

A Virtual 3D City Model for Urban Planning and Decision-Making - The East Jerusalem Case

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Abstract. This contribution presents an approach for generating and modelling spatially referenced, multi-dimensional urban models from remote sensing data for regions where no reliable reference data are available. The focus is on a modular service-oriented process chain covering the entire process from data acquisition to effective web-based visualization, addressing raw data, preprocessing, management, spatial analyses, visualisation and applications. The use case, investigated in the framework of a EU-funded multidisciplinary R+D project, is the cityspace of East Jerusalem (about 190 about 190 sqkm). Due to the controversial geopolitical situation, usable and high-resolution reference data of the complex, granular urban fabric is unavailable. Hence very high-resolution stereo aerial images (571 pcs. à 10 cm GSD) were acquired and photogrammetrically processed to build a high-resolution 3D reference point cloud. Corresponding semantic data from various sources and household surveys (3,500 pcs.) specially conducted were integrated into the data and managed within a unified, fully-referenced 3D database (open-source). The resulting virtual urban 3D model includes functionalities for geospatial exploration and analysis, allowing spatio-temporal applications, such as land use/management, social/technical infrastructure, or tourism for documentation, information, education as well as decision-making. It addresses both the local civil society and, through specific functions, urban planners and decision makers. Analysis and interaction functionalities are provided in a user-oriented and application-related framework, taking into account effective visualisation (cartographic and visual gestalt principles). The independent spatial reference of a multi-scale grid is used for spatial analyses and visualisation purposes. The generic construction of the dedicated virtual cityspace allows for the transferability of results.

Keywords: Service-oriented workflow · Lack of reference data · Virtual multi-dimensional model

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1 Overview: Modelling

Abstraction and modelling serve as tools for understanding complex relationships. Models allow for complex systems to be made comprehensible and manageable. A model is an abstraction of reality under aspects relevant to problem solving. Thus, a model is - per se - always domain-specific [9]. A virtual city model designed for tourism purposes accordingly follows different principles or expectations than, for example, a model of the atmospheric circulation for meteorologists. As a rule, a model describes reality. By means of a model, it is possible - to a limited extent - to try out or simulate certain actions without directly manipulating objects within the real world. Regardless of their domain specificity, models are usually assigned to either data models or process models. Furthermore, modelling at its core involves abstraction and thus, to some extent, generalisation. Objects and entities of reality are consequently simplified in modelling. A model should describe or depict the real counterpart in terms of its objective characteristics and features so precisely and accurately that conclusions can be drawn about future events with a high degree of probability. Such a model can be seen as a kind of 'experimental sandbox'. Given a comprehensive synchronisation of the twin, which is mostly digital today, crown scenarios (e.g. accessibility of local transport), planning (e.g. housing construction) or simulations (e.g. flood modelling) may be transferred to reality with a high degree of probability. Figure 1 illustrates this relationship in a concise manner.

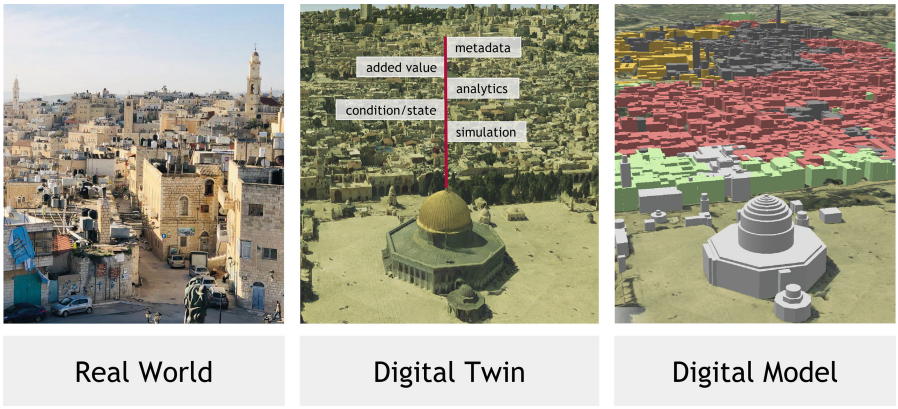


Fig. 1. Illustrated problem statement

1.1 Modelling: Virtual City Models

Virtual city models represent an application case where the spatial reference takes on an elementary and decisive factor [12]. Hence, at least two, usually three or more dimensions of a datum are already fixed by the spatial location.

