

Geodesign Apps and 3D Modelling with CityEngine for the City of Tomorrow

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Abstract

This paper describes the development of 3D models and applications for the district of Mülheim South, Cologne, Germany, within the framework of the Fraunhofer Society's project "City of Tomorrow". GIS technologies are used as support for the implementation of a holistic approach to sustainable urban development as part of the Cologne smart city efforts. 3D GIS visualisation technologies are applied not only for the district in its current state, but also for simulation of future scenarios of sustainable and innovative development. Web-based applications are under development to allow a clear presentation of the new city development projects and scenarios, and to facilitate future citizen participation in the planning and decision making process.

1 Introduction

Smart city development has become a major issue in the past few years, with cities all over the globe claiming to be smart or adopting measures to become one. A plethora of smart city definitions, projects, initiatives, and solutions have emerged; programs have been developed to modernise and transition cities into "smart", and efforts made to develop methodologies and tools that support this transition (DEAKIN 2013, HOLLANDS 2008).

Although there is still no consensus of what constitutes a "smart city", a common understanding is that smart cities are well performing in the economy, people, governance, mobility, environment, and living sectors, and present smart, green and inclusive growth. Energy management, smart grid and storage, intelligent buildings and lighting, e-mobility and smart transport, emergencies and security, are only some of the smart cities' goals (GIFFINGER et al. 2007, HERMANT-DE CALLATAÿ & SVANFELDT 2011).

The contribution and benefits of Information and Communication Technology (ICT) to the modernisation of cities is considerable (YANRONG et al. 2014, SANSEVERINO et al. 2014), and Geographic Information Systems (GIS) are an integral part of any smart city effort (KUNZE et al. 2012, MCROBERTS 2015, OSTRU & SCHRÄDER 2015).

“Morgenstadt: City Insights Innovation Network” or *m:ci* ⁽¹⁾ is an innovation network facilitated by the German Fraunhofer Society for the promotion of applied research that comprises stakeholders from Europe and around the world in the field of urban sustainability. Using leading-edge innovation management methodologies, *m:ci* aims to develop and implement socio-technical innovations for the city of tomorrow. It focuses on the interplay of technologies, business models and governance approaches for sustainable urban development, aiming to accelerate developments that help to reduce energy and resource consumption while enhancing the liveability and prosperity of cities.

After on-site analysis of six leading cities, identification of best practices and development of an integrated action-oriented model for sustainable urban development during the project’s first phase, the *mc:i* Phase II (*m:ci*²) focuses on creating the city of the future by implementing pilot projects or “city labs” for the development and deployment of innovative solutions for sustainable and resilient cities.

Within the framework of the *m:ci*², Esri Germany and Professor Schaller UmweltConsult (PSU) are currently developing in cooperation with the Fraunhofer Society and the city of Cologne 3-dimensional visualisation GIS and spatial analytical tools for the Mülheim South “city lab”, on the right bank of the river Rhein, with approximately 70 hectares of mixed land uses that include a harbour, a park, old industrial, commercial and residential areas.

The main goal of this effort is to test new upcoming 3D GIS technologies as support for planning and implementation of sustainable urban development. In addition to the 3D analysis and visualisation of Mülheim South’s *status quo*, the project also simulates future scenarios of sustainable and innovative development. The specific objectives include:

- Development of Geodesign (STEINITZ 2012) applications for 3D visualisation and analysis as supporting tools for development planning, considering energy efficiency, sustainable mobility and environmental quality;
- 3D visualisation of the district *status quo* and alternative future sustainable and innovative development scenarios, based on existing data of the city of Cologne, existing plans and proposals for this area (STADT KÖLN 2014) and on the requirements of the *m:ci* project;
- 3D GIS analysis and mapping of environmental impacts, energy and mobility data by coupling standard model outputs with the 3D GIS database;
- Implementation of a 3D GIS citizens data portal for city planning, mobility and environment;
- Development of an interactive 3D GIS cloud-based web portal for citizen participation and a dashboard for decision support within the city government.

With the applications and tools currently under development, planners and decision makers of Cologne shall have by mid-2016 instruments that allow a clear presentation of the new city development projects and scenarios, and citizen participation shall be allowed and promoted. The results presented here are preliminary.

¹ www.morgenstadt.de/en

2 Input Data and Software

As a Morgenstadt project partner, the City of Cologne kindly provided high quality data on environment, transportation, real estate and development plans in various raster, vector and CAD formats, as well as high resolution imagery and LIDAR datasets. Ground level photographs of building facades were also taken in Mülheim South using a GPS camera Ricoh g700SE.

