Conceptualizing a Web-based 3D Decision Support System Including Urban Underground Space to Increase Urban Resiliency

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Abstract: The urban underground is increasingly recognized as a multifunctional resource important for achieving urban resilience. However, it is often neglected in planning processes. Since this can lead to undesired urban developments, approaches are required to take both the space above and below ground into account. In particular, there is a lack of visualization instruments (mainly due to available data) to foster a better understanding of the above and below ground urban system and interacting effects on urban ecosystem services. In this paper we demonstrate how urban infrastructure above and below ground can be visualized in a web-based platform using the open-source JavaScript library Cesium. Then, based on the presented prototype we illustrate its possible advancement for supporting a more comprehensive design and evaluation of possible urban developments in a collaborative planning setup. Testing and enhancing the visualizations in collaboration with stakeholders and complementing them by including 3D point clouds and 3D urban ecosystem services, the suggested platform could effectively help to explore the design of resilient urban systems and to co-develop urban transformation pathways desired by the stakeholders.

Keywords: Collaborative spatial planning, urban design, online planning platform, 3D DSS, CesiumJS, 3D underground infrastructure

1 Introduction

Increasing the resiliency of urban systems is a major objective in designing sustainable urban developments in order to ensure the well-being of the continuously growing urban population (ELMQVIST et al. 2019; MA et al. 2020). Resilience can be defined as the ability of an urban system to cope with disturbances, to reorganize itself, maintaining essentially the same functions and responses over time and evolving further along a certain path (ELMQVIST et al. 2019). Whether or not a resilient path is sustainable, however, depends on ensuring a development pathway that is also desired by stakeholders (ELMQVIST et al. 2019). The importance of achieving such desired urban development pathways is stressed in the United Nations' Sustainable Development Goal 11 (of 17) "Make cities and human settlements inclusive, safe, resilient and sustainable" (UNITED NATIONS 2015), which requires, inter alia, improving urban planning by an active management of wanted and unwanted urban resilience (ELMQVIST et al. 2019).

One important resource of the urban system for achieving urban resilience is the space below ground (PARRIAUX et al. 2004; ADMIRAAL & CORNARO 2016, 2020; VOLCHKO et al. 2020). It is increasingly recognized as a multifunctional resource, which offers physical space, water, energy, materials, an archive of historical and geological heritage, and several further ecosystem services, such as life-support systems, contributing to human well-being (PARRIAUX et al. 2004; ADMIRAAL & CORNARO 2020; VOLCHKO et al. 2020). However, the underground space is often neglected in planning processes or treated without a long-term management

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(VOLCHKO et al. 2020). Furthermore, through the deficiency of cross-sectoral planning, the underground space is used up for prevalent mono-functional uses in a "first-come-first-served" manner without taking into account possible other functions and interactions with the provision of ecosystem services – above and below ground – of the urban system (PARRIAUX et al. 2014; ADMIRAAL & CARNARO 2016; MA et al. 2020; VOLCHKO et al. 2020). This can lead to undesired developments, for example, an urban densification above ground to minimize urban sprawl can lead to an increase in the urban heat island effect, shortage of recreational area for the urban population, deteriorated storm water runoff resulting in flooding, and decreased quality of other ecosystem services due to diminishing urban green spaces (CORTINOVIS & GENELETTI 2020). Taking into account the underground space for creating built-up space, e. g., by building underground car parks combined with water retention basins, can help maintaining multiple services in a more resilient way (ADMIRAAL & CORNARO 2020). Yet, there is a lack of systematic approaches on how the underground can be integrated into spatial planning processes (VOLCHKO et al. 2020). To overcome this shortcoming, an active management of resilience in the respective urban contexts above and below ground and across scales is required, which should include experimenting with alternative solutions and knowledge co-production by involving multiple actors (ADMIRAAL & CARNARO 2016; ELMQVIST et al. 2019). Thereby, crucial issues are (1) to make the urban underground space visible, and, hence, to bring it into the decision-makers mind, and (2) to identify synergies and conflicts between urban developments above and below ground (VOLCHKO et al. 2020).

