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Distributed agency between 2D and 3D representation of the subsurface

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1. Abstract

Although severely altered, the urban subsurface is the base of the natural system, and is crucial for a stable, green, healthy, and liveable city. It is also the technical space, the engine room of the city where vital functions such as water, electricity, sewers, and drainage are located. This hybrid state needs to be recognized when designing resilient and durable (subsurface) infrastructure within urban renewal projects, so as to properly employ the parameters of both natural and technical systems. Interdisciplinary work is needed in order to be able to link natural systems (a) the water cycle, (b) soil and subsurface conditions, (c) soil improvement technology, and (d) opportunities for urban renewal (e.g. urban growth or shrinkage) in an efficient way.

The importance of implementing “boundary spanning” when doing interdisciplinary work that deals with the effects of climate change is a widely recognized method, and has been an object of study in the city of Rotterdam in the past decade. The particular need for a “distributed agency” became clear during several research projects dealing with climate change, because it enables different actors to contribute to the development of the project at different phases. The representation of the city as both a natural and technical construction has been tested through the use of 2D and 3D information, which has played a significant role in enabling designs to incorporate the dimension of the subsurface. 2D and 3D information needs to anticipate different scales of specific planning and/or design phases, and they must also address various topics of the subsurface. For each phase of urban development, the distributed agency between 2D and 3D information is investigated and reflected upon. Conclusions are then drawn on the relationship between 2D and 3D information, and how it could relate in a productive, boundary spanning act that is inclusive of the subsurface. Based on these potential connections, the design of a new concept which implements boundary spanning as a facilitator is presented.

Keywords: planning, design, subsurface, visualization, distributed agency

2. Introduction

Although severely altered by human interference, the urban subsurface is the base of the natural system, and is crucial for a stable, green, healthy and liveable city. It is also a technical space, the engine room of thr city where vital functions such as water, electricity, sewers and drainage and tunnels are located. This hybrid state needs to be recognized when designing resilient and durable (subsurface) infrastructure within urban renewal projects, so as to properly employ the parameters of both natural and technical systems. Interdisciplinary work is needed in order to be able to link natural systems (a) the water cycle, (b) soil and subsurface conditions, (c) soil improvement technology, and (d) opportunities for urban renewal (e.g. urban growth or shrinkage) in an efficient way (Norrman et al., 2016). This is an urgent issue that can be tackled in order to deal with both the ill effects of climate change and energy transition in spatial planning (Hooimeijer and Tummers, 2017). It is because of these threats that the urban systems of cities need to adapt to a rapidly changing climate by accommodating pluvial, fluvial, and coastal flooding. Cities need to also implement green strategies that control their microclimate in order to reduce health problems related to heat stress; new urban systems need to be implemented, as energy suppiles and demands change and new technologies in dealing with sewer treatement are introduced. In all these issues, the subsurface plays a crucial role in future urban development, and its inclusion both a natural and engineered space will bring about innovation in both the urban development process and the construction of urban systems (Hooimeijer and Maring, 2018).

However, due to the heterogeneity of surface and subsurface characteristics, a large number of various experts (such as planners, designers, traffic specialists, economists, socialists, geologists, archaeologists, hydrologists, civil engineers, and geotechnicians) are involved in urban development, and all have their own specific perspectives, knowledge, concepts, language, and instruments. This issue of heterogeneity has been part of the main question which has guided several research projects in Rotterdam - how could communication between these different fields be facilitated in an effective manner? The main conclusion of these researches was that it could be done by using “boundary spanning” or “knowledge brokerage” which are methods specifically aimed at building, bridging, and connecting fields of different natures. In relation to the processes regarding spanning boundaries, Garud and Karnøe (2003) argue that this method is necessary in order to be able to create innovation due to the need for “distributed agency,” a process in which different actors contribute at different phases of a project’s development. However, human activity in the digital era is dependent on communication to increase knowledge sharing capacity and creates a condition for information integration, but is unfortunately often neglected and replaced by digital tools and platforms. The human side of “knowledge sharing” is defined here as “direct” or “binding” boundary spanning in which trust, respect, and shared responsibility (or distributed agency) is key (Van Campenhout et al., 2011). It is because of this that the visual representation of data and the ability to generate necessary synergy between the design of the surface and subsurface is the focus of this paper. These ideas are not necessarily new, as the field of architecture already has centuries of experience in representing technical projects in a stakeholder setting of different disciplines and actors, but this paper intends to push interdisciplinary work and design to a new level of understanding how and when to use 2D and 3D instruments.

The representation of heterogenic construction in cities is done in both 2D and 3D information, both by different actors and at different phases of project development. However, the conducted research made it clear that in order to enable designs of the subsurface to take the fourth dimension (time) into account, it is necessary to understand when to use/apply 2D and 3D representation effectively. Doing so will allow for communication between experts by making linkages between the static conditions of construction, and the dynamic conditions of natural processes such as ecological and water systems. The 2D and 3D information needs to anticipate different scales of specific planning and/or design phases, and they must also address topics of the subsurface, which is a new issue in urban development processes. In the creation and development of urban system projects, engineering tends to follows design. The collaborative and interdisciplinary process of mapping therefore becomes a major boundary spanning part of a project, making it possible to link multiple scales, and enables strategic thinking with operational tactics. It also links the past with the future by using time as a medium that orchestrates large-scale effects through the implementation of simple interventions.
As previously stated, there is currently no defined role between 2D and 3D information, with the latter being viewed as merely the next step in representation, and in that sense beeing seen an improvement solely due to its dynamic character. However, in the varying phases of urban development, different boundary spanning activities between different actors and varying resolutions of data is needed. In each phase of project development, actors use and generate multiple types of data and information. Each actor also uses language and concepts according to their knowledge field and expertise. Because of the specialization each actor brings to the project, the consequences of acts by one actor are not directly visible for the other disciplines, and it is not possible to evaluate these various interventions as a coherent whole. After each phase is completed, a set of decisions that determine the possibilities and impossibilities of the next phase; new actors become part of the process, with their own need for information. The transition of going from one planning phase to the other is not accompanied by boundary spanning. Changing plans in later phases also requires the review of knowledge in earlier phases but usually this information already has been lost (Van Campenhout et al., 2016).

This paper is the result of research projects in Rotterdam entitled “Design with the Subsurface” (2012), “Balance4P” (2016), and Intelligent Subsurface Quality (2018) of which the objective of each study was to integrate the subsurface analysis into surface development (Hooimeijer and Lafleur, 2018, 2018a, 2018b, 2018c; Hooimeijer, Bacchin and Lafleur, 2016; Hooimeijer and Tummers, 2016; Hooimeijer and Maring, 2012). The scientific contribution of these projects was the System

Exploration Environment and Subsurface (SEES), the Technical Profile, and ideas to develop the Voxel model (which resulted in several papers). However, while reflecting on the results of all three projects, it is important to state that the quest of this paper is to oversee specific communication tools of a different nature, and how these various tools can cooperate together. To scientifically frame these analyses, the theory of distributed agency is used to explore possibilities in regards to how 2D and 3D visualization support boundary spanning and/or knowledge brokerage between various stakeholders to stimulate innovation in urban development processes. Knowledge boundaries can be bridged through the collaborative generation, integration, and application of so-called "boundary objects". Star and Griesemer (1989) define boundary objects as "tangible artefacts or object-like forms of communication that inhabit several intersecting social worlds and satisfy the information requirements of each of them." These boundary objects are generated, integrated, and applied by professionals who work on either side of any identified community boundary.