The main software used for data processing and visualisation were ArcMap, CityEngine², LumenRT Geodesign for CityEngine, Adobe Photoshop and Aldensoft Snippet.

3 Methods and Initial Results

With the help of dedicated geoprocessing tools, the provided datasets were migrated into the GIS environment. To develop a state-of-the-art 3D GIS, all geospatial and non-spatial datasets had to be processed and homogenised. With procedural 3D modelling technology (PARISH & MÜLLER 2001, ULMER et al. 2007) applied with CityEngine an almost fully automated modelling process was developed to create different scenarios. Finally, the 3D rendering for a realistic representation was tested with LumenRT Geodesign for CityEngine.

The most relevant steps of the processing workflows are described below.

3.1 Data Processing and Homogenisation

The data processing consisted of the following steps.

Raster datasets:

- Laser scanning data were processed and generated as digital elevation model in the forms of Digital Terrain Model (DTM) and Digital Surface Model (DSM). The DTM is the foundation for all 3D modelling operations in CityEngine, such as flood, traffic or environmental quality. After generating statistical information on the DTM files (such as Average Point Spacing), the dataset was converted into a feature class, saved in a geodatabase and converted into a raster file in TIFF format; the extent was adjusted via the corresponding .tfw World-File. The DTM was then opened in ArcMap and exported as GeoTIFF (TIFF file with embedded georeferencing information). Imported into CityEngine, the DTM serves as height map file and can be textured by the supported available images (the high-resolution orthophoto or the ALK5000). The editing process of the DSM was similar to the DTM's. A height adjustment of two bridges in the study area was performed by matching DTM and DSM against each other. In CityEngine the DSM is used as a basis for the street network.
- High-resolution orthophotos were adjusted and optimized for 3D modelling. They were resampled to 50 % of their original resolution and used as a (temporary) texture for the DTM, as well as the roof-shapes of buildings.

Vector datasets:

² <http://www.esri.com/software/cityengine>

- Data from the official German real estate cadastre information system (building footprints from ALKIS) was directly saved in a geodatabase as a key feature in GIS.
- Road network data from Cologne's Open Data Portal (www.offenedaten-koeln.de) and OpenStreetMap (www.openstreetmap.org) were imported into CityEngine and manually edited to correct errors particularly in complex structures. The rule file "Street Construction" was used to bring the streets to life; the rules file "Complete Streets" shall be used additionally to revise and further improve the streets. The network was then aligned to the terrain (DTM) using an offset of about 1 m.
- Open areas, green spaces and water bodies were extracted from the ALKIS dataset based on land use attributes; texture was added in CityEngine.
- Tree cadastre was imported and missing trees manually digitized from the orthophoto, LIDAR data and DSM. The trees were then aligned to the terrain (DTM).
- CAD data generated by landscape architects and city planners for future development scenario (STADT KÖLN 2014) were migrated into the 3D geodatabase. These datasets were then enriched with building textures, heights and roof forms.

Tabular information with geospatial context:

- Energy consumption certificates of existing buildings (BEST tables / EnEV analyses) were joined with the existing building dataset in GIS. A 3D model with building energy consumption was generated.
- Traffic data were joined with the existing street network in GIS.

Environmental data comprised noise maps for a multidimensional 3D representation of traffic noise impact and flooding maps for flood events and simulations in 3D.

Other data are the georeferenced facade photos used for realistic 3D modelling of buildings.

3.2 Procedural Generation of LOD 3 Buildings

The 2D building footprints were loaded into CityEngine and aligned to the terrain; 3D models were then generated from rudimentary shapes up to the Level of Detail (LoD) 3, i.e., with high detail, facades, roof-shapes, and suitable for high-quality renderings.

Rudimentary 3D shapes were initially generated using CityEngine's CGA-scripting (Fig. 1). Due to the low resolution of the DSM, calculating the correct building height and roof angles for non-flat buildings can become complex. A simple solution was to use an approximate approach that employs 80 % of the maximum building height with a 30° roof angle for buildings with shed-type roofs. At this stage, a representative large-scale model was generated semi-automatically using attribute data (floor count, building use) and a generic texture set.