In order to facilitate a better understanding of the above and below ground urban system, 3D visualizations are regarded essential tools, which can provide a common language for heterogeneous stakeholders (MA et al. 2020; SCHOKKER et al. 2017). Yet, the 3D visualization of the urban underground space is not very common in practice and poses several challenges (SHOJAEI et al. 2013; SCHOKKER et al. 2017; MA et al. 2020). For example, required essential characteristics of the 3D model are inter alia the handling of massive data, interactivity, providing underground and cross-section views, and allowing usability and accessibility also for non-expert users (SHOJAEI et al. 2013). In addition, the 3D model needs to be able to integrate further data relevant in different urban planning contexts (SHOJAEI et al. 2013; SCHOKKER et al. 2017). In this regard, web-based 3D decision support systems offer access for multiple users without requiring special software on the user's computer (SHOJAEI et al. 2013). They can facilitate collaborative creation and analysis of spatial scenarios, whereby multiple objectives are taken into account and traded off against each other (GRÊT-REGAMEY et al. 2017; SCHITO et al. 2020).

The objective of this paper is to visualize urban infrastructure above and below ground level in a web-based 3D decision support system (3D DSS) for supporting the planning of electricity transmission lines on regional scale in central Switzerland and on local scale in the city of Zurich. The 3D DSS uses the open-source JavaScript library Cesium (CESIUM 2020a) to load diverse data sets as well as spatial modelling results on a 3D digital globe. We present the general setup of the 3D DSS for the area of Switzerland and focus then on the urban study site Zurich for details on the urban infrastructure visualization. Furthermore, we want to illustrate how such 3D DSS prototype could provide a platform for iterative loops between urban design development and evaluation. Based on recent examples from literature, we address compatible functionalities for the 3D DSS and explain how they could contribute to this end. We discuss the suggested platform concerning its current quality and provide an outlook on possible further enhancements of the visualization.

2 Method and Results: Visualizing Urban Infrastructure Above and Below Ground in a Web-based 3D DSS

2.1 Web-based 3D DSS Prototype

A recent example of a web-based 3D DSS is a platform developed for supporting the planning of electricity transmission lines in Switzerland (SCHITO et al. 2020). Users of the platform can weight relevant spatial criteria of the dimensions “nature and environment”, “spatial planning and people”, and “technical feasibility”, which are input in form of raster data (1 ha cell size) for a Multi-Criteria Decision Analysis (MCDA) that runs in Python [1]. By collaboratively discussing the weighting of the criteria and providing different settings of the weights, heterogeneous stakeholders can together create and visualize alternative scenarios of transmission line paths in short time (SCHITO et al. 2020). In the remainder, the focus is on the visualization part of this platform.

The web-interface of the 3D DSS includes a viewer for 3D visualization of data based on the digital open-source 3D globe Cesium (CESIUM 2020a). The terrain and the orthophotos of the area of Switzerland are retrieved directly from a server of the Federal Office of Topography swisstopo as Tile Map Service (TMS) [2] by applying a JavaScript code (Fig. 4). Swisstopo also offers the buildings and vegetation of Switzerland as 3D tiles via its web access service. Thus, in the 3D DSS, this above ground infrastructure is streamed directly from the swisstopo server. The modelling results of the MCDA (resistance maps, least cost path surfaces) are automatically saved on a geo-server as image files (png), which are displayed on the Cesium globe as 2D maps, and the resulting path is saved as points (csv) providing the location of 3D-objects of pylons with overhead lines in between, transition buildings, and earth cables. The latter are visualized as polyline volumes calculated directly in Cesium (CESIUM 2020b; see Fig. 1, blue tubes).

