Une approche de planification multidimensionnelle (MDPA) - Vers une nouvelle justification de la planification et de la visualisation des espaces souterrains dans le cadre du métabolisme urbain

A Multi-Dimensional Planning Approach (MDPA) - Towards a New Rationale to Planning and Visualising Underground Spaces as Part of the Urban Metabolism

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Résumé

Dans les villes de demain, l'espace deviendra un bien de plus en plus précieux. Nous devons planifier l'espace dans nos villes plus soigneusement que jamais. Une demande croissante de logements, d'espaces de bureaux, d'infrastructures et d'espaces publics est en concurrence pour les zones souterraines et les surfaces urbaines. Notre ville ressemble à un métabolisme urbain, à un être urbain. Ce métabolisme est vivant et continue de croître et de s'adapter à de nouvelles formes et fonctions. L'espace souterrain est une partie complexe de ce métabolisme. Pour que les urbanistes puissent comprendre cet être urbain, la planification des espaces souterrains nécessite une approche radicalement nouvelle. Pour obtenir une meilleure vue d'ensemble et une image globale du sous-sol, une approche de planification globale et coordonnée est nécessaire. Dans le passé, on a argumenté qu'une visualisation en 3D était nécessaire, par opposition à l'approche traditionnelle en 2D appliquée aux plans de développement de nos villes. Pour intégrer le sous-sol dans la planification urbaine, il faut passer d'une réflexion en termes de surface à une réflexion en termes de volume. À notre avis, cette approche ne tient pas compte des caractéristiques spécifiques du sous-sol. Une approche multidimensionnelle, qui inclut la géologie et le temps comme paramètres, doit être utilisée pour comprendre pleinement les opportunités et les défis que le sous-sol apporte aux villes. Nous examinerons pourquoi cette approche est nécessaire pour permettre le développement des espaces souterrains et pour évaluer le rôle du sous-sol dans la résilience urbaine. Les meilleurs exemples du monde entier seront décrits et une nouvelle législation destinée à guider le développement futur sera examinée.

Abstract

In tomorrow's cities space will become an ever-greater valuable commodity. We need to plan the space in our cities more carefully than ever. A growing demand on housing, office space, infrastructure and open space is competing for the underground and urban surface areas. Our city resembles an urban metabolism, an urban being. This metabolism is alive and keeps growing and adjusting itself to new forms and functions. Underground space is an intricate part of this metabolism. As much as urban planners are trying to understand the urban being, underground spaces require a radically new approach. To gain better insight and an overall picture a coordinated planning approach is required. in the past it has been argued a 3D visualisation as opposed to the traditional 2D approach of the urban fabric is needed. To include the subsurface into urban planning requires a shift from thinking in area to thinking in volume. In our opinion this approach lacks in its appreciation of the specific characteristics of the subsurface. A multi-dimensional approach, which includes geology and time as parameters, must be used to fully understand the opportunities and challenges the subsurface brings to cities. We will discuss why this approach is necessary to allow development of underground spaces and to assess the role of the subsurface in urban resilience. Best cases from around the world will be described and new legislation to guide future development will be examined.

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1 Introduction

In tomorrow's cities, space will become an ever-greater valuable commodity. Cities are rapidly running out of space, making further sprawl no longer possible. Contained sprawl leads to calls for higher density, which increases the pressure on available space. For cities to be liveable, they require more than just space for buildings and infrastructure. The appreciation of the need for green spaces and blue spaces, i.e. open water bodies, is rapidly growing as we realise this is what makes cities habitable. Green spaces and blue spaces play a vital role in helping cities cope with climate change. These spaces can reduce the urban heat island effect, absorb carbon emissions and catch rainfall. To balance all these needs, we need to plan the use of space in our cities more carefully than ever. The growing demand for housing, office space, warehousing, logistics, infrastructure, and open spaces, is competing for the underground space as much as it is for urban surface areas.

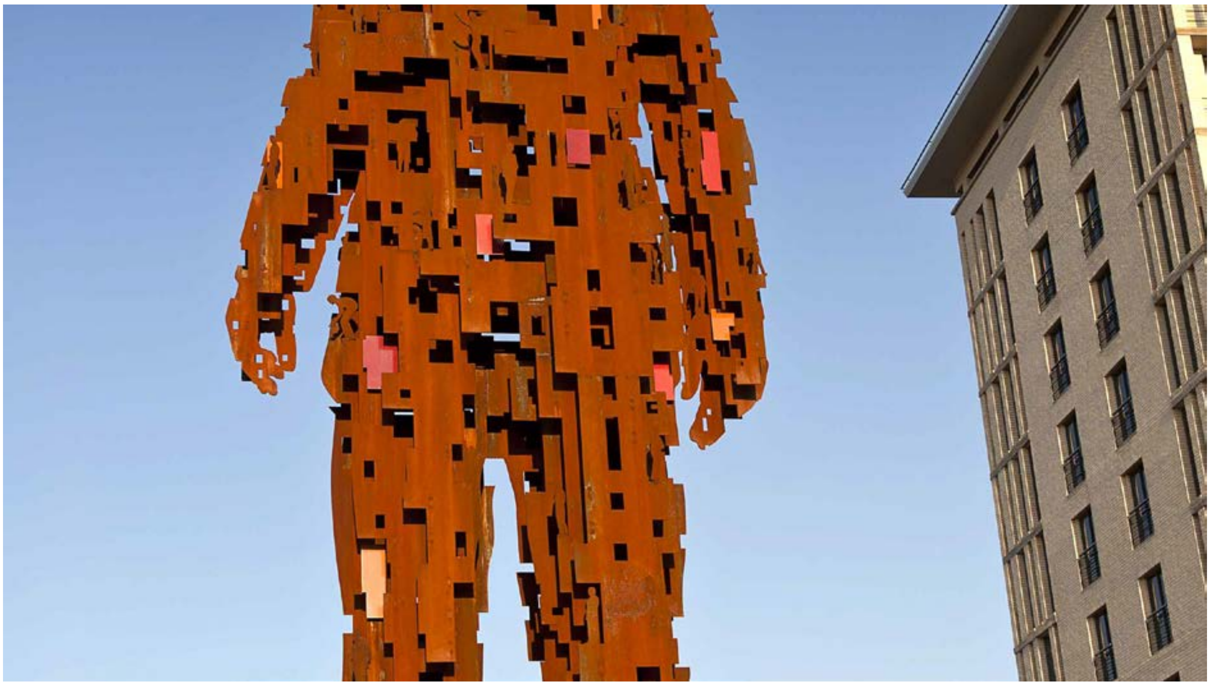

Figure 1. The urban being as metaphor for the urban metabolism. Urban Being by Marco Cianfanelli (Hatfield, Pretoria, South Africa).