To generate building models reflecting their real-life counterpart, each building required a custom rule to generate its facades. Before this step, the base model was simplified into a cuboid (plus roof shape) to maximize the use of repeatable patterns. Since the final model draws textures from a unique folder, placeholder textures were used for orientation. The simplification process differed from building to building, ranging from, if necessary, cleaning up redundant polygon vertices to removing protrusions.

To reproduce accurate facades, georeferenced photographs were used as a visual guide and supplemented with imagery from Google StreetView and Bing Maps Bird's Eye View to

patch up areas where street-level photography was not possible. Since most buildings in Mülheim South are too large to fit in one single photograph, panoramas were built from multiple images and then rectified to compensate for perspective distortion using Photoshop “Photomerge” and perspective crop. The resulting image was then projected onto the basic building shape and used to create component splits, which were then used to define the final splits with reference texture-loading rules. In this step, the buildings were also split up into separate horizontal floors according to their floor count attributes (Fig. 1).

Since building facades in the area follow repeatable patterns with slight deviations, an automated method to generate them was used, speeding up the processing workflow. Additionally, as patterns not only repeat within buildings but across multiple buildings, a library with reusable splits was built to further accelerate the workflow. A tree-style solution provided a flexible interface to store snippets of code (Aldensoft’s Snippet).

The final step in the building creation consisted of assigning textures to the defined splits (Fig. 1). Depending on the desired accuracy and quality, renders, components extracted from panorama photos or close-ups taken alongside the panoramas were used. The latter two represent the most faithful but also most time-consuming options, as each object needs to be extracted and usually edited for example to remove reflections from glass.

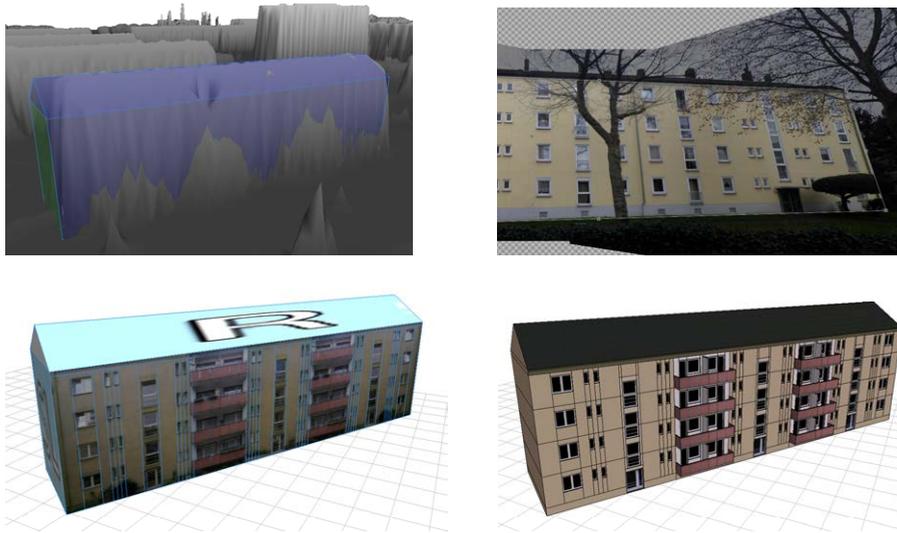


Fig. 1: 3D building generation steps – rudimentary 3D shapes, facade texture from photos, split component, and final result with texture and horizontal floors

Should time constraints prohibit this modelling method, an alternative semi-accurate approach can be used with an attribute-switch driven “base rule” that contains several facade forms (collected from the modelling procedure described above, or created separately) and serves as template. Here the height of the building is derived from the floor number attribute multiplied by a fixed floor height, which is then added to a base foundation height. Parameters such as building direction or wall texture can be switched with a simple attribute change. Generic facade textures can be sourced from a shared folder; unique items can

be stored in unique building-specific folders. With this method, a simple building can be faithfully recreated within minutes, provided the base rule contains facade variations that reflect the building's structure.

The 3D building models were generated for Mülheim South's current state (Fig. 2) and for the future scenario planned by the city of Cologne (Fig. 3). In the latter case, the sketches of architects and landscape planners (STADT KÖLN 2014) were used as the main source of information on the shape and facade of the planned buildings.