Thus, 2D and 3D tools can be considered boundary spanning objects which take part in different phases of urban development. The conceptual framework in a urban development project is first designed by combining the theoretical background of multiple methods such as boundary spanning, knowledge brokerage, and "distributed agency" (Garud and Karnøe, 2003) together with the Decision Model Spatial Plans (2004) which are developed by the Municipality of Rotterdam to characterize multiple phases in urban development. This model is useful because it already describes both the actors and types of information necessary to create a project. The second step is to describe the methodology required to produce, both general and specific subsurface, 2D and 3D representations and visualizations. The following paragraph will expand on this methodology by reflecting on the experimental Bloemhof-Zuid Rotterdam project, in which both 2D and 3D support in boundary spanning was consciously applied in its design processes. The results of this project feed into a discussion which evaluates the appropriateness of 2D and 3D representations per phase, and concludes with insights about how 2D and 3D visualizations can be used during urban development processes by optimizing their distributed agency.

3. Conceptual Frame

Spanning boundaries within urban development is of major importance because it can be used to utilize existing qualities, synchronize opportunities and solutions, make optimal designs, and organize cities' maintenance regimes. In dealing with and incorporating the subsurface in urban development, it is especially important to recognize the city as a technical product that needs to be continuously innovated on a daily basis. In that sense, urban developers can be seen as technical entrepreneurs; entrepreneurs are actors within the institutional field that change institutional formal and/or informal rules (Klein Woolthuis et al., 2013). Garud and Karnøe (2003) focused on the purposes of a technical entrepreneur, describing their role in developing new technical products as a shared stakeholder commitment during a process they call "distributed agency." In this process, stakeholders may change according to the steps, or phases, taken in the development of the product. This approach is particularly suitable within the perspective of the city as technical product, or the result of a complex process with existing and varying arrangements. Garud and Karnøe (2003) cite three conditions for the genesis of new technology: (1) the steady accumulation of input into a technology development path, (2) the involvement of a wide range of actors, and (3) the involvement of market processes. The necessary input for innovative technology is generated by the accumulation of knowledge, introduced through a variety of actors. Mutual learning is crucial in technology development, with market processes also playing a role later in the development process.

Knowledge brokers are defined by Hargadon (1998) as "individuals or organizations that profit by transferring ideas from where they are known to where they represent innovative new possibilities." This definition has an overlap with the term "boundary spanning," which refers to the activities that are undertaken to promote cross communication (and thus organizational) boundaries (Slob and Duijn, 2013). These activities obviously do not come easily,they are both difficult and are "prone to bias and distortion" because of excessive specialization in organizations (Tushman and Scanlan, 1981). "Specialization and the existence of organizational boundaries are also associated with the evolution of local norms, values, and languages tailored to the requirements of the unit's work"

(Tushman and Scanlan, 1981). These localized norms, values, and languages hinder communication and interaction also during urban development processes, and thus the transfer of knowledge. There should be a conscious act in an interdisciplinary approach to overcome the fact that “individuals use different meanings in their functional setting” (Carlile, 2002). Slob and Duijn (2013) define four key conditions within the concept of boundary spanning theory: boundary spanning objects, boundary spanners, boundary spanning process, and joint production process.

Table 1: The most important concepts of boundary spanning theory (Slob and Duijn, 2013).

Concepts in boundary spanning theory	
Premise	Communities are separated through boundaries that hamper communication and joint action.
Boundaries	Perceived boundaries between communities that can be of a different nature (organizational, cultural, geographical, etc.).
Boundary spanning	Activities that are undertaken to cross boundaries, such as communication or joint activities.
Boundary spanning objects	Tangible products of joint activities that satisfy the involved communities, such as maps, action plans, policy notes, etc. because they contain knowledge and provoke action.
Boundary spanners	People who cross boundaries and intermediate between different communities. For instance, they are accepted in this role by the communities involved because they are “part” of the different communities.
Boundary spanning processes	Processes that are needed in order to produce the boundary spanning objects with the communities involved.

In order to be able to identify the groups involved, their information needs, the information exchanged, and when possible, the knowledge gaps or misalignments (with respect to the conceptualizations used within the groups), the outline of the urban development processes of the former Dutch Ministry of Spatial Planning (VROM) and the “Decision Model Spatial Plans” (DSMP)[*Het Besluitvormingsmodel Ruimtelijke Plannen*](2004) need to be used.

According to the VROM, the urban development process consists of four phases: the initiative, feasibility, implementation, and maintenance phases (VROM, 2011). The initiative phase is intended to assess if the area being developed is desirable (or whether there are better alternatives) for a vision and an initial plan that can be prepared and approved. The feasibility phase is an intensive and complex phase which can be divided into three sub-phases that are each characterized by its own partial results: (1) the definition phase, which defines the project and its administrative constraints; (2) the design stage, which implements a design that fits the outcomes of the definition phase; (3) the preparation phase, which produces an implementation plan. These sub-phases are part of an iterative process in which calculations and designs are conducted simultaneously. The implementation phase is focused on the allocation of responsibilities, organizing risk management, legal aspects, and streamlining stakeholders. The maintenance phase is the last phase after implementing development of the area.

These VROM phases align closely to the phases that are used in Rotterdam, where both designing and engineering municipal departments work together with the Project Management Department by cooperating on the foundations of the DMSP (2004) by implementing the following phases:

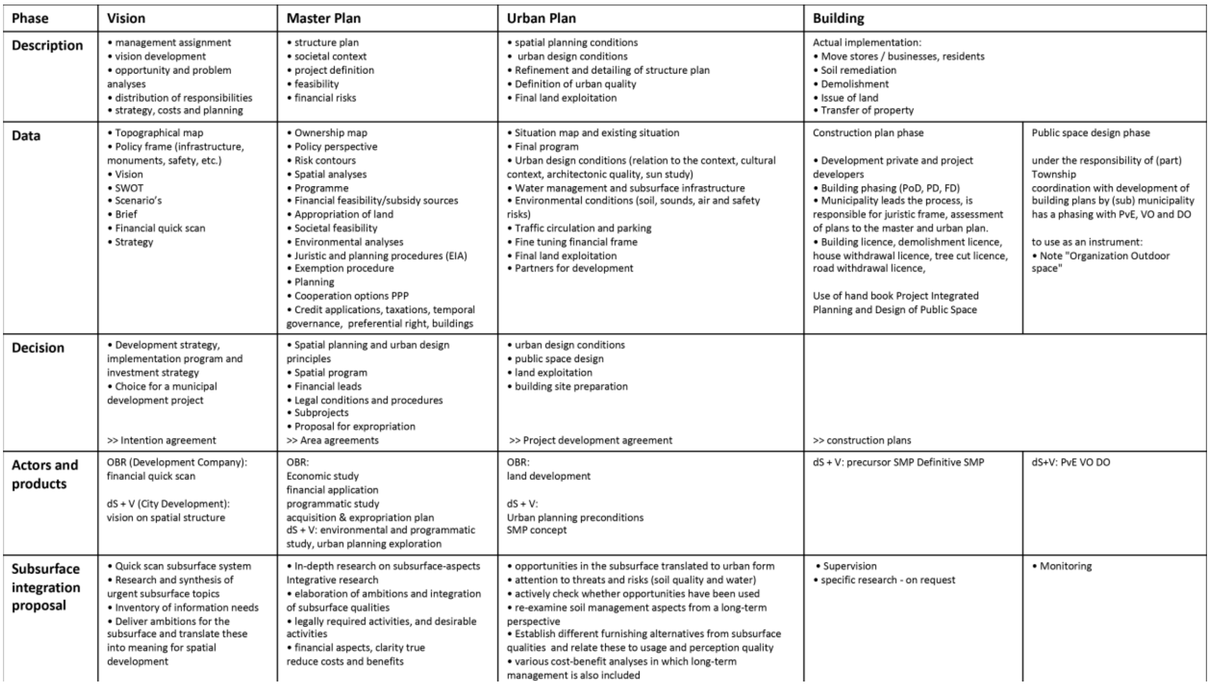
- The vision phase, which involves a financial quick scan;
- The master plan phase, where the determination of financial possibilities and goals are made;

- The urban development phase, verifies the final land exploitation;
- The building phase, where no financial instrument is specified.