Renner (2018) proposes to see our cities as resembling an urban metabolism, an urban being (see Figure 1). This metabolism is alive and keeps growing and adjusting itself to new forms and functions. Hajer & Dassen (2014) argue the necessity for planners to unveil the urban metabolism. Only then will it become clear what contemporary urban life consists of. Underground space is an intricate part of this metabolism (Admiraal & Cornaro, 2018, 2020). As much as urban planners are trying to understand the urban being and the urban metabolism, understanding underground spaces requires a radically new approach. To gain better insight and an overall picture, a coordinated planning approach is required. in the past it has been argued that 3D visualisations as opposed to the traditional 2D approach of the urban fabric is needed. To include the subsurface into urban planning requires a shift from thinking in area to thinking in volume. The existing paradigm, which consists of extending surface planning practice downwards, is in the view of the authors incorrect. The overarching reason for this is that underground space planning calls for a volumetric approach which includes thinking in layers. Abbott (1884) in his novel ‘Flatland’ describes what it would be like to live in a 2D world. The world he describes is a far cry from how we observe our physical world. In the same way we propose that planning of the subsurface is radically different from how we have been planning our cities up to now. To adequately plan underground space, a first step is to move from Flatland to Spaceland (see Figure 2), from a 2D area oriented approach, to a 3D volumetric oriented approach.

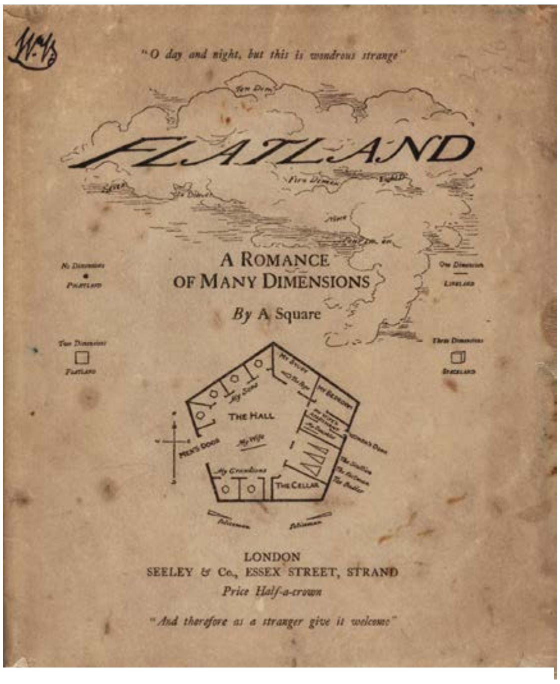

Figure 2. Flatland. Courtesy of: EC85 Ab264 884f, Houghton Library, Harvard University

Interestingly, in the 1920’s it was observed that Abbott also included the concept of time in his observations. In the case of a sphere passing through flatland he observed that it would look like a circle growing and then contracting until it had become a point and then vanished. Not unlike what we can observe ourselves as the sun sets over the horizon. Time in 2D space is linked to growth and contraction. In 3D space, time is linked to motion. Abbott identified the space-time relationship well before the concept of the fourth dimension was formulated by Albert Einstein in his general theory of relativity. Time, as fourth dimension, must be considered when discussing underground space. The planning of underground space requires us to address temporality. Admiraal & Cornaro (2018) point this out when writing about the former mines under the city of Heerlen in the Netherlands: *“The only evidence that these mines existed remains deep below the surface, in the largest industrial complex in the country, invisible, preserved for posterity, and trapped in time in underground space.”* Underground spaces are created by nature or by humankind. Once created they exist, but only for as long as they are in use. Once abandoned, they become trapped in time and underground space, until they are rediscovered and repurposed. An interesting example of this are the former WWII shelters beneath London, now being used as an underground farm to produce vegetables and herbs. Temporality makes that underground spaces are not unlike Schrödinger’s Cat (see Box 1), they can exist and not exist. We need to, as it were, open the box, to unveil what is contained inside the subterranean. By addressing time as planning dimension, underground space planning ensures that those spaces will always exist through being identified as being part of the urban fabric. They will no longer be trapped in time and underground space.

In the authors opinion the contemporary planning approach lacks in its appreciation of the specific characteristics of the subsurface. Other than on the surface where buildings are surrounded by air, below the surface buildings are contained inside the earth. As such they become part of the subterranean.

A multi-dimensional approach recognises this fact and therefore must include geology as the single most determining factor. The Yaodong dwellings that are found in China are a good illustration of this point (see Figure 3). These dwellings have been dug into the subsurface allowing habitation on the barren Loess Plateau where surface conditions require constant shelter. The geology of the region ensured that digging out these habitats was relatively easy. In comparison, creating underground spaces in soft soils with high water tables requires additional technology to create the space. When planning the underground space, geology must therefore be considered as the overall determining factor.