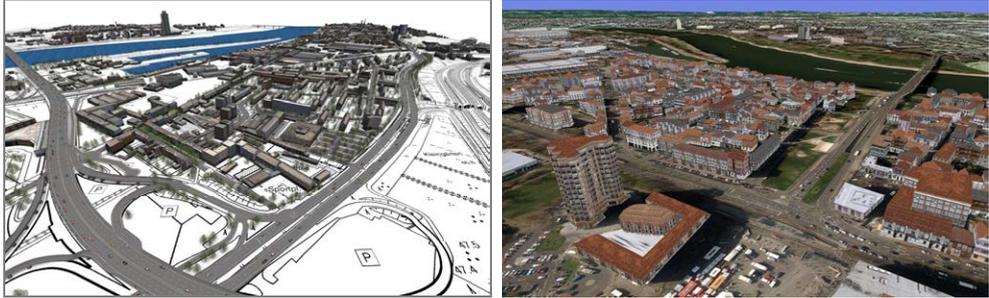


Fig. 2: CityEngine 3D visualisations of Mülheim South *status quo* with facades



Fig. 3: CityEngine 3D visualisation of Mülheim South future development scenario

3.3 Environmental Applications

As examples of environmental application development, Figures 4 and 5 illustrate the coupling of model calculations with the 3D buildings database of Mülheim South.

The existing 3D noise model used by the city of Cologne to assess the noise impact on buildings was displayed with 3D noise level points on the streets and at the building facades (Fig. 4). The visualisation of the noise impact on different building floors shall be improved.

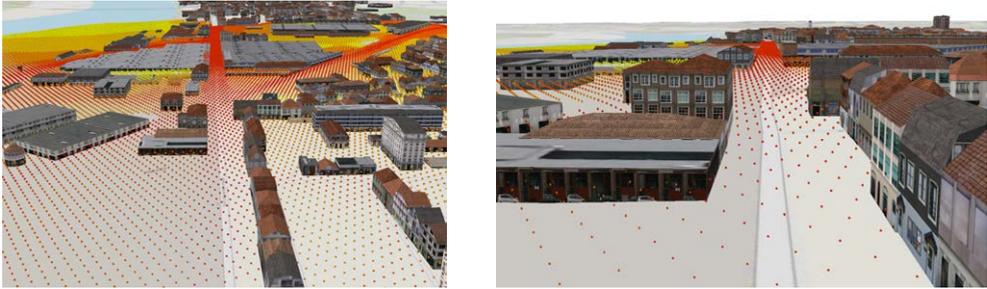


Fig. 4: Coupling of the 3D noise model points (x, y and z values) with the 3D geodatabase

The other thematic example depicts the visualisation of building energy demands (Fig. 5). CityEngine's CGA conditional rules were used for the thematic analysis of the 3D buildings based on their energy use attributes and a defined colour scale as well as a texture switch to blank out textures to enable a uniform coloration. Depending on the data available, a floor-level coloration was also possible.



Fig. 5: Visualisation of energy demands of individual buildings in Mülheim South

3.4 Web-Based Application for Citizen Participation

A public participation tool is under development at Esri's cloud-based ArcGIS platform as a method for assisting participatory planning processes. The 3D visualisation of the *status quo* and the development scenario helps citizens to better understand the terminology used in the urban planning process. CityEngine helps to visualise alternative implementation scenarios using several iterations using CGA rules.

As depicted in the workflow (Fig. 6), firstly geospatial data was processed. Once the geodatabase was ready, all data was uploaded to the cloud solution of "ArcGIS Online". Using several application templates with a minimum software development effort, a series of applications were deployed. When we consider usage of mobile devices, the most crucial part of the development process was to deploy the apps in a way that they would be accessible through all mobile and desktop devices, so all apps developed are fully platform-independent.