Also important are the scale levels for these phases for information resolution:
- The vision phase, which is concieved at the 1:25.000 to 1:2.500 scale;
- The master plan phase, which is implemented at the 1:10.000 to 1:1.000 scale;
- The urban development phase, which developed at the is scale 1:2.000 to 1:500 scale;
- The building phase, which has no specific scale specified.

Due to the fact that a conscious integration of the subsurface into urban development is lacking in these models, the research "Design with the subsurface" (Hooimeijer and Maring, 2012) and "Balance4P " (Norrman et al,. 2014) were aimed at adding the subsurface dimension to the DMSP. In addition to the research, products, decision-making, and actors were coupled to subsurface topics as well (Hooimeijer and Maring, 2012 and 2014). These major additions are implemented to help assess urgent issues in the subsurface, while also translating opportunities to urban qualities.

Table 2: Abstract of Decision Model Spatial Plans (Municipality Rotterdam) with the addition of the subsurface to the development process (Hooimeijer and Maring, 2012).



Phase	**Vision**	**Master Plan**	**Urban Plan**	**Building**	
Description	• management assignment • vision development • opportunity and problem analyses • distribution of responsibilities • strategy, costs and planning	• structure plan • societal context • project definition • feasibility • financial risks	• spatial planning conditions • urban design conditions • Refinement and detailing of structure plan • Definition of urban quality • Final land exploitation	Actual implementation: • Move stores / businesses, residents • Soil remediation • Demolishment • Issue of land • Transfer of property	
Data	• Topographical map • Policy frame (infrastructure, monuments, safety, etc.) • Vision • SWOT • Scenario's • Brief • Financial quick scan • Strategy	• Ownership map • Policy perspective • Risk contours • Spatial analyses • Programme • Financial feasibility/subsidy sources • Appropriation of land • Societal feasibility • Environmental analyses • Juristic and planning procedures (EIA) • Exemption procedure • Planning • Cooperation options PPP • Credit applications, taxations, temporal governance, preferential right, buildings	• Situation map and existing situation • Final program • Urban design conditions (relation to the context, cultural context, architectonic quality, sun study) • Water management and subsurface infrastructure • Environmental conditions (soil, sounds, air and safety risks) • Traffic circulation and parking • Fine tuning financial frame • Final land exploitation • Partners for development	Construction plan phase • Development private and project developers • Building phasing (PoD, PD, FD) • Municipality leads the process, is responsible for juristic frame, assessment of plans to the master and urban plan. • Building licence, demolishment licence, house withdrawal licence, tree cut licence, road withdrawal licence, Use of hand book Project Integrated Planning and Design of Public Space	Public space design phase under the responsibility of (part) Township coordination with development of building plans by (sub) municipality has a phasing with PvE, VO and DO to use as an instrument: • Note "Organization Outdoor space"
Decision	• Development strategy, implementation program and investment strategy • Choice for a municipal development project >> Intention agreement	• Spatial planning and urban design principles • Spatial program • Financial leads • Legal conditions and procedures • Subprojects • Proposal for expropriation >> Area agreements	• urban design conditions • public space design • land exploitation • building site preparation >> Project development agreement	>> construction plans	
Actors and products	OBR (Development Company): financial quick scan dS + V (City Development): vision on spatial structure	OBR: Economic study financial application programmatic study acquisition & expropriation plan dS + V: environmental and programmatic study, urban planning exploration	OBR: land development dS + V: Urban planning preconditions SMP concept	dS + V: precursor SMP Definitive SMP	dS+V: PvE VO DO
Subsurface integration proposal	• Quick scan subsurface system • Research and synthesis of urgent subsurface topics • Inventory of information needs • Deliver ambitions for the subsurface and translate these into meaning for spatial development	• In-depth research on subsurface-aspects Integrative research • elaboration of ambitions and integration of subsurface qualities • legally required activities, and desirable activities • financial aspects, clarity true reduce costs and benefits	• opportunities in the subsurface translated to urban form • attention to threats and risks (soil quality and water) • actively check whether opportunities have been used • re-examine soil management aspects from a long-term perspective • Establish different furnishing alternatives from subsurface qualities and relate these to usage and perception quality • various cost-benefit analyses in which long-term management is also included	• Supervision • specific research - on request	• Monitoring

In this paper, the distributed agency per phase is defined and coupled with representation options in both 2D and 3D. In general, the importance of visualization can be summed up by landscape architect James Corner, who defines it as a medium that deals with imagination, abstraction, and relations, but also comments that it must involve preciseness and achieve aesthetic conditions (Corner, 1994). "Through rendering multiple visible, and sometimes disparate field conditions, mapping allows for an understanding of terrain only as the surface expression of a complex and dynamic imbroglio of social and natural processes. In visualizing these interrelationships and interactions, mapping itself participates in any future unfolding. Thus, given the increased complexity and contentiousness that surrounds landscape and urbanism today, creative advances in mapping promise designers and planners greater efficacy in intervening in both spatial and social processes" (Corner, 1994). Following the boundary spanning theory (5 concepts) in the conceptual framework for analyzing the distributed agency between 2D and 3D information in the 4 urban development phases (or the boundary spanning processes, 1st concept) should consider the following aspects to make representations tangible boundary spanning objects (2):

- The boundaries themselves which are found to be diminished (3),
- The boundary spanning activities that need to be undertaken (4),
- And the role of the boundary spanners (4).

These aspects will be discussed further after describing the methodologies involved in the creation of 2D and 3D visualization and the Bloemhof-Zuid project which will be used as a case study.

4. Methodology in 2D and 3D Visualization

In Latin, the act of gathering, comprehension, and understanding is translated as *concipere*, *conceptum*, or concept. The “concept” in design or art represents the connection of the brief - or conditions set by the program of material use being structured with a personal interpretation or passion. The concepts in urban development are usually based on a narrative that will help stakeholders understand the choices made, and by doing so, garner their support for the project. When looking at concept developent through the lens of urban development, there are many stakeholders that need to be appeased, and the process can be described as wicked (Sternberg, 2000). Another important aspect of design in urban developent is that support for the project needs to be there before any project is built. In this sense, visual representation is not a luxury, but a necessity that tests, communicates, and sells the concept. The means in which to depict concepts such as sketches, plans, sections, and models has expanded with an explosion in technological possibilities such as computer-aided drafting, photo-realistic rendering, and virtual reality. However, despite these vast strides, the tools of 2D and 3D representation are a blend of old and new – from techniques that have existed for centuries to the technology of our century alone (Frampton, 1995).

The architectural sketch may be the first tool that every student comes into contact with in design school, and possibly the most practical of them all. Quick and expressive, the sketch not only conveys the basic idea of spatial composition, but also contains the individual style of the designer. Producing plans and sections are a large part of the process in an urban design project. Its greatest advantage is that they present the urban tissue in specific proportions which allow sketches to enable the linking between scales. Also, urbanism should be considered interdisciplinary in essence, and an essential method for boundary spanning. Another important aspect in urban development projects is the re-connection of the plan with the section, or the horizontal and vertical dimensions, which needs to be done in order to encompass all scales of the urban project. The integration of the horizontal and vertical dimensions suggests multiple possibilities (and most often the best options) to link scales in a hybrid urban infrastructure, merging strategic and operational design together. In addition to this representation, the development of models, renders, and virtual reality all help visualization escape from the two-dimensionality of a sheet of paper. 3D models offer the possibility of observing the volumetric composition of the project from various points of view, and the ability to add values to elements in order to perform analyses (Van Campenhout and Vuijk, 2015). This is a significant benefit 3D rendering, as they not only offer a realistic representation. but are easy to use to see how interventions affect multiple natural and technical conditions. Virtual reality is also beneficial in another way because it allows the observer to “enter” into space and be part of it.