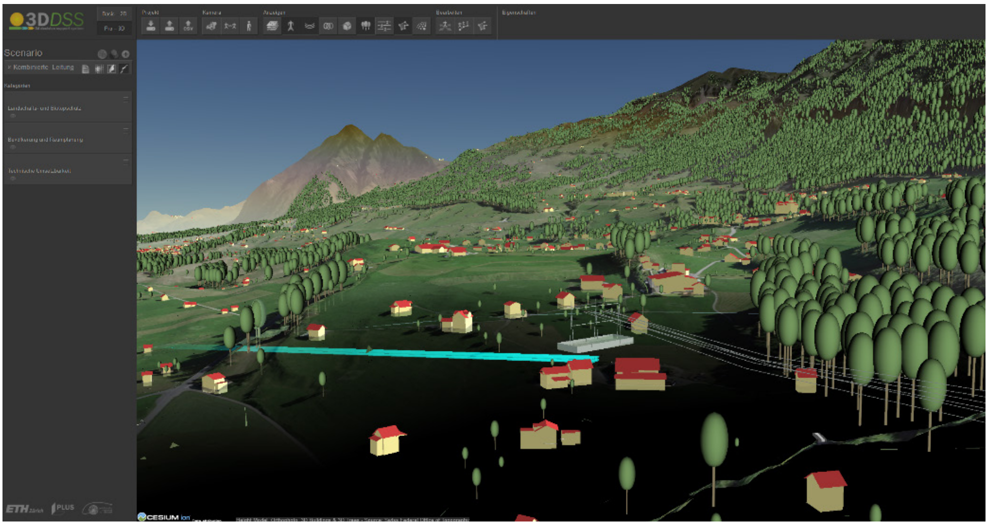

Fig. 1: 3D visualization of the modelling results in the interface of the 3D DSS: Transition building (grey) where the overhead lines change to earth cables (blue tubes)

2.2 Processing of the Urban Underground Infrastructure Data

For a perimeter with a size of 757 ha in the city of Zurich, where paths for new earth cables of electric power lines should be identified in the urban area on local scale, the transmission line planners required also the visualization of the existing infrastructure below ground. Furthermore, information on the building use, and indicators on possible conflicts with high-voltage transmission lines should be displayed. In the following, the approach for visualizing the relevant information is presented for this urban study area.

The available data of existing underground infrastructure belong to a cadastre of the city of Zurich (STADT ZÜRICH 2020). They comprise digital information on gas, water, district heating, telecommunication, and existing electric transmission lines. This data had to be processed for 3D visualization below ground in the 3D DSS. First, the width and depth of the different underground infrastructure types was identified. Therefore, the data was inspected regarding their attribute values. Most of the data contained information on the tube diameter. However, the depth of the tubes below ground and the width and depth of the pipe trenches were not provided. In an internet search, values for the dimensions of the pipe trenches commonly used in practice were determined. Thereby, inter alia, the standards for the construction of drainage systems and roads of the civil engineering and waste disposal department provided helpful information.

Although it is possible to display tubular 3D volumes in Cesium below ground (CHOW 2020), due to the size of the case study data (up to 250 MB for individual data sets) and CPU and GPU memory constraints of many potential users' computers, we decided to provide simpler representations in form of 2D polygons and 3D boxes. Therefore, the vector data (lines) was converted (e. g. from DXF /DWG or Interlis), and imported into Esri's ArcMap 10.5 for further processing (Fig. 2).