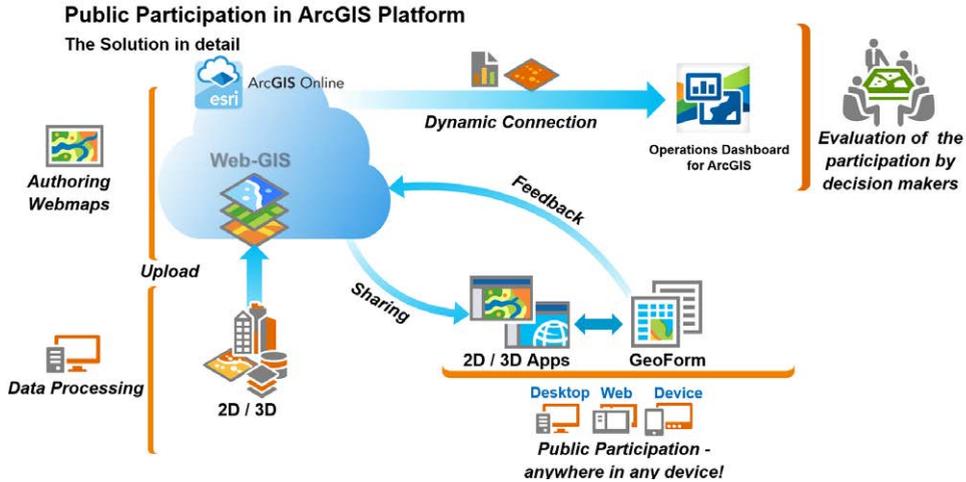


Fig. 6: Workflow to provide a web-based public participation tool

The starting point of the workflow is the web app as seen on Figure 7.

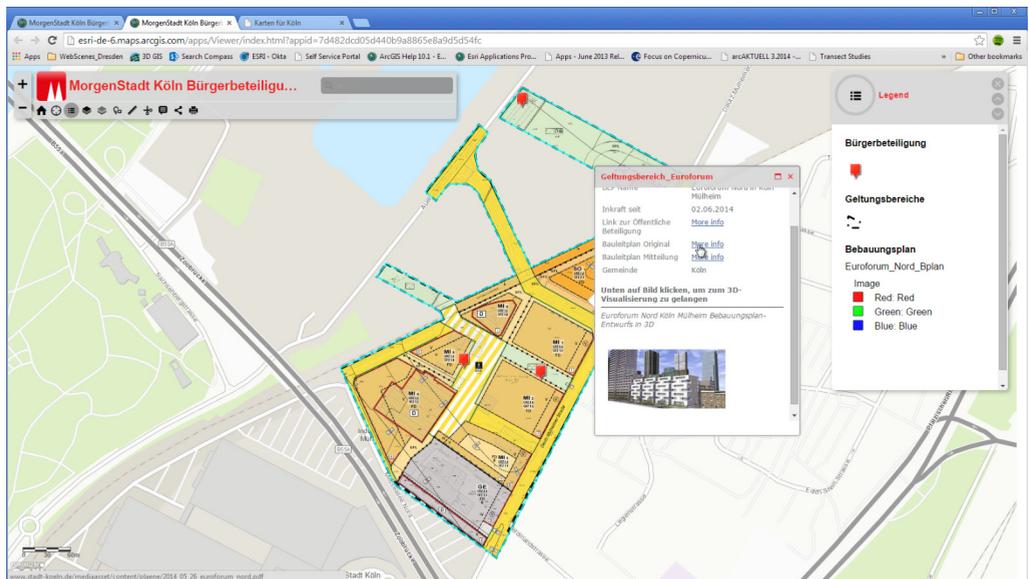


Fig. 7: User interface to select a planning area

The next step is to go through the pop-up menu by clicking the links given. One of the links provided is the 3D scene of the planning area, which is authored using CityEngine and published via ArcGIS Online. This 3D web scene doesn't require a plug-in and can run in any browser that supports WebGL technology (Fig. 8).

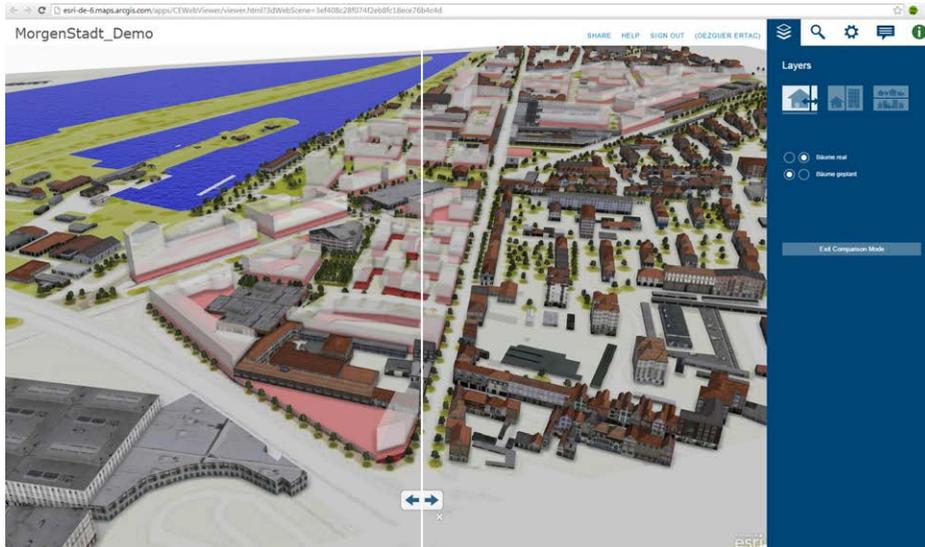


Fig. 8: 3D webscene with sliding bar between *status quo* and development scenario