The georeference of a datum therefore already represents a fixed characteristic of any city model, since the topology of space, i.e. the relationship between objects to each other, is decisive [13]. Consequently, a virtual multi-dimensional city model consists of geodata. Modern IT technologies, ubiquitous data availability, efficient management, processing and visualisation frameworks allow those models nowadays to be, by their appearance at least, deceptively close to reality. As already mentioned, this is the first stage of the fully synchronised replica of reality, the digital twin. An example of this is the current version of the simulation game Microsoft Flight Simulator, in which a large part of the real world has been reconstructed to scale as well as real weather events are synchronised at game time. Another example is the Google Earth system, which in the meantime has become a 'de facto standard' that can realistically represent spatial relationships and simple functionalities in almost every large metropolis in the world, in terms of appearance. The basis of virtual city models is usually municipal geodata, such as a digital elevation model, orthophotos, buildings of the real estate map, vegetation, street furniture, architectural models, development plans, domain-specific data, but also increasingly volunteered geographic information (e.g. OpenStreetMap), which is more and more available for urban areas and metropolises up-to-date, area-wide and in particularly high quality [3]. With the integration of these data stocks into a multi-dimensional city model, they can be used in a variety of ways and help, for example, to modernise urban planning and administrative processes and make them more transparent or allow applications, for example, in the areas of visualisation of traffic routing/flows, environmental analyses of noise and flood propagation, planning variants/scenarios in construction, energy and the economy. Furthermore, the presentation of e.g. geographic business locations or in city marketing for tourism purposes is an essential application [16]. The central task of the virtual (city) model, however, always includes communication and dissemination through the spatial representation, the 'spatial readability' and the ability of each person to efficiently and effectively derive connections and conclusions through orientation in space. As a result, a multi-dimensional (city) model can serve as a central information hub, analysis or information system, which above all makes it easier for decision-makers to visually link complex factual relationships to real structures and to share them in a universally easy-to-understand way [4].

1.2 Problem Statement and Application Domain

Typically, the essential factor 'data' is rarely considered in this type of model; most of the time, data is simply available. The case that a city model starts with data acquisition is hardly considered in the literature. Nevertheless, every city model is inevitably defined and characterised from the outset by its data. Within the framework of a research project funded by the European Union, the aim was to generate a model embedded in a web-based platform that allows both decision-makers and civil society to visualise spatial information and analysis results based on a virtual model of the urban Middle Eastern region of East Jerusalem.

Accordingly, the key research question is how to create spatially referenced, multi-dimensional virtual city models for spatial planning in urban areas that lack reliable spatial planning bases. The objective is therefore to construct 3D virtual city models for geospatial exploration, analysis, planning and decision-making, and to facilitate spatio-temporal applications for information, planning and participation of urban planning stakeholders (government and civil society). The application domain is the East Jerusalem region, the centre of the Jerusalem urban agglomeration. It is a complex cityscape (historical Oriental city with modern expansions), a complex situation of urban planning actors (Israeli municipality vs. Palestinian civil society), and a complex geopolitical status (UN two-state solution vs. Israeli annexation) [1,2]. As a result, there is a lack of reliable, up-to-date and high-resolution geodata for spatial planning applications [14].

2 Approach and Methodology

Given the lack of suitable reference data, the research question and the original objective, the creation of a virtual multi-dimensional city model, is expanded to include the transfer into a complex service-oriented process that is component-based or modularised. However, the objective of this process is to create a virtual multi-dimensional city model in the absence of suitable reference data, and to transform it into a complex service-oriented process that is component-based and modularised.