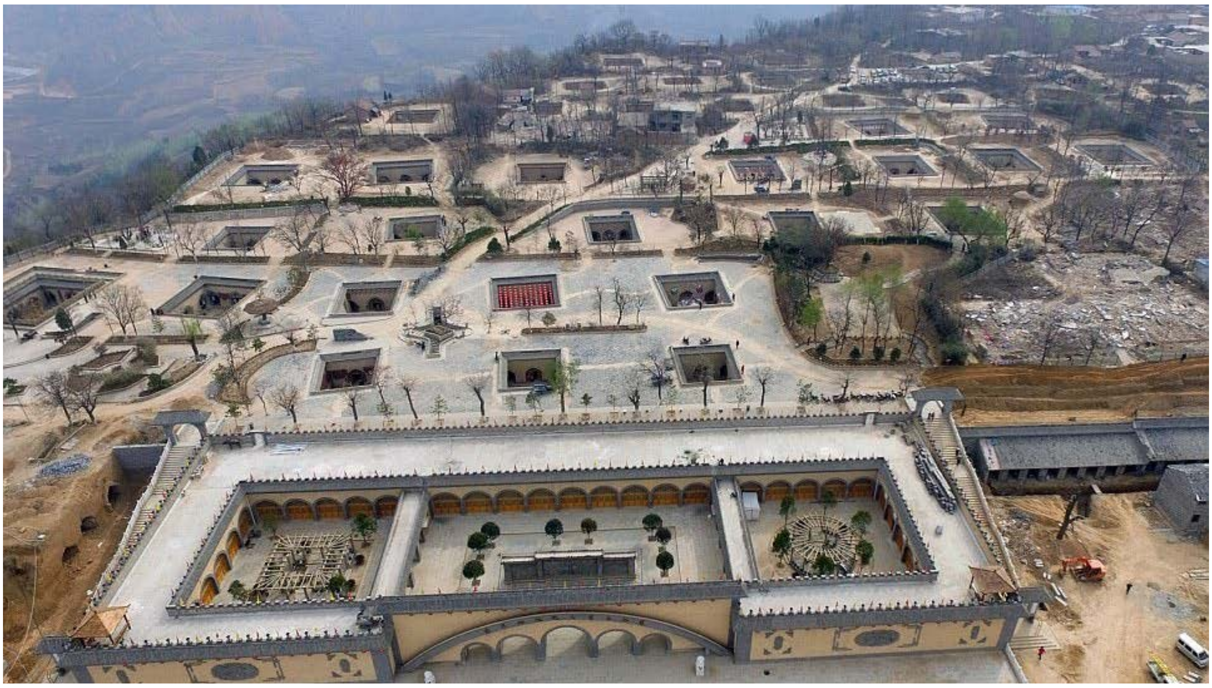

Figure 3. Yaodong in China. Image © imaginechina/REX/Shutterstock

Finally, the concept of underground space as ’sub terra nullius’ (Melo Zurita, 2020) needs to be addressed. Planning underground space requires a critical appraisal of its role within the urban metabolism. Rather than approaching it as a ‘nothingness’ that can be colonised by humankind, it needs to be seen for what it represents. A multi-dimensional planning approach requires us to ask questions as part of the planning process that *“(…) move subterranean urban development away from a technoscientific tunnelling decision-making process to one that engages with the social, cultural, political, and economic implications of urban infrastructural projects”* (Melo Zurita, 2020).

Box 1. Schrödinger’s Cat

Schrödinger’s Cat explained

Schrödinger's cat is a thought experiment, sometimes described as a paradox, devised by Austrian physicist Erwin Schrödinger in 1935, though the idea originated from Albert Einstein. The scenario presents a hypothetical cat that may be simultaneously both alive and dead, a state known as a quantum superposition, as a result of being linked to a random subatomic event that may or may not occur. A cat, a flask of poison, and a radioactive source are placed in a sealed box. If an internal monitor detects radioactivity, the flask is shattered, releasing the poison, which kills the cat. The Copenhagen interpretation of quantum mechanics implies that after a while, the cat is simultaneously alive and dead. Yet, when one looks in the box, one sees the cat either alive or dead, not both alive and dead (Wikipedia, 2020). Underground spaces behave in a similar manner in that until they are observed they exist and not exist. Only through observation will they exist or not exist.

2 Beyond sub terra nullius

Melo Zurita (2020) argues that underground development projects mostly come about as part of a technical and technocratic approach. They are part of the common position of engineering that if you can think it, you can build it. It is the thinking that leads to a technological arrogance that is equivalent to the perception of the European nations that set out with their sailing vessels to explore and colonise other worlds (see Figure 4). These other worlds were seen as ‘terra nullius’, empty lands that could be occupied. In hindsight, we are now gradually acknowledging this doctrine as false, whilst at the same time slowly acknowledging the role and rights of indigenous people.

If, and this is a big if, we are to move towards a multi-dimensional planning approach of underground spaces, we need to move beyond our awareness campaigns that are so often built on the perception of how the underground is relevant and central to our urban narratives, imaginaries and realities (Melo Zurita, 2020). We need to comprehend that the emptiness, the nothingness we associate with underground space, the state where objects can both exist and not exist, requires us to approach it with the utmost care. Planning the urban underground as part of the urban metabolism requires us to move beyond the state of perceiving underground space as sub terra nullius.

Figure 4. Captain Cook at Possession Island. Samuel Calvert (1828-1913), Public domain, via Wikimedia Commons

Pérez & Melo Zurita (2020) observe that human geographers, especially in geopolitics, *"(…) have been arguing for greater engagement with the verticality of spaces: a deeper understanding of how height and depth are entangled with the horizontal."* It is a development where a more 'volumetric' perception of space is required for analysis and understanding. In their paper they describe how within geography a new understanding of the subterranean is emerging. They quote (Squire & Dodds, 2019) in that the subterranean should be conceptualised as a volume containing multiple undergrounds with different material qualities. A second observation is that the State's concern with the underground is often limited to appropriating spaces or contents for its own use of for the use of corporations. Think in this sense of large-scale extraction of minerals and hydrocarbons. When developing the idea of a multi-dimensional planning approach for urban underground space we need to realise this is the case. Admiraal & Cornaro (2018) describe how the development of a National Planning Strategy for the Underground in the Netherlands eventually limited itself to those uses that were deemed to be of national importance. As Pérez & Melo Zurita (2020) observe: *"The underground's control in legalistic regimes generally emerges out of a political economic necessity."*

The consequence of acknowledging that 'sub terra nullius' consists not of a homogenic volume, but of heterogenic undergrounds, is far fetching. It explains why the regulatory legalistic framings fail as they simply cannot cope with this heterogeneity of the multiple undergrounds that exist.

Melo Zurita (2020) proposes we rethink urban underground through the application of four stratums: (1) the more-than-human subterranean, (2) volumetric dispossession, (3) owning the underground, and (4) subterranean access. These stratums lead to four fundamental questions that need to be asked and that are starting points for planning urban underground space: (1) what already exists underground; (2) who will get dispossessed and affected by the development; (3) who should own the underground and how; and (4) who will have access to the urban underground?

It is by asking these questions that we can move away from the hitherto technoscientific tunnelling decision-making process and move towards a planning process that engages with the social, cultural, political, and economic implications of urban underground development. A parallel can be drawn with what Admiraal & Cornaro (2018) write on 'Development in harmony with nature' and the model they propose for sustainable development of underground space. In their model they propose the need to identify: (1) the suitability of the subsurface for human intervention; (2) the impact any intervention has on ecosystem services being provided by the subsurface; (3) the interaction with existing underground structures; and (4) the underground space development itself in terms of how sustainable it will be in both its development and use.

If we are to move beyond ‘sub terra nullius’, a multi-dimensional planning approach requires us to take these questions into account. Above all it requires us to perceive the subterranean as a volume consisting of multiple undergrounds. Identifying and analysing these undergrounds is a first step toward a better understanding and appreciation of urban underground space.

3 From Flatland to Spaceland

As we already observed, geographers are moving towards a volumetric approach to gain a better understanding of height and depth in relation to the horizontal. Zhang & Schabel (2016) observe how Shelton defines ‘volumetric’ as *“(…) multiple modes of movement and varied programs stacked up across many levels, which are above ground and below ground (…)”*. They argue that for the analysis of multi-level morphology of high-density cities, a volumetric approach is required. In their analysis they identify three requirements that need to be considered: (1) redefining ground; (2) movement in space; and (3) layered functions.

The 2D approach, or Flatland approach, considers the city as collapsible from a 3D reality into a 2D model. The planning map is a representation of a complex urban being. The plane formed by the map represents ‘ground’, i.e. the level that is the boundary between that what is above and that what is below. If any acknowledgement is given to what is below, it is usually denoted through dashed-lines, thereby indicating its shady existence below ground.

