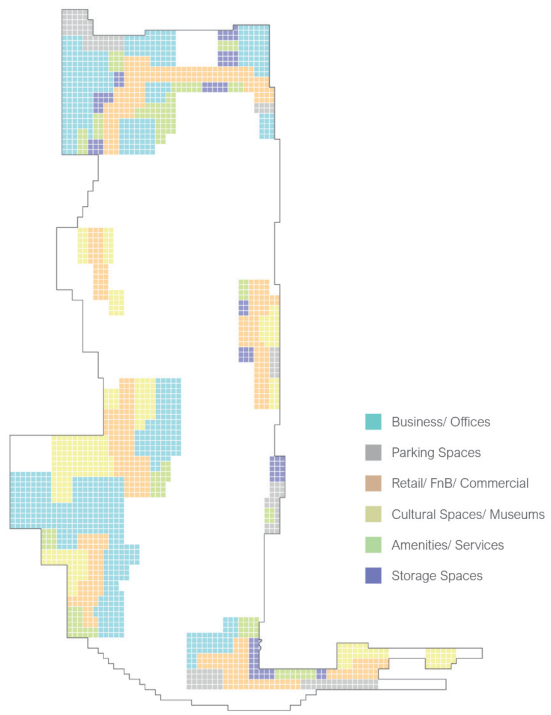


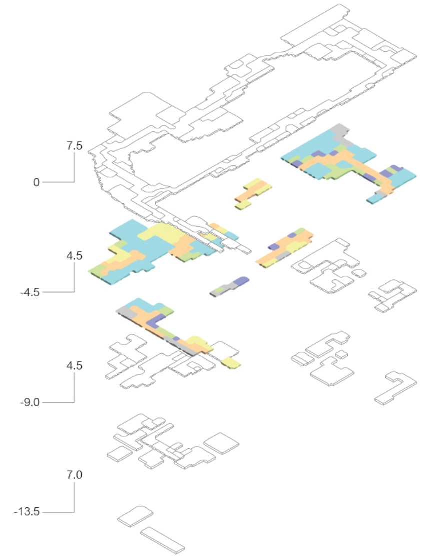
Fig. 8.5: Vertical functions
Level 1
Source: Author

c. Vertical Program Integration

Level 1: Macro Nodes and Streets

The first level of the workable substreet acts as a common conjugating element across the macro site, connecting footfall from the 3 metro stations within the area i.e., Europaplein, Amsterdam Zuidas and RAI. These transit nodes each bear passengers of distinct dominant trip purposes owing to the land-use type in vicinity to the station. The scale of infrastructure on surface often led to users feeling disoriented and their paths obstructed by several typologies of transit infrastructures. The underground street helps pedestrians access nodes on both sides of the ring road activated by programs such as shopping streets, active frontages, exhibition spaces, and so on. The first level, designed to be the most liveable, engages with maximum non-residental function on surface where the primary character of subsurface nodes is aimed at enabling social interaction.





Level 2: Local Nodes and Streets

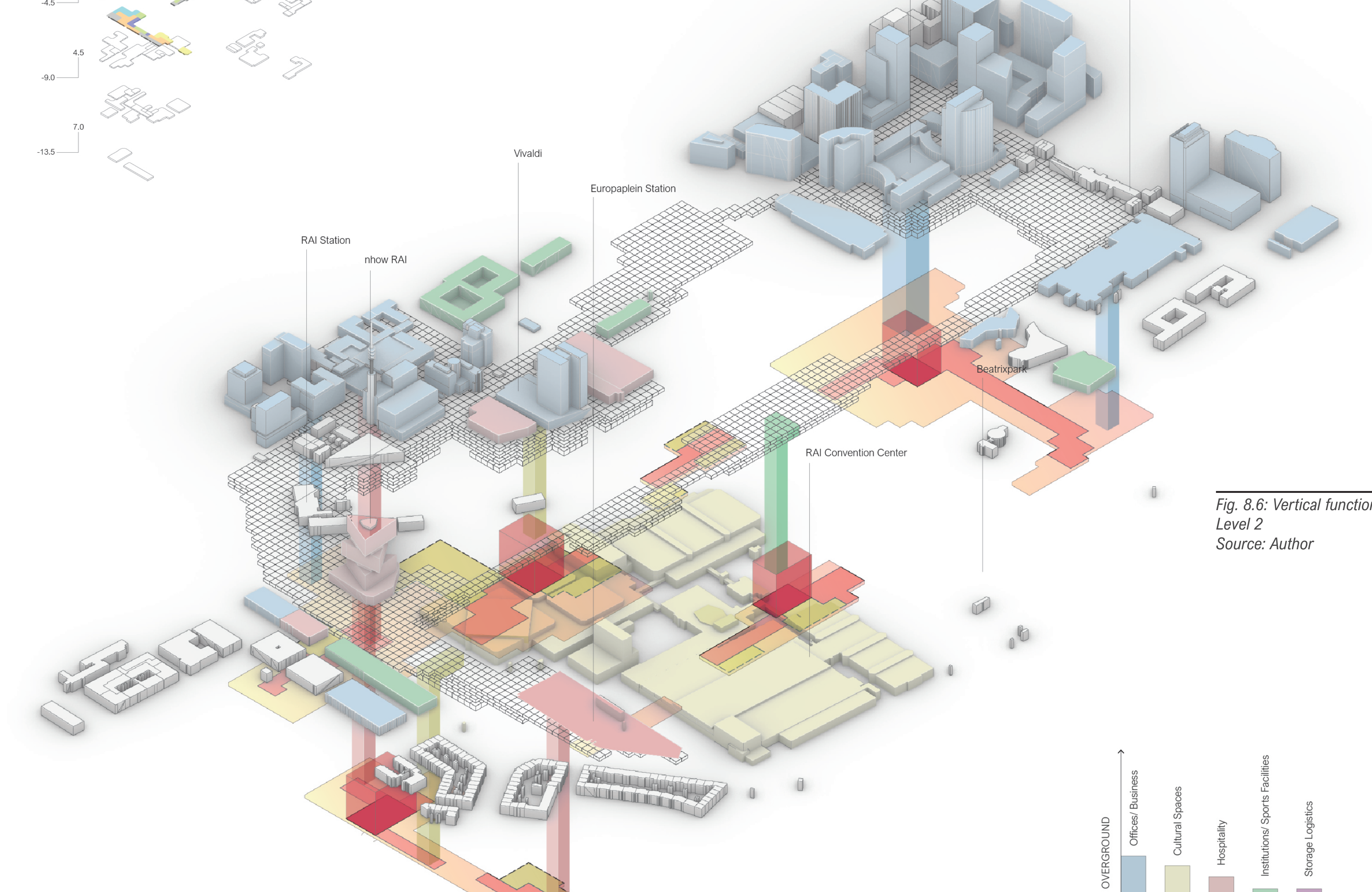
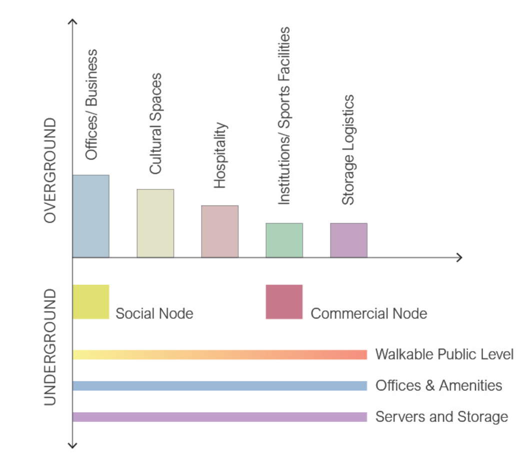
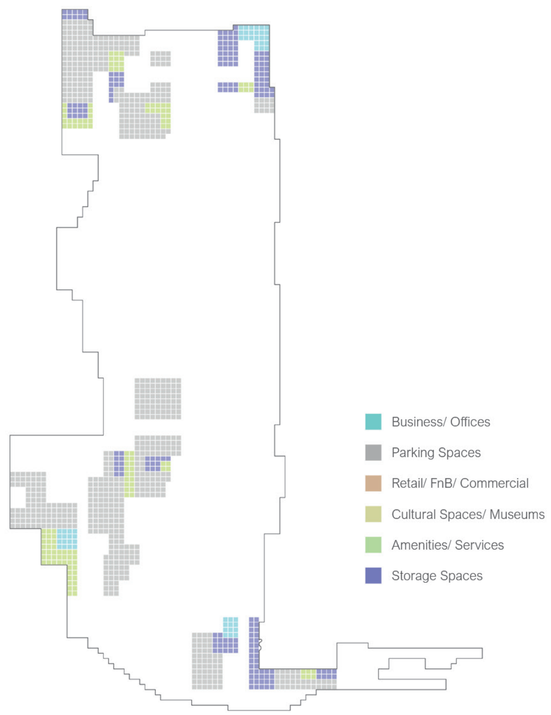


Fig. 8.6: Vertical functions
Level 2
Source: Author



Level 2: Local Nodes and Streets

The construction of local nodes is intended at consolidating the use of space without causing congestion of additional volumes and sprawling of supplementary functions on surface. Programming this levels is carried out according to depth and time spent below surface. The character of nodes on this level shift to that of commercial and the local subsurface islands are composed of standard forms of squares, avenues and blocks. The length of local avenues is directly proportional to the span of time spent by users and their functions resonate with the compositions of dominant functions on the surface. Programs for public life are present at larger scale per unit on this level. While the first level enables pedestrian city life, level 2 lower streets follow a gradient with increased flexibility of interface for people, workplaces and mobility.



Level 3: Services and Utilities

The level below localized lower streets primarily serves the business establishments, educational institutes and cultural spaces in terms of supplementary spaces for parking infrastructure and space for utilities and services. This layer serves a limited non-residential functions where the delineated spaces have limited to no connections across identified areas of interests. At this depth it is not feasible to introduce liveable spaces housing cultural or social nodes and construction at this depth requires is viable for private sector in terms of capital.

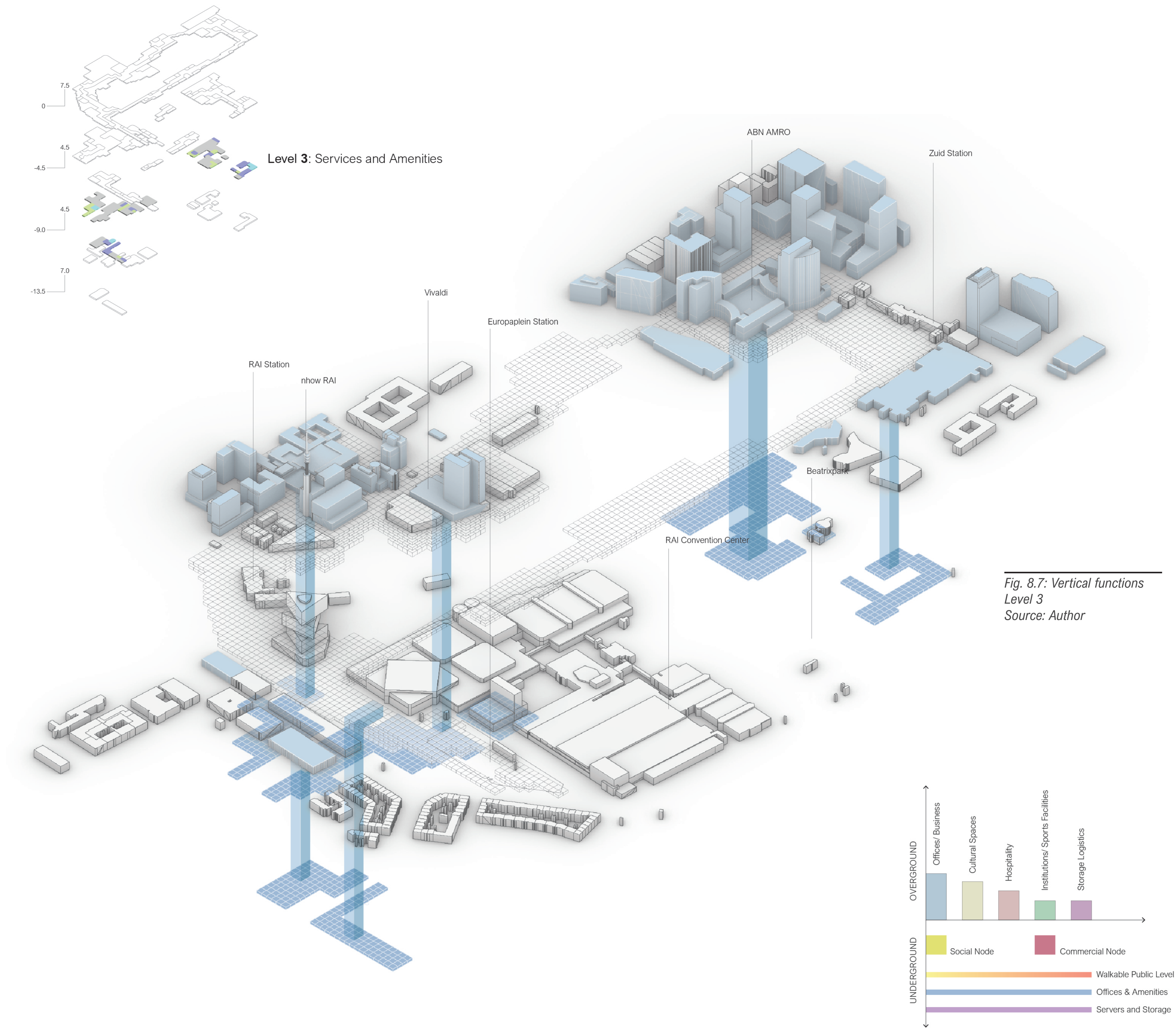
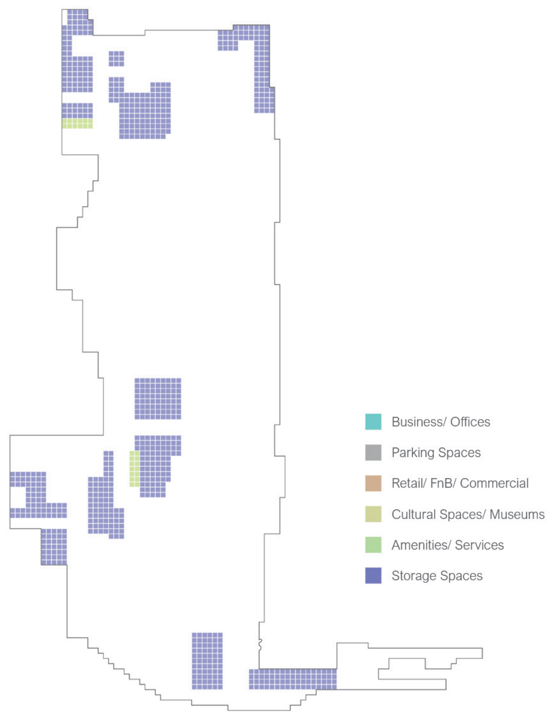


Fig. 8.7: Vertical functions
Level 3
Source: Author



Level 4: Storage and Logistics

Functions at this depth i.e., 20m are more suitable for non-human industries and spaces for warehousing and archives. Hence the nodes are allocated to office spaces (for server storage and data centers) and logistics facilities such as RAI convention center. For such industries, block height of 6-7m is suitable to leave enough space for machinery and storage.

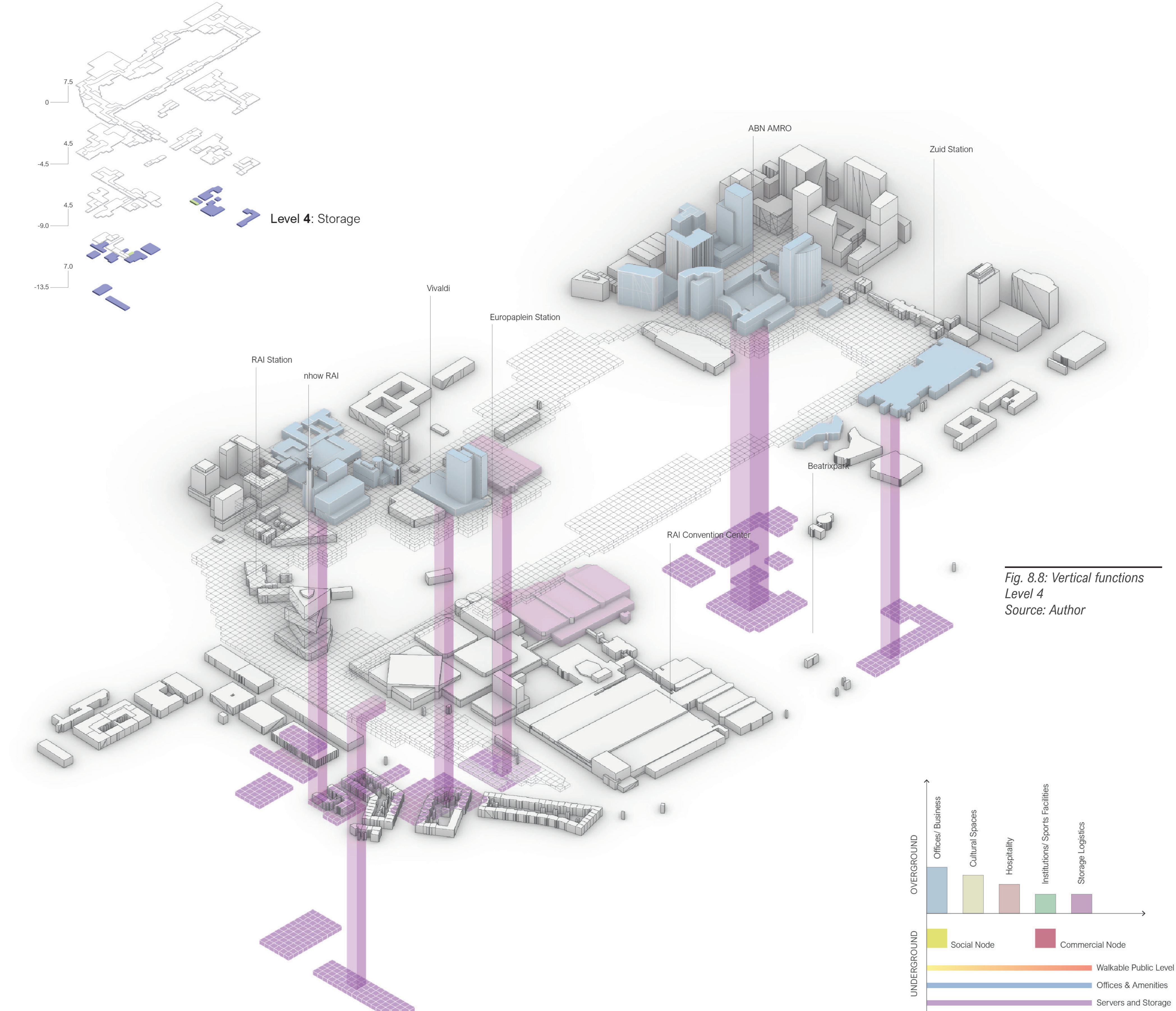


Fig. 8.8: Vertical functions
Level 4
Source: Author

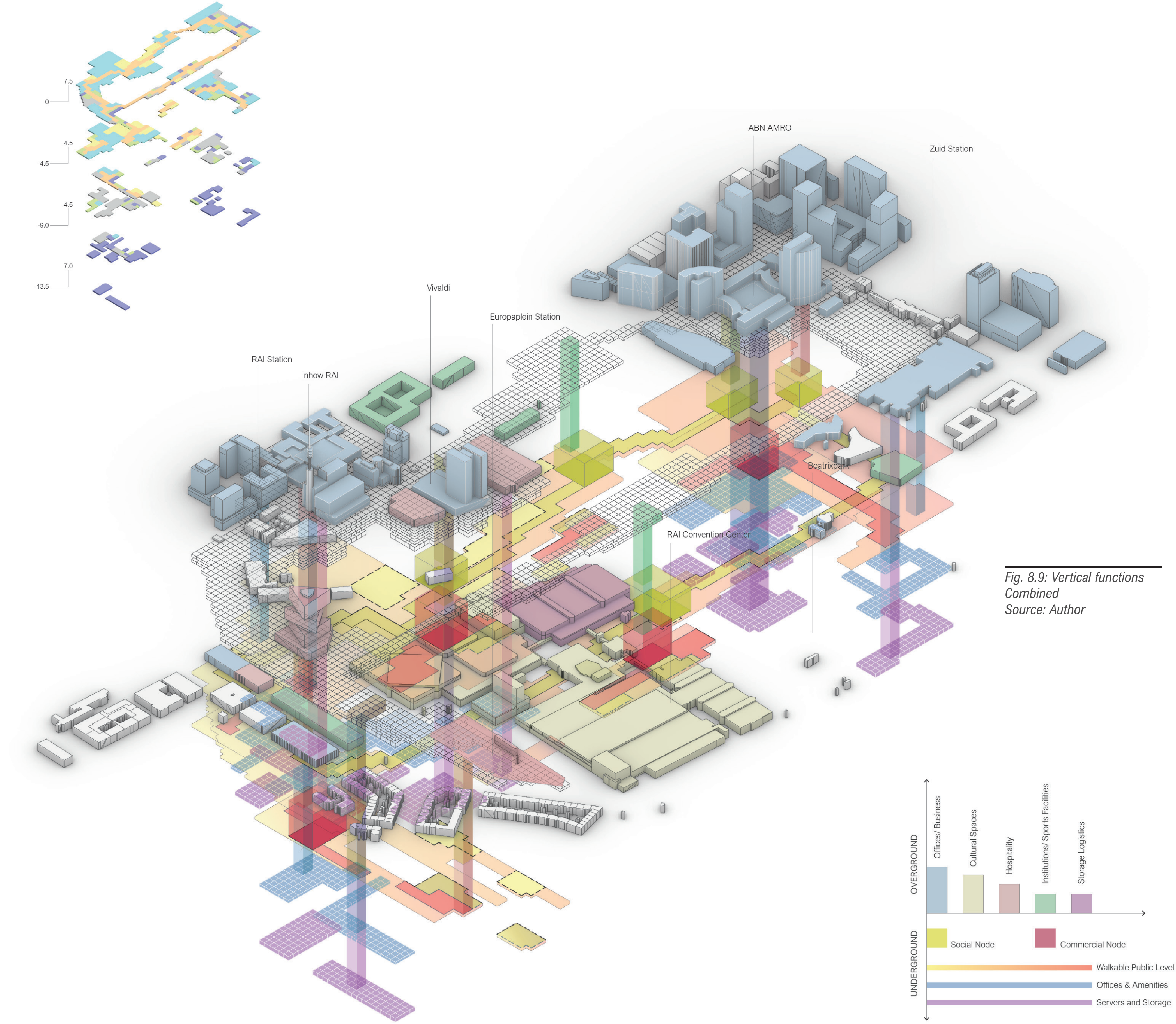


Fig. 8.9: Vertical functions Combined
Source: Author

Integrated Vertical Systems

On superimposing the networks functioning at respective levels, a gradient of programs is obtained where depth is inversely proportional to concentration of liveable spaces. Level 1 and 2 function in sync ensuring alternating vertical interchanges and double heighted nodes to enable a sense of volume for users. It is interesting to observe the spectrum of buildings activated by these levels on surface, indicating the extensions of groundscape to different vertical levels. Hence, an integrated vertical system of nodes and planes is obtained.