2.1 Related Work

Multi-dimensional virtual models are mainly available in large metropolitan regions or cities nowadays. This is primarily due to better data availability, both geometrically and semantically, compared to, for example, rural areas [13]. Open Data Portals or VGI, such as OpenStreetMap, also demonstrate their strengths in metropolitan areas [4]. Comparative work and processes for generating virtual city models - without adequate reference data - therefore usually disregard the aspect of data acquisition due to the initial situation described [5]. A comprehensive workflow, including data acquisition, is therefore as yet not available or usable, far less transferable [18]. Paradoxically, the 'de facto standard' for virtual city models, the CityGML standard, does present obstacles, because this conceptual model or exchange format only allows a standard-compliant transfer once a database is available. Acquisition is not part of this concept. Special methods and techniques for processing geodata, storing them and making them usable are partially available and used as sub-modules of the presented concept of a comprehensive workflow.

2.2 Service-Oriented Workflow

The comprehensive process presented in this paper 'from data to a feature-rich virtual city model' can be structurally divided into the essential segments 1)

(Raw)Data, 2) (Pre)Processing, 3) Management, 4) Analytics, 5) Visualisation, and 6) Applications. To a certain extent, this contribution represents a kind of bracket around already conducted own assessments and published results of research. An essential introduction to the service-based concept has already been given in [8]. Furthermore, in [6] it can be read how data acquisition was made in detail and how the necessary data stock was generated and managed. Finally, in [7] methods and techniques have been presented on how a virtual multi-dimensional city model can be created from acquired geometric geodata and semantic context. An overview of the workflow is shown in Fig. 2.

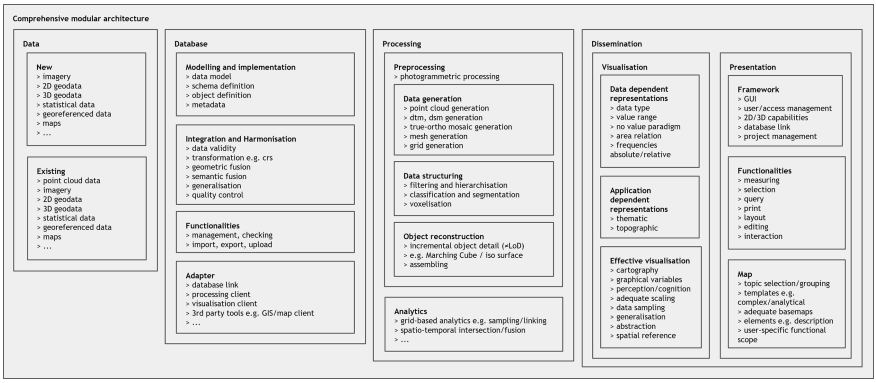


Fig. 2. Modularised overview of the service-oriented workflow

Data. An indispensable and important, base-relevant component of the workflow is geodata. Geospatial data, also known as geographic data or spatial data, refers to data and information explicitly or implicitly associated with a location in relation to Earth [9]. Common types of geographic data include vector files consisting of simple points, vertices and paths, raster files consisting of pixels and grid cells, geographic databases that typically store vectors and rasters (0D, 1D, 2D, 3D), and multi-temporal data that add a temporal component to the information (4D). Moreover, if further feature spaces are added by means of semantic enrichment, it can be referred to as multi-dimensional geodata. Such geographic data can be recorded and generated, for example, using telematics devices (GNSS or total stations), geographic aerial and satellite images, lidar or laser scanning, the Internet of Things, and VGI or geotagging. Authoritative or accessible geodata usually form the backbone of any application. In this case, it is about the most accurate representation possible of the geometric characteristics of an object and the semantics attached to it. In this context, it is referred

to as geo-reference data. For a digital city model, geometric representations of the contained objects (including buildings) are crucial. Depending on the purpose of the model, further thematic data (demography, economy, traffic, official) and topological data (heights, environment, hydrography) are used for modelling [10].