Zhan & Schabel argue that a volumetric approach requires to acknowledge the existence of multiple ‘grounds’. They distinguish duplicate ground, split ground, multiple ground, and borrowed ground. As they observe in cities like Hong Kong, many building have multiple entrances at different levels as the pedestrian walkways no longer exist in one plane, but at multiple levels, i.e. at the traditional street level, but also at the elevated walkway level. As people use these levels and thereby exist at multiple levels, they have to move through space to connect to these levels. This requires in their opinion a volumetric design for the emerging movement pattern to work.

Layered functions are a direct consequence of the concept of multiple grounds. Functions can be freed from their conventional position on the horizontal as they move upwards and downwards. Mixed-use spaces come into existence either as part of planning or through informal planning (see Figure 5). Whilst planning departments can plan high-rise buildings to create density, autonomous development takes place on rooftops with unplanned gardens or even habitats being created. In the same way planned development of underground spaces can lead to unplanned subcultures through occupation of abandoned spaces or underground art being drawn on the walls of metro tunnels during non-operational hours.

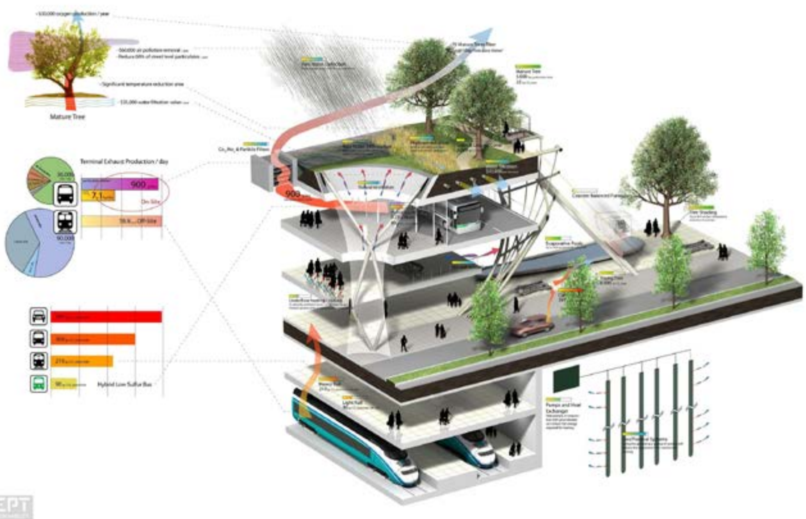

Figure 5. Transbay Transit Centre, San Francisco. Courtesy of Except, Utrecht, the Netherlands.

The concept of a volumetric approach is not one that is exclusive to the understanding of the subsurface. It is a concept that we need to fully comprehend the urban being. In order to analyse and understand the urban metabolism contained in our high-density cities that extend both upwards and downward, a Flatland approach that only considers the horizontal no longer suffices. We must move away from Flatland and embrace Spaceland.

Moving from 2D planning to 3D planning requires a bold move. At the same time, 3D has now become the 'de facto' standard of design, both in architecture and engineering. The use of the Building Information Model (BIM) is derived from 3D design and enhances the models by attributing information to objects. In much the same way Geographic Information Systems (GIS) has opened the way to 3D visualisation in mapping and adding information to data objects. In this sense the technology to visualise underground space in 3D is widely available.

Having the technology, however, is not sufficient as a new paradigm. We need to develop new methodologies when planning underground space. These new methodologies need to consider that underground space shows a remarkable likeness to air space when looking at it from a spatial planning perspective.

One of the similarities we identify is that as we ascend into air space, the use by humans diminishes whilst at the same time the relationship with the horizontal changes as well. The same holds true when descending below the surface. The deeper we go, the less human presence or activity is to be found. The impact on the surface becomes less as well. To further illustrate this, consider an aircraft passing over city at 40,000 ft. On a clear day we might hear it passing overhead and see the contrails it leaves behind. Most of the time it will pass over the city, unnoticed by millions. Now consider an aircraft approaching to land at an airport. As it descends its relationship with the city grows. The approach route to the airport has to be clear of obstacles, navigation aids require that in the vicinity of the airport building height is regulated (obstacle limitation surface, see Figure 6). As the plane comes in to land, the closer it comes to the horizontal, the more noise we observe. This relationship prevents housing being built under flight paths or the need for noise abatement procedures for aircraft when departing airports.

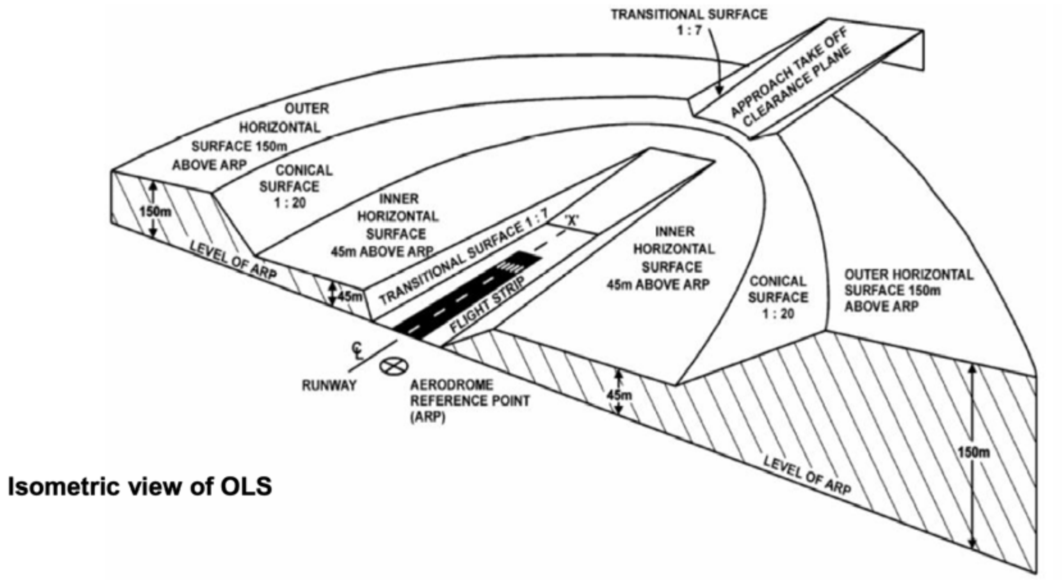

Figure 6. Obstacle Limitation Surface. Air Traffic impacting Urban Planning.

The same holds true for underground activities. Mining 3,000 meters below the surface will not impact life on the surface. From the author's own observations, in Paris hotels, built on top or nearby underground Metro lines, the rumbling and vibration caused by the metro carriages as they pass can keep you from sleep (Ropars, et al, 2018). The closer we are to the surface, the greater the impact. Congestion of underground space starts in layers closest to the surface that are used for utilities. At the beginning of the 20th Century these concerns were already being voiced by people like George Webster, the city surveyor of Philadelphia (Webster, 1914).

In terms of methodologies we can learn from air space design and management in that the aviation industry thinks in terms of volume. Blocks of space are allocated to various functions, with horizontal airways running around them, or at times round them. Prohibited air space volumes exist in the same way we can envisage underground water aquifers as being identified as volumes that need to be protected.