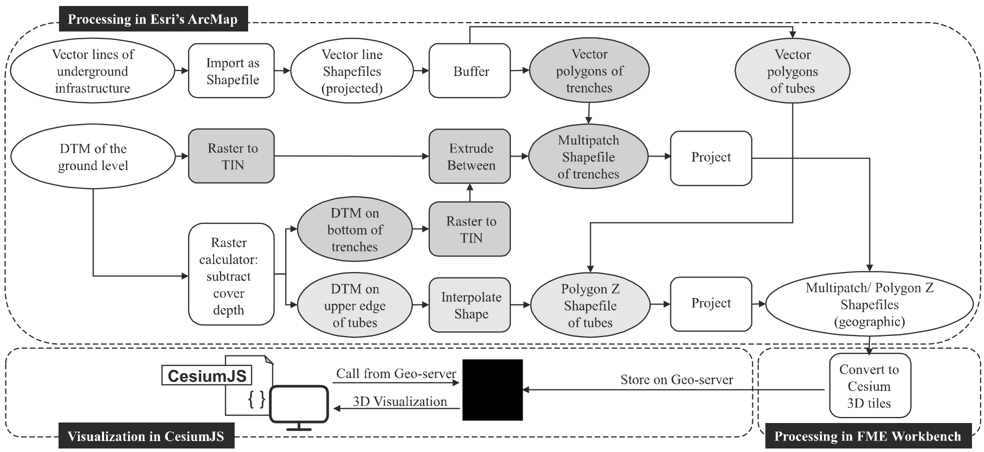

Fig. 2: Flowchart of the underground data processing for visualization in CesiumJS

First, by buffering the lines according to the attribute values of the tube diameter and the general trench width, polygons with the width of the tubes and the trenches of the respective infrastructure types were generated. In order to assign the depth of the polygon for the tubes below ground, the tool «Interpolate Shape» (ESRI 2017a) was used. «Interpolate Shape» adds a z-value from a Digital Terrain Model (DTM) to the polygon. With the tool «Raster calculator», using the DTM with the actual height of the terrain as input and subtracting the respective depth, we created surfaces, which are on the assumed depths of the upper edges of the tubes. These surfaces provided the input for interpolating the shape of the polygons of the tubes, resulting in Polygon Z-Shapefiles. For generating 3D box models of the trenches, two surfaces had to be created in the described way. Additionally, the resulting surfaces were converted to TIN Layers (tool «Raster to TIN»), the required input format for the tool «Extrude Between» (ESRI 2017b). These two TINs provided the surfaces for extruding the respective polygons between, resulting in MultiPatch-Shapefiles.

Finally, the 3D polygons processed in the described way had to be converted to Cesium 3D Tiles, the format to load data efficiently in the Cesium globe. As the Cesium globe uses the World Geodetic System WGS84 (EPSG:4326), the Polygon Z-Shapefiles and the MultiPatch-Shapefiles were projected in ArcMap into geographic coordinates (tool «Project»). Then, the shapefiles were converted with FME Workbench (Version 2020.0) [3] to the format Cesium 3D Tiles with the respective writer, whereby the coordinate system was set to "Same as the source". The resulting Cesium 3D tilesets were stored on a geo-server, from where it is called with a JavaScript code (Fig. 4) and displayed in the viewer of the 3D DSS.

In order to get an impression of the varying depth of the different tubes and trenches, the functions to display the terrain in a transparent mode (Fig. 4) and a «Clipping plane» tool for creating sections were programmed [4] When clicking on the button «Clipping plane», the tool is activated. The terrain should be displayed in the opaque mode. Then, with a first click on the ground, the beginning, and with a second click to the left side, the direction of the clipping plane is defined. As result, all features in front of this virtual clipping plane are hidden. Now, the terrain transparency can be activated to provide a view on the underground infrastructure (Fig. 3.1 and 3.2).