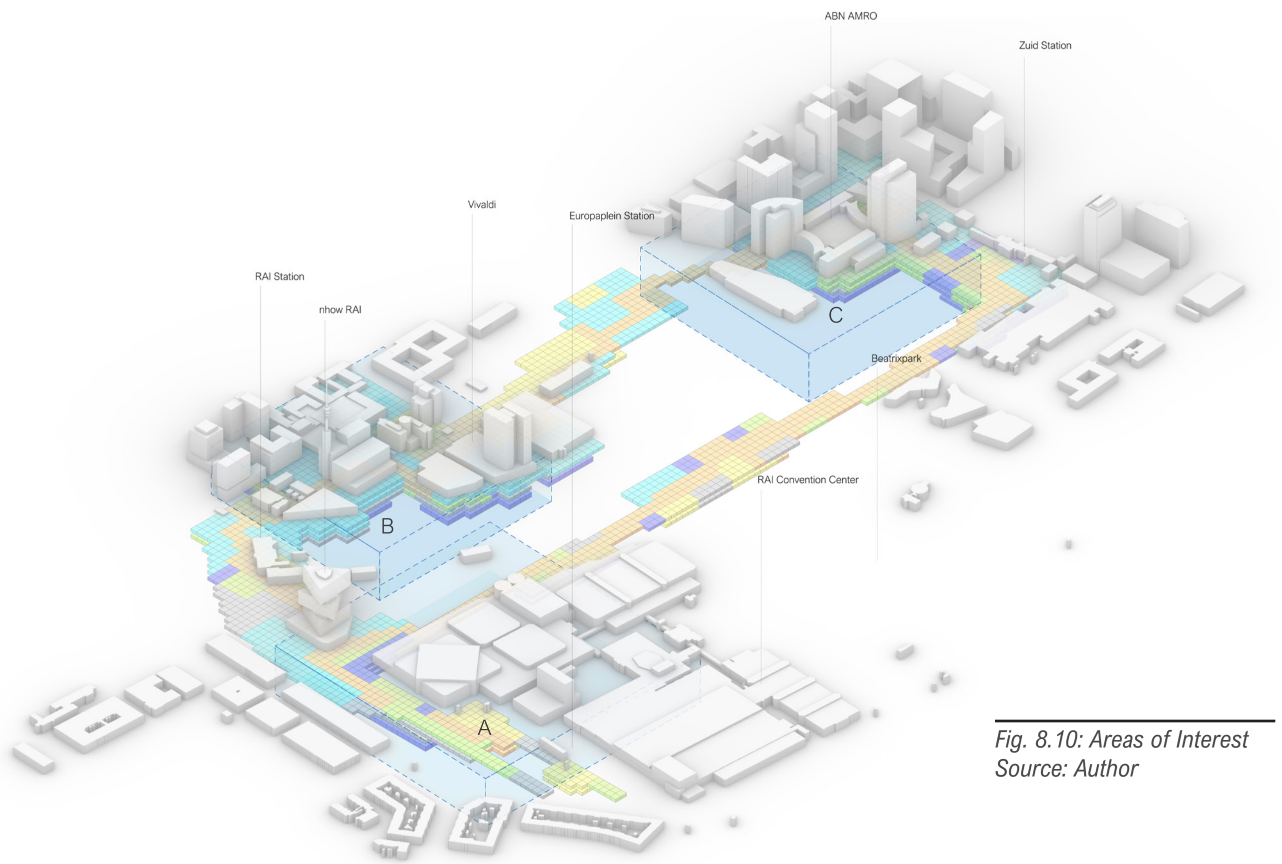


Fig. 8.10: Areas of Interest
Source: Author

Areas of Interests

For understanding the composition of spatial features in detail, three areas of distinct dominant functions were chosen:

- Site A: Cultural Hub
- Site B: Shopping District
- Site C: Business Center

d. Design Interventions

Spatial Characteristics and Context

The independent parameters of perception of underground in terms of interior public space are governed primaily by surrounding fixed context and spatial characteristics:

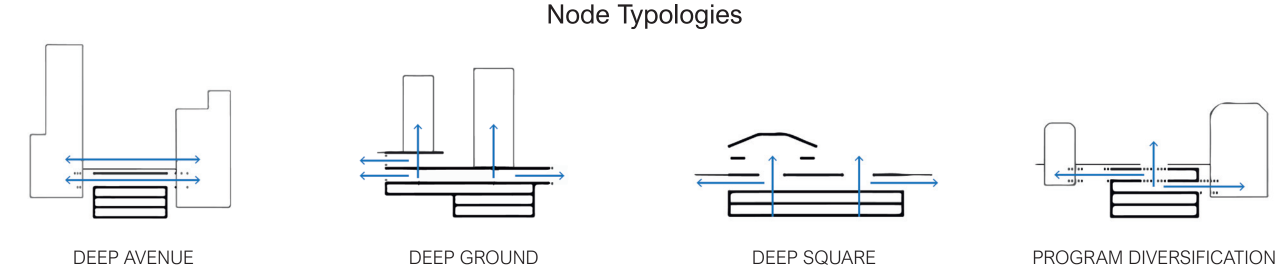
1. The context impacts spatial organization i.e., linear or complex spaces, type of functional organization, and space in relation to functions including entrances, interchange and places of temporary habitation.

2. The spatial characteristics are influenced by formal aspects such as material, construction type, dimensions, signing system and furniture positioning, and functional aspects including layout, connectivity patterns, adjacency, spatial continuity and physiological comfort.

Modification of spatial characteristics of implemented programs divides the underground network into three distinct systems: Urban corridors that ensure sense of orientation and maintain the inertia of movement, the Anchors placed as buffer volumes around urban corridors to supplement and extend dominant programs, Nodes and Planes guiding the dimensional aspects and drivers of movement. The distribution of specific programs within the allocated landuse depends upon form and dimensions of adjacent corridor. Corners and turns within the walkable loop may disorient the user. As a solution, corridors should ensure placement of most active frontages and uses at these locations to attract pedestrians and propel further movement.

Fig. 8.11: Meso-scale Networks
Source: Author

Node Typologies



Multilevel street infrastructure placed below the primary circulation axis of dense local center.

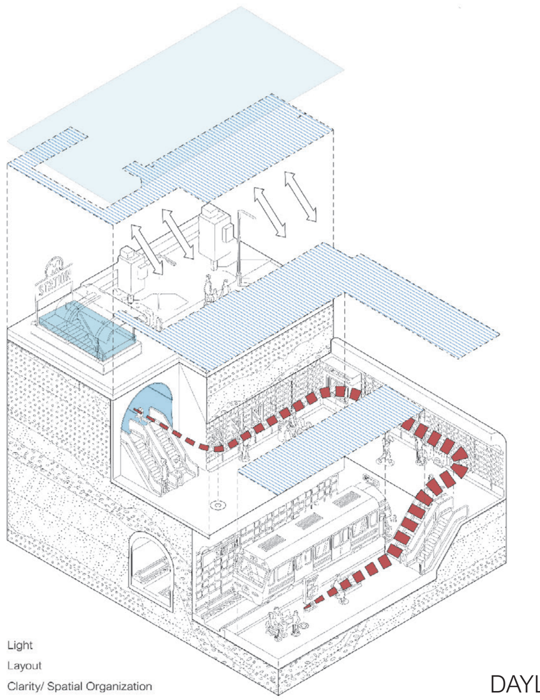
Thick common ground providing integrated services and amenities to the structures above

Public space with integrated undeground utility servicing a square and a commercial hall.

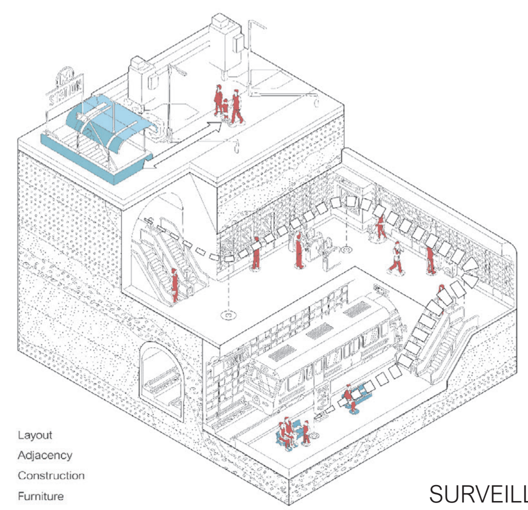
Reconversion of existing U.G. assets through programmatic diversification.

Dependable Variables: User Safety

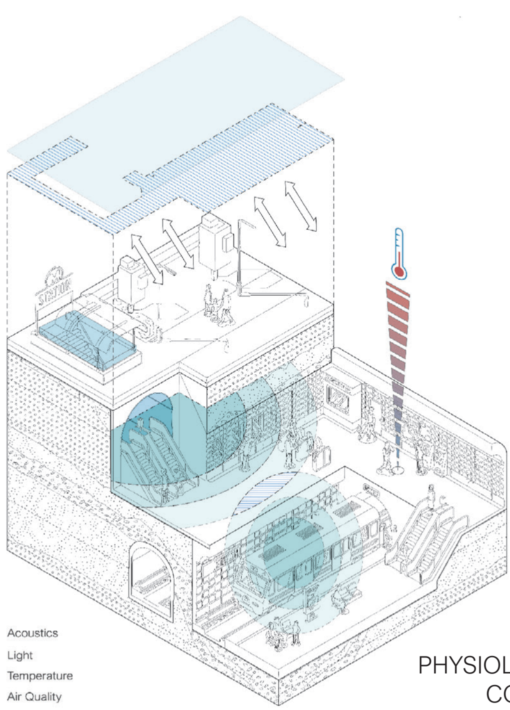
These parameters are influenced by user behavior and associated with the feeling of personal safety. Space ensuring user safety offer no possibility of existing cues and patterns of hiding, include less obstructions in layout and clear spatial continuity. The adjacency to crowds and materiality of context act as additional contributors to overall safety.



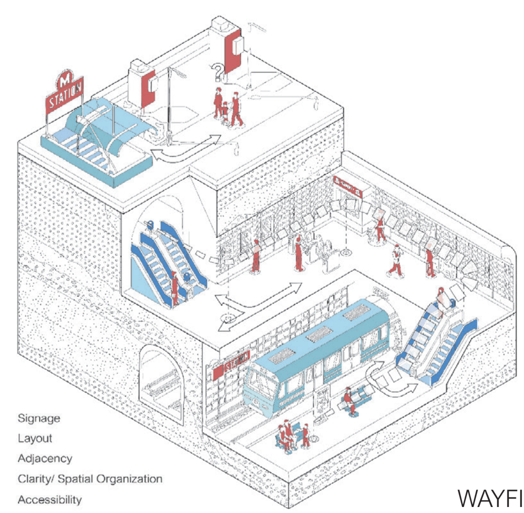
DAYLIGHT



SURVEILLANCE



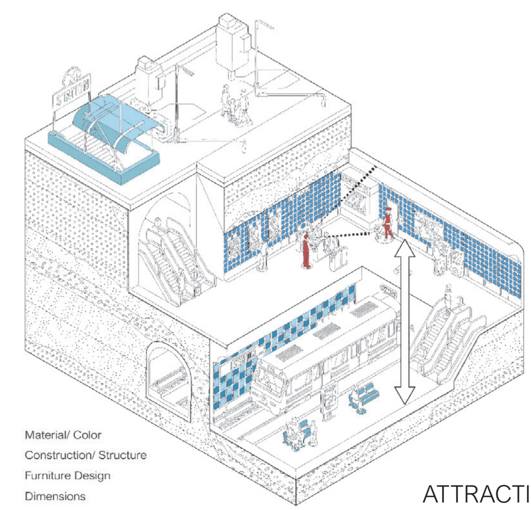
PHYSIOLOGICAL
COMFORT



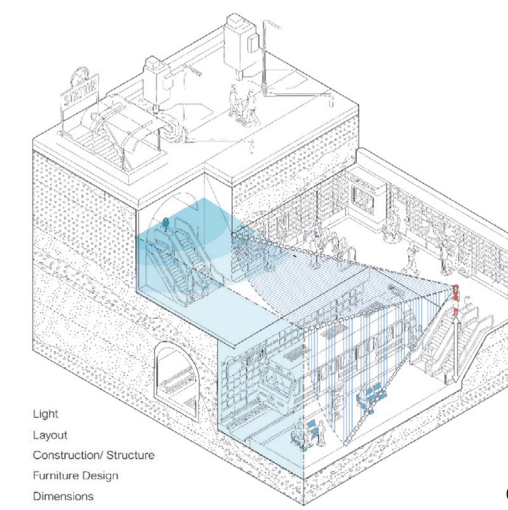
WAYFINDING

Dependable Variables: User Comfort

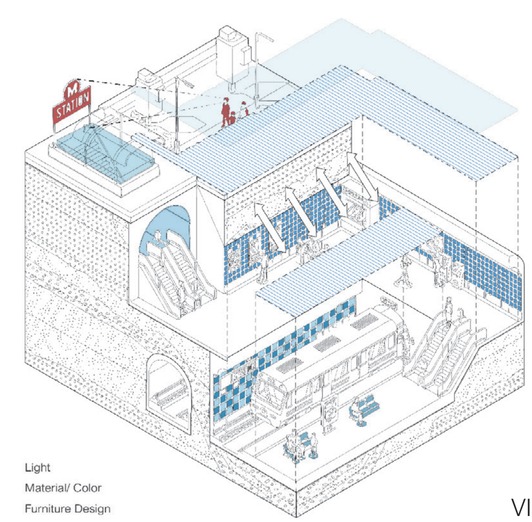
User comfort is impacted primarily by convenience of organization and clarity of spatial characteristics within underground construction. Engaging frontages and attractive anchor points direct movement of pedestrians while aspects of physiological comfort improve the overall liveability of space. Dimensions of volume and proportions play an important role at the human scale to influence feeling of comfort.



