Multiple perspectives on a point cloud

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MULTIPLE PERSPECTIVES ON A POINT CLOUD

Interview with Gerhard Schrotter

From a technical point of view, what do you understand by a three-dimensional reconstruction or a point cloud?

Coming from the field of photogrammetry, I was used to reconstructing a space in 3D with the help of oriented photographs and digital images. With the known orientations and positions of the recording locations and the calibration of the camera (also called inner and outer orientation), a three-dimensional reconstruction can be brought about with the help of detected, identical points in the image space. Therefore, I can see the situation I want to measure on the images and can then reconstruct specific points, lines, or surfaces. By taking several photographs, I can optimize the quality of the reconstruction and validate it afterwards. This method also has similarities to binocular human vision and our ability to locate and orientate ourselves in space.

With laser scanning, we do not know which elements we are measuring in reality and at what time. A laser scan provides us with a large number of 3D points – almost a 360-degree point cloud. This point cloud seems to correspond to reality. We see structures that we recognize, but we also perceive points that cannot be directly assigned to reality, so-called artifacts or blunders. There are many terms for this, depending on which field you come from.

Can you clarify the statement "we do not know what we are measuring"?

Let's assume the following situation: we want to record a static object in a static environment. The distance measurement by laser scanning without the use of special reflectors is done directly on natural surfaces. In contrast, we know traditional surveying where a reflector is used for a specific distance measurement – point by point. For example, say we buy a laser rangefinder in the hardware store and attempt to measure a distance with the red laser dot. In that moment, we are aiming at a surface that we assume is flat and aligned approximately orthogonally to us. We probably wouldn't think of aiming at a window-pane, would we? Also, we are satisfied if we then get the distance

Fig.13 ETH Zurich Main Building, 2021.
Axonometric view of a staircase.
By Kaspar Stengele, Morris Widmer

displayed in the millimeter range and the reliability is guaranteed. After all, we want to be certain and take responsibility for ensuring, for example, that a wardrobe fits perfectly into a room. We also avoid the laser beam splitting at edges or corners. This can lead to beam divergence at convex or concave edges, or to step light or light stripes. However, the concentration of the laser beam on natural surfaces almost always reflects enough light. Therefore, the reflectorless distance measurement can fail or can be falsified or systematically influenced due to the reflection properties, particularly the described geometry and material of the target. The color of an object, the absorption spectrum of the material, is also decisive. If a red object is illuminated with a red laser, very little light is absorbed and the so-called reflectance for the laser light is particularly high. Extreme temperatures, air pressure, and humidity also influence the measurements. All these factors must be taken into account, especially for long distances and, for example, in tropical countries. The calibration of the instrument must also be checked to reduce the systematic influences mentioned.

What does the actual situation or the real application look like?

Let us now change the assumed situation of the static object in a static environment – welcome to reality – to an environment in constant change. Let's take the facade of a building. The trees in front of it move due to a slight breeze and cast shadows on the building's facade, cars are being parked, and the picture changes due to bicycles passing during the scan. Objects that move during the scan create so-called ghost effects. These are clusters in the 3D point cloud that cannot be assigned to reality. In short, many challenges arise even with a single scan and in a local point cloud system. In the further course of the evaluation, the individual local point cloud systems must be connected with each other (co-referencing) and possibly referenced to a higher-level coordinate system, georeferencing in the case of earth-based spatial reference systems. Identical 3D points must be found in the local systems so that the link can be established. Subsequently, this system needs to be fitted into an absolute coordinate system via existing control points. This means that there is a continuous error propagation until the final result is achieved, which makes it difficult to guarantee a given accuracy.

These are alarming views on the method of laser scanning. How can we apply the method despite these difficulties?

The requirements for the quality of the scan depend on the user and its intended application. All the described challenges can be put into perspective and classified if the purpose of the scan and the further processing are clear. There are also excellent filters that can improve the point clouds, but operators must be aware that a scan never represents reality 1:1. We are striving for a digital abstraction of space. Operators should also be aware that not all problems that occur in a scan can be corrected in post-processing in front of the computer. There is a term in the surveying world called GIGO, an initialism for "garbage in – garbage out." Therefore, scanning should be done with care, and low-quality scans should be repeated on site after visual inspection. Information about scans should then be summarized in metadata (information about the data) and in the documentation of each project. Metadata formally describe the characteristics of the data collected and then made available. They are essential because they allow a user to learn about existing data and to compare and combine multiple data sets. Standardized metadata and procedures for accessing and managing metadata catalogs are needed to support the interconnection of datasets. It is precisely in making 3D data or geodata accessible that we have a lot of catching up to do. Here, terms such as a common, available point cloud server or the expansion of the spatial data infrastructure are in the air.