The positive and negative aspects of 2D and 3D representation are quite clear in urban development. A great aspect of 2D is that it is possible to map both tangible and intangible (or non-physical) aspects of urban development, and through icons or colours, these aspects can be made present in the urban construct. Another positive aspect is that it is easy to handle, to share, and it is possible have an informal discussion over coffee about the content presented in a hardcopy. It is also possible to sketch on it while conducting direct exchange and communication infront of stakeholders. The negative aspect to 2D is that it is limited in its ability to convey the complexity of urban constructions, which is exactly one of the positive aspects to 3D visualizations, as they allow for the integral evaluations of various topics. Alongside this is another important aspect of 3D to consider, which is the factor of time. By creating 3D animations, it makes it possible to present various visual scenarios within a short period of time. The next step is from 3D visualizations to 3D models that contain information that allows for a quantitative analysis of a plan. Beyond this, the use of 3D can help visualize complex processes, and can always be translated into 2D. Even after all these positives, one negative aspect is that the development of 3D visualization can be a “black box” which is not easy to handle, as it can take a lot of time to fill, and is unclear what data was used in creating it.

5. Subsurface Representation and Modelling

Most instruments that produce 2D and 3D information are aimed at visualization of the urban project above ground level. In connecting the subsurface with surface developments, several researches have been conducted by looking into the representation of surface and subsurface as one united space (Hooimeijer and Maring, 2018). The System Exploration Environment and Subsurface (SEES) and the Subsurface Potential Map are instruments developed with this aim in mind. The SEES is a system overview in which the domains involved in urban development are mapped out. Each domain has its own specific specialists, concepts, and language that need to be recognized if true interdisciplinary working is to be achieved. The subsurface potential map is a 2D map in which data has been translated into thematic sub-surface information under the categories civil construction, water, energy, soil. and ecology (Hooimeijer and Maring, 2015). In the Intelligent Subsurface Project (TU Delft), the subsurface potential map is being refined and contextualized in the form of a Technical Profile in which multiple scales are represented with a shared precise legend that annotates static, solid, and process items (Hooimeijer et al., 2017). This 2D map is quite functional as a communication tool between disciplines during both the initiative and design phases, and has a specific function which aims at internalizing the subsurface information within the urban design process (Hooimeijer and Lafleur, 2018).

Recent developments in 3D visualization software has been accelerating at a swift pace, and is both contributing to a multidisciplinary approach within the surface domain, as well as an ability to evaluate urban developments in a qualitative manner. At present, 3D visualizations contribute to the evaluation of a particular phase, but not to an optimal boundary spanning between the different phases of the urban development process (Mielby et al., 2017). Alongside this issue, there are 3D models that are focused on either the surface development or the subsurface development, but not on both at the same time. Currently, there are no examples of a fully integrated above ground and underground models in existence. Software such as Urban Strategy and GIM have been working on the inclusion of the subsurface in their models. Two other software programs called SKB ROO and (one out of many BIM tools) BIM environment by Curnet have been specifically developed to analyse and include some topics dealing with subsurface. In addition to these programs, there are serious games which incorporating above ground and the subsurface are increasingly used to create awareness of the contribution of the subsurface to the start of an urban development process prior to its inception.

Experimenting with LEGO building blocks during a “U-scan” workshop with the Urban Development and Engineering Department at the Municipality Rotterdam has led to the conclusion that creating a simple 3D model helps significantly by giving urban planners insight into how the subsurface is built up, while also showing how specific functions are claiming dedicated space below the ground. There are other different types of 3D modelling software which exist, and urban planners make extensive use of of them. There are 3D interactive programs such as TNO’s Urban Strategy, which can be used to quickly run through various scenarios, while also answering questions such as “What are the consequences for the environment if I change the course of this road?” There is another program developed by Strategis called the “Gebiedsontwikkelaar” [Area Developer], whose purpose is to quickly go through the economic effects of such measures stated above. When looking below the ground level, civil engineers make use of their BIM software, while in the same shallow zone TNO and the Geological Survey of the Netherlands have presented several geological and geo-hydrological 3D models. In addition to these types of subsurface modelling, the petroleum industry uses sophisticated software for the geological evaluation of the deeper layers of the ground. Unfortunately, the ability to exchange information and models between these various platforms and approaches is still quite complicated to achieve.

Due to the absence of a 3D visualization and modelling package that integrates above ground and subsurface data with the various scales (from object level to regional scale) and phases of urban development, a number of cities have developed their own 3D visualization and modelling tools for specific urban planning projects, as depicted in Figure 1 (Schokker et al., 2017).

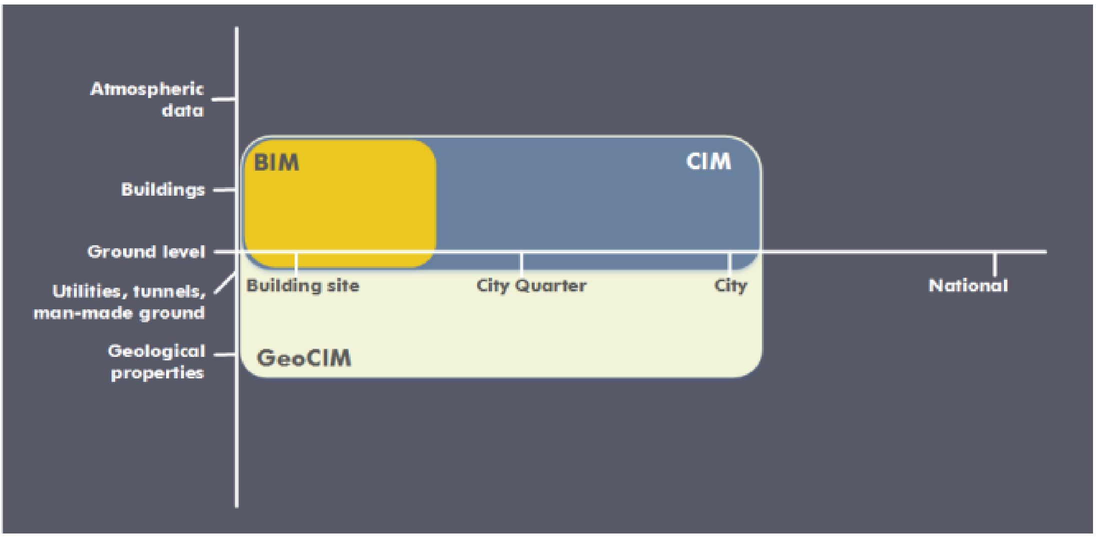


Figure 1: BIM, CIM, and GeoCIM relationships by both geographical scale of interest (x-axis) and data themes that differentiate themselves based on whether they are above or below ground (Y-axis) (Schokker et al., 2017).

Within the organization of the City of Rotterdam, the subsurface is regarded as an integral part of designing the public space of area development projects, as it involves the collaboration of numerous disciplines, and the municipality has to manage a large amount of subsurface data and information when implementing these projects. In order to be able to develop, integrate, and manage both subsurface and surface spaces in an effective way, it is necessary to have a correct representation of that subsurface when it is used, By doing so, properties can be evaluated in connection with the functions it performs, and the potential impact a project may cause in the subsurface. The 3D voxel model of the subsurface, as developed by Odense, was studied and taken as an inspiring example for the City of Rotterdam (Pallesen & Jensen, 2015). An example of this model is shown in Figure 2.

So, why choose Voxel based modelling? The City of Rotterdam decided to construct a 3D model of the subsurface in which the various uses of the subsurface could be evaluated in an integral way. As the use of the subsurface is influenced by geology, it was decided to combine ground use and geology into one common model. TNO’s Geological Survey of the Netherlands had already constructed the Geotop 3D Voxel model of the geology in the Netherlands, so subsurface use information just needed to be inserted into it.