Moving from 2D planning to 3D planning might seem a bold move. At the same time, we can see various disciplines, from geographers to architects, advocating a volumetric approach. We have the instruments to visualise and analyse 3D through BIM and GIS. Air space design and management provides us with a concept which we can apply equally to underground space. As such the move from Flatland to Spaceland certainly seems feasible.

4 Temporality

4.1 Time disruptor

Admiraal & Cornaro (2018) write on humankind's need for speed, to evolve, adapt and, ultimately, survive as a species. Space and time are linked through speed. The speed of light, but also the speed at which humans can travel. Marchetti's constant evolves around the idea that people commute around one hour a day. This is what they base their choice of transport, their work location and their living location on. The distance they travel is therefore determined by speed. Before the advent of the car people travelled by foot or using animals. This obviously limited their span of contact. In this age of planes and automobiles we travel much further. But it seems our daily commute is governed by Marchetti's constant.

What if underground space could contribute to greater speeds for travel? Would it be possible to travel distances of over 500 km in just 30 minutes using a transport system not unlike the train? This is the idea being pursued by various groups based on the Hyperloop idea made popular by Elon Musk. What if we could use underground space to deliver goods at a constant and uninterrupted rate? A goods system that would behave as a physical internet?

When it comes to looking at the relationship between underground space and time, this is one aspect we need to consider. It also strengthens the observations made by Pérez & Melo Zurita (2020) that underground spaces transcend traditional territorial structures and State control. European cohesion could be transformed through a network of just 10,000 km of Hyperloop connecting cities with a transport system capable of transporting people and freight at hyper speed. Such a system is already being thought out. It requires not just imagination, but also a multi-dimensional planning approach to ensure it will ever be delivered (see Figure 7).

Figure 7. Hyperloop system. Courtesy of Hardt Hyperloop, Delft, the Netherlands.

4.2 Time constant

Historical buildings can easily exist for centuries. Once they are older than 50 years, they become part of a Nation's heritage (Sprinkle, 2007). Other buildings have shorter lifespans and are demolished long before they reach 50 years. In the Netherlands reorganising the health system coupled with new insights into hospital design led to hospitals merging and creating new facilities. In Vlaardingen and Schiedam, the old buildings were demolished, and the space reused for housing. A new land tunnel[1] in the A4 motorway between the same towns has sport fields on its roof, enabling the city to build new housing on the former sport fields (see Figure 8).

Figure 8. Sport park 'Willem Alexander' above the Kethel Tunnel (NL). Courtesy of Gemeente Schiedam

Urban redevelopment is an important part of the planning process, helping cities had to adjust to new circumstances. An ISOCARP/ITACUS Young Professional's Think Deep Program workshop was held in Glasgow. It focussed on former shipyards along the river that runs through the city. What once was a hive of activity now lays forlorn, waiting for better times. In stark contrast with the former mines in the Netherlands, an industrial complex frozen in underground space, these forlorn spaces can be redeveloped. The relationship between the building and the space is such that the building can be taken away and the space given new meaning. Underground spaces lack this ability. Most spaces that have been created up to now can be characterised as the building being the space. A tunnel for an underground transport system is designed by engineers that look for the most optimal spatial design, often driven by cost considerations. That space cannot easily be enlarged or changed from a circular shape to a rectangular shape. Demolishing the building is not possible, it cannot be taken out. One humankind has intervened below the surface, it is very difficult to undo the space created through the volume extracted. This is the conundrum faced with former mines, former military shelters, and disused transport systems underground. The New York Lowline project is attempting to create an underground park inside a former Tramway depot that was lost in underground space since the 1950's (see Figure ***9***).

[1] A land tunnel is a term used in the Netherlands to denote a roadway encased in a tunnel-like structure aimed at isolating the motorway from the surrounding environment but not placing it below the surface, i.e. the tunnel is built at grade.

Figure 9. Lowline Artist Impression. Courtesy of RAAD Studio, New York, USA.

The longevity of underground structures is greater than surface structures due to the inability to remove them once created. This simple fact poses an interesting challenge for planners and architects alike. This can be clearly illustrated from examples of the subsurface used for underground car parks. These structures are created based on the assumption that the use of cars will outlive the lifespan of the structure. With the demise of the car as personal mode for transportation being predicted to happen between 10-20 years, urban planners and architects need to not only consider what to do with abundant inner city underground car parks, at the same time they need to consider how in new underground developments this aspect of multi-use over time can be dealt with. One answer could lie in designing from the outset with multi-use in mind. In new buildings floors dedicated to parking are now being designed in such a way that this transformation can be made. *"One of the country's biggest apartment developers is working on plans for a grand residential complex in downtown Los Angeles that includes what appears to be an ordinary garage. There will be row upon row of lined stalls at street level and two floors underground to store nearly 1,000 cars of tenants and visitors to the trendy Arts District, where parking is relentlessly hard to find. But when it's completed in about four years, the ample garage will be one of the first of its kind in Los Angeles: It's designed to eventually serve other uses."* (Vincent, 2017).

4.3 Time critical

A third aspect of the temporality of underground space is the relationship between underground development and surface development. Admiraal & Cornaro (2018) give the example of the elevated railway that ran through the city of Rotterdam in the Netherlands and was placed in a tunnel. The space freed on the surface was partially released for new urban developments. The fact that these developments took place sequentially in time led to a major delay in the redevelopment. Although from an engineering perspective building on top of the tunnel was accounted for, the question of tort or liability caused a substantial postponement of the redevelopment. Property developers were confronted with additional risk of disrupting rail services or damaging the tunnel structure. It illustrates the relationship between surface and subsurface that requires careful consideration of how development of underground spaces come about.

When integrated buildings, that are partially above and partially below the surface are build, this time criticality is absent. It arises when buildings are built on the surface and then the decision is made to develop underground and vice versa. This touches on the very reason for urban planning of the subsurface. If it is possible and seen as necessary to develop the city downwards, time criticality can be a major challenge. At the same time, linking underground basements using corridors to create an underground pedestrian network, depends as much on planning and policy, as on geology. When all constructed at the same time, e.g. four office towers with basements that are connected below the surface, the underground lineages are not seen as a challenge. Trying to create these corridors 20 years after the office buildings were constructed will prove to be a challenge.

Time plays a major role in a multi-dimension planning approach, albeit as time disruptor, time constant or time critical. Time-space is defined by speed. The ability to travel at speed will shape cities and connect people. Underground space will certainly play a role in this development. Time as a planning dimension must be considered as much as depth. It is the fourth dimension of our multi-dimension planning approach.