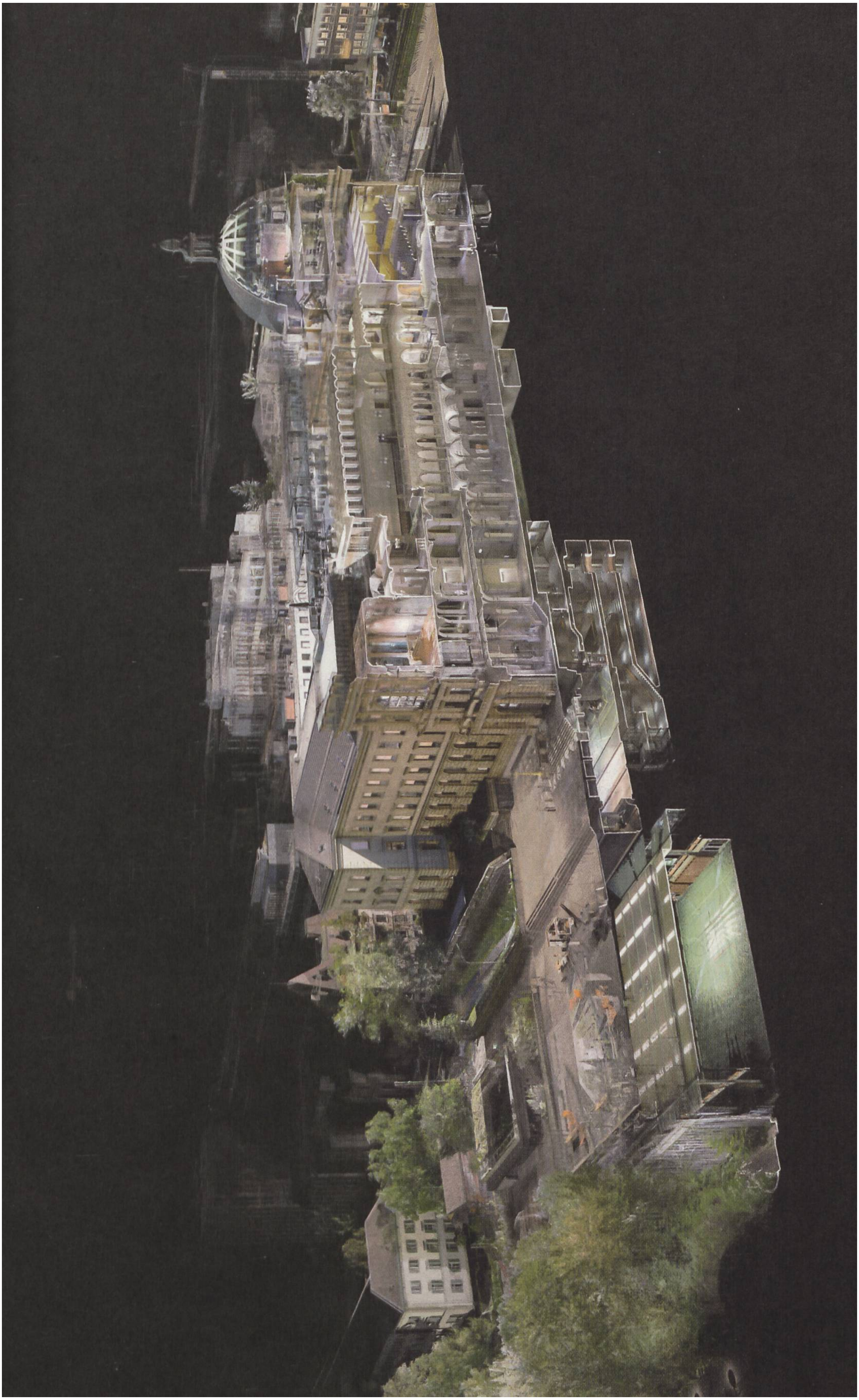
If we shift our focus, what does the term "geodata infrastructure" mean for a city like Zurich?