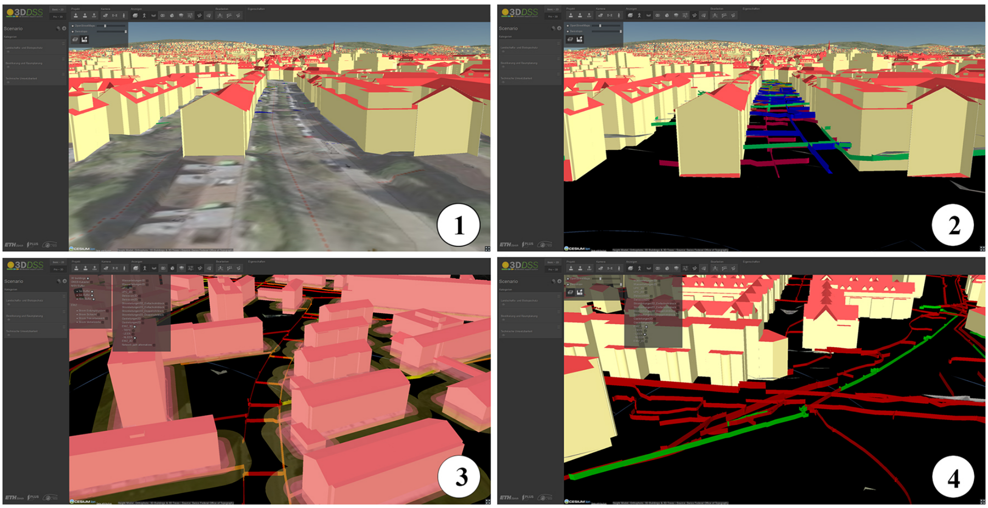

Fig. 3: (1) Section view of the urban scene with opaque terrain and (2) with transparent terrain, where the underground infrastructure is visible. (3) Information layer NISV-Buffer. (4) Colouring by attribute: green = empty pipe blocks.

2.3 Information to Support Analysis

Further information layer were added in different ways. For example, the zoning plan of the cadastre of public-law restrictions on ownership is available as web feature service (WFS) layer from the geographic information system of the Canton of Zurich. In the 3D DSS, the data including the legend is directly called from the cantonal geo-server with the function «Cesium.WebMapServiceImageryProvider». Accessing the data in this way also ensures that the data layer is always up to date.

For analysing whether there might be conflicts with the Swiss regulation on the protection against non-ionizing radiation (NISV), three different buffers (3 m, 5 m, 10 m) around the buildings were calculated and then converted to GeoJSON files using Esri's ArcMap. The polygons are loaded in the 3D DSS with the function «Cesium.GeoJsonDataSource.load». As a side effect, in areas overlapping with these polygons, 3D objects of the buildings or trenches get automatically the polygons' colour (Fig. 3.3).

Further data contained detailed information on the occupancy of the pipe blocks, e. g., whether they are empty or not. Hence, we used the function «Cesium.3DTileStyle» to colourize the respective 3D data according to these attributes (Fig. 3.4, Fig. 4) [5].

```
// Code tested in Cesium Sandcastle with Cesium 1.76.
//Sandcastle_Begin
var viewer = new Cesium.Viewer("cesiumContainer", {

// Complete the swisstopo web access inscription form for accessing the image and terrain tiles.
// Load Swisstopo Images (swissimage-product)
imageryProvider : new Cesium.UrlTemplateImageryProvider({
        url : "//<ServerName>/<Version>/ch.swisstopo.swissimage-product/<StyleName>/<Time>/
<TileMatrixSet>/<TileSetId>/<TileRow>/<TileCol>.<FormatExtension>",
        subdomains: '0123456789',
        availableLevels: [8, 10, 12, 14, 15, 16, 17, 18],
        minimumRetrievingLevel: 8,
        maximumLevel: 17,
        tilingScheme: new Cesium.GeographicTilingScheme({
            numberOfLevelZeroTilesX: 2,
            numberOfLevelZeroTilesY: 1
        }),
        defaultAlpha: 0.5,
  })}
  );

// Load Swisstopo Terrain (terrain.3d)
viewer.terrainProvider = new Cesium.CesiumTerrainProvider({
        url : 'https://<ServerName>/<Version>/ch.swisstopo.terrain.3d/<StyleName>/<Time>/
<TileMatrixSetID>/',
 });

// Globe Translucency. Set front face translucency to 0.3 when the camera is 3500 meters from the surface and 1
as the camera distance approaches 15000 meters.
viewer.scene.globe.translucency.frontFaceAlphaByDistance = new Cesium.NearFarScalar(3.5e2, 0.3, 15.0e2, 1);
viewer.scene.globe.translucency.enabled = true;

//Load the tileset "PipeBlock" and colour it FUCHSIA
var tileset = viewer.scene.primitives.add(
    new Cesium.Cesium3DTileset({
        url: 'http://localhost:8080/Specs/Data/Cesium3DTiles/Tilesets/PipeBlocks/tileset.json' ,
    }));

var defaultStyle = new Cesium.Cesium3DTileStyle({
    color : "color('#FF00FF')", //FUCHSIA
    show : true
});
tileset.style = defaultStyle;


// Load and colour a Cesium 3D tileset "PipeBlocksEMPTY" by the attribute "EMPTY".
var tileset2 = viewer.scene.primitives.add(
    new Cesium.Cesium3DTileset({
```

```
        url: 'http://localhost:8080/Specs/Data/Cesium3DTiles/Tilesets/PipeBlocksEMPTY/tileset.json' ,
    }));
function colorByEMPTY ()   {
  tileset2.style = new Cesium.Cesium3DTileStyle({
     color: {
        conditions:  [
          ["${EMPTY} === 1", "rgb(0, 245, 0)"],
          ["${EMPTY} === 0", "rgb(245, 0, 0)"],
          ["true", "rgb(245, 0, 0)"],
      ],
    },
  });
}
        tileset2.style = tileset2.style;
colorByEMPTY();
//Sandcastle_End
```