5 Geology as determining factor

5.1 Science and medium

Geology is the science that aids us in exploring the undergrounds below the surface. It provides us with the insights that the subterranean is far from one homogenic medium such as air. The subterranean is a heterogenic being, consisting of many layers of differing qualities that interact and intertwine (see Figure 10). All these undergrounds are part of the volume that we call geology. So, geology, the medium, as determining factor relies on geology as science to make sense of it all. Geologists have a clear vision of their role. This can be seen from Figure 11, showing all the various ways in which geologists interact with the subsurface for the uses humankind sees it fit for.

Figure 10. Quebrada de Cafayate, Salta (Argentina). Courtesy of travelwayoflife, reproduced under CC BY-SA 2.0.

Pérez & Melo Zurita (2020) argue that geology as medium can determine whether underground development should take place. They show how karst deposits form undergrounds that have been explored and indeed used by previous civilisations. Any intervention by humankind from the surface, whether it be for mineral or hydrocarbon extraction or for the physical development would destroy these natural artefacts and habitats. Quite rightly they observe that they are not static volumes but that they are shaped by human interaction. As such they are part of our heritage. Invasive development of those geologies would be as unacceptable as creating a high-rise tourist hotel in the middle of Machu Picchu in Peru.

At the same time the geological layers formed by tectonic plates literally rub against each other causing earthquakes and volcanic eruptions as pressure relief for the inner core processes of our planet. Geologists explore these natural phenomena as they are hazards that threaten humankind, while at the same time looking at harnessing the natural heat to produce energy.

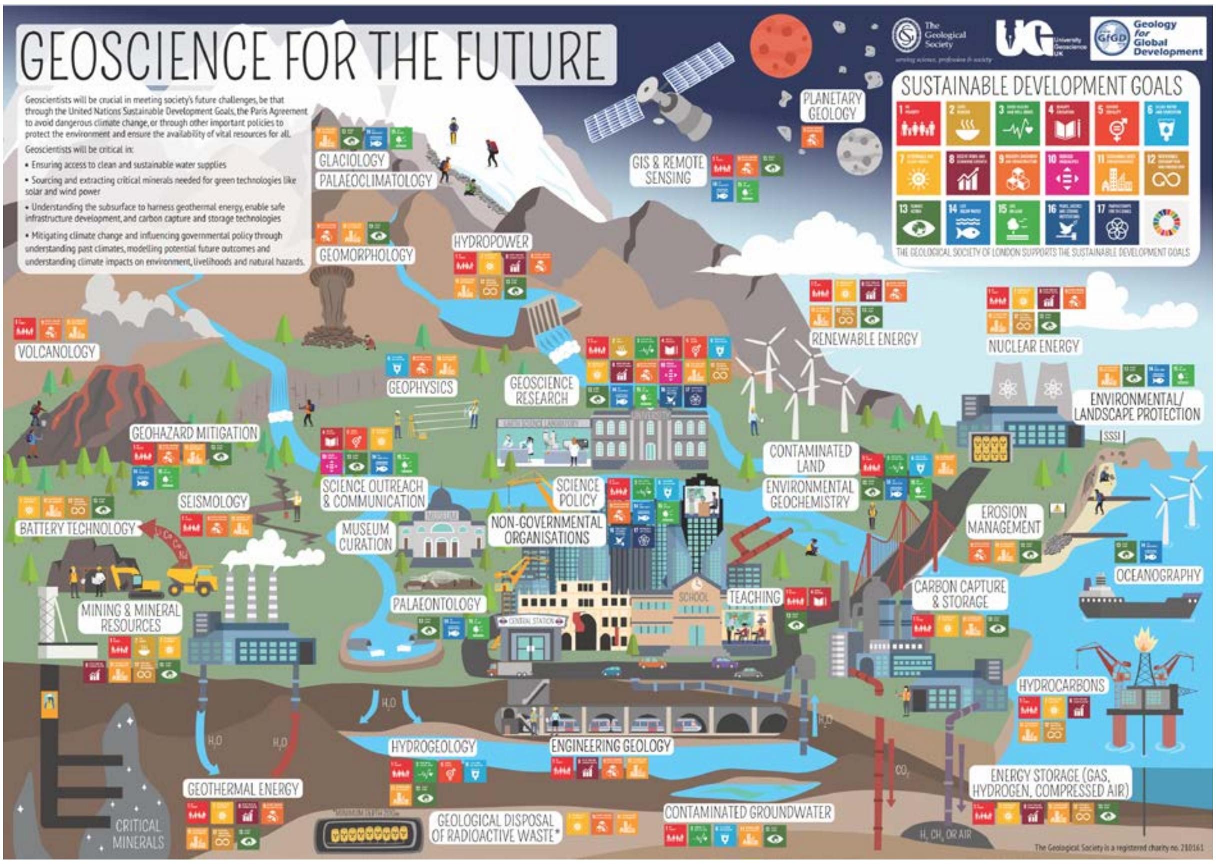

Figure 11. Geoscience for the Future. Courtesy of The Geological Society of London.

Geology is a determining factor in a multi-dimensional planning approach in that it helps in answering the first question posed by Melo Zurita (2020) on considering what already exists underground. The same as it holds true for above ground, we need to consider the various geographies that exist, e.g. cultural, geological, biological, social infrastructural geographies, when looking at underground urbanism. The urban metabolism needs to be understood to ensure urban planning takes the entire urban being into consideration. Geology can aid us in that process by providing the data linked to the various undergrounds.

Geologists are struggling with big data as much as anyone else. Firstly, we see that through key registers of the subsurface, for instance both in the United Kingdom and the Netherlands steps are being made to ensure that data which often is exclusive to one party, becomes inclusive for everyone by building up open-access databases. The second struggle is the realisation that the data cells they normally use for their own more global analysis of geologies are too big for the specific needs of geotechnical engineers. This at the same time enlarges the databases required enormously. The third struggle is to ensure that data formats are such that data can actually be shared, stored and accessed. Finally, there is the question of visualisation. Urban planners can only use knowledge of the undergrounds if this is represented in accessible models and linked to the desirability of using those undergrounds. In parallel with air space design, these are the space volumes or blocks that are marked red. The volumes where no further development should take place. These volumes need to be avoided and preserved. Knowing where not to go is a first step in the planning of underground space. One of the key aspects of the Helsinki Masterplan is to reserve volumes for future use. It is interesting that this consideration is purely based on the quality of the rock mass as having the ability to create space inside it in future. The much-praised Helsinki Masterplan in our eyes deserves praise for being the first attempt at planning underground space. It is however far removed from a multi-dimensional planning methodology we describe in this paper. Parriaux et al (2004) proposed to model the subsurface from a resource perspective consisting of space, energy, water, and geo-materials. The shortfall of this approach from a planning perspective is the fact that the subsurface is modelled as having a resource perspective without questioning whether it should be used in the first place. In that sense it confirms what Melo Zurita (2020) observes in terms of terra sub nullius. It does however help in terms of identifying some of the undergrounds that make up the subsurface.