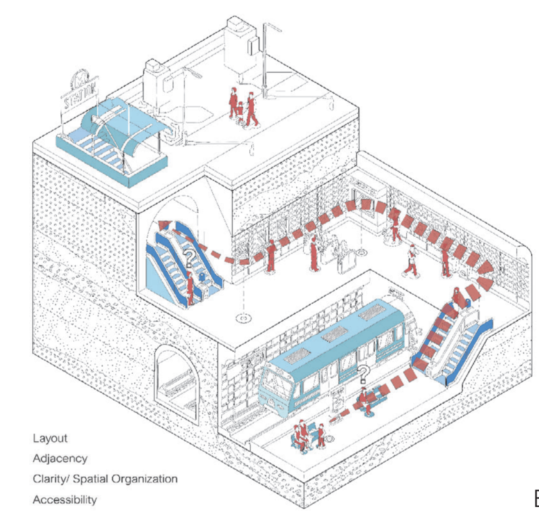
ATTRACTIVENESS



OVERVIEW



VISIBILITY



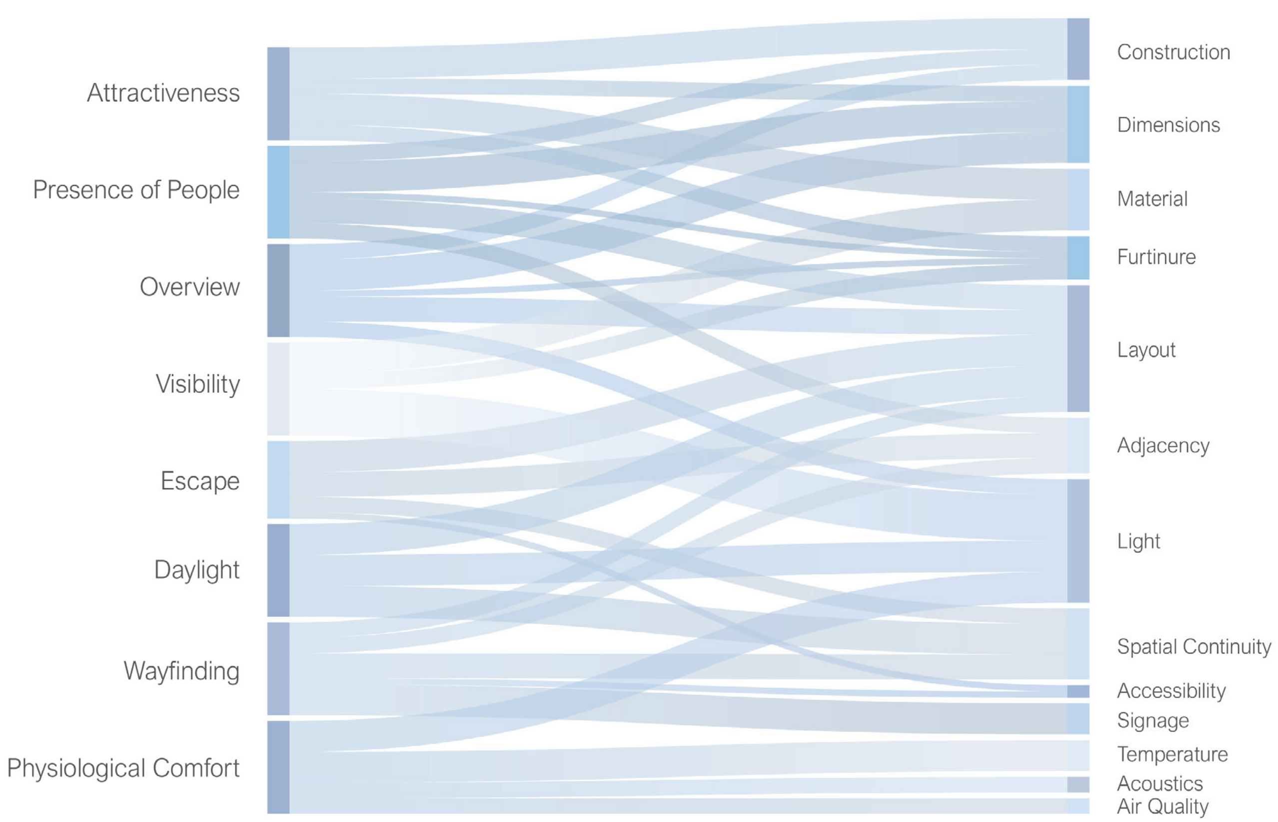
ESCAPE

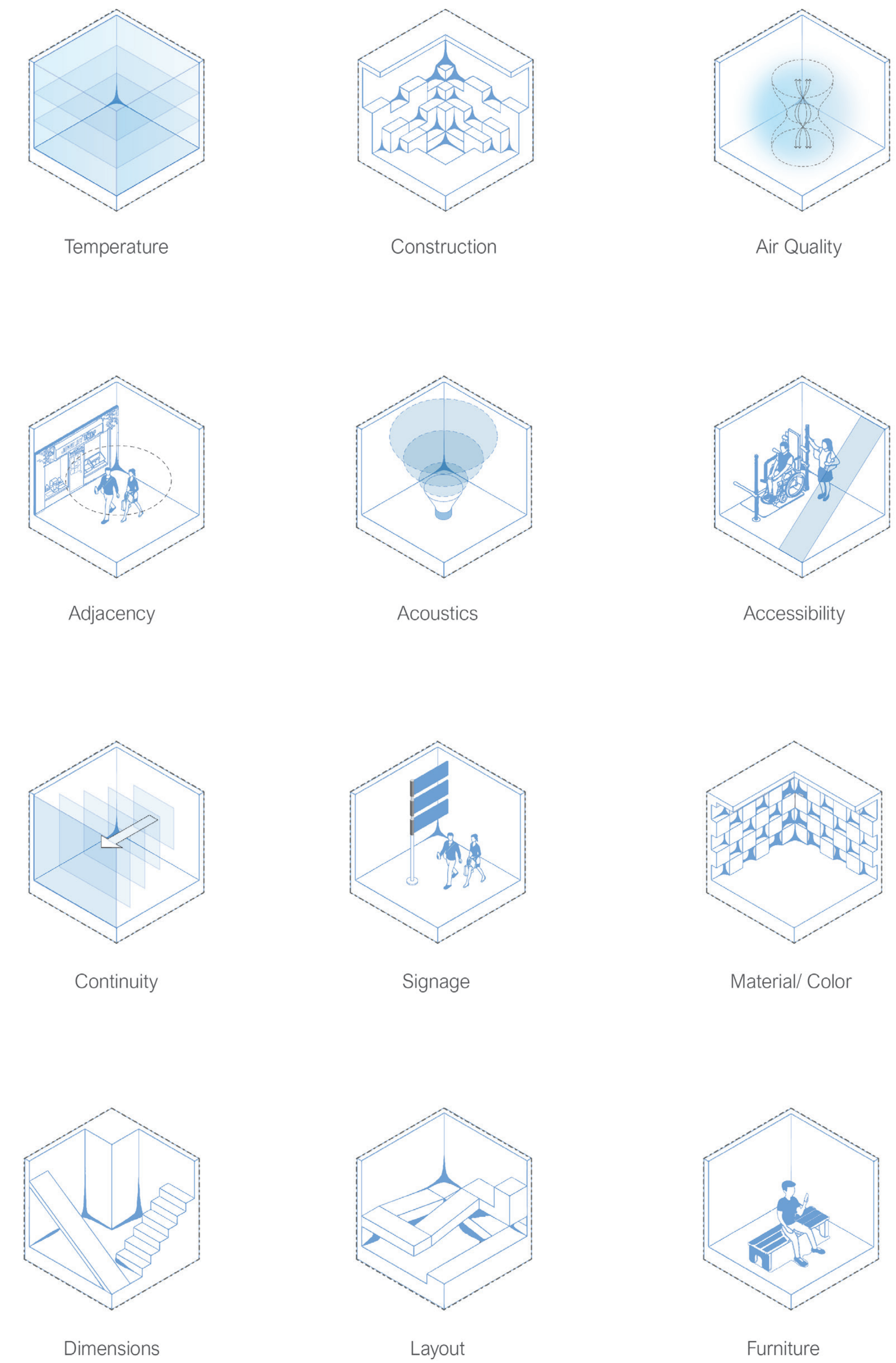
Spatial Characteristics: Sub-parameters

Dependent spatial characteristics identified before can be broadly categorized into formal and functional aspects. While the formal aspects constitute the physical space and materiality of ahieved volume, functional apsects primarily deal with organization of space according to technical and qualitative design goals. These parameters are essential in determining the user's perception of underground space and can be used as guiding principles of micro-scale interior space design along the delineated loop. The sankey diagram shows a tentative composition of relationships between the dependent parameters and their sub-parameters according to weightage. The composition was retrieved during interviews, site observations and extensive literature research.

While the dependent parameters inform the overall quality of space to be achieved, these sub-parameters can be used in varying combinations to achieve different typologies of nodes according to local functions and user needs. These guide specific interventions including types of furniture, separation walls, basic street layout and technology structure to ensure appropriate physiological comfort for the users. It is important to observe the planning and design is conducted at different scales according to different user groups. Urban and Meso-scale design was conducted according to large stakeholder groups and organizations while small-scale design caters to indivudual needs, making the interventions more localized.

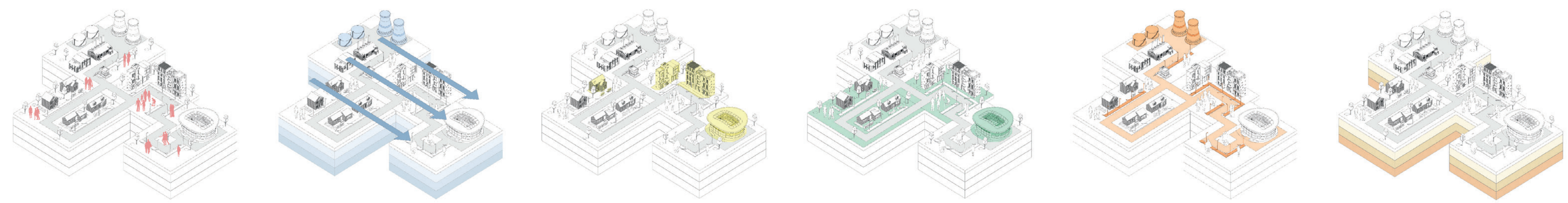
Fig. 8.12: Relationship between dependent parameters and sub-parameters of perception Source: Author





Identifying Technological and Ecological Needs

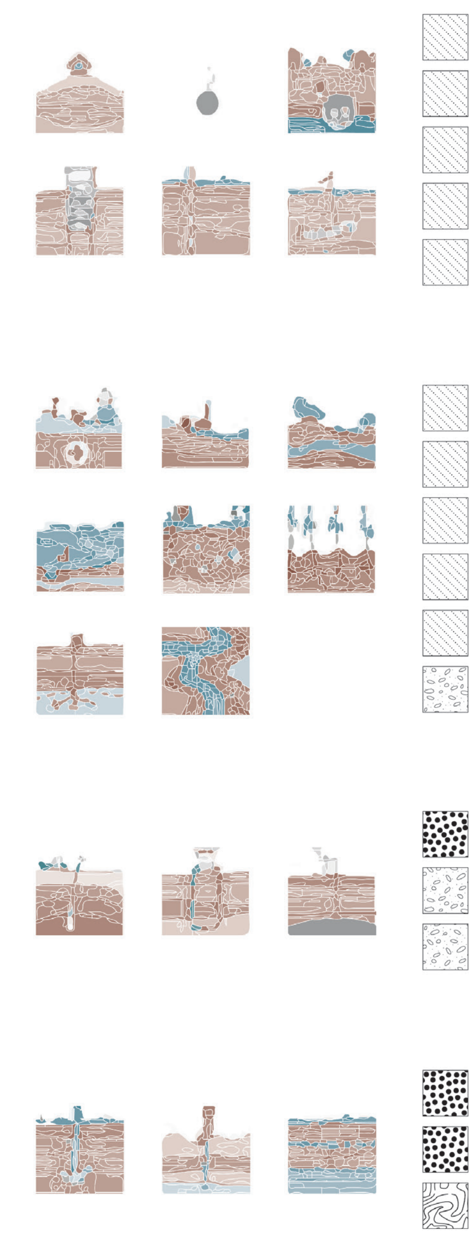
SEES Analysis



A SEES analysis was conducted to evaluate the impacts and challenges posed by small-scale underground construction within the site. The resultant matrix takes into account the needs of existing natural assets, local residents, business centers, and infrastructure facilitators gauged alongside their respective ecological risks. The exercise is essential to determine the types of utilities and services to be provided at the local scale to supplement the needs of designed underground volumes. The Analysis evaluates the relationship shared by the subsurface with civil construction, energy resources, and water resources. The matrix highlights connections to be engaged with to devise ecological interventions that are economically, structurally and technologically viable for the site.

Fig. 8.13: SEES Analysis
Source: Author

	Subsurface/ Subsoil	People	Metabolism	Buildings	Public Space	Infrastructure
Civil Constructions	Archaeology				Amstelpark, Beatrixpark eco-reserves	
	Explosives					
	Underground Building	Less Visual Connection to U.G.		Parking spaces adjacent to tunnels	U.G. walkable public spaces needed	Multi-levels tunnels below Ringroad
	Cables and Pipes	Utilitarian capacity for Residents		*MENZ* loop added in Zuidas	80% U.G. cable networks cleared	
	Carrying Capacity	Prominent future M.R.T. Node	Foundation Code 1,2 (Safe)	Moderate subsidence in Built areas		Widening A10, Viaduct construction
Subsurface	Clean Soil				Heavily polluted soil at1-2 m depth	
	Subsoil/ Crop Capacity				Limited space for roots to grow	
	Geomorphological Quality	Preparation: Hazards/ Climate crisis				
	Ecological Diversity	Green spaces enable Social Env.	Transit barriers vs Ecology		<5% tree-cover per neighborhood	A10: barrier to ecological metabolism
	Soil as Resource		Excavated soil as new Geography			
	Subsurface Storage	Basements as Additional Real Estate	Water storage and filtration assets	Server storage for Business centers	Peat and Clay located at 10 m depth	Demand for freight storage space
Energy	Aquifer Thermal Energy		Multiple systems installed in vicinity	Avg. Building Energy Label: A, B		
	Geothermal Energy	Energy requirements for new Housing	Aquifer >10m; may affect soil stability	Data center nodes require high energy		U.G. infrastructure requires less energy
	Fossil Fuels					
Water	Water Filtering Capacity		Water Seepage 0.1-0.5 mm/day	Avg. Flood Depth: 13-15 cm (140 mm)	Avg. Groundwater depth: 1.2-2 m	U.G. tunnels limit water filteration
	Water Storage Capacity	Surface Blue networks as Social Env.	Low Flood probability within site	Underground water storage tanks	Subsurface storage: 150-250 mm	
	Drinking Water Resources					



	People	Metabolism	Buildings	Public Space	Infrastructure	Subsurface
Shallow	Social Structure	Energy/ Food	Office Spaces	Living Environment	Mobility	Subsoil
Shallow and Water Layer	Social Behavior	Water	Housing	Culture	Networks	Water
Water Layer	Labour Productivity	Waste Management	Utilities & Services	Nature		Energy
Deep (>500m)	Labour Capital	Materials &Products	Culture	Agriculture		Civil Constructions

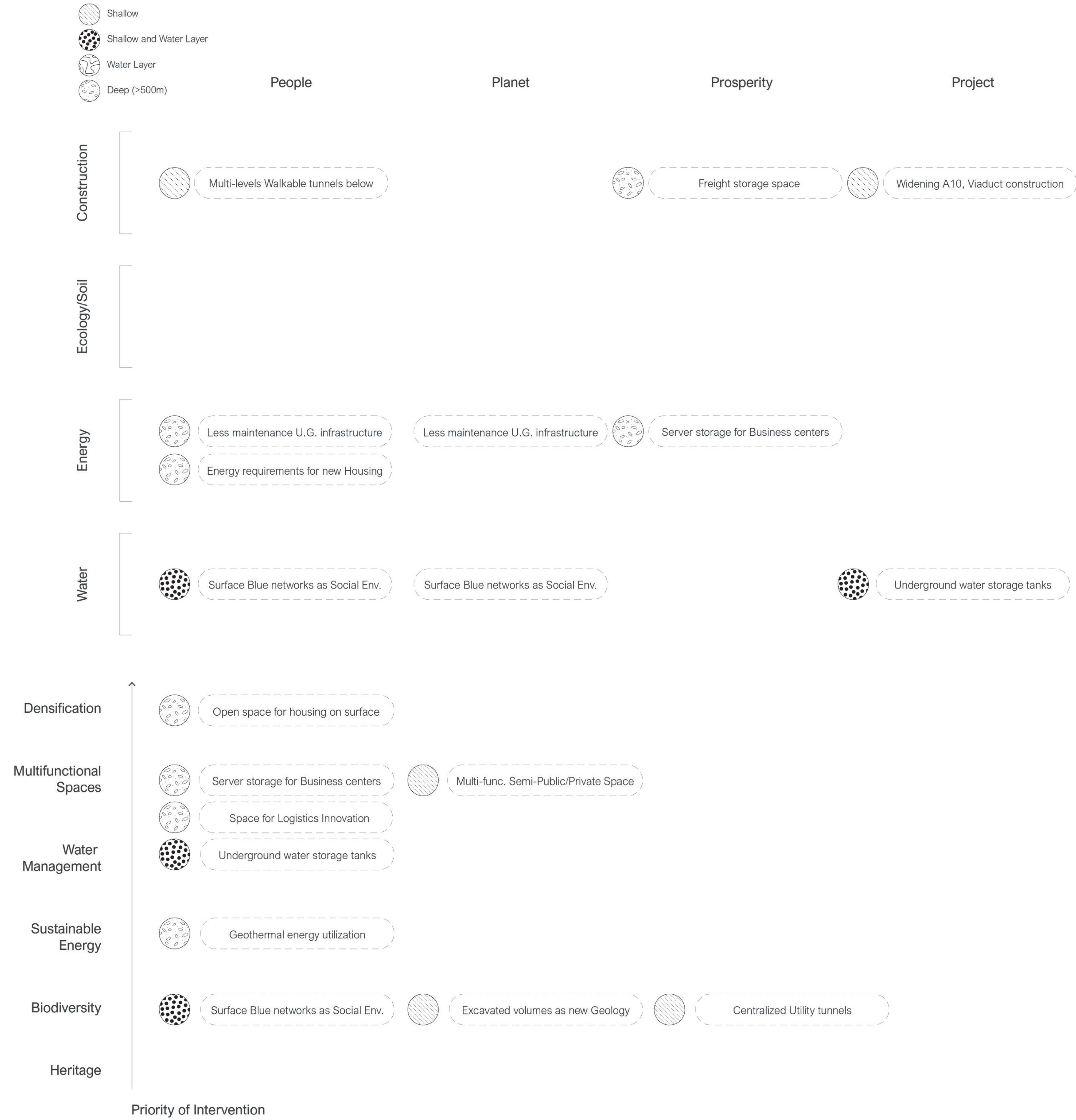


Fig. 8.14: TOHOKU Analysis
Source: Author

Prioritizing Strategies

TOHOKU

The challenges and impacts identified within the SEES exercise inform project-based interventions at urban as well as micro-scale. These are evaluated on the basis of their contribution to within different domains towards people, ecological advantages, economic benefit and development. The strategies framed from this matrix are then prioritized on the basis of immediate and long term needs of the site and its users. The exercise is beneficial for determining vision-based goals from the subsurface and linking these interventions to the allocated programs according to the context on surface. SEES and TOHOKU also add to the physical limitations of site beyond analyzing ecological risks, eventually refining the scope of the project as a whole.

Designing with Socio-economic Parameters

Infrastructure

Integrated Transit
Parking Networks
Server Storage
Parking Integrated with Commercial
Excavated Resorces

Facility

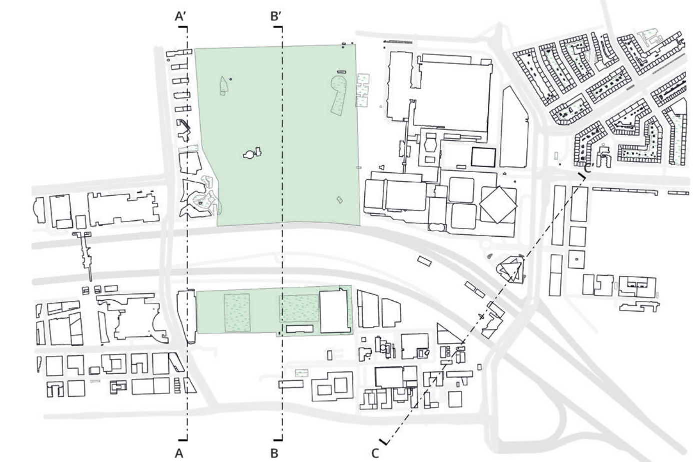
Light as an instrument
Functions w.r.t. Depth
Groundscape Configuration
Acoustics
Landscaping to Assist Transition
Alternating Levels
Soft Borders

User

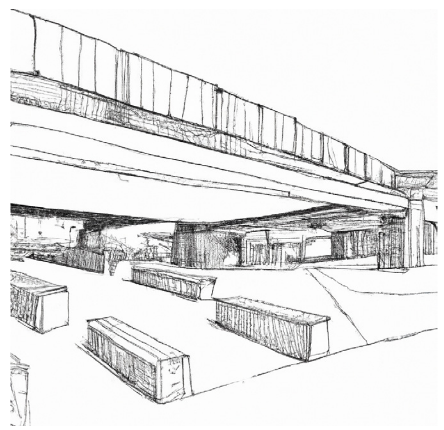
Active Frontages
Public Spaces on surface
Social Safety and Orientation
Link to Surface
Well-lit and Legible entrances
Shelter from Heatstress

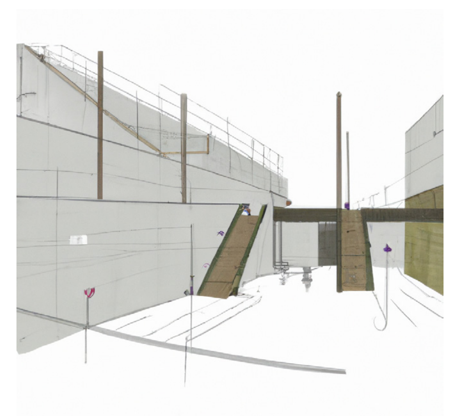
Commercial

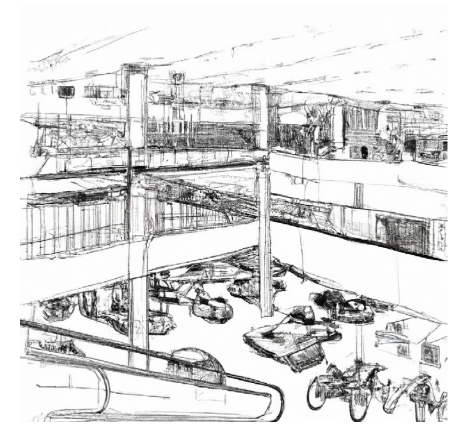
Linear Retail
Virtual Offices
4D Building Envelope for Real Estate
Extended Logistics
Shell-based Volumes