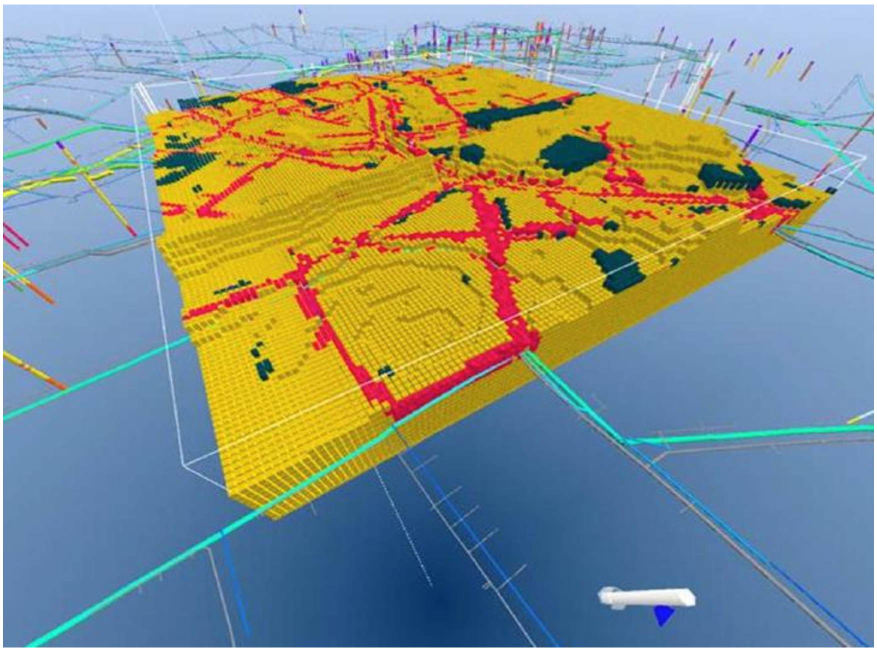


Figure 2: A 3D Voxel representation of both the surface and subsurface in Odense, Denmark (Pallesen & Jensen, 2015).

Together with TNO, the test 3D Voxel model was made for the centre of the city (see Figure 3). In this model, the 3D surface model was combined with various layers and voxel-based geological models (to a depth of 4 km). The next step that will make this very useful in development projects involves the integration of this surface model with the 3D subsurface model that has the information dealing with the subsurface layers (cables, pipes, tunnels, geothermal, oil, gas etc.). Due to differences in scales between geology information and layers such as cables and pipes, this is already a major challenge. The attractive packaging of this inclusive 3D model will represent the final but crucial step in order to make it an effective boundary spanning tool.[1] The first derived application of this model was done for the Bloemhof-Zuid project, which is studied in the case section of this paper.

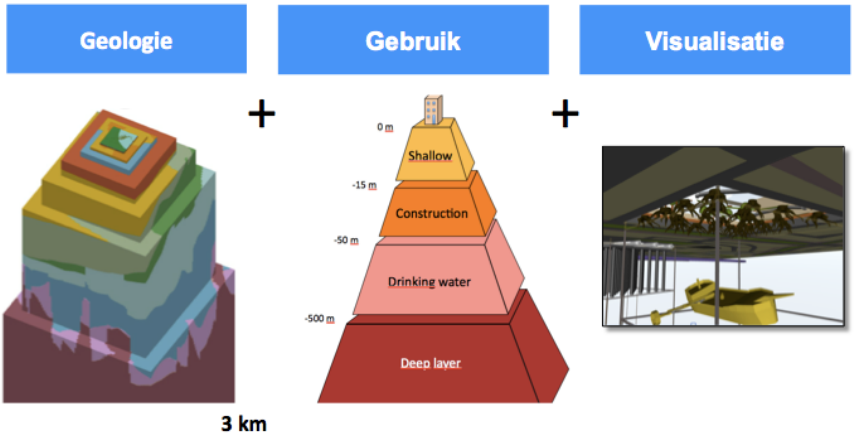


Figure 3: 3D Subsurface pilot for the Centre of Rotterdam (Van Campenhout and Vuijk, 2015)

6. Experiment: The Case Study of Bloemhof-Zuid Rotterdam

Bloemhof-Zuid is an urban district that was built in the 1930s on a very wet and soft terrain with ongoing subsidence issues. In the middle of this district, houses were built on slabs, while houses along the borders of the district were built with wooden bearing piles, thus making the management of groundwater level extremely complicated in this area. The owner that bears the responsibility of most

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[1] See link: https://youtu.be/pLLbRRIr1Ys

of the slab houses, the housing corporation *Woonstad*, has placed water pumps in a number of places around them to prevent flooding. However, these houses are not future-proofed, and the urban infrastructure does not meet modern standard of living requirements. The houses exist along narrow streets, have very little space to park, and have only a few green spaces and play grounds around them.

The key challenge that this district presents is how to develop the real estate in the long term while taking the subsidence issues into account. To prevent any further flooding problems, the municipality of Rotterdam and *Woonstad* are cooperating in making a vision (Phase 1 in the DMSP) in which the subsurface conditions dealing with subsidence and water management become an important aspect of design, which is quite new for this phase. Since there was no experience in how to integrate technical knowledge into a vision, there was a need for conscious knowledge brokerage, and thus presented itself the perfect setting to test the use of 2D and 3D tools. The content for the 2D, and the role of the Technical Profile, was developed more precisely in the process of vision-making. This content was made by combining together effort and expertise the municipality of Rotterdam's technical specialists with experts from TU Delft who are involved in the research project Intelligent Subsurface Quality. For 3D visualization, the Voxel model (which was developed by the municipality) was used in the area to test how the crucial topics can be modeled to enable decisionmaking for the vision proposal.

The Technical Profile that had been created for Bloemhof-Zuid is comprised of the translation of all relevant technical data into a series of drawings that allow for various natural and engineered elements to be analyzed simultaneously (see Figure 4). The drawings in the profile include a map with a longitudinal and cross section, additional cross-sections of street profiles, and thematic maps at a larger scale. Linking the smaller scale of the street profile to the more regional scale is important to check the impact of specific technical conditions. These include systematic elements such as water and ecology, which in particular have performance dependencies at the higher scale. At the largest scope, regional scale includes topics of relevance such as ecology, water, energy, and infrastructure. While at the smallest scale, details of the subsurface infrastructure are presented, which include cables, pipelines, and foundations (Hooimeijer, Lafleur and Trinh, 2017; Hooimeijer and Lafleur, 2018a).

The Technical Profile was created on the basis of a workshop where by using SEES, all subsurface experts presented and discussed their field's data and approach for the specific district. The workshop was essential to the gathering and translation of data from specialists and into information that can be used and interrelated. The urban designer then collected the information from the specialists attending the workshop, and finalized the drawings based on the data and help which they provided. The urban designer responsible for the spatial vision used the Technical Profile as backbone of which to deal with the issues at hand. The 2D visualization exercises resulted in the following conclusions (Hooimeijer and Lafleur, 2018a and 2018b):

- The section makes it possible to understand both technical and natural constructions as a hybrid space, and is the best point of departure for the drawing of plans.
- Visualization is a communication tool that is very inward oriented towards its relating field, and the use of forms and colors are expected to be recognized by the expert in the field.
- Visualization is not only a technique for communication, but also a technique for the internalization of data. The Technical Profile as drawn was very much a product that would help the urban designer to get a proper understanding of the technology in an area, and is less so an image to communicate to a wider audience.
- A new research approach was found which answers how to seperately visualize for both decision makers and stakeholders.
- It is important to look at natural and technical artifacts as a hybrid system, to see it in its complexity, and consider its visualization as common shared language. The technical and natural elements represented in the drawings offer a "step between analyses and design" as an important aspect of "design thinking."