5.2 Determining and inhibiting

Geology can be both a determining and an inhibiting factor. In the same way geology can literally support a city in terms of being its foundation whilst at the same time it can threaten a city through sinkholes. When we look at hard rock geologies we find for example in Hong Kong, geology can be used to create spaces inside mountains. These spaces can be made purposely or can start out as mineral extraction sites. By extracting material which can be used for building and road construction, space is created that can be used over time for multiple uses. One use is for waste water treatment plants. In placing these in a cavern, valuable space is freed at the surface for other use. Geology in this way is very much beneficial to underground development in that it allows for multi-use spaces to be created at little cost. The cost of creating the multi-use space is offset by the value of the minerals extracted. In terms of planning this makes a lot of sense; not just the cost-effectiveness, but also the space-effectiveness.

In comparison when we look at softer soils that can be found in Deltaic regions, the geology consists mostly of water with soil. The subterranean consists of aquatic milieus, biotopes in their own right. This places pressure on the question of whether to develop underground in the first place. Once that hurdle has been taken, investments need to be made in physically creating the underground spaces. The geology does not help, indeed geology becomes a load together with the ground water on any structure placed below the surface. This requires engineers to design diaphragm walls to cope with these loadings and to counteract buoyancy to avoid the whole structure uplifting as it starts to float. A good illustration is the ARTEZ Faculty of Dance in Arnhem, the Netherlands (see Figure 12). Initially diaphragm walls were built and anchored sideways to counteract the loads on the walls. Once build, struts under the roof are part of the architecture to take the loads as the anchors corrode away in the groundwater over time.

Geology is truly a determinant for underground development. It determines whether or not development should take place based on the specifics of the undergrounds being targeted by the development. At the same time it determines whether the geology itself is load bearing or whether physical structure is required to bear loads. In the first case the use of the created space becomes independent of the structure. There is no need for cost-reducing design as the space is created for the purpose of mineral extraction. In the latter, cost-reducing design is required as the cost of the load bearing structure is by large determined by its size. There is a direct relationship between use and size. As we saw before, this can partially be offset by considering time as constant. It would require the architect to primarily create a space which could over time accommodate multiple uses. This can only be achieved through policy building and urban planning which aims at creating a new paradigm for space use. In the traditional context a building is built for one purpose. In the future we may need to be more flexible. A case not dissimilar to the challenge of repurposing the many churches that have lost their original purpose in the Western world. They are a good example of time constant as they have become part of the heritage and cannot be demolished, yet in their design they prove to be quite inflexible when it comes to other purposes. Successful repurposing is often achieved by seeing the church itself as an outer shell within which a new shell is created. Much in the same way we propose to see caverns as an outer shell within which new shells can be created depending on the intended use.

A final way in which geology can be a determinant for use is the fact that undergrounds are layers that run past territorial borders created on the surface. They are a continuum below the surface and are capable of transmitting sounds and vibrations past the artificial boundaries man has created throughout history. An interesting example of this is the proposed Einstein Telescope, a planned underground facility aiming at detecting gravitational waves (see Figure 13). The University of Maastricht is one of the backers of this plan. Recently they announced the geology of Limburg in the Netherlands was sufficiently stable for constructing the telescope. As project owner they look at the geology for accommodating their facility. Given the nature of their facility, long tunnels with beams projected down them, the question urban planners should ask is, how restrictive is this facility for future developments? Is it acceptable for instance to build a tunnel in the vicinity creating vibration during construction and use? Does the specific characteristics of the geology contribute to the need of creating a volume where no other activity can take place given the specific use by the first user?

Figure 12. Underground Theatrium ARTEZ, Arnhem (NL). Courtesy of Arminiuzz CC BY 3.0

We also see this when geology is favourable for geothermal energy or aquifer thermal energy storage systems. By utilising this asset to its maximum, other developments could become impossible. In the absence of planning, the first come first served principle applies. Geology influences the potential development of the subsurface. It also determines whether we should stay away and preserve what is there, or whether we can, within limits, exploit the subsurface. The line between preservation and exploitation is a fine one. Therefore, geology should always be part of the discourse on underground urbanism and part of a multi-dimensional planning approach as the fifth dimension.

6 Discussion

The need for a multi-dimensional planning approach is based on two arguments. The first is that it is necessary for any city to unveil what is to all intent and purposes hidden beneath. This necessity arises from the simple fact that without any knowledge it is impossible to claim that a city is developing sustainably or that it is resilient. Urban planners need to incorporate the subsurface into their practice because not doing so poses a credible risk for the city. If we are serious about discovering the urban metabolism, we need to appreciate that this can never be achieved by ignoring the subterranean undergrounds.

Any planning attempts need to be multi-dimensional given the specific characteristics of the subterranean and the undergrounds contained within it. Only by using a three-dimensional approach are we able to visualise and understand its intricacies. By moving from Flatland to Spaceland, a better understanding will be gained as the complexity of the undergrounds and its volumes can more easily be represented.

Temporality is a dimension that needs to be considered as well. Human activity below the surface either uses existing voids or creates them. Underground spaces are negative volumes that are created inside the subterranean. Time is a factor to be considered as disruptor, constant and critical to underground urbanism.