A geodata infrastructure (GDI) is understood to be a generally available system of procedures, institutional facilities, technologies, data, and people that enables or sustainably ensures the common exchange and efficient use of spatial data. The geodata infrastructure of the City of Zurich enables the networked use of spatial information by means of geographic information services and corresponding specialized applications. Legally, the GDI is based on the Swiss geoinformation legislation (GeoIG/GeoIV). Among the geodata, few 3D datasets are made available. The digital 3D city model by Geomatics + Surveying Office (GeoZ) is available over the entire municipal area. The 3D city model has a three-level structure and shows different levels of detail. The basis for the terrain model is a raster file of the Canton of Zurich, generated from LiDAR (light detection and ranging) images with a resolution of 50 centimeters. In areas close to bridges, additional break lines were recorded. Manual adjustments were made in areas of the lake and the River Limmat. The road geometries of the official cadastral survey were additionally introduced as break lines.

The block model is based on real and projected building ground plans located below the terrain. The two photogrammetrically determined heights of eaves and gables are assigned as attributes to the ground plans. In the case of buildings with a high recognition value and striking differences in height, the ground plans are subdivided such that the buildings are represented by several prisms of different heights. In addition to the buildings, the 3D block model includes prominent bridges. The roof model consists of the walls and detailed roof structures of the buildings. Analogous to the block model, the building ground plans of the official cadastral survey serve as a basis. The roofscape is evaluated using semi-automatic stereo aerial photography. In addition to the buildings, prominent bridges and walls are included. Thus, the digital terrain, more than fifty thousand buildings in different levels of detail, as well as walls and bridges, are available.

The 3D geodata are mainly used in the city administration in special applications in the fields of environment and urban planning and are released in extracts to third parties for the visualization of planned construction projects. The requirements regarding content, accuracy, tracking, and reliability have been developed in cooperation with various users of the city of Zurich. The data of the 3D city model are made available internally via the GeoServer and externally via the Geoportal. The updating and creation of 3D geodata is the responsibility of the respective internal unit, which usually also maintains the underlying 2D data. This principle of responsibility, as enshrined in the aforementioned geoinformation legislation, thus also applies to the data of the 3D city model. The data sets show the model for different years. For an attractive visualization, an internet application was also built, which is called Zurich 4D.

Fig.14 ETH Zurich Main Building, 2021.
Sectional view.
By Robin Rohner, Dominic Steigmeier



You mentioned the term "3D city model." Is this the digital twin of the city of Zurich?

The digital twin of the city of Zurich is a digital, spatiotemporal depiction of the city, meaning a representation of the present, the past, and the future. It is a collection of digital spatial data from GIS (geographic information systems) and BIM (building information modeling). Thus, it encompasses much more than the 3D city model, which is limited to homogeneous, city-wide 3D geodata. The digital twin of Zurich is used to simulate scenarios and is updated with varying frequency as needed. This digital representation of the city can be used, for example, to investigate questions of urban development and urban planning in the context of climate change and climate neutrality. The digital twin of Zurich is anchored in the city's strategic focus as a digital city. The term is very well suited at the strategic level to make the complex subject matter comprehensible. In addition, it connects the areas of GIS and geo-information with BIM. In the future, both areas in the City of Zurich will be managed by the BIM–GIS control and driven forward by two coordination bodies.

The term point cloud no longer appears in these descriptions?

The point cloud is a valuable basis for a wide variety of derived applications. Let's take the example of the Streetscape 3D project. All public urban and cantonal roads and the entire tram network of the City of Zurich as well as selected cycle paths and squares are surveyed. The facades bordering the streets are also visible on the data. High-resolution photos are taken continuously (every two to three meters, depending on the speed of travel) while the scanning vehicle is in motion. In combination with a laser scanner that scans the surroundings while driving, a point cloud is generated. With this project, the City of Zurich is creating a digital image of its streets and all public spaces. Municipal employees now have the ability to go virtually to any place in the public space and quickly get an impression of the situation. In addition, lengths, widths, heights of objects, and the exact geographical location can be measured on the computer. On-site inspections and measurement campaigns can thus be reduced. The project facilitates, for example, the survey and inspection of benches, trees, parking spaces, road markings, lane guidance, and signaling. Temporary diversions and alternative routes can already have been driven on the computer before the actual test drive. The data provide an initial planning and visualization basis for measuring road cross-sections, lane widths, and clearance profiles. They are a basis for digital models of infrastructure structures. Preliminary clarifications for window replacement, facade insulation, color concepts, and shading can take place virtually. The recordings help in deciding on applications for the use of public land, and for the police they are an additional tool for deployment planning. They are another data set for the periodic updating of the official cadastral survey and generally improve the data quality of the municipal GIS data.

Where is the underground in this model?