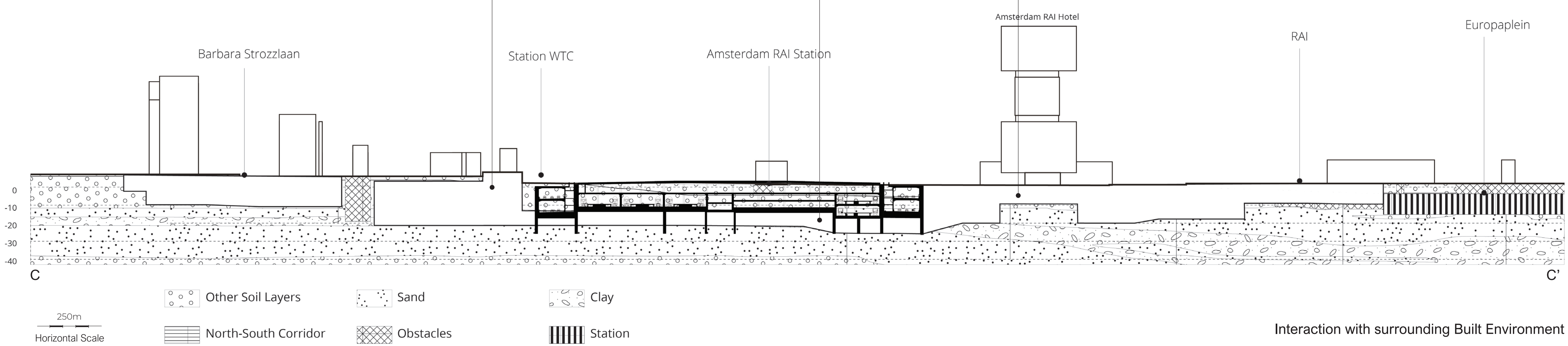


keymap


Shelter for pedestrians from heatstress

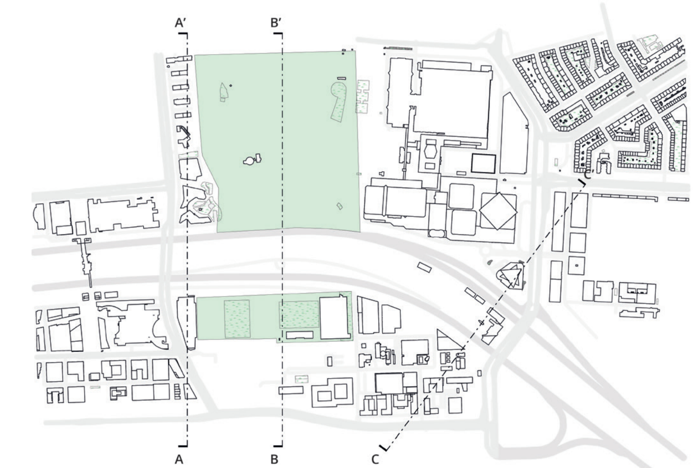

Linear walkable corridors


Shell-based volumes instead of individual plots



Interaction with surrounding Built Environment

Groundscape Experience and Interior Spaces



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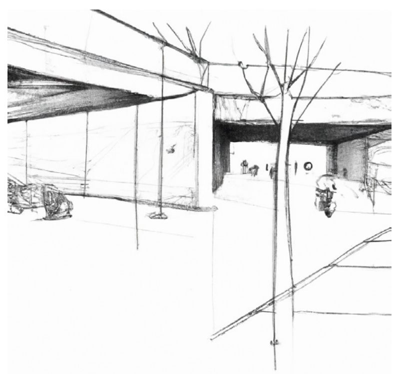
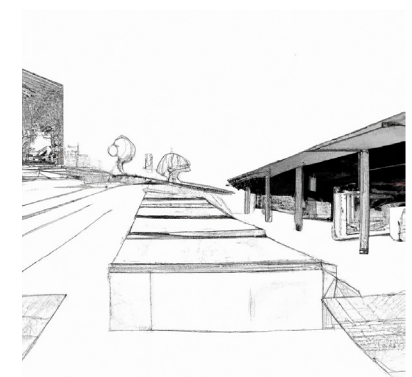
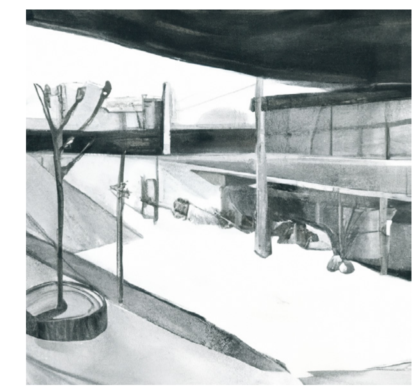
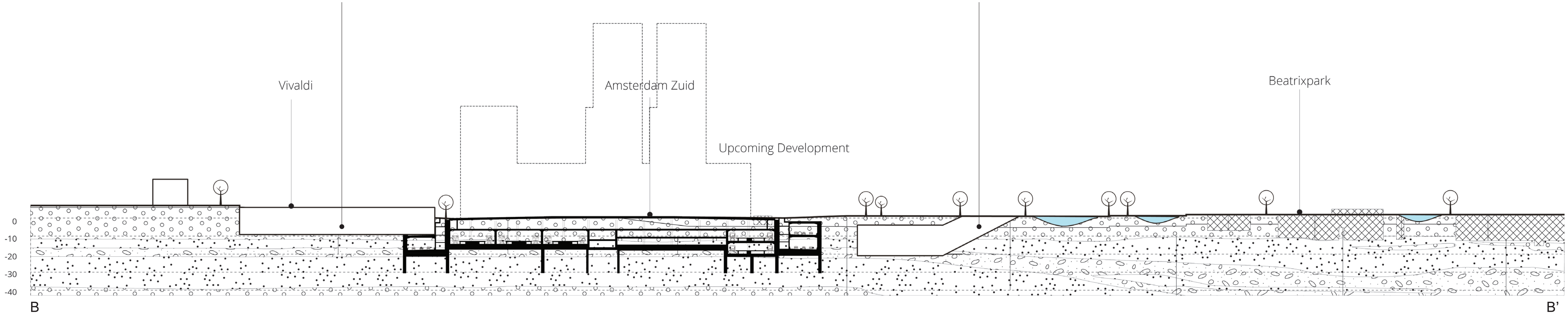

Alternating Levels


Well-lit and legible entrances


Transition: Soft-border Geography


Landscaping to Assist Transition



Other Soil Layers
Sand
Clay
250m
Horizontal Scale
North-South Corridor
Obstacles
Station

Interaction with surrounding Built Environment

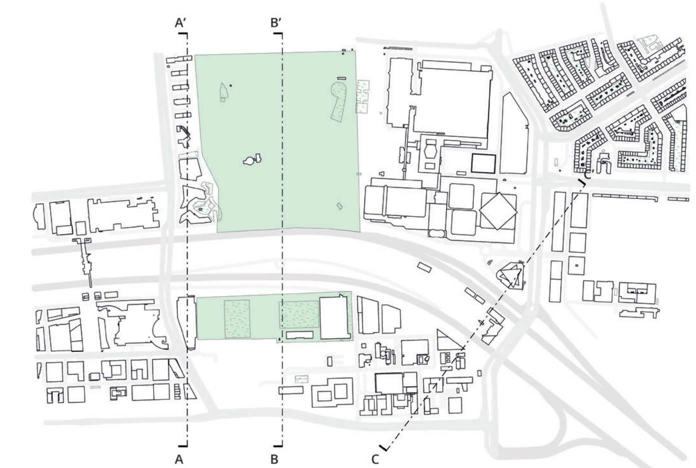
Opportunities for Subsurface Real Estate

A comparative split of functions through case studies results in the composition of division of activities according to different vertical levels.

The excavated resources and soil can be utilized for economic purposes and to restructure the geography and landscaping around the site.

The case studies chosen to draw comparative underground program split focused specifically on success of commercialized underground spaces similar to Zuidas business district. The research considered chinese case studies since the exisiting use of subsurface at a zonal scale is not a commonly observed phenomena in european cities. When observed based on levels of utilization, distribution of typologies were benchmarked following the delineation of workable underground corridors and nodes in Zuidas.

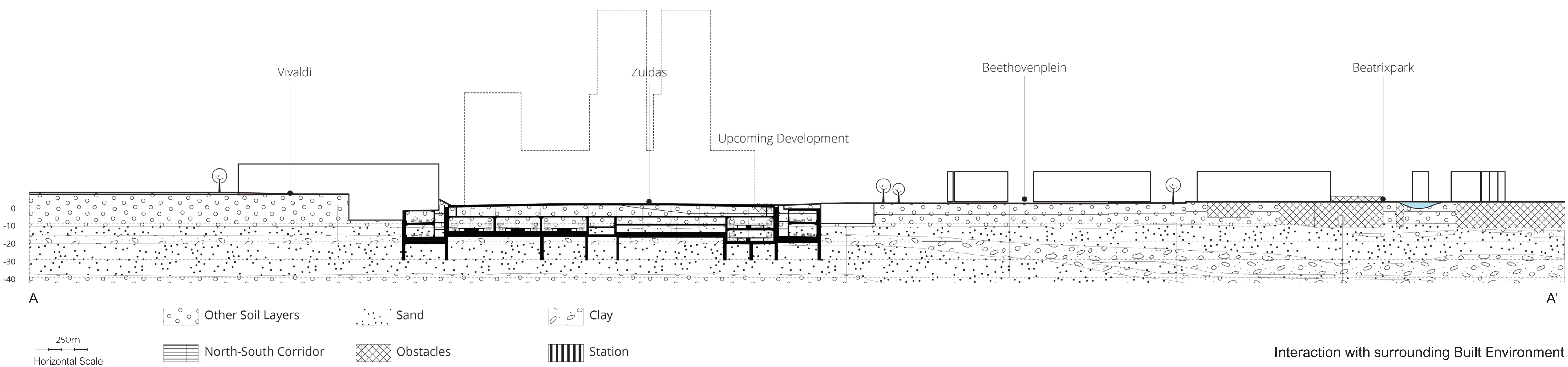
Comaprative Cases Studies for U.G. Construction



keymap

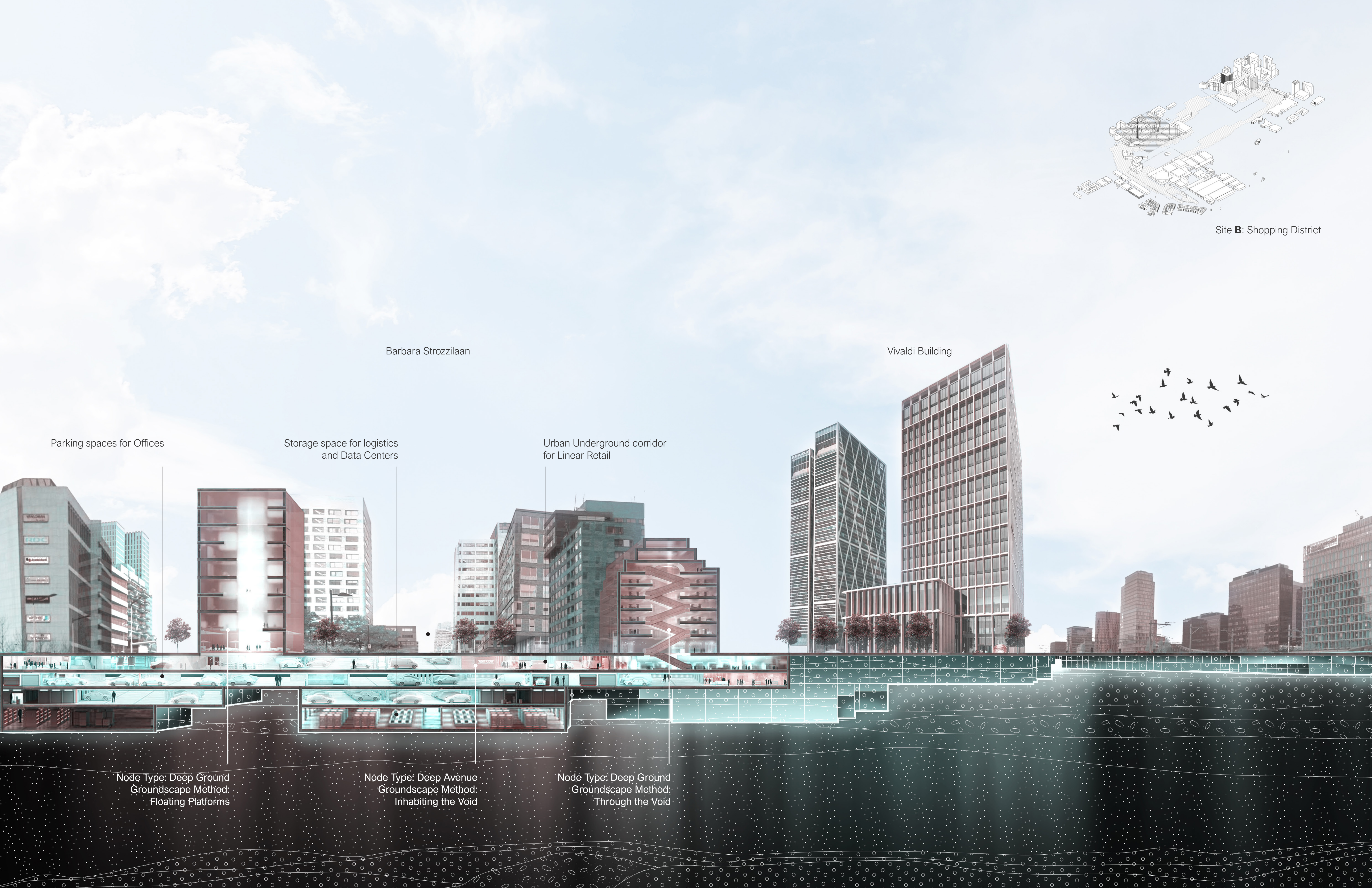
Case Studies	Tianjin	Shanghai	Shenzhen
City Area (Sq.km)	11917	6340	2050
Population (million)	14.5	24.2	14.1
Utilized UUS (Sq.km)	15	60	22

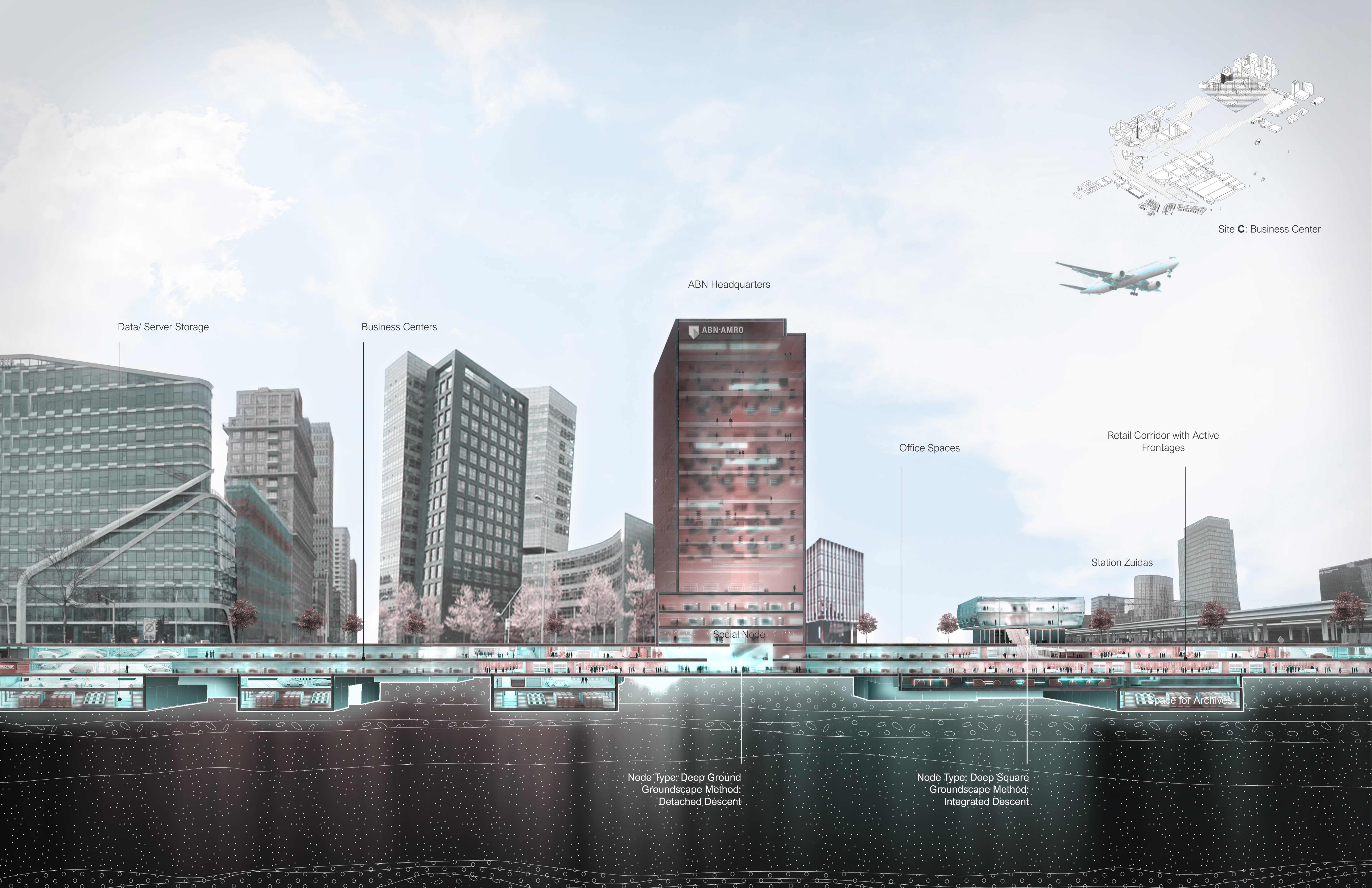
Average UG Real Estate (% Use)	Parking	Retail	Commercial	Hospitality
Level -1	20.96	40.56	37.91	0.57
Level -2	31.96	59.1	8.81	0.13
Level -3	85.55	7.67	0	0



Interaction with surrounding Built Environment


nHow Hotel
Site A: Cultural Hub
Extended exhibition spaces for convention center
Connection between RAI and Europaplein
RAI Convention Center
Towards RAI station
Cultural Node as intersection
Space for Archives
Node Type: Deep Ground
Groundscape Method:
Inhabiting the Ground
Node Type: Deep Square
Groundscape Method:
Detached Descent
Node Type: Deep Square
Groundscape Method:
Detached Descent


Site B: Shopping District
Barbara Strozzilaan
Vivaldi Building
Parking spaces for Offices
Storage space for logistics
and Data Centers
Urban Underground corridor
for Linear Retail
Node Type: Deep Ground
Groundscape Method:
Floating Platforms
Node Type: Deep Avenue
Groundscape Method:
Inhabiting the Void
Node Type: Deep Ground
Groundscape Method:
Through the Void


Site C: Business Center
ABN Headquarters
Data/ Server Storage
Business Centers
ABN·AMRO
Office Spaces
Retail Corridor with Active
Frontages
Station Zuidas
Social Node
Space for Archives
Node Type: Deep Ground
Groundscape Method:
Detached Descent
Node Type: Deep Square
Groundscape Method:
Integrated Descent

Shana Debrock
Policy Officer Flemish Govt.

Consultant in Underground Urbanism research in collaboration with COB tunnel engineering.

Tom Benson
Research and Business Manager, Senseable City Lab (Ams)

Research in digital transition and its impact on urban mobility.

Han Admiraal
ITACUS Planning Advisor

Research and community engagement for European subterreanean projects

Joyce van den Berg
Designer, Municipality of Amsterdam

Regional and long term planning for public space design.