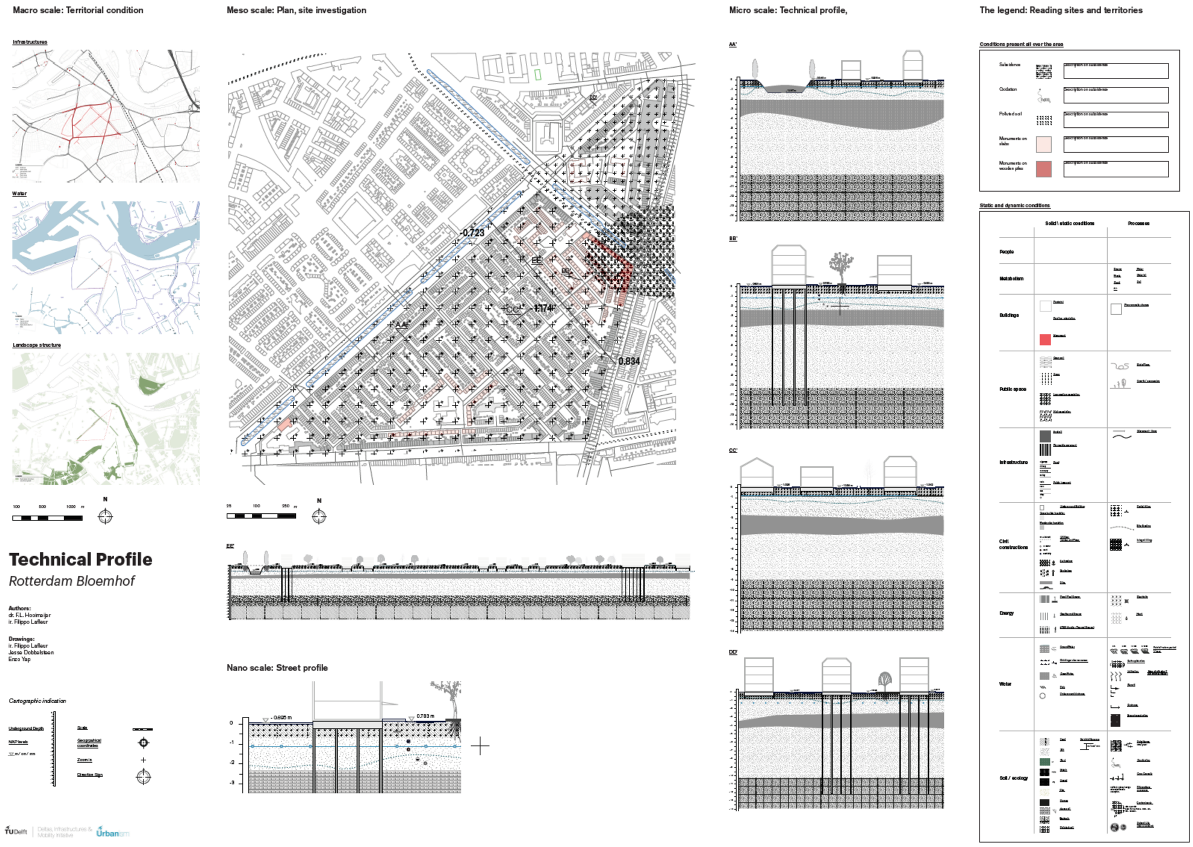
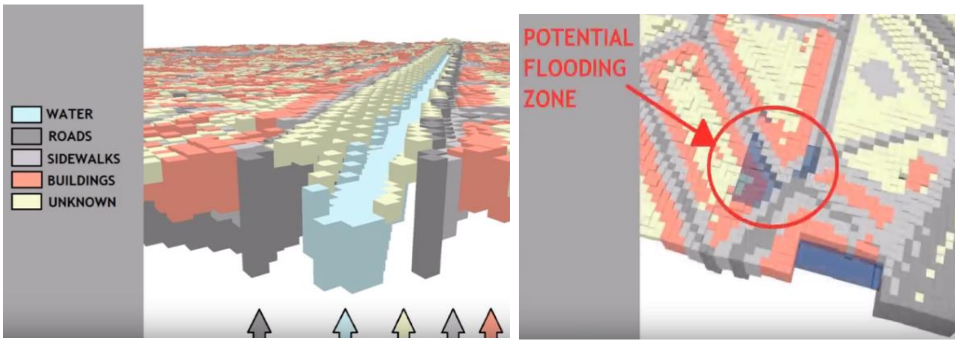


Figure 4: The Technical Profile of Bloemhof-Zuid (Hooimeijer and Lafleur, 2018b).

The SEES workshop also provided for the group that was in charge of developing the 3D model of Bloemhof-Zuid the Voxel model. It combined information from the geological composition and structure of the subsurface (from ground level to a depth of 20 meters) together with the uses of the subsurface (shown as a layered surface), and the model presented together in a single visualization (see Figure 5). The Bloemhof 3D Voxel model was constructed in order to allow better decision making for houses in the area which are at risk to problems with their foundations that are both a result of subsidence and flooding due to exceptional rainfall. This was achieved through the implementation of the following building blocks of the model: elevation map, water (canals), roads (including a 3m section below), sidewalks (including a 2m section below, including cables and pipelines), buildings, foundation piles, groundwater level, and geology. The geology block was created in 100*100*1m voxels, ground water was represented in 25*25*1 m voxels, and the buildings, sidewalks, roads, and water were made in 5*5*1 m voxels (see Figure 5).[2]



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[2] https://youtu.be/GYl11mwDSIg

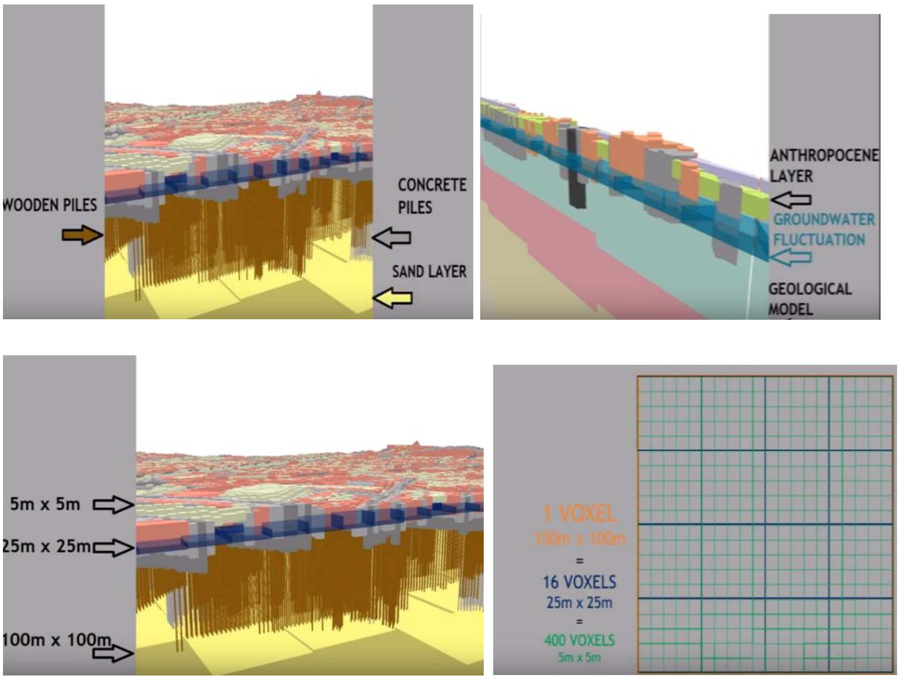

Figure 5: Images from the 3D Voxel model of Bloemhof-Zuid (Van Campenhout and Vuijk, 2017).