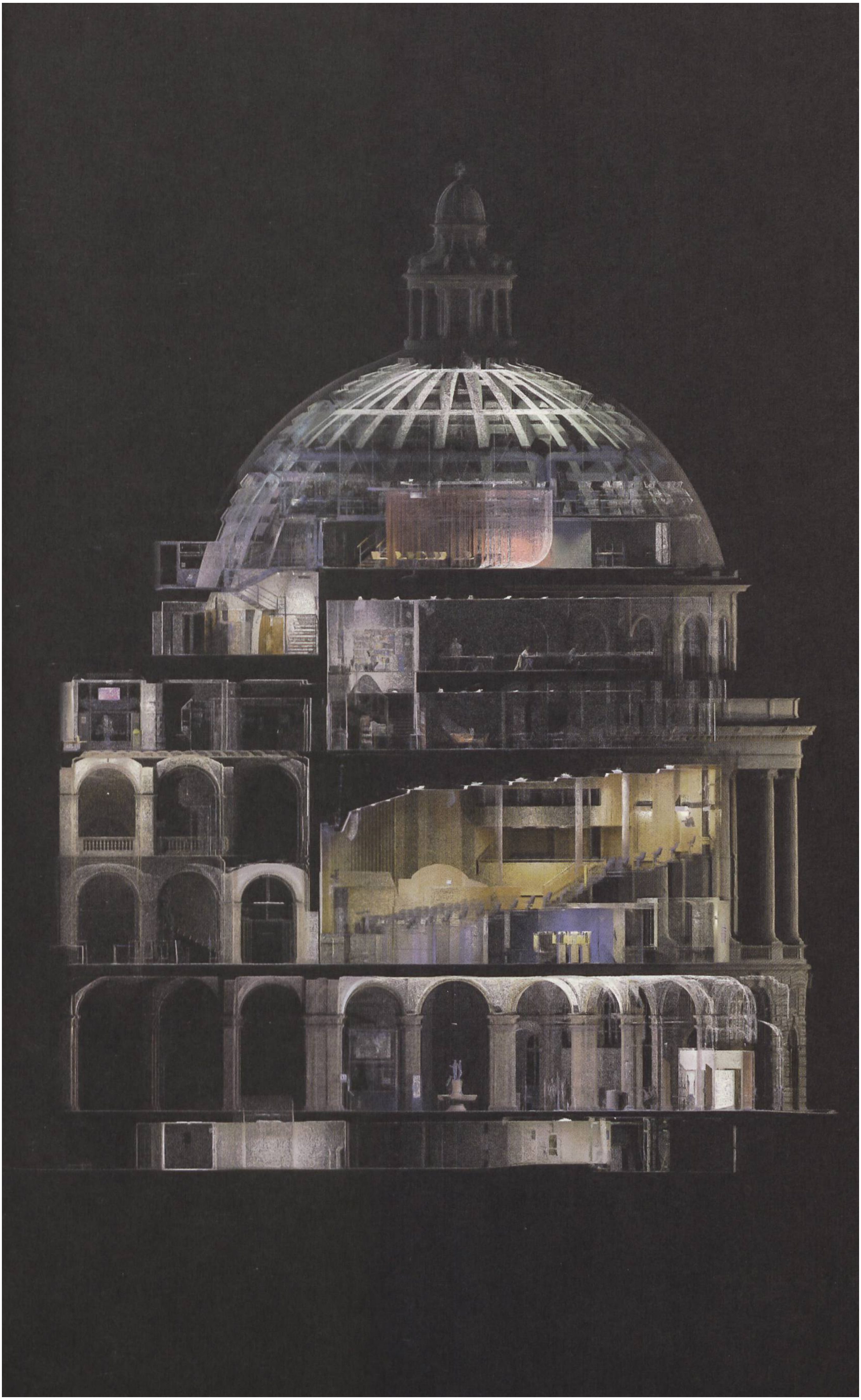
We know a lot about underground utilities. Since July 2013, the city of Zurich's utility data has been submitted centrally via the Geomatics + Surveying Office. The service includes data from the Zurich Disposal and Recycling Services, Electricity Service, Water Supply Service, Energie 360° SA, and Public Transport Service. Most of the lines have been digitized from traced plans, and the positional accuracy is in the range of twenty centimeters. Utilities due to construction work, for example, are marked as inaccurate. The utilities cadastre of the City of Zurich is a subset of the digital utilities documentation of the utility owners. The data is delivered automatically by the utility owners to the pipeline cadastre operator (GeoZ) at least once a week and held centrally. In terms of content, the suppliers remain responsible for the data (timeliness, completeness, location accuracy, and so on). The operator is responsible for ensuring that the data is taken over and offered completely, regularly, and unchanged. The utility owners in the City of Zurich already measure 3D coordinates. However, this information is lost on the interface to the utilities cadastre. This is now to be adapted and the creation of BIM-capable utilities cadastre extracts is to be made possible. In the Digital Underground project at the Singapore-ETH Centre, various measurement methods are being evaluated in cooperation with the Singapore Land Authority and industrial partners for pipelines that have already been laid but whose location or depth is uncertain or for which no useful information is available.[1] In addition to the measurement methods, new modeling approaches are also being pursued. An exchange platform, DUConnect, has also been created to discuss experiences worldwide. In connection with planning and building underground, the City of Zurich has some catching up to do. However, this topic is currently being addressed by the city administration.