Antonia Cornaro
Expert Underground engineering at Amberg

Project management and Business development expertise

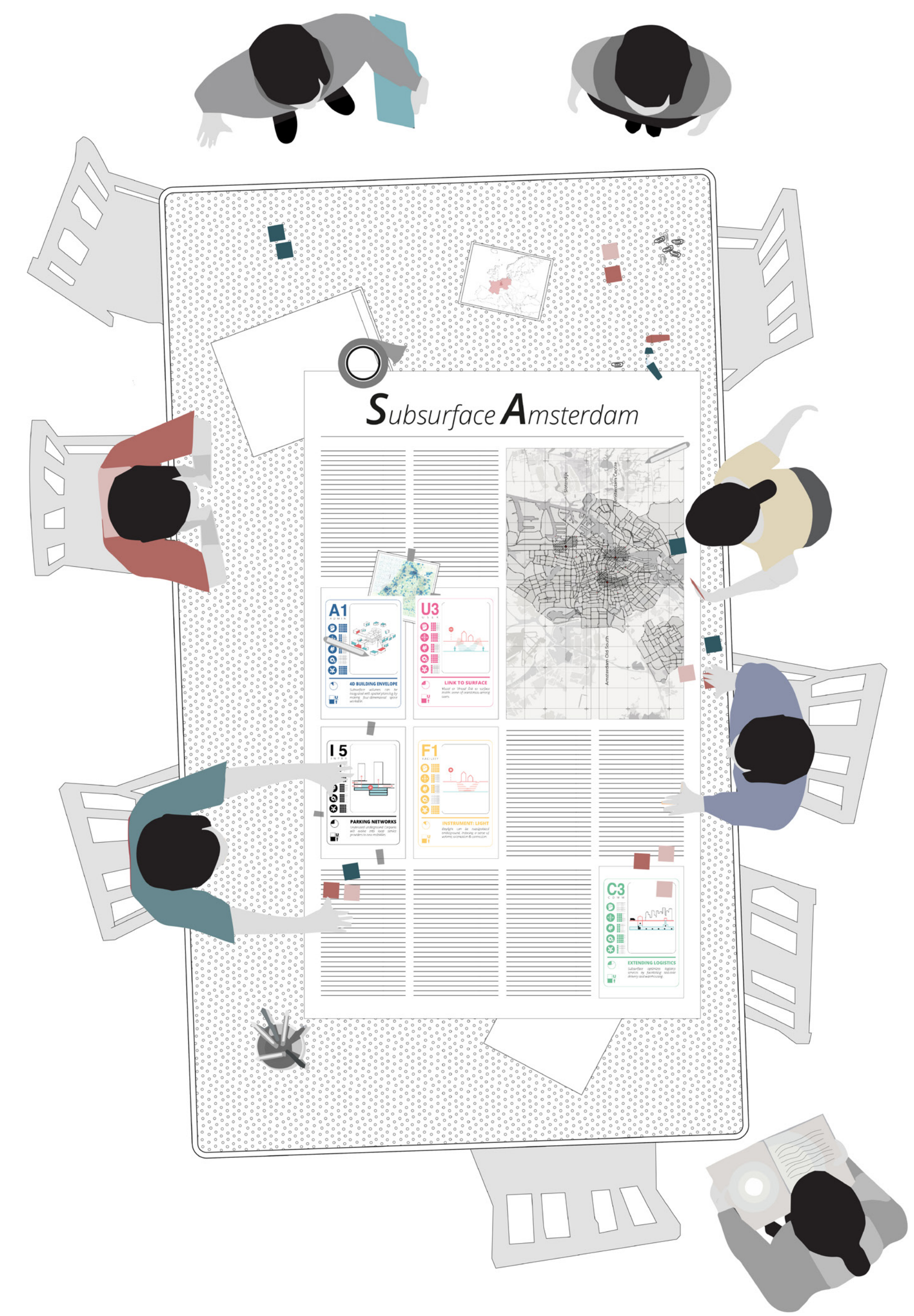
Matthias Vollmer
Architecture and image production at ETH Zurich

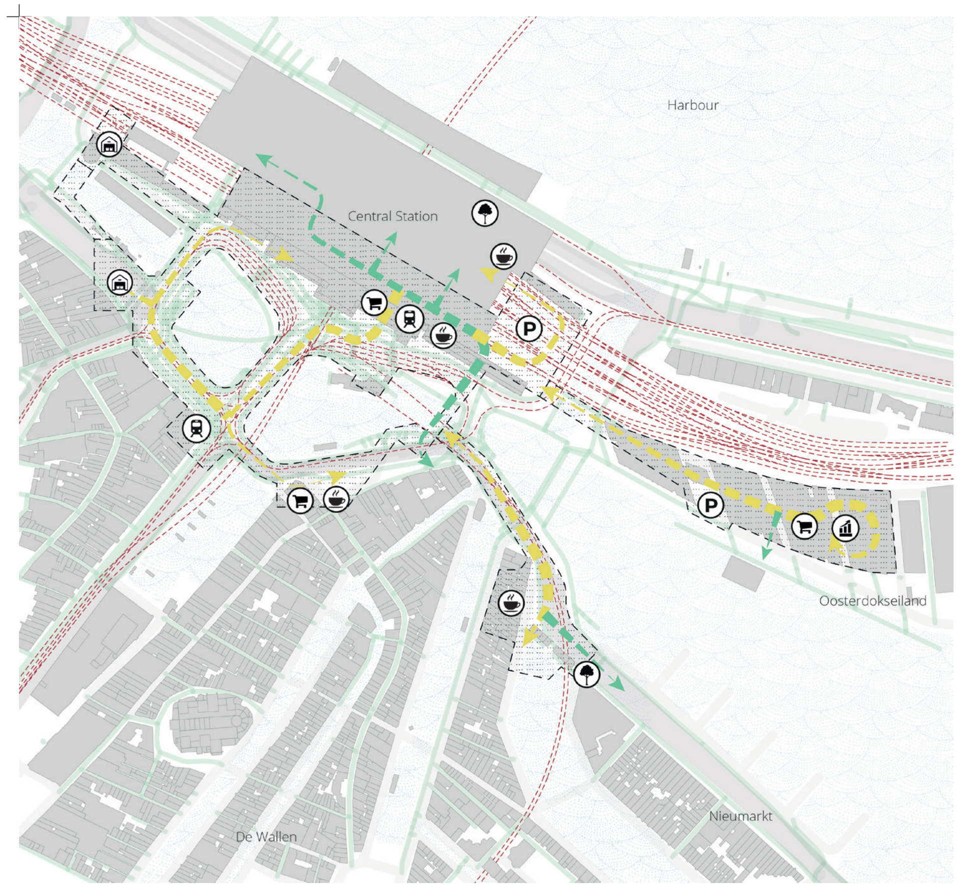
Research in LiDAR scanning and point cloud technology for underground spaces

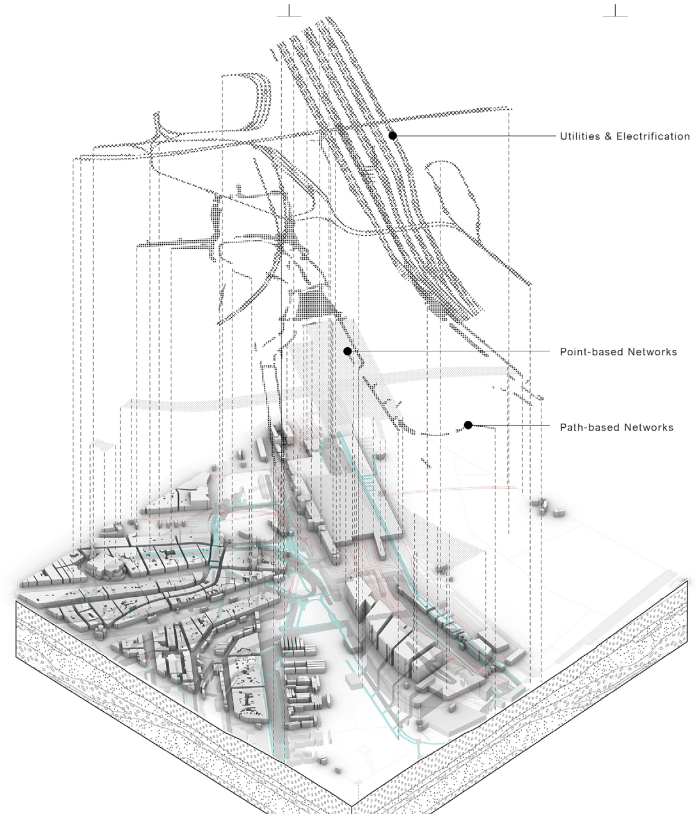
The project was supported by expert consultations from personnel belonging from a range of actors with stakes in underground construction including the municipality of Amsterdam, educational institutes and engineers. Through workshops and interviews, the perspectives of these actors were used to draw parameters while framing the theoretical framework, and developing policy-based recommendations to operate and maintained urban underground districts chosen within this research.

Design process delves into several parameters influencing subsurface planning including infrastructure facilitation, regulations, user-perception, to describe a simplified systems-understanding of platforms shared by various actors. The parameters help obtain a toolbox of collaborative interventions to develop macro and micro-scale strategies. These can be tested to evaluate design interventions and their impacts on the chosen sites in a participatory manner.

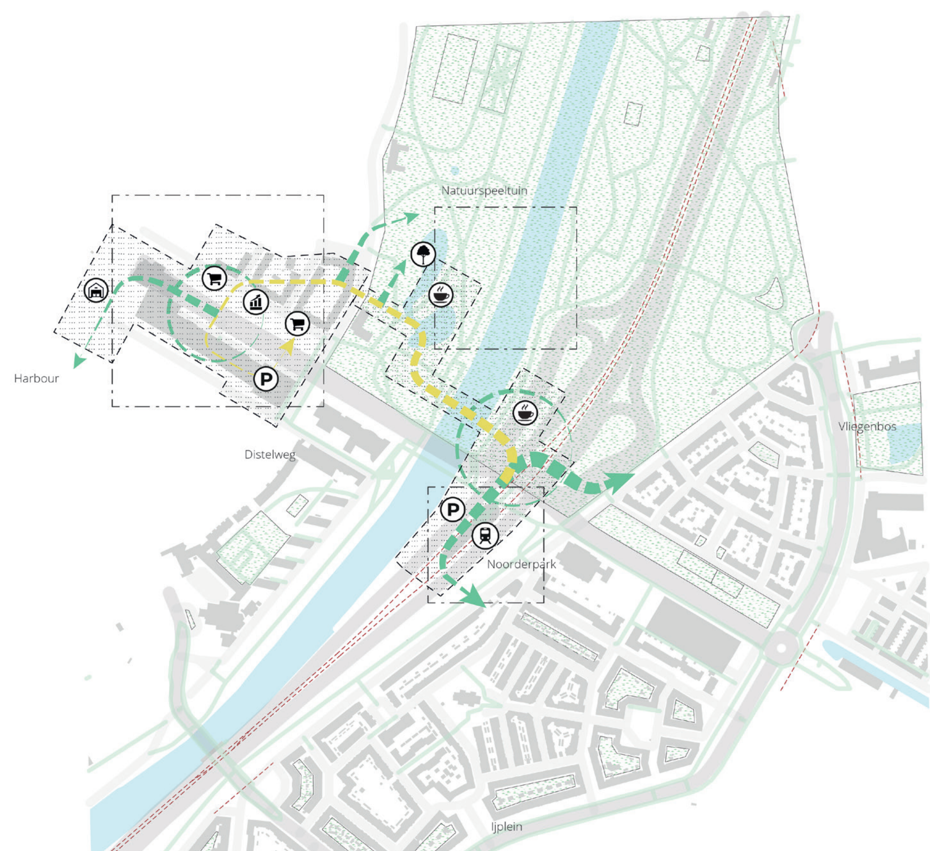
Collaborative Workshops: Operational Framework

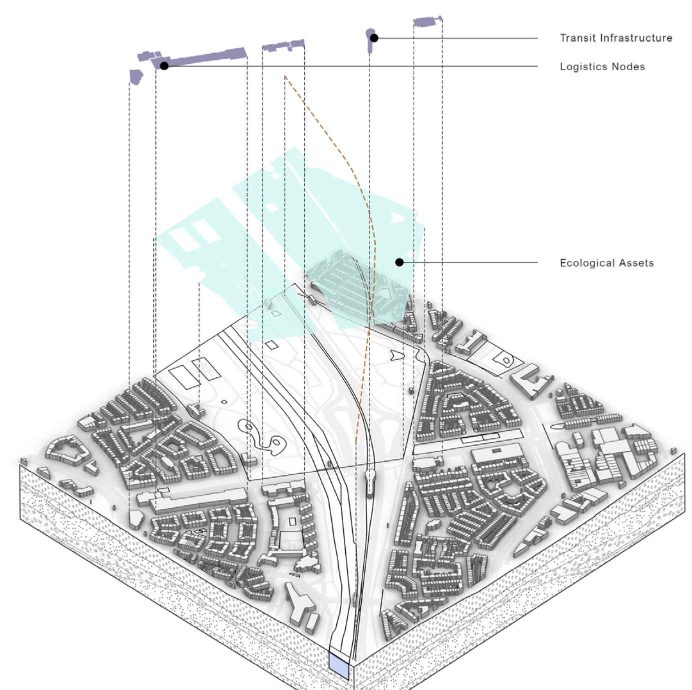






Dense Subsurface Infrastructure Networks: Amsterdam Central Station





Networks: Noorderpark

Amsterdam Central Station

- Amsterdam central is complex in terms of landuse and typed of constructions around the site.
- Composed of dense transit infrastructure and underground parking spaces.
- An important national node for passengers as well as logistics.

Noorderpark

- Located north of the harbour, the site describes predominantly residential land use with isolated small-scale commercial nodes in the vicinity.
- To balance this growth in the future, there are projects planned northwards.
- Being the station closest to Amsterdam Central, the site is suitable for greenfield subsurface development to cater to future projects.

Projection: Research by Design

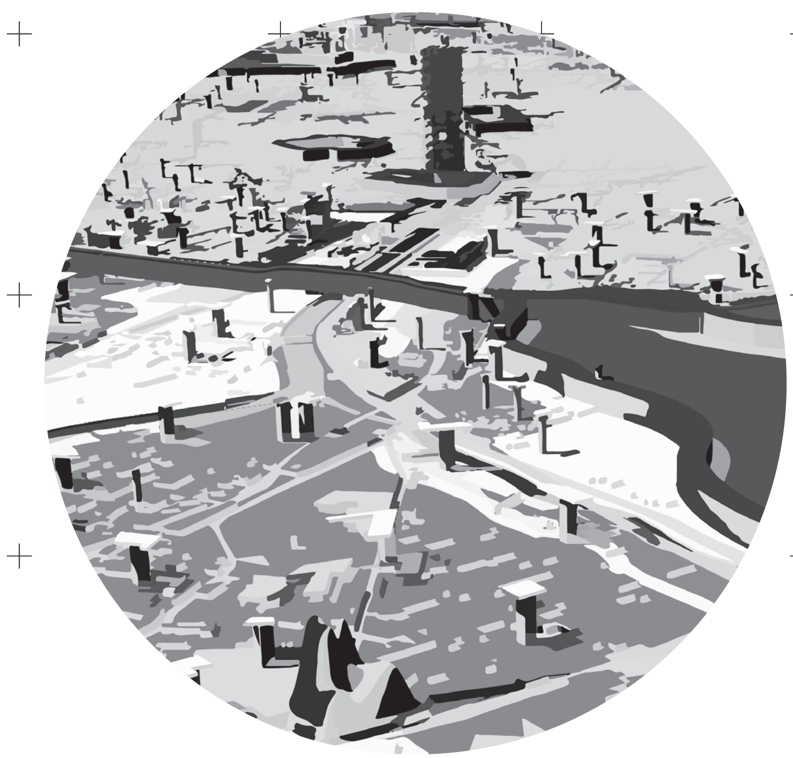
The design process carried out for Zuidas draws prototypical guidelines to design combination of transformation as well as greenfield underground construction. The range of analysis conducted for the site lent insights into selection and delineation of workable underground spaces, safe depths of construction and identifying integration opportunities. Similar steps of analysis can be carried out for the other two areas of interest along the N-S metro line to delineate grids for underground construction.

While planning designing the site at different scales, several parameters to determine suitable interventions were used for environmental planning, architectural and urban design. These parameters and similar steps can be used to define walkable loops and system of points and planes for Amsterdam central station and Noorderpark where assigned functions supplement the dominant functional requirements of surface. This process can be repeated for districts across the city where potential for underground construction is high, using parameters of delineation. The identified districts can then be worked with for zone-based planning of underground spaces to form a holistic long-term vision plan enabling infrastructure integration, subsurface construction and transformation.

9. Towards Underground Urbanism

Overview

The chapter includes an sums up the learnings from 'Research by Design' exercise by implementing city-scale paramters and guidelines to delineate potential districts for subsurface expansion in order to build a vision plan for zone-based underground planning for the city of Amsterdam. It also reflects on vertical zoning of underground functions based on liveability and composition of resource and infrastructure to balance the access of subsurface between actors belonging to public and private sector.



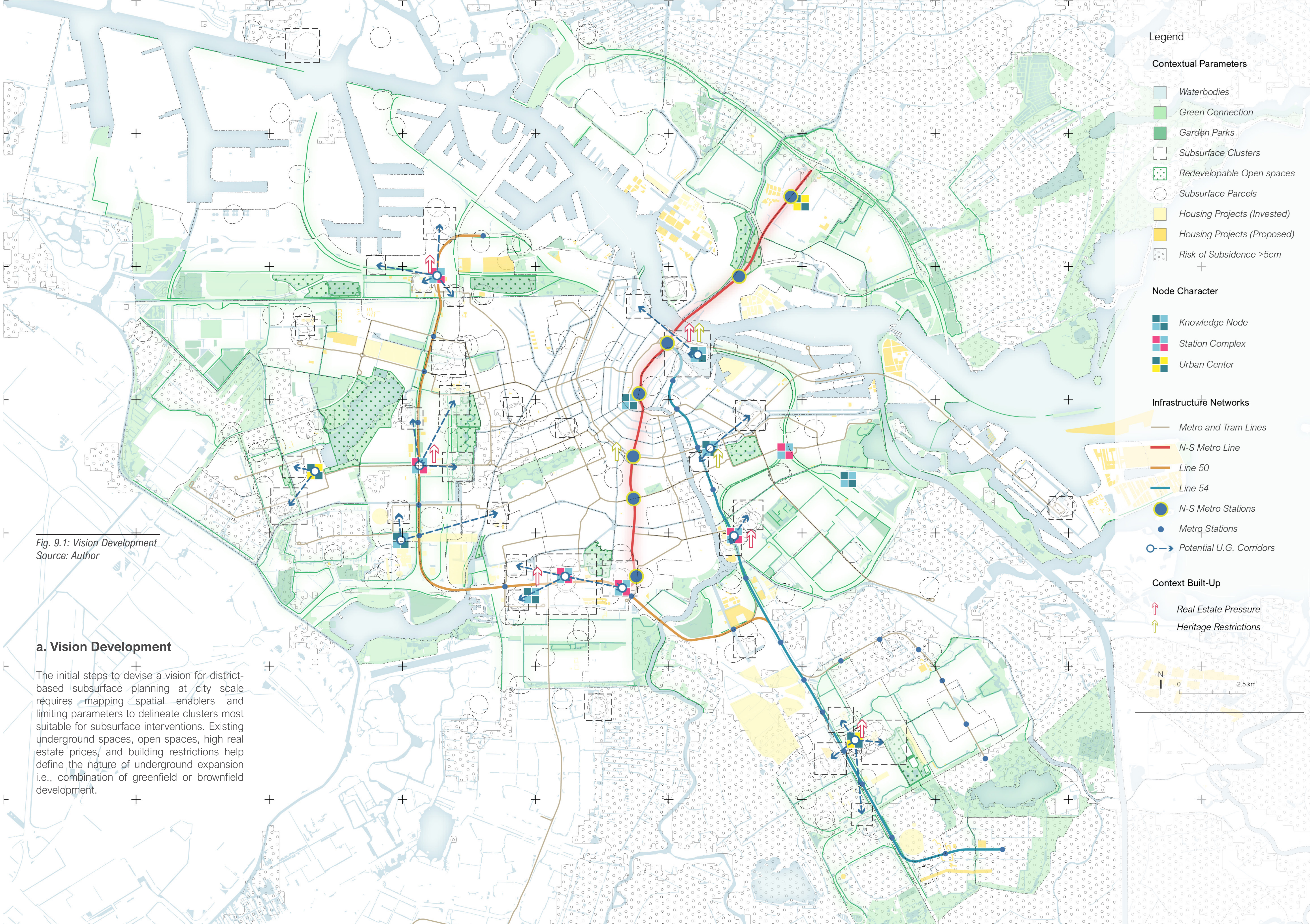


Fig. 9.1: Vision Development
Source: Author

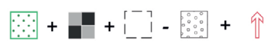
a. Vision Development

The initial steps to devise a vision for district-based subsurface planning at city scale requires mapping spatial enablers and limiting parameters to delineate clusters most suitable for subsurface interventions. Existing underground spaces, open spaces, high real estate prices, and building restrictions help define the nature of underground expansion i.e., combination of greenfield or brownfield development.