Fig. 4: Generic code example for loading the swisstopo terrain and orthophotos, enabling globe translucency, loading and colouring a Cesium 3D tileset, and colouring a tileset by an attribute

3 Aspects for Advancing the Visualization Prototype

The presented approach is suitable for 3D visualization of infrastructure above and below ground in a web-based platform on regional and local scale, including interfaces for interactive spatial development modelling. However, we did not yet evaluate how well stakeholders understand and can use this information in a planning process. Whereas transmission line planning experts rated the visualization of underground infrastructure based on a demonstration as rather to very helpful (SCHITO et al. 2020), testing these visualizations also with other stakeholders such as the general public is still required to analyse whether they are able to use this information meaningfully. Furthermore, few experts found the visualization rather not helpful or were undecided (SCHITO et al. 2020). In order to understand the further requirements regarding the visualization of underground infrastructure, hence, continued collaboration with different stakeholders is necessary. Thereby, the focus must be kept on the main purpose of the visualization platform. For fostering urban resilience, macro-level information across different spatial scales supporting strategic planning and policy decision making is required. Therefore, supporting the integration of the data above- and below ground and providing meaningful indicators to understand the relationship between 3D urban patterns and ecosystem services (ALAVIPANAH et al. 2016) is then more important, than visualizing the accurate position and diameter of the tubes. In contrast, for facilitating design on the micro-level, i.e., the building scale, a level of detail and accuracy is necessary that is "as-built", which is provided by building information models (BIM, WANG et al. 2019).

4 Discussion and Conclusion

Including the urban underground space into design and evaluation of urban development scenarios is crucial facing current trends of urban densification. The presented 3D web-platform is feasible to visualize urban infrastructures above and below ground using CesiumJS. With the suggested advancements, namely, testing the visualization platform with different stakeholders as well as complementing it with 3D urban ecosystem indicators for supporting iterative processes of designing and evaluating urban development scenarios across scales, it could become an effective digital tool, which can help to explore the design of resilient urban systems. To further improve collaborative design and evaluation in three dimensions above and below ground, new approaches using 3D point clouds are promising (URECH 2020). As recent developments already enable web-based visualization and exploration of massive 3D point clouds in CesiumJS (DISCHER et al. 2019), their integration into the visualization platform should be envisaged.

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