After collecting all required information, like zoning regulations with maximum heights or land use about the planning area, citizens can attend to the process by filling the geo-enabled web-form as depicted in Figure 9. The technology used here is so-called GeoForm template, which is also publicly available in Github³. The citizen populates a table of a point features by filling the form in an easy way.

Fig. 9: Form for citizen's input

Once the citizen submitted his/her opinions with a pin on the map, the online geodatabase is immediately updated. But how the decision maker can assess the citizen's participation? Does a decision maker need a deep GIS knowledge to understand the meaning of the point

³ <https://github.com/Esri/geoform-template-js>

feature that stands for the participation? The Operations Dashboard was the answer to those questions by providing a simplified but informative solution.

As seen in Figure 10, the dashboard view provides a summarized view for each decision maker. Several widgets like performance gauge to test the success of the public participation play a crucial role to make better decisions for the future.

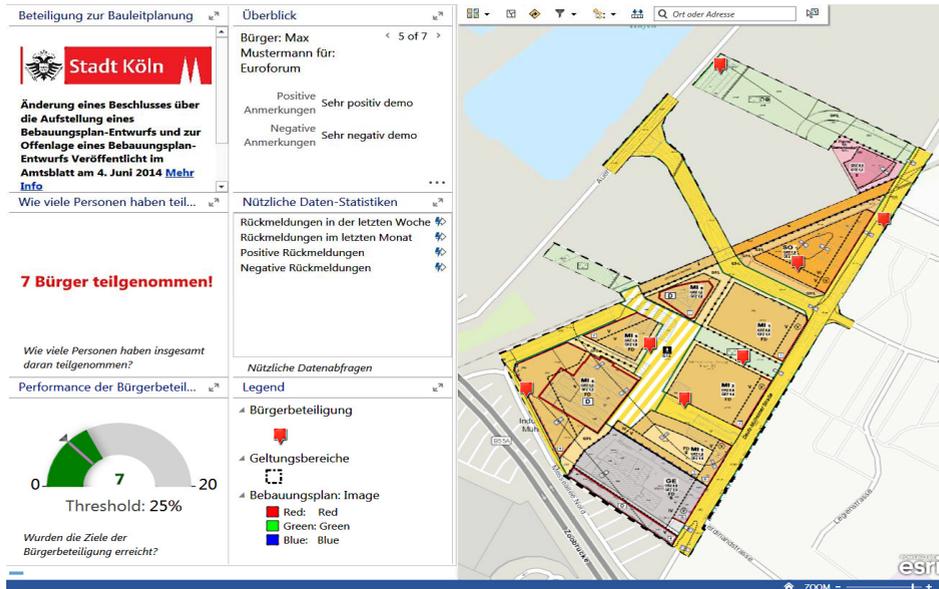


Fig. 10: Dashboard of citizen's inputs

4 Conclusion and Outlook

The GIS software industry delivers advanced tools for 3D visualisation and analysis, but the implementation of a holistic approach to sustainable urban development requires not only the knowledge of the software tools and the capability to make an applicable geodatabase design, but also deep know how on the interpretation of environmental and planning data.

Within the framework of the Fraunhofer "City of Tomorrow" project, 3D Mülheim South GIS models, several tools and web applications are under development to create an interactive 3D decision support platform for the city administration, planners and citizens. The platform is expected to be available on the City of Cologne's website in mid-2016.

From the experience of Mülheim South, we expect to identify the best combination of integrated tools for urban and landscape planners. Potential future applications of the results of this effort include:

- Use of the 3D city models for various tasks, e.g. modelling of flood, traffic, energy consumption, water supply and disposal, air pollution, noise and environmental quality using the available data and models of the city administration;

- Realistic visualisation of *status quo* urban landscape and of future development scenarios to facilitate participation of citizens, urban planners and decision makers in the planning and decision processes.

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Disclaimer: this paper describes the preliminary results of an ongoing project that is expected to be concluded in June 2016.

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