Nature of U.G. Development

Transformation + Greenfield 

Greenfield U.G. Development 

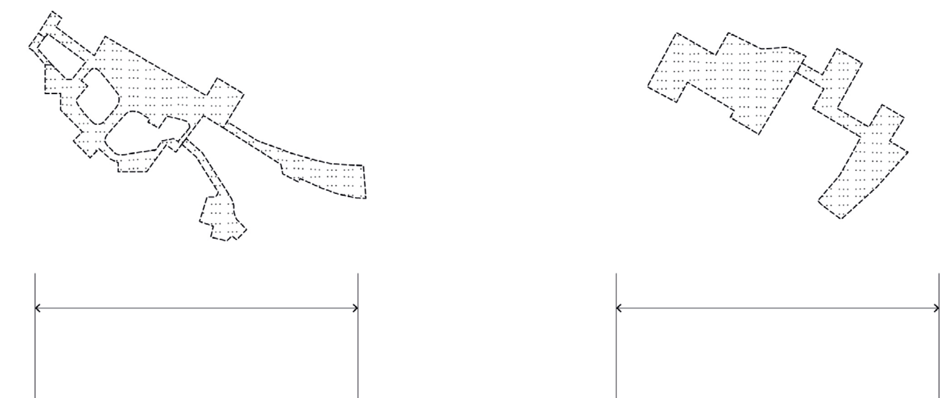


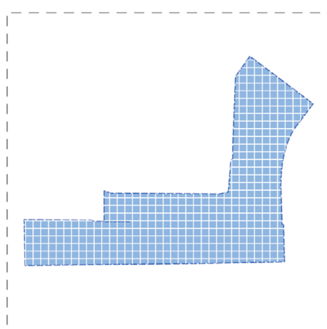
Transformation existing U.G. 

Districts for Subsurface Planning

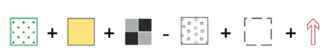
Based on the inferences and guidelines for soil and building construction, it is possible to conduct design exercises for several districts and neighborhoods across the cities. These were chosen on the basis of projections for metropolitan urban programs, upcoming housing projects as delineated by Amsterdam's structural vision 2040 and the city's Environmental Vision. Vicinity to areas of risk and essential water bodies are kept as filtering parameters for limitations.

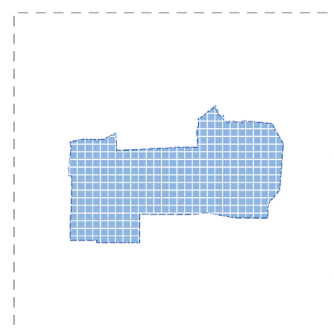
Workable Underground Loops



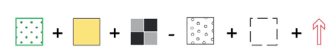


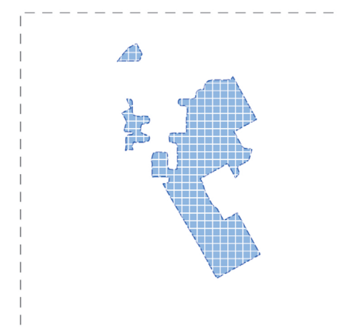
Amsterdam Sloterdijk



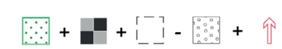


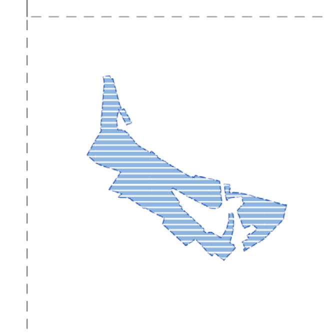
Zuidas



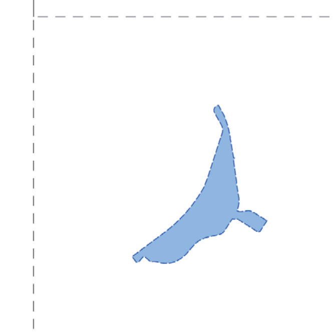


Amsterdam Port e.o.

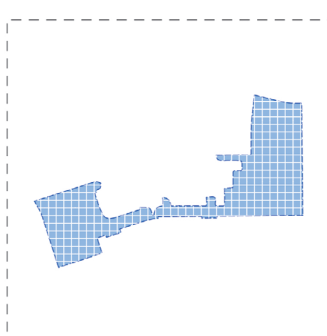




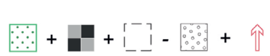
Amsterdam Centraal

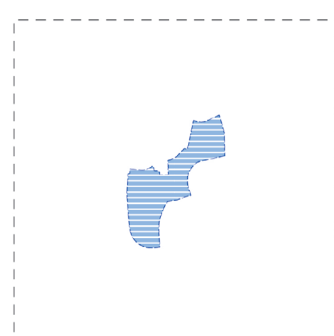


IJplein/Vogelbuurt

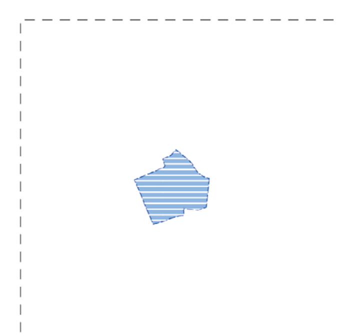


Osdorp-East

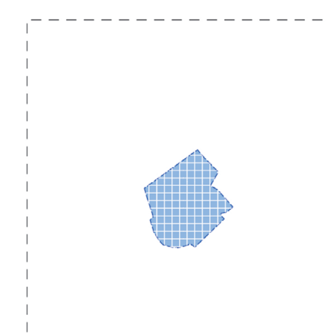




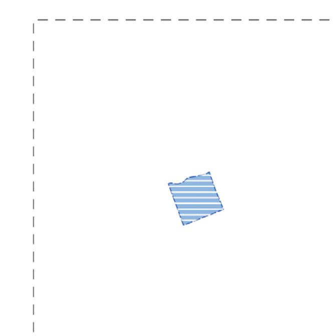
Zuidas



Museum Quarter



Frankendael



Oosterparkbuurt

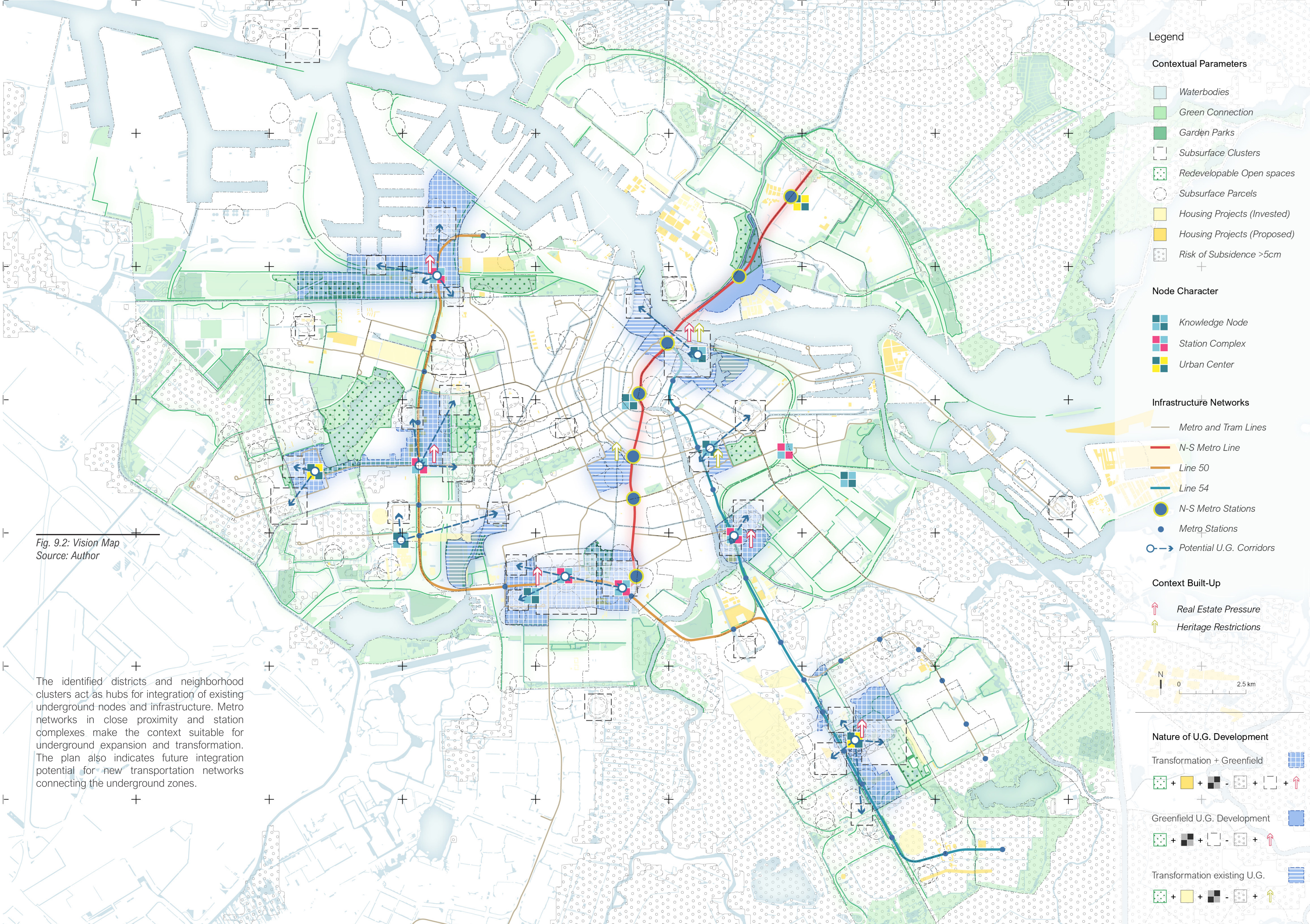


Fig. 9.2: Vision Map
Source: Author

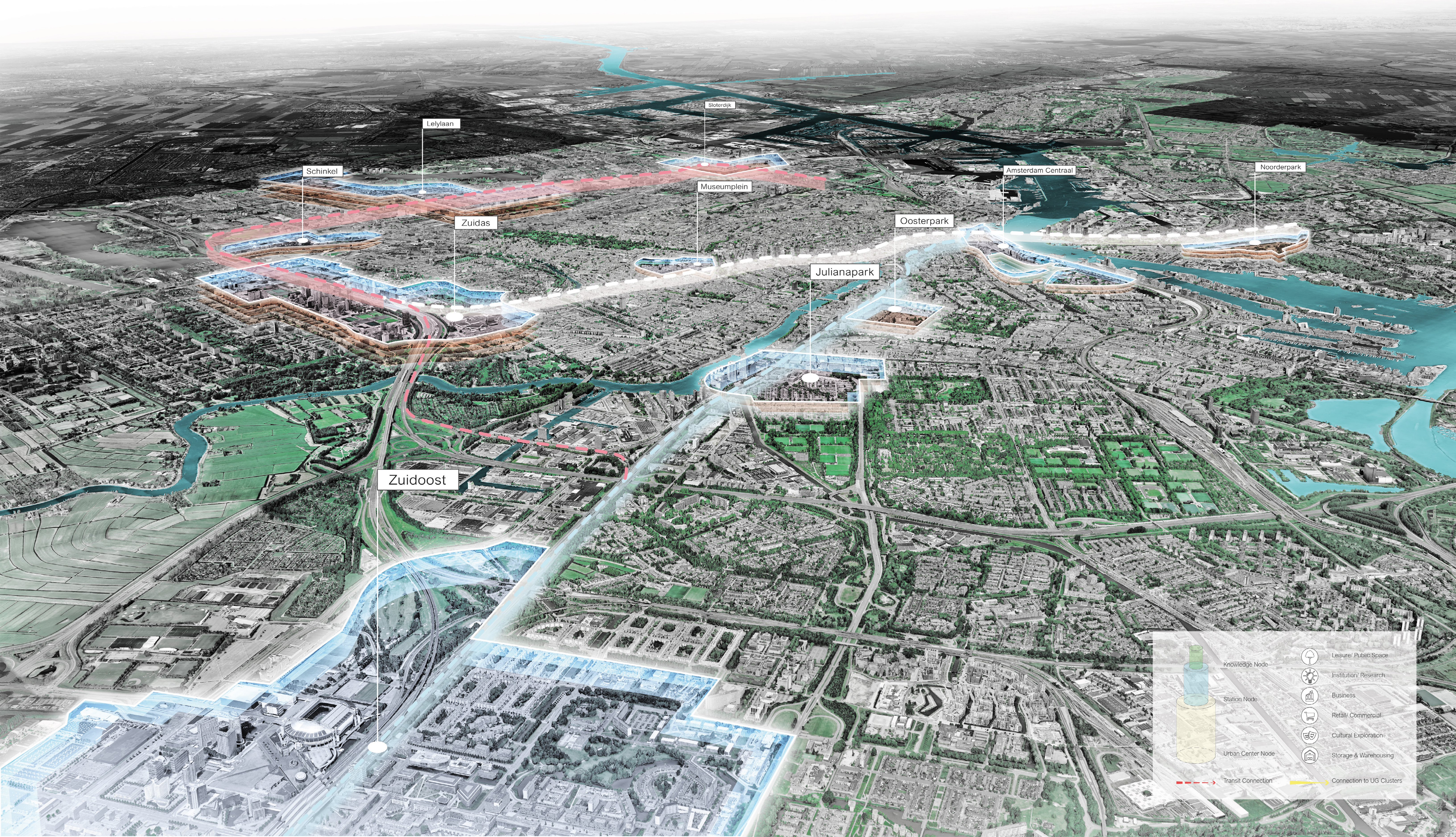
The identified districts and neighborhood clusters act as hubs for integration of existing underground nodes and infrastructure. Metro networks in close proximity and station complexes make the context suitable for underground expansion and transformation. The plan also indicates future integration potential for new transportation networks connecting the underground zones.

b. Atmosphere: Future Transitions

URBAN SYSTEMS INTEGRATION

Linking Subsurface Districts to Transportation Infrastructure

Fig. 9.3: Birdseye Vision
Source: Author



URBAN SYSTEMS INTEGRATION

Establishing Local centers and Functional character supplemented by Underground Spaces

Fig. 9.4: Birdseye Vision systems integration
Source: Author

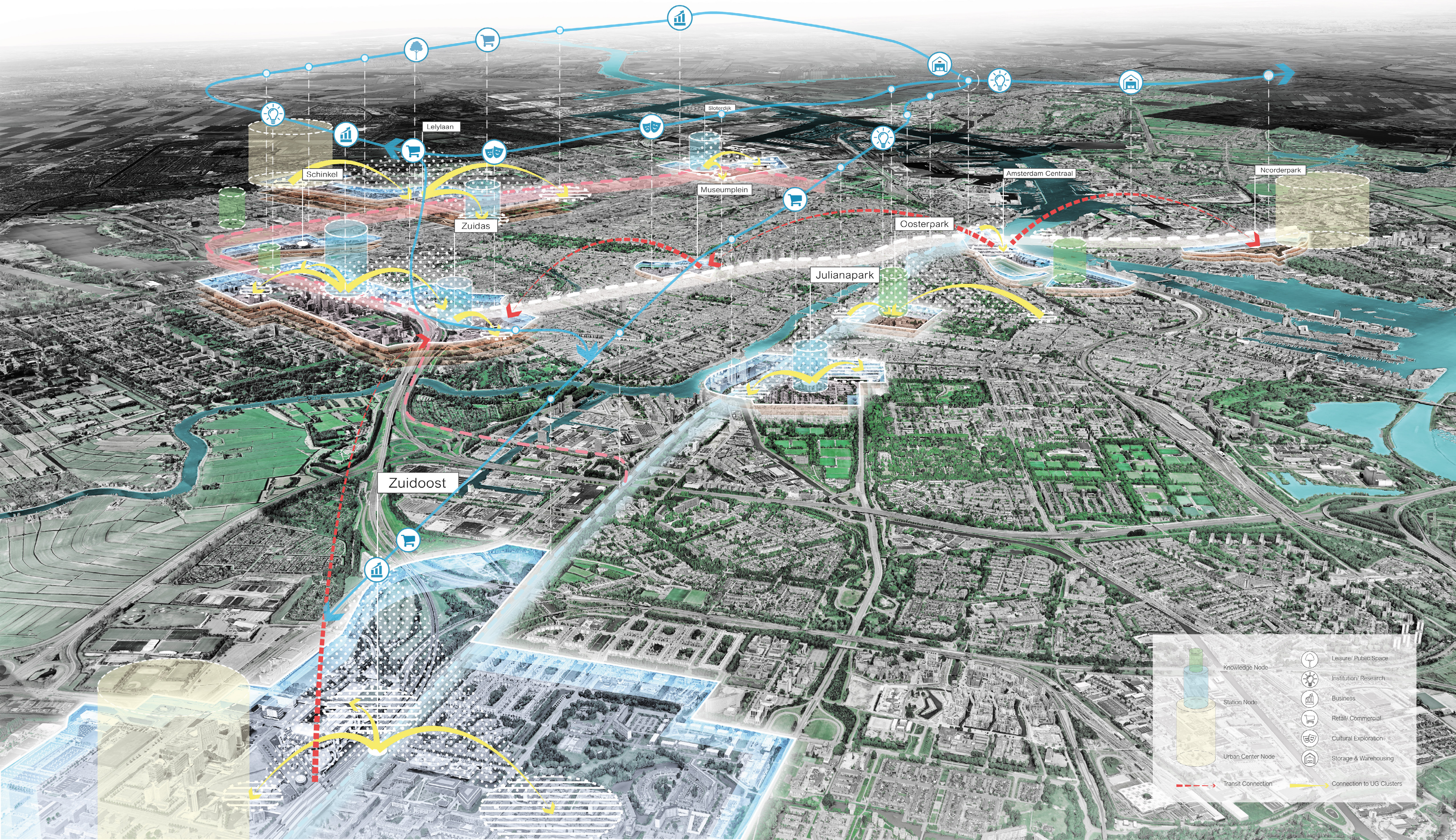


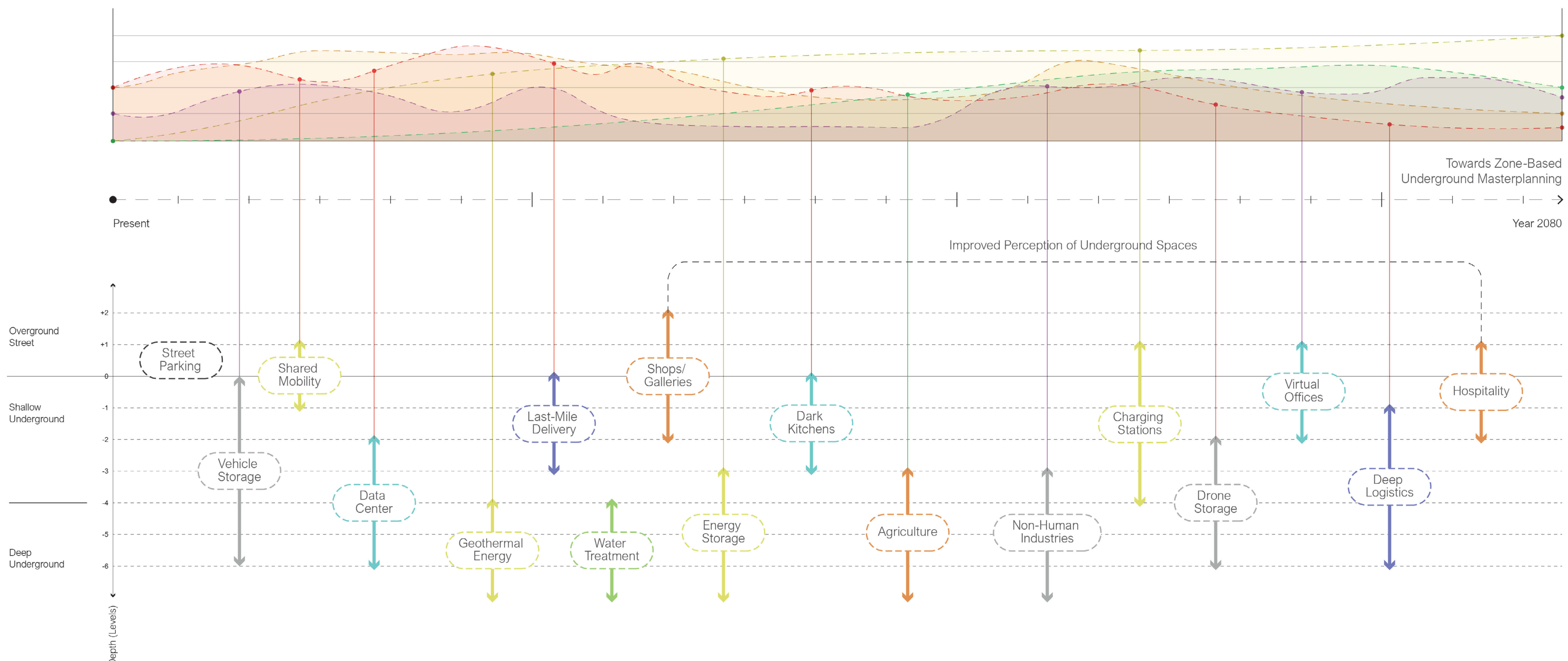
Fig. 9.5: Incorporating future transitions
Source: Author

Incorporating future transitions

It is important to consider the vertical dimension while planning for underground spaces. Since underground construction is a relatively permanent change in city's geography, the assigned functions need to be open ended and progressional in nature. Underground spaces can contribute towards tackling several future transitions catering to energy, technological innovation, climate chage and even shift in perception of spaces among citizens. These transition were laid on a timeline towards next 60 years where subsurface use may pursue various technological shifts and alternative economies. For sustainable management of these functions, it is important to categorize underground realms including the groundscape in gradients of liveability, techniques and services.