How about the modeling of vegetation?

In my diploma thesis I dealt with the topic of 3D city models on the internet. This was twenty years ago. Back then we worked with the Virtual Reality Modeling Language (VRML). This is a description language for 3D worlds and was originally developed as a human-readable 3D standard for the internet. Over the years, this standard has long since become obsolete. To minimize the transfer of data volume, the so-called billboard technique was used. Trees were abstracted with images, then these images were scaled accordingly to indicate the real height and implemented in the virtual world. These billboards adapted to the viewing direction and aligned themselves orthogonally to it. This more or less worked as long as one moved within the terrain of the model and took a virtual walk through it. However, this method failed completely for perspectives from above and below. It was also useless, for example, for simulations, profiles, and so on. Then computer graphics tried to form an abstraction from a small number of real points using so-called voxels. This method is used, for example, in geology to represent the subsurface or can be realized in urban development in various participatory computer games (such as Minecraft) for the development of a neighborhood in collaboration with the residents. Then came the first attempts at rough abstractions of trees via standardized trunks and, depending on the tree species, adapted tree crowns mostly from aerial photographs. Then came the failed attempt to generate solid objects by elaborate

1 Rob Van Son et al., "A Framework for Reliable Three-Dimensional Underground Utility Mapping for Urban Planning," International Archives of the Photogrammetry, *Remote Sensing and Spatial Information Sciences* 42 (2018), 209–14.

Fig.15 ETH Zurich Main Building rotunda, 2021. Vertical palimpsest. By Tom Bauer, Philipp Eitel



triangulation of trunk, branches, and so on from laser-scanning data. There are libraries on the internet where different models of different vegetation can be found. The amount of data exploded quickly. They tried to reduce it again and ended up with a point cloud, which is the best compromise between representation, analysis, and simulation at the moment. A textured point cloud provides a realistic representation of the vegetation. The amount of data can be easily regulated (also in real time), which in addition enables dynamic provision on the internet. Laser scanning can also be used to analyze effects such as permeability of the vegetation (in principle a negative effect, as artifacts are created). Profiles can be calculated. This type of representation, in combination with solid objects such as buildings, seems to be gaining acceptance at the moment. In the City of Zurich, we try to apply a mixture of different methods for different demands. The demands range from very realistic representations of trees for integral visualizations of squares (surface and underground) to very abstract modeling of vegetation for the analysis of strategic issues (heat mitigation, urban trees). The basis for all visualizations and analyses or simulations is the tree cadastre, which is maintained by the Office of Parks and Open Spaces. In addition to the position of more than 60,000 trees on public land in the city of Zurich, it also includes various attributes, such as the description of the growth form, the tree type, and so on.

In summary, what is the value of a point cloud from your point of view?

Three-dimensional point clouds are valuable basics which complement or provide the foundation for different measurement methods. If we add the intensity of a 3D point in addition to the geometric information – we also talk about 4D points, where the fourth dimension describes the intensity and not the temporal dimension – then we already have impressive visualization possibilities. The project Urban Landscape and Underground investigates precisely the process of merging, supplementing, and displaying above- and below-ground data in a point cloud model. By capturing the urban space, all accessible underground spaces (such as tunnels, sewers, and basements) by laser scanning (LiDAR), and the inaccessible underground by processing existing measurement data, a model can be created that represents the aboveground and underground elements and spaces of the city simultaneously and in detail. Through this form of visualization of the urban landscape, information and knowledge about a place can be conveyed quickly and comprehensibly, from which strategies and decisions for planning and design can be derived. Visualization makes information about a place easy to grasp and thus accessible and readable for a wide range of interest groups.