The integration of the subsurface in the vision phase was supported by both 2D and 3D representations and modelling. As the 2D Technical Profile considered all subsurface topics, the Voxel model was more focused on the relationship between three topics of which were the most urgent. The model was essential in helping to make decisions about future real estate development, and was the main concern of the involved housing cooperation. Both the Technical Profile and the Voxel model were quite influential in the vision making process. The Technical Profile was successful at developing a proper understanding of the current construction situation of the area, and it allowed for the easy transfer of this type of information in the urban design process.The Voxel model helped significantly in understanding the crucial issues, while also being able to project these issues into the future, and even helped in modeling trends of precipitation. The major difference between 2D and 3D representaiton is that as a part of the urban development process, the urban designer is responsible for both the spatial design of the vision and the 2D visualizations. The 3D, however, is done by a separate expert that has no knowledge of the subsurface topics, and is also not a part of the urban development process. This lack of synergy between the various fields means that the boundaries that needs to be spanned are actually quite large: from subsurface experts to 3D modeller, and from 3D modeller to the actors in urban development. Also, in this urban development phase the resolution of information is not that high, and it is due to the fact that there is a wide span of information that needs to be integrated together. The resolution becomes higher as the project develops through the different phases. In the next section of the paper, the discussion will place these results from the first phase of the DMSP within the context of the other following phases.

7. Discussion

To ensure a smooth spatial planning process, it is necessary to have access to accurate information in both the right form and at the right time. Different actors are involved in every phase of the planning process, and the information provided is often in various formats which do not transition well from one phase to another. As a result, time is often lost when progressing phases, but also actors get lost in translation as well. A need exists for an unambiguous distributed agency between 2D and 3D information in which the subsurface is represented, which must remain available during all phases of project development.

This section presents the analysis of the DMSP of Rotterdam (see the content in Table 2) in which the actors, information needs, and products are defined per phase. These are linked to the representation options available in both 2D and 3D in order to clarify their distributed agency in the development process (see Table 3). It is important to note that the model is for newly developed greenfields, and not for urban renewal or brownfield development. The difference between the two types of developments is that the information in newly built areas is usually owned by fewer stakeholders (water board, farmers, state, and provincial governments etc.) while in areas already built up, there are many more stakeholders that own data and information (such as owners of lots and buildings, utility companies, and multiple municipal departments). In addition to this, the phases in brownfield or urban renewal development tend to overlap (maintenance can also be development), therefore making the process more complex.

Table 3: The distribution of 2D and 3D visualization of the subsurface in the phases of DMSP.

	VISION	MASTER PLAN	URBAN PLAN	BUILDING
2D	Maps: topography, monuments, and infrastructure Pictures: ambitions	Maps: ownership, spatial structure, risks, spatial analyses, programme, and environmental	Map: situation, programme, urban design conditions, water, infrastructure, and environmental conditions Sections: soil, water	Maps: urban and architectural design, construction, and drawings
3D	Serious Game	SIM, GIM, US SKOO DOO		BIM
	In the vision phase, general information is processed to be able to make decisions for the project, while also creating carrying capacity amongst stakeholders. The resolution of this information is quite rough, and preexisting materials such as pictures are used to support the vision, in addition to topographical maps or data graphs used to create an appropriate understanding of the vision and strategy. In existing built-up areas, the amount of information that needs to be gathered and processed is greater and more complex.	The master plan - also called a structure plan - is the physical translation of the vision and program at the larger scale of an area. The master plan is usually the result of running different scenarios. After the visioning phase, the stakeholders return to their sectoral visualizations, then the issues are clear and able to be developed in a sectoral or bi-sectoral fashion. The resolution has sharpened at this stage, but the planning and design is still based on rough lines and decisions. The definition of newly gathered data and information is also conducted.	As part of the master plan, the urban plan is a detailed phase of development in line with the vision, and is directly connected to spatial quality. At the smaller scale, the information has a high resolution and should become a self-evident part of the urban design. Usually, all data is gathered and clear, while some gaps in information are allowed for the time being.	During the building phase, all data and information should be at the table and translated into construction plans.
	No information on the subsurface	Some information on the subsurface	More information on the subsurface	Detailed information on the subsurface

This table presents an overview in which the necessary information per urban development process phase is presented and connected to the employed 2D and 3D visualizations. It also shows that during the urban development process, several 2D and 3D models that represent the subsurface are used. These models all have varying data needs and scales, and present different information for different purposes to different users. Another important notion to take note is that the information from societal or economic sectors are especially important in the urban development process. This data presented is not visual, even though some has been visualized in the past years with the same aim as this research, which is to integrate it better in the design process of urban development projects (Tillie and Van der Heijden, 2015)

During the vision phase of urban development, there is currently hardly any mention of subsurface topics. Even though the scale and details of the earlier stages can vary significantly from those at the later stage, some topics that influence the project as a whole (such as the water system, soil quality, and subsidence) should be included at the beginning, particularly in the case of urban renewal or brownfield development (Hooimeijer and Maring, 2012 and 2014). The case of Bloemhof-Zuid showed various ways how both 2D and 3D representations can interact and distribute their agency by:

- Collecting data and transforming it into information as an action (not through data platforms),
- Using 2D drawings requires a less detailed focus on the integration of topics,
- Creating 3D visualizations require more detailed resolutions that focus on modelling scenarios of only urgent topics.

As studied in the Bloemhof-Zuid case with regards to the vision phase of area development, the resolution of subsurface information is too high, but it is important to note that there is a real need for a 3D modelling tool (or rather a 4D scenario role) in which only the size and function of space can claim reservation of an object. This model produced during the first phase can evaluate through the other following phases of the DMSP, all while additional data can be added into the development process. In each phase, the 2D maps and 3D models can also be combined with information concerning societal and economic opportunities. The information derived from one sub-process forms the base data for the other sub-process within each phase of the DMSP (see the diagram of Figure 6).

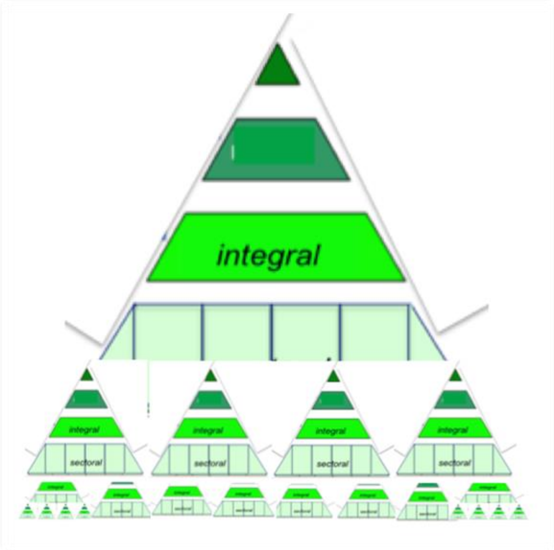

Figure 6: Derived information during one process serves as base data in the following processes (Van Campenhout et al., 2016).

The need for data, information, and modelling is different in every phase of DMSP. Making the right information available at the right time, and in the right format, for the right people - this is the crux of the matter. In the final phase of the development process, the evaluation of the whole, in its coherence and between the parts, should be made possible. In order to do this, a 3D or 4D sectoral modelling that implements the highest resolution of data is needed, but it should be made possible with linkages between the various sectors. Therefore, the question is if this should be a boundary spanning object (a model), and if it should be a spanning process (integrated in the DMSP), should it be organised through boundary spanning activities or specific boundary spanning specialists? Considering all these interconnecting concepts of boundary spanning, the distributed agency between 2D and 3D can not only be considered in the objects themselves, but also as a part of the complete urban development process (actors, products etc.). For DMSP, this means that per phase of development, the information should not only be synchronized in order to integrate surface and subsurface planning, but there should also be the integration of actors over different phases. For example, this is done in the oil and gas industry where there are various types of exploration and production geologists that work on a shared platform. This is a field where models communicate and visualizations from different software packages can be shared (Wen, Tang and Suc, 2017).