Incorporating Future Transitions

- Climate
- Technology
- Energy
- Mobility
- Infrastructure



c. Envisioning the Subsoil with Groundscape

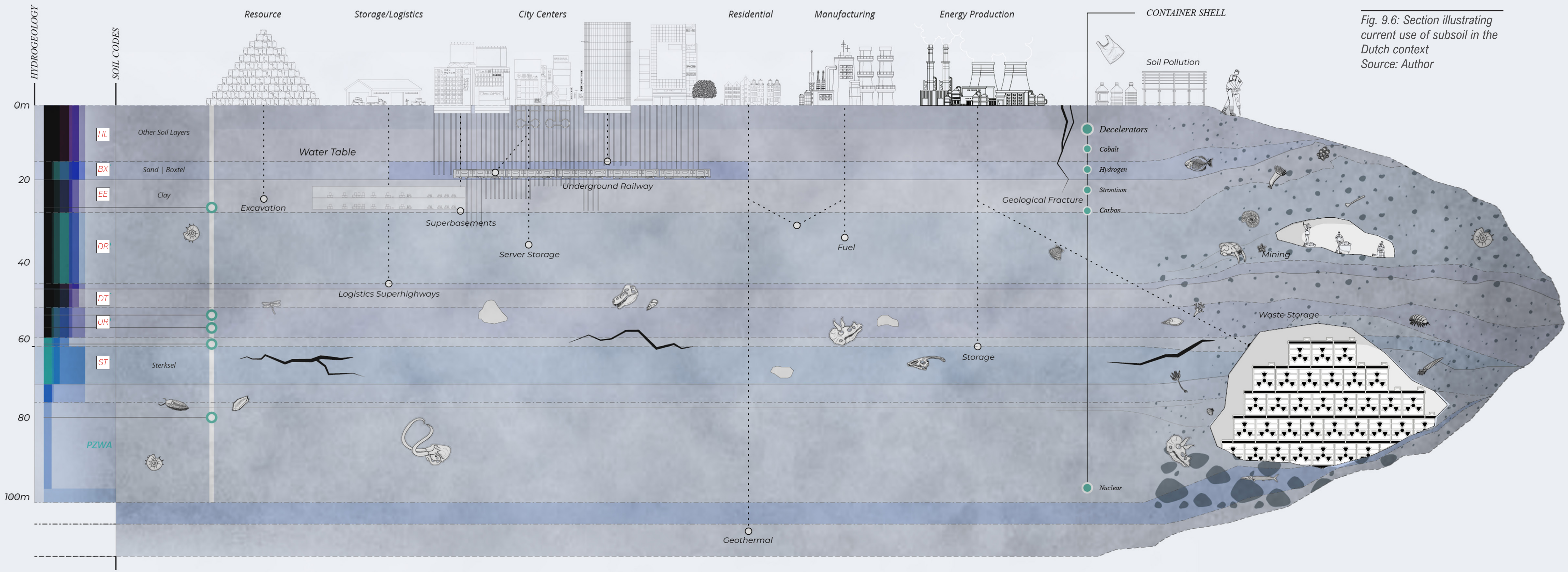


Fig. 9.6: Section illustrating current use of subsoil in the Dutch context
Source: Author

The concept of underground development and subsurface cities is not a novel or recent initiative for urbanists. A wide range of uses already exist ranging from transportation, resource extraction, building foundations, storage, and mining. However, desiging the layer of incision on the surface is a recent endeavour. The groundscape functions with the physical relationship between land, water and other fundamental elements. The practice of placing program remainders within the subsurface needs to be challenged by unveiling and showcasing its constituent elements.

At a depth of 0-12 meters, gradient of ecological benefits offered by subsurface including temperature and acoustics, are progressive in nature. However, these benefits remain lower than the entropical needs of surface functions. Hence, the current subsoil is primarily composed of service-based infrastructural networks. Designing new spaces in the subsoil should replicate planning practices overground to some extent i.e., taking into account expanse of streets and spaces to move beyond an individual built structure while switching parameters of material and volume to light and void.

At a depth deeper than 15-20 meters, construction underground is constraint to soil integrity. Buildings at these levels may exist as shells unlike parcelized establishments overground. Since their construction requires substantially extra mechanical input and extraction for ventilation, ownership of such volumes is only feasible under private entities, resulting in functions like parking, storage and distribution logistics, and server spaces. The functional profile beyond this depth belongs to long-term service-based uses operational for drawing national resource value including minerals and energy.

The distinct gradients of subsurface use with respect to depth are evident in the illustration above. Design exercise focused at the groundscape should account for the current gradient while integrating isolated nodes and introducing new programs. The current spatial distribution trend describes the user perception of undergound spaces, willingness to shift, and nature of activities preferred. The new Groundscape should address, inform and innovate these program gradients with respect to livability and accessbility of subsoil by different types of users and organizations.

c. Envisioning the Subsoil with Groundscape

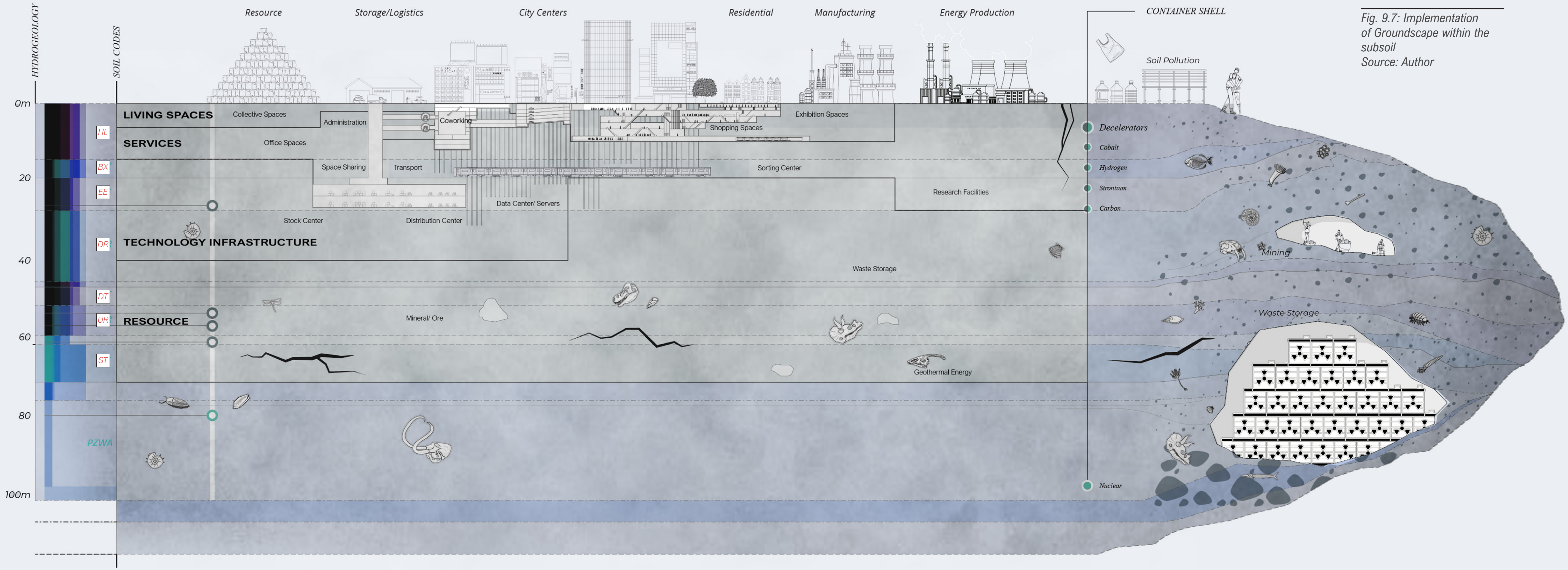


Fig. 9.7: Implementation of Groundscape within the subsoil
Source: Author

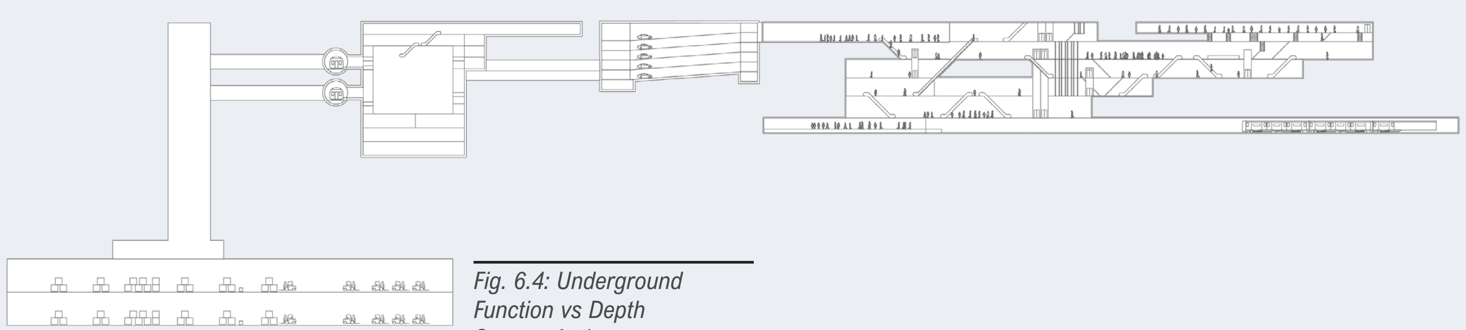


Fig. 6.4: Underground Function vs Depth
Source: Author

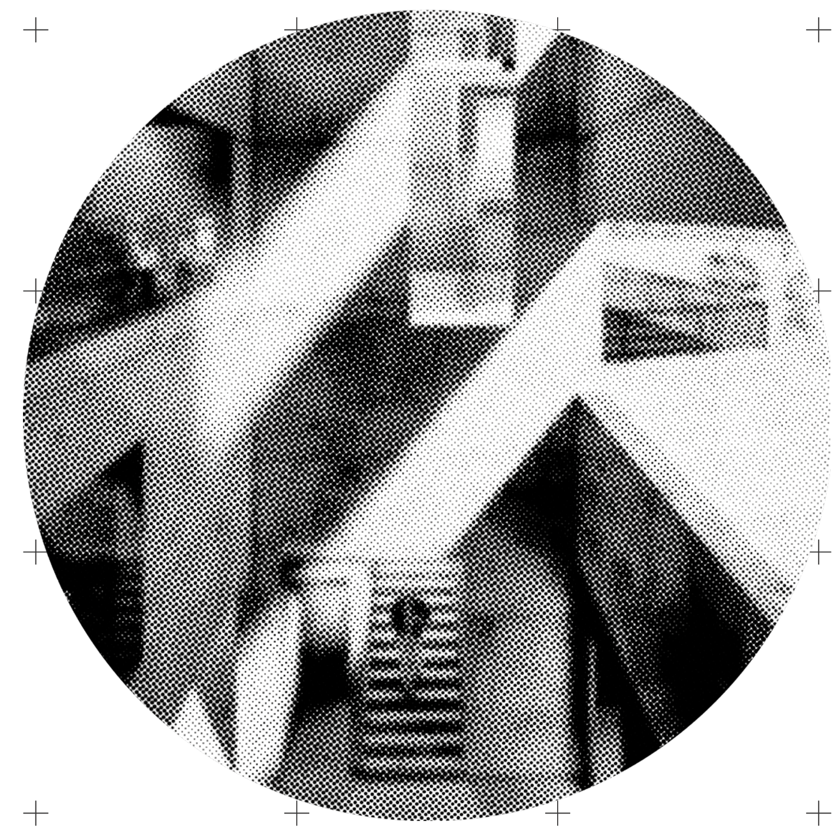
It is essential to study the potential of diversified public spaces in the subsurface. Public functions offer richness in the quality of spaces designed as it traverses beyond conventional methods of urban composition. The multiplication of permeable surfaces that can fit integrated small-scale programs enable users to facilitate their sense of orientation adn appropriation of rightful spaces. The interaction with groundscape depends upon the accesibility of light, natural air and sense of volume.

Since vertical depth is an inversely proportional parameter of accessibility, construction of groundscape must be conscious of the value of these 3 resources. They must be directed, driven and distributed as a gradient within the subsoil. Hence, the functions vary with availability of light and volume, placing public programs within the immediate underground while functions related to services and infrastructure are shifted deeper where private sector can bear their feasibility.

10. Conclusions & Reflections

Overview

The chapter includes an summation of key inferences and challenges observed within the research process focusing on answers obtained for respective sub-research questions and reflections on the research's role as an urbanist, including a critical introspection upon the discipline of urbanism and need of further study in the field of underground cities.



Conclusions

Primary Research Question

How can the existing isolated subsurface uses can be integrated to form a **Collective Functional Geography** composed of **Integrated Urban Underground Systems** through Design interventions?

In conclusion, the research conducted under this project centered around Dutch urban landscape, sought to study how design interventions can integrate previously isolated and concealed underground programs into a collective functional geography by generating demand for new public functions and introducing integrated urban underground systems. The results of 'research by design' exercise describe numerous potential benefits for Amsterdam. Efficient use of subsoil and resources it constitutes can optimize the vertical programs and landuse, subsequently reducing the pressure of urbanization over the city's current built environment. It can encase comprehensive and connective transportation systems and utilize them as a tool to attract public programs into the groundscape, opening up new possibilities for underground public spaces and mixed-use developments.

To achieve the primary vision of the project, it is essential to consider the physical constraints attacher to Amsterdam's subsurface. The unique Dutch geography, building restrictions due to existing heritage buildings, delicate balance of soil, water table and presence of water bodies requires innovative design solutions at an architectural and urban design scale.

The findings of this projects offer a methodology and set of filteration parameters and construction typologies depending on availability of resources, surrounding context, form-based restrictions and ecological constraints for policymakers, urbanists and other associated actors in shaping the subsurface realm as a futureproof and fluid geography conscious of transitioning opportunities and urban pressures.

SQ.1

What is the extent of current **Underground space inventory** in the city of Amsterdam?

Through the field study, extensive data collection, mapping and reviewing literature related to scanning underground spaces, various subsurface uses were identified. A significant volume of these uses are composed of utilities and services, transit infrastructure associated with the North-South Metro line, parking superbasements, storage and large-scale commercial spaces. The inventory provides a baseline perspective for urbanists as well as potential users to understand the characteristics of these spaces, challenging and eventually improving their perceptions through optimized and efficient design solutions. Moving forward, the generated maps can serve as a base for superimposing development plans from various actor groups. The exercise proved essential to generate dialogue between experts during workshops to validate chosen guidelines. It helped highlighting the opportunity nodes for integrating isolated systems into cohesive complexes utilizing cyclic geographies, while also enunciating the city's distinctive geographic challenges.

SQ.2

How to **map and visualize** the existing underground assets in a participatory manner?

The branched nature of components and their respective categories makes it crucial for their documentation to be a participatory exercise. Some key strategies during mapping were the intitial expert consultations to derive the primary parameters of underground construction, technological and cost thresholds to consider for underground excavation and beneficial modes of visualization. It is important for actors and designers to understand the experience of subsurface volumes. Techniques such as virtual reality, 3D interactability, and digital twins take advantage of digitalization and geographic information system to enable the actor networks in shared-decision making, platform generation, promotion of inclusive and transparent data collection. Several challenges and limitations emerge in generation of the design parameters for derivation of such parameters like outsourced/privatized datasets, accessibility, cost of implemented technologies etc., further establishing the need for data collection and mapping to be a collective practice monitored by public institutions.

SQ.3

How to **integrate isolated** project-based underground development into a collective subsurface network?

The strategizing stage of the project was aimed at synergizing disjoint urban nodes without hindering existing technological and ecological networks within the sites. The inceptive steps of research by design included drawing technical profile and promoting standardized construction and urban design practices to maintain interoperability and cohesiveness among existing neighborhoods and new infrastructure networks. The identified spatial barriers provided subsurface with the opportunity to act as a connective tissue through an alternating system of subways, skyways and overground assets. The primary inferences drawn from this exercise were directed towards appropriate site selection and thresholds of footfall and commercial spaces to bear shifting underground. The resultant design was an open-ended system welcoming future demand, and requiring suitable Special Purpose Vehicles for the operation and maintenance of overground and underground zones, equipping the district with a holistic spatial planning approach.

Conclusions

SQ.4

How to phase and design the Groundscape for public life and infrastructure development?

The post-design discussions during collaborative workshops emphasized on groundscape being a vital constituent of zone-based designing. While designing Europaplein, this layer took shape of strategic urban incision into the existing concrete fabric, softenting the existing green and grey borders. Since underground public spaces are a relatively recent concept in the Dutch context, several case studies from south-east Asian cities provided with an appropriate proportional split of area occupied and suitable functions across various vertical levels. Prioritizing human-centered scale and design of subsurface entrances helped different users engage with flexible development. To make the engagement more adaptive and efficient, stakeholder involved in underground construction must focus on balancing provisions of public parks and pedestrian-friendly linear underground networks. Public spaces on surface were the most economically viable points of entering the subsoil where the actors also realized the benefits of shifting functions below also opens the surface up for wider open areas in addition to space for buildings and parking.

SQ.5

How to strategized balanced use of underground space at the city scale?

Along the North-South Metro line, the gradient southwards gradually shifts to non-residential, cultural and commercial landuse with large-scale isolated private establishments. While utilizing an existing underground infrastructure as the spine of future subsurface projects is beneficial, this gradient challenges the users' right to the subsurface with balance between public and private functions. User categorization process and resulting adaptive spaces should be conscious of risks of spatial and social segregation. Private sector entities are relatively better equipped with the capital required for underground construction while public sector rests with distribution of space and policy frameworks related to new underground spaces. This results in a demand-supply scenario paving way for collaborative opportunities for both sides. Groundscape design should capitalize on this relationship by conscious planning of public functions without compromising the ability for space to generate revenue. The output would eventually benefit both private and public sector, leading to the collective economic development of designed zones.

Way forward to Underground Cities...

Amsterdam exists in a state of constant flux. The constraints placed by the sensitive landscape give the impression of a city with low entropy and substantial room for horizontal growth. However, with development plans envisioning layered regional integration, there are numerous upcoming local centers with promising demand and low vacany rates. These local zones present a unique opportunity for integrated vertical masterplanning. Building on the inferences from this research, there are several gaps to be addressed on the way forward on an institutional and munipal scale to sustainably guide future development. A city-scale subsurface regulatory framework is imperative, generated as a product of consistent and effective collaboration of disciplines beyond design and civil engineering. Initiatives carried forth by COB in the south of Netherlands lay a promising foundation for such platforms in the future. Further research goals should entail policy frameworks to regulate structurally stable, cohesive and vibrant public realms circulated along the future groundscapes of Amsterdam.

Relfections

Relationship between the Project and Urbanism Track

The Urbanism track at TU Delft is especially unique in pursuing causes that justify public needs, even if they move past the spatial realm. It draws from the idea of solving and at the same time, enhancing all things urban while translating impacts on and beyond the 2D spectrum. This is what drew me towards pursuing my master's degree at TU Delft in the first place.