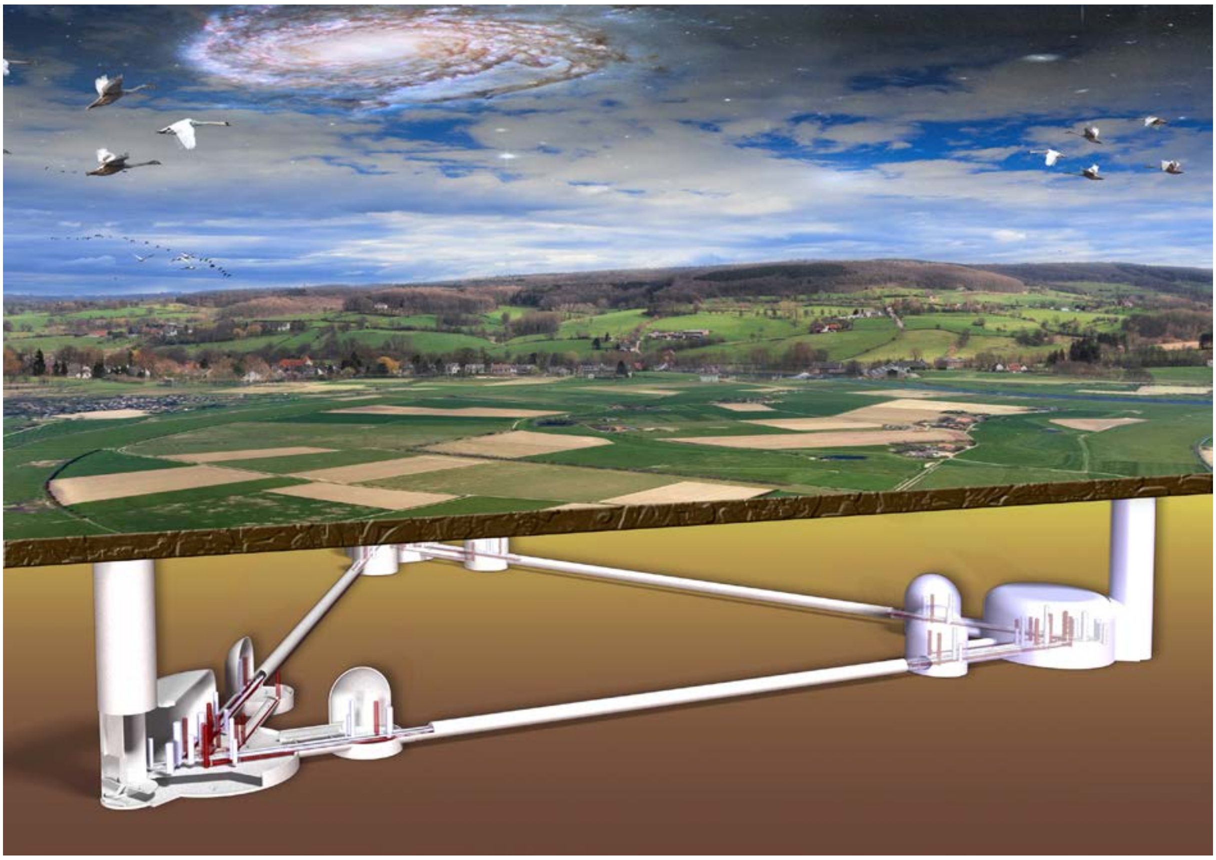

Figure 13. Artist impression underground Einstein Telescope. Courtesy of Marco Kraan, Nikhef.

The concept of the subterranean consisting of multiple undergrounds captures the heterogenic character of the subsurface. This requires us to use geology to identify these undergrounds. Not just to quantify rock or soil characteristics, but also to identify for example karst deposits with a high likelihood of interconnected caves and water flows below the surface.

Above all, a multi-dimensional planning approach is a participatory process. A process that involves both the public and professionals alike. In terms of professionals it requires a multi-disciplinary discourse to fully comprehend what lies beneath our cities. The multi-dimensional planning approach starts by asking the most fundamental question of all, the question that looks at the suitability of the subsurface for human intervention. This approach requires us to move away from a position that we have the technology and therefore can use this spatial reservoir, to a critical appraisal. It is the lack of this critical appraisal that has led to humankind depleting the Earth in just more that 200 years of resources it took our planet millions of years to create. The human timescale is totally different to the timescale that created our planet and what we now call the subterranean. That simple fact requires us to pause, reflect and then decide, based on a critical appraisal, if and for what we might use the subsurface.

What is the role of the urban planner in this all? It could very well be that of the director conducting a symphony orchestra and assuring the individual instruments melt together in harmony (Admiraal & Cornaro, 2018). More precise it could lie in what Melo Zurita (2020) writes: *"There is a need to 'de-alienate' underground urban space, to reintegrate it into the web of social connections, thus reorienting the city away from being an engine of capital accumulation towards a space of more cooperative social relations among urban inhabitants".*

7 Conclusion

Planning the subsurface requires a multi-dimensional approach that moves away from the traditional two-dimensional plane to three-dimensional space. In itself this is not enough, two more dimensions need to be included in this approach. Temporality and geology are needed to appreciate the unique character of the subterranean. Not just because of its heterogeneity, but also because of the complex relation the subsurface has with life on the surface.

Any socially adequate planning process is required to be participatory. In case of the multi-dimensional planning approach it needs to be multi-disciplinary as well. It begins with querying the suitability of the subsurface for human intervention. This is done much along what is common practice on the surface by considering the cultural, geological, biological, and social infrastructural geographies of the multiple undergrounds and existing volumes that constitute the subterranean.

The urban being and the urban metabolism are complex and dynamic. Making them inclusive with the subterranean does not increase the complexity, rather it helps complete them. To do this we must 'de-alienate' underground urban space. Urban planning is key to this but will need methodologies based on a multi-dimensional approach and with participation of the public and across professional disciplines.

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9 References

Abbott, Edwin A. (1884). Flatland: a Romance of Many Dimensions. London: Seeley & Co.

Admiraal, Han and Cornaro, Antonia (2018). Underground Spaces Unveiled: Planning and Creating the Cities of the Future. London: ICE Publishing.

Admiraal, Han and Cornaro, Antonia (2020). Future Cities, Post-Oil Cities: Underground Spaces as Vital Part of the Urban Metabolism, In: Post-Oil Urbanism, Review of World Planning Practice, Vol. 16. ISOCARP, The Hague, the Netherlands.

Hajer M and Dassen T (2014) Slimme Steden: de opgave voor de 21e-eeuwse stedenbouw in beeld. Nai010, Rotterdam, the Netherlands. (In Dutch.)

Melo Zurita, M. de L. (2020). Challenging sub terra nullius: a critical underground urbanism project. Australian Geographer, 51(3), 269–282. https://doi.org/10.1080/00049182.2020.1723829.

Parriaux, A., Tacher, L., & Joliquin, P. (2004). The hidden side of cities—towards three-dimensional land planning. Energy and Buildings, 36(4), 335–341. https://doi.org/https://doi.org/10.1016/j.enbuild.2004.01.026.

Pérez, María Alejandra & Melo Zurita, Maria de Lourdes (2020). Underground exploration beyond state reach: Alternative volumetric territorial projects in Venezuela, Cuba, and Mexico. In: Political Geography 79 (2020).

Renner R (2018) Urban Being: Anatomy & Identity of the City. Niggli, Salenstein, Switzerland.

Ropars, Vuylsteke & Augis (2018). Vibrations Induced by Metro in Sensitive Buildings; Experimental and Numerical Comparisons. In: Proceedings Euronoise 2018, Crete. Retrieved: http://www.euronoise2018.eu/docs/ papers/ 231_Euronoise2018.pdf

Sprinkle, J. (2007). "Of Exceptional Importance": The Origins of the "Fifty-Year Rule" in Historic Preservation. The Public Historian, 29(2), 81-103. doi:10.1525/tph.2007.29.2.81

Vincent. A (2017). When car ownership fades, this parking garage will be ready for its next life. Los Angeles Times, 16 April 2017. Retrieved: https://www.latimes.com/business/la-fi-car-future-real-estate-20170405-story.html

Webster GS (1914) Subterranean street planning. Annals of the American Academy of Political and Social Science 51: 200–207.

Wikipedia (2020). Schrödingers cat. Retrieved from: https://en.wikipedia.org/wiki/Schrödinger%27s_cat

Zhang, Yingyi and Schabel, Aurel (2016). Mapping Volumetric Urban Space: A Critical Development Analysis of Multi-level Morphology of High-dense Cities. In: Proceeding of the 11th ISAIA, Spet. 20-23, 2016, Miyagi, Japan.