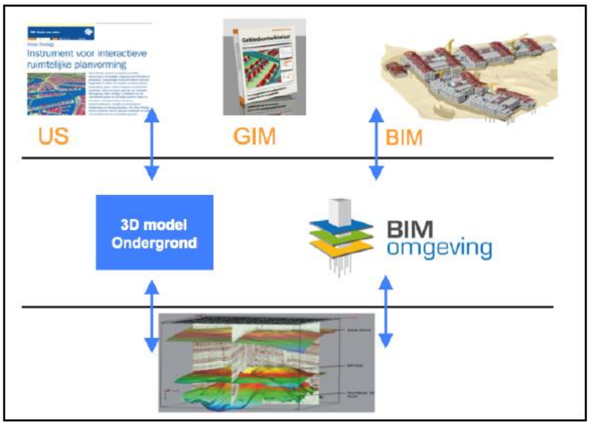

Figure 8: Different 3D Models for different purposes. What is needed is an exchange platform in between various actors (Van Campenhout et al., 2016).

An analogy to this example is in the form of an exchange platform (depicted in Figure 8) for DMSP, and could offer a score depending on the quality of subsurface information, which is based on: (1) how the resolution increases per phase, and (2) how the data of various natures can perform in different stages of development. For example, how data can perform at a more informal setting during the first phase, in comparison to the exchange of very precise data and contracts in the last phase. The distributed agency between 2D and 3D visualization is characterized by the fact that the role of 2D decreases as the role of 3D increases.

In the case of a greenfield development, the platform could first be filled with 2D data, and can start with an empty 3D LEGO model which allows for all stakeholders to input an idea about how their field is a part of the whole project. This process can also reveal how their interest relates to the stakes of others in the process. This beginning is necessary to be able to construct a shared vision with all the stakeholders.

In the case of an urban renewal project or brownfield development, there should already be 2D and 3D information. In this case, the 3D LEGO scale and the detailed level of planning exist in the same dimensions of space and time. This means that you need to be able to switch very quickly from high to detailed scales and resolutions of data and information. For each zoom in resolution, you need new data, which in turn sets the conditions for further zooming.

This platform therefore targets two problems with the boundary spanning between the surface and subsurface involved in urban development, one being that the field which needs to be spanned/bridged, is very wide and deep. Wide in the sense of process and time, and deep in the sense of specialized content. This is all connected through distributed agency, and is guided in the project by the project manager. However, for the exchange of information to happen, there is a gap in which self-evident distributed agency between 2D and 3D information could be realized. This platform could therefore fill this gap, and can be considered a new concept in boundary spanning by being the facilitator in which the people, processes, objects, and activities can cooperate within each of the urban development phases. Unfortunately, this reality is way too complex to be represented in a “one size fits all” model. Therefore, the disciplinary fields will continue to work within their own habitats and with their own tools. However, within these bubbles is also where the technological innovation takes place. The platform will be able to bring 2D and 3D tools together with surface and subsurface data, and with a great synergy fully support the urban development process as a whole.

8. **Conclusions**

This paper reflects on tne results of three research projects titled “Design with the subsurface” (2012), “Balance4P” (2016), and “Intelligent Subsurface Quality” (2018). This is done to get insight on the role and interaction of both visual representations and data in the urban development process in order to support synergy between the surface and subsurface as a unified space. The theoretical background required to understand what is needed in order to be able to create this support lies within the fields of boundary spanning and distributed agency. The DMSP of the Municipality of Rotterdam was used to get a firm grip on the urban development, including its actors, processes, information needs, and products in different phases of an urban project. After describing the general 2D and 3D information requirements, visualization options and methods needed to make the subsurface visible within the urban development process were presented. Two of these instruments, the Technical Profile (2D) and Voxel model (3D) were applied in the Bloemhof-Zuid project, which is the case study that provided new tools and processes in the first phase of the DMSP. After these were explained, discussion goes into the general distributed agency of 2D and 3D visualization, and the proposition of a boundary spanning facilitator.

The first obvious conclusion is that the tradition in planning and design of using the integrated approach on surface level is much more developed then in the subsurface. The integration also synthesizes various specialists who make 2D and 3D representations, such as architects, urbanists, and actors in the urban development process itself. Subsurface planning is a new (or maybe even non-existing) field to which there is no tradition. Moreover, previously there had been no participation in the urban development process at all. On top of that, the specialists that make 3D models are not specialists in the knowledge and understanding of subsurface content, thus unable to integrate as a boundary spanner in the urban development process.

The experiment that took place within the case of the Bloemhof-Zuid Rotterdam project involved testing the two boundary spanning objects: the Technical Profile and the Voxel model. It showed that they cooperate in spanning both wide and deep fields by distributing the agency. It was concluded that 2D visualization is important for bridging the with: it is able to bring all different types of surface and subsurface aspects together, therefore activating these in the planning and design process. The 3D Voxel model, bridging depth, was found that it provides the synergy needed to combine various sets of data and information for the most deep and urgent of technical issues.

Conclusions about the distributed agency between 2D and 3D visualization per phase is that it is characterized by:

- The span of instruments go from the use of a pencil to the use of a super computer: design is a matter of the head, the hand, and the heart and these are all connected by the pencil, or 2D, the complexity of cities now needs super computers to be able to describe and analyse;
- 2D is about internalizing data to extract information in order to design, and it is more interactive and informally available, while 3D is about visualizing complexity that is evaluated and projected through modelling. These are complementary boundary spanning objects to the urban development process;
- The constant increase of resolution per phase increases the importance of 3D modelling, this should be a conscious act which can reduce the existing tension between the specialist 3D models and information developed in the planning process;
- The hybrid Voxel model (3D) & pixel model (2D) can communicate with specialist data and have 3D models produce 2D outputs, like complex sections on multiple cuts;
- There are boundary spanners needed between 3D technicians and subsurface specialists, and also between 3D technicians and spatial planners;
- There is a clear accounting of information: inventory of topics, building a 3D model for the vision, the ability to add aspects during the process, and the use of specialist models for the realization phase.

The scientific contribution of this paper is the introduction of the “boundary spanning facilitator” as an expansion of the boundary spanning theory. This facilitator is needed to reach the divide created by the wide and deep spans of information demand in the urban development process that it sets out to bridge. By integrating the subsurface into the processes of urban development, this synergy bridges enormous spans of (1) disciplines and knowledge fields, (2) phases and time, and (3) also low and high resolutions, which may be the most important issue considering 2D and 3D visualization. This facilitator is necessary to enable the boundary spanning actors, processes, objects, and activities in order to cooperate in covering the wide and deep spanning fields of urban development. This is proposed in the shape of a platform in which the distributed agency between 2D and 3D tools can be consciously organized in order to conceive innovation in the urban development process.

The distributed agency needs more than one model of seeing surface and subsurface as one united space due to the span and character of the urban development process. Specialists will and never should give up their specialist models, as they are necessary for the development of in depth knowledge and experience. Therefore, it is important to fill in the gap between the required tools with a method of distributed agency between all formats of 2D and 3D visualization at the phase that they are most significant. This platform will allow for crossovers by utilizing linkages in order to gain precious expertise and information. Here all 2D and 3D models can exchange information, supply information, and store data utilizing the qualities of the 2D and 3D to their maximum potential. The good quality of 2D visualization is that it can play a role in informal processes that happen between specialists, because it can be printed on paper and is easily traceable. This supports the human side of knowledge transfer, as can be a place where people meet to exchange knowledge in a spontaneous manner, and will enhance knowledge of other professional attitudes, culture, capabilities, and knowledge fields. It will also enhance shared responsibility and distributed agency that can be transferred into the 3D models. The 2D, 3D and 4D tools are crucial to visualize space and time as concepts that might contribute to this common interest of urban development.

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