The evolution of my project has been a distinctive learning experience in observing the cyclic nature of the research process and design by discovering new feedback loops while approaching subsequent research questions. I have tried to illustrate the scope of an urbanist to include spatial verticality along a holistic spectrum of stakeholders to demonstrate the complexity and collectiveness of 'space'. The thesis is being carried out as a part of the City of The Future studio that focuses on collaborative interdisciplinary research to explore the vision-based potential of urban spaces. As a result, balancing solutions for future crises and opportunities across professions has been a consistent learning exercise while working on this project.

Envisioning the subsurface as a collective geography in the Dutch Landscape is an essential part of my ongoing research on defining the potential of underground spaces not just as an economic venture, but also as a new way of imagining climate-conscious future-proof cities. The increasing density of infrastructure networks and the rising demand for space make it impossible to imagine the functionality of any constituent layer in isolation. While catering to the delicate nature of resources in the urban inventory, there is a time-sensitive need to make space for public functions beyond the current surface, by altering or extending the current geography. The project contributes to the goals of the studio by exploring alternate and functional reorganization of urban space to compact and integrated urban systems.

Relationship between the Project and Research by Design

To explore the initial research gaps highlighted within the project, a research-by-design approach was adopted. An inventory of design parameters and strategies for subsurface expansion was developed through a literature review including the 'Groundscape' concept, future parking spaces, entrance design, and parameters of perceiving underground spaces by a range of users. Research by design was used to identify contextual potentials of subsurface use concerning the Dutch Landscape. The speculative design of one of the chosen sites/ contexts helps illustrate a holistic view of environmental, user-ended, economic as well as infrastructural challenges. Case-based site evaluation added insights and comprehensive parameters of appraisal to the existing inventory. The feedback received during the P4 presentation pointed out the importance of categorization and benchmarking of chosen sites to structure context-based strategies used for designing underground spaces efficiently.

The exercise of subsurface planning for the site Europaplein and Amsterdam South brought forth the potential of integrating the existing development plan with new workable underground spaces at macro and micro scales. The presence of existing transit nodes and non-residential functions ranging from office and hospitality spaces contributed to the direction of future Groundscape as a public realm catering to different users and their respective perceptions/needs from underground spaces. This was done to identify spatial barriers and spaces of opportunity in the given context. The process of identifying potential spaces and functional reconfiguration itself described the need for temporal evolution and phasing instead of a permanent change in the existing geography. The study also accounted for the economically feasible redevelopable areas such as public parks and sports facilities. Superimposing layers of spatial constraints specific to the Dutch landscape including subsidence risk and depth of water table provided, combined with a comprehensive soil study revealed potential nodes where construction was possible at greater depths and the remaining areas as possible urban corridors or transition spaces. It was important to consider the surface and underground as a continuous geography where the site's natural elements may also act as tools to soften borders between different functions as well as the transition between vertical levels.

Visualizing the design solutions in the form of consecutive vertical sections informed the existing inventory of context-based parameters of evaluation. The parameters would later enable linkages between scale and spatial transition and hence enhance the bank of solutions derived from initial analysis and literature review, which would not have been possible through a conventional design exercise for respective sites. Through research and experimentation, the revised methods and guiding principles would help obtain a toolbox of collaborative interventions to develop parameters for influencing subsurface planning, infrastructure facilitation, regulations, and user perception. These can be further tested to evaluate design interventions and their impacts on remaining sites in a participatory manner, where potentials of transformation vs creation vary.

Social and scientific relevance

The projects function at the junction of tapping opportunities and tackling crises attached to densification, both urban and infrastructural. Urban development places considerable pressure on the spatial, economic as well as social aspects of Dutch cities. The city of Amsterdam is an effective case of studying the upcoming digital and spatial transitions to evaluate the role of subsurface functions concerning changing geographies. The balance of vacancy vs rising real-estate pressure also superimposes the potential of the subsurface as an economic resource to justify geographical change at a city-wide scale. In the existing development model of chosen cases, the focus for underground has been limited to parking, transit infrastructure, storage & logistics, and linear connective spaces. Studying this context lends insights into the efficient transformation of existing assets as well as additional functions in workable underground territories between the public and private sectors.

To imagine the underground realm in sync with surface geographies, urban design is a key tool that draws from ancient and contemporary literature to address specific challenges of development. Better practices can be derived from it to develop the subsurface realm not as a concrete assembly of urban functions, but as a void that addresses upcoming urban challenges and morphs with time to cater to new and old operations. In this process, analyzing the technical profile of the Groundscape is essential to ensure the sustainable creation of new territories. Hence, the methodology involved maintaining an inventory of contextualized solutions for shifting larger-scale city identity, much like an urban jigsaw puzzle. Contextualizing design challenges through parameters, thus, can be an effective tool to prepare underground spaces for future transitions.

Reflection on Methodology

The 'Research by Design' approach and subsurface appraisal by delineating workable underground inventory were used for micro-scale analysis alongside conventional methods of city-scale study towards expanding the existing set of evaluation parameters derived from literature. However, engaging with site-specific urban issues was a time-consuming process that led me to rethink and readjust the scope of the project in terms of the scale of chosen sites and utilizing the adjoining infrastructure landscape. The project started with the intent of collectivizing the subsurface and tackling the initial objectives of the methodology through workshops that involve all stakeholders attached to underground construction. However, the case-based design minimized the need for actor consultation at several stages of the research, limited to interviews and expert reviews during the literature study. It was realized that a better strategy would be to account for the reviews as parameters feeding into the existing parameters and choice of computational methods of analysis. It helped streamline the narrative of the project, focusing on the problem statement at a smaller scale rather than a cross-territorial phenomenon. The methodology was revised to include the potential of digital twins and laser scanning for developing existing underground inventory, as a set of recommendations for the public sector for city-scale evaluation and involving the project's concept in future zone-based development plans.

The feedback during different stages of the presentation also led to a clearer structure and chronology of methods used to define site selection based on categorizing possible types of transformation. This helped further contextualize the solutions for new sites to be chosen for underground development in the future in the Dutch Landscape. My previous research in this field from a real-estate perspective added to the justification of economic feasibility and impacts of subsurface expansion. The methodology acted as an extension for the same, considering a wider spectrum of actors and the role of an urbanist as a mediator to enable such a transition. Through feedback, a need to reexamine and choose new potential case studies was also realized, which accounted for all possible contextual challenges for The Netherlands in understanding the potential of the subsurface beyond spatial resources.

11. References

References

1. Zhu, W. Development of strategic new space for urban development. Beijing : Tsinghua University, Department of Civil Engineering, Underground Engineering Research Institute , 2014.
2. Planning and development of underground space: a systems perspective. Zhou, Yingxin. 2015, Defence Science and Technology Agency, Singapore.
3. Zaini, F., Hussin, K. and Raid, M.M. Legal Considerations for urban underground space development in Malaysia . Shanghai : Elsevier, 2017.
4. Master planning for underground space in Luoyang: a case of a representative historic city in China. Yong-Kang Qiao, Fang Le Peng. 2014, 15th International scientific conference "Underground Urbanisation as a Prerequisite for sustainable development".
5. Vollmer, Matthias. LiDAR Scanning for Visualizing the Underground. [interv.] Akhilesh Singh Shisodia. December 12, 2022.
6. Employee Experiences in Underground Workplaces: A Qualitative Investigation. Vinita Venugopal, Adam Charles Roberts, Kian W. Kwok. 2020, Ergonomics.
7. The Role of the Public Sector in Urban Development: Lessons from Leidsche Rijn Utrecht (The Netherlands). Verhage, Roelof. 2003, Planning Theory and Practice, pp. 29-44.
8. Advancing urban transitions and transformations research. Torrens, J., Westman, L., Wolfram, M., Broto, V. C., Barnes, J., Egermann, M., Ehnert, F., Frantzeskaki, N. 2021, Environmental Innovation and Societal Transitions, pp. 102-105.
9. Tomar, R.S. Govt. DMRC Construction Contractor . [interv.] Akhilesh Shisodia. January 1, 2020.
10. London's Green Belt: The Evolution of an Idea. Thomas, David. 1963, The Geographical Journal , pp. 14-24.
11. Shisodia, Akhilesh. Unlocking Underground Real Estate: A Case of Connaught Place, New Delhi. Bhopal : School of Planning and Architeture, Bhopal, 2020.
12. Sharma, Vaishali. India, Perception of Urban Public Squares in India. Bengaluru : Manipal University, 2015.
13. Intelligent overall planning model of underground space based on digital twin. Shao, Feng and Wang, Yanshang. 2022, Computers and Electrical Engineering.
14. Adherence to Environmental Regulation in the European Union Common Agricultural Policy: Social Representations and Conditionality among French Farmers. Sandrine Gaymard, Boris Goujon, Marianne Lefebvre. 2020, Journal of Agriculture and Food Information, pp. 104-125.
15. Reynolds, Elizabeth. Underground Urbanism. New York : Routledge, 2020.
16. Reynolds, Elizabeth and Reynolds, Paul. Planning for Underground Spaces "NY-LON Underground". London : ISOCARP, 2015.
17. The Price of Urban Land and the Application of Land Rent Theory: A case of Bhuvaneshwar, Odisha. Praharaj, Mayarani. 2019, ITPI, India , pp. 61-82.
18. Perrault, Dominique and Lee, Yonnhie. Sublab: A Groundscape Story . Seoul : NemoFactory, 2017.
19. Perrault, Dominique. Ground Scapes: Other Topographies. Orleans : Editions HYX, 2016.
20. Underground space and urban sustainability: an integrated approach to the city of the future. Paraskevopoulou, C., et al. Chania, Greece : University of Thessaly, 2019. International Conference on Changing Cities IV: Spatial, Design, Landscape & Socio-economic Dimensions.
21. Mona Sharma, IAS. Right of user permission on private land for make-up water transmission . Odisha : Govt. of Odisha, 2016.
22. Designing Urban Squares. Memluk, Murat Z. 2013, Intech Open Science, pp. 513-530.
23. Community Participation in Local Government Planning Processes: A Paramount Step Towards a Successful Service Deliver. Madzivhandila, Thanyani Selby. 2014, Mediterranean Journal of Social Sciences, pp. 652-657.
24. Urban underground development; an overview of historical underground cities in Iran. M. Montazerolhodjah, M. Pourjafar, A. Taghvaee. 2015, International Journal of Architectural Engineering and Urban Planning .
25. Apple LiDAR Sensor for 3D Surveying: Tests and Results in the Cultural Heritage Domain. Lose, Lorenzo Teppati, Spreafico, Alessandra and Chiabrando, Filiberto. 2022, Remote Sensing.
26. Locsin, Aurelio. Virtual offices . small business . [Online] February 5, 2020. https://smallbusiness.chron.com/define-virtual-office-13476.html.
27. Liu, Cixin. The Dark Forest. s.l. : Head of Zeus, 2008.
28. The extreme primacy of location : Beijing's underground rental housing market. Kim, Annette M. 2016, Cities: The International Journal of Urban Policy and Planning .
29. Jones, Lauren. Effecting Social Change: Architecture as Servitude. Cultural Resistance Reader. 2002, pp. 91-110.
30. Urban Land Expansion and Sustainable Land Use Policy in Shenzhen: A case study of China's Rapid Urbanization. Jing Qian, Yunfei Peng, Cheng Luo, Chao Wu. 2016, MDPI Sustainability .
31. Underground imaginations, environmental crisis and subterranean cultural geographies. Hawkins, Harriet. London : s.n., 2019, Culture Geographies, pp. 3-22.
32. Design's factors influencing social interaction in public squares. Hajmirsadeghi, Reihaneh Sadat. 2013, European Online Journal of Natural and Social Sciences, pp. 556-564.
33. Legal considerations for urban underground space development in Malaysia. F. Zaini, K. Hussin, M. M. Raid. 2017, Underground Space 2 , pp. 234-245.
34. A Psychosocial Approach to Understanding Underground Spaces. Eun H. Lee, George I. Christopoulos, Kian W. Kwok. 2017, Frontiers in Psychology , pp. 1-7.
35. Durmisevic, Sanja. Perception Aspects in Underground spaces using Intelligent Knowledge Modelling . Delft : DUP Science, 2002.
36. Daniels, Matt. Human Terrain. The Pudding. [Online] May 6, 2015. https://pudding.cool/2018/10/city_3d/.
37. Deconstructing the Global City: Unravelling the Linkages that Underlie Hong Kong's World City Status. Chu, Yin-wah. 2008, Urban Studies, pp. 1625-1646.
38. Life Between Buildings: Using Public Spaces (Book Review. Campos, Beatriz. 2012, The Journal of Space Syntax, pp. 125-130.
39. Underground Space as an urban indicator: Measuring use of subsurface. Bobylev, Nikolai. 2015, Tunnelling and underground space Technology .
40. Cities Think Underground – Underground Space (also) for People. Besner, Jacques. 2017, Proceedia Engineering, pp. 49-55.
41. Community Perception on Public Open Space and quality of life in Medan, Indonesia. Achmad Delianur Nasution, Wahyuni Zahrah. 2014, AMER International Conference on Quality of Life, pp. 586-594.
42. UN-DESA. World Urbanization Prospects: The 2014 Revision. s.l. : Department of Economic and Social Affairs, United Nations, 2014.
43. ITA Global . Urban Underground Space in a Changing World . Geneva : ITA Global Perspective, 2013.
44. Knight Frank. Think India. Think Retail. Delhi : Knight Frank , 2015.
45. WSP. Taking Urban Development Underground: Future-ready solutions for ensuring urban sustainability. s.l. : WSP Global Inc., 2018.
46. Harvard University: GSD. New Geographies 10: Fallow. New York : Actar, 2019.
47. Knight Frank Research. Knight Frank Prime Global City Index. Delhi : Knight Frank , 2019.
48. Knight Frank . India Real Estate . Mumbai : Knight Frank Research , 2018.
49. University of Amsterdam. Historical Amsterdam in 3D/4D - Pilot Study. Time Machine. [Online] 2019. https://amsterdamtimemachine.nl/historical-amsterdam-in-3d/.
50. CBRE. Global Prime Office Occupancy Costs Survey. New Delhi : CBRE, 2019.
51. Down to Earth. Down To Earth: Fortnightly on politics of development . Bhopal : Environment and Health , 2019.
52. Cushman and Wakedfield . DELHI NCR retail Marketbeats Q1. Gurgaon : Cushman & Wakefield , 2019.
53. Cushman & Wakefiled. Delhi NCR Retail Marketbeats. Delhi : Cushman & Wakefiled, 2019.
54. DPA-X . Carpark Futures: Opportunities for the underground. Paris : Indigo Group , 2020.
55. DPA; Indigo Group . Carpark Futures. Paris : Dominique Perrault Architecture, 2021.
56. "Depthscrapers Defy Earthquakes. 1931, Everyday Science and Mechanics, pp. 646,708.
57. Harteveld, Maurice. Interior Public Spaces: on the

Mazes in the Network of an Urbanist. Delft : Delft University of Technology, 2014. ISBN 978-94-6186-264-8.
58. Frampton, Adam, Solomon, Jonathan D. and Wong, Clara. Cities without Ground: A Hong Kong Guide book. s.l. : Oro Editions, 2012. ISBN 9781935935322.
59. Rowe, Colin and Koetter, Fred. Collage City. Cambridge : MIT Press, 1984.
60. A systematic quality assessment of underground spaces: public transport stations. Durmisevic, Sanja and Sariyildiz, Sevil. 1, London : Elsevier Science, 2001, Vol. 18.
61. CGREA | Rijksvastgoedbedrijf. The Vivaldi Building. Amsterdam : CGREA | Rijksvastgoedbedrijf, 2017.
62. Underground space utilisation for urban renewal. Cui, Jianqiang, Broere, Wout and Lin, Dong. s.l. : Tunnelling and Underground Space Technology, 2020, Vol. 108.
63. Urban Problems- Underground Solutions. Broere, Wout. Singapore : Research Publishing (The Society for Rock Mechanics & Engineering Geology), 2013. ISBN 9789810737573.
64. Planning with water and traffic networks: Carrying structures of the urban landscapes. Tjallingii, Sybrand. s.l. : Research in Urbanism Series, 2015, Vol. 3.
65. Gemeente Amsterdam. Portefeuille Programma en Regie Afdeling Regie en Advies. Amsterdam : Gemeente Amsterdam, 2015.
66. Zuidas; Gemeente Amsterdam; ARUP. Zuidas Vision Document. Amsterdam : Amsterdam City Council, 2009.
67. Charlier, Karlien. Going Underground. Antwerp : Universiteit Antwerpen, 2021.
68. ARUP; MGR Infra. Ontwerpstudie Stad x Ruimte. Amsterdam : s.n., 2021.
69. Citywide parking policy and traffic: Evidence from Amsterdam . Ostermeijer, Francis, et al. Amsterdam : Tinbergen Institute, 2021, Vol. 8.
70. Amsterdam Zuidas. Construction Projects. Amsterdam Zuidas: Keeps you up-to-date. [Online] https://zuidas.nl/en/construction-projects/.
71. Arjan Harbers, Martijn Spoon, Hans van Amsterdam, Johan van der Schuit. Ruimte Dichtheden en Functiemenging in Nederland. s.l. : Planbureau voor de Leefomgeving, 2019.
72. Systems approaches to urban underground space planningand management – A review. Loretta von der Tann, Raymond Sterling, Yingxin Zhou, Nicole Metje. s.l. : Tongji University and Tongji University Press, 2019, Vol. 5.
73. Bonte, Matthjis. Impacts of Shallow Geothermal Energy on Groundwater Quality. s.l. : MB-Water, 2013.
74. Vahaaho, Ilkka. Urban Underground Space: Sustainable Property Development in Helsinki. Helsinki : City of Helsinki, 2014.
75. Gemeente Amsterdam. Omgevingsvisie Amsterdam 2050. Amsterdam : Gemeente Amsterdam, 2021.
76. Urban Subsurface Planning and Management Week, SUB-URBAN 2017, 13-16 March 2017, Bucharest, Romania. F.L. Hooimeijer, F. Lafleur, T.T. Trinh. s.l. : Elsevier, 2017, Vol. 209.
77. Hooimeijer, F.L. SUET Production Process. Delft : s.n., 2023.
78. Gemeente Amsterdam. Economically strong and sustainable structural vision: Amsterdam 2040. Amsterdam : Gemeente Amsterdam, 2011.
79. Jansma, Rein. AMFORA Amsterdam. Amsterdam : ISOCARP, 2009.
80. COB Netherlands. Tijdschrift over ondergronds bouwen en ondergronds ruimtegebruik. De Onderbouwing. 2015, Vol. 8, 20.
81. Gessel, SF van. Underground Space in Pictures: Towards an informed decision. s.l. : COB Netherlands, 2011.
82. The onset of underground urban planning in Flanders. Debrock, Shana. s.l. : IOP Conference, 2021.
83. Hans de Boer, Shana Debrock, Thomas Dillon Peynado, Marleen Duflos, Fransje Hooimeijer, Joran Kuiper and Schuur, Gijsbert. De ondergrond als bouwsteen voor de toekomstbestendige stad. s.l. : Public Space, 2022. ISBN 9789491789335.
84. Haentjens, Geert. Kansen voor ondergronds ruimtegebruik. s.l. : Vlaamse Overheid.
85. Opdrachtnemer, team TU Delft. Verrijking van het ruimtelijk uitvoeringsplan. Delft : TU Delft, 2020.
86. Development of the under-channel space of the center of Moscow: reducing regulatory risk. Belyaev, Valery. Moscow : EDP Sciences, 2021.
87. Different approaches to the Reconstruction of Vosstaniya Square in St. Petersburg. Yu.A. Nikitin, Antonina I. Ushakova. Saint Petersburg : Elsevier, 2017, Vol. 189.
88. PORTUS. Rotterdam Underground: In-Depth History, Present and Future. Rotterdam : PORTUS online.
89. Use of Underground Space. Herpen, Frans van, et al. Delft : TU Delft, 2011.
90. Underground City Planning: A French born concept for sustainable cities of tomorrow. Duffaut, Pierre. Sharm El-Sheikh : French Tunneling and Underground Space Association, 2006.
91. New planning and design concept for urban underground spaces based on geo-environmental factors. Xu, Hui. s.l. : IOP Conf. Series: Earth and Environmental Science , 2020, Vol. 570.
92. The Negative Influence of Urban Underground Space development on urban microclimate. Xiaoling Cheng, Xudong Zhao, Qiaoyi He, Xiaochao Su. s.l. : Sustainability, MDPI, 2022.
93. Dronkelaar, C. van. Underground Buildings. s.l. : TU Eindhoven, 2013.