Point clouds are particularly suitable for modelling the most accurate possible representation of reality. A point cloud or a point heap is a set of points of a vector space that has an unorganised spatial structure [5]. It is described by the points it contains, each of which is captured by its spatial coordinates. Point clouds with georeferencing contain points in an earth-related coordinate system. Additional attributes can be registered for the points, such as geometric normals, colour values, time of recording or measurement accuracy. As a result, the point cloud represents an ideal invariant reference data set. However, for the object formation (for example of a building) a multitude of digital processing techniques are necessary [5, 7].

Import. The integration of new data sources or the updating of existing data starts with the import. This must be carried out per data format or data source in order to comply with all technical limits. The import can be adjusted to the data collection system, as it does not change. However, the time of collection (for example, in a year) can change the data. The constancy of data collection by modern sensor systems usually makes it easy to fully automate the import process [15].

Cleaning. The first step is to check loaded data to remove errors and outliers. This step usually has to be done per data source and increases data quality from the beginning [15]. Secondly, in some cases the raw data needs to be adjusted by modelling accuracy (approximate and interpolate). Thirdly, it can be helpful to convert all data to the same coordinate projection to avoid later processing problems. Modern geoprocessing tools allow the on-the-fly integration of those subprocesses. The cleaning process can also be automated in most cases, but it does not replace a final check and quality approval; this remains mandatory [10].

Assessing. Each data source must be assessed in terms of its quality. This is because each source has a different accuracy and level of detail (for example, age or measurement accuracy of different recording systems). The same applies to official cadastral data [9]. Geospatial data can be generated or referenced using high-precision differential geodetic measurements, while other geospatial data is acquired using, comparatively simpler, handheld GNSS trackers to record a position (without reference station or post-processing of errors). The assessment process can also usually be automated for each individual data source, especially if reference data is available for verification. Metadata is suitable as documentation in this case [10].

Processing. Following processing, more information can be derived from the imported and cleaned data compared to the direct use of the raw data. For example, the diameter of tree crowns and the tree heights at the time of measurement can be calculated from laser scan or point cloud raw data, so that there is no need to resort to official cadastral data, which are updated less frequently. Aerial imagery can be used to determine the location and quality of objects for large areas without the need for small-scale measurements [18]. The disadvantage is that aerial photographs are sometimes not spatially resolved precisely enough to use the derived data directly, however. In this respect, data may sometimes need to be adapted for use in subsequent processing steps. Information about buildings, for example, can be very detailed and include protrusions and niches, for example. It may therefore be necessary or required, depending on the modelling purpose, to remove such details from the very beginning and procedurally recreate building models to make them more suitable for further processing steps [5]. Occasionally, the data must also be converted into another data format during processing. Nevertheless, data processing can usually be automated as well. This is especially true if the data source with its data semantics does not change and the structure of the data remains the same. If one of these points changes, the processing algorithms must be adapted.

Harmonisation. Various data sources have to be amalgamated in order to obtain an overall representation. Data of a city are versatile and consist for example of vector-based cadastral data derived from mobile maps and aerial imagery or volunteered geographic information. These different data have to be merged despite their temporal and spatial differences. For the fusion process, the results of the assessment are useful to select the best source as ground truth or reference for all other sources [13]. This selection must be made for each crucial element. The fusion of the data is the most difficult part of the whole process chain. Especially when different and many heterogeneous data sources are needed for further processing, the fusion process has to be adapted consistently. This is because the sources used usually do not provide updated data at the same time, or sometimes there is no data at all [17]. Therefore, the ground truth selection may also change. Information that is only tangentially linked to other data is easy to include in the description, whereas this is more complicated for data that is already an amalgamation of different data sources. This principle leads to a multi-stage fusion process. The more information is linked to other data, the more complex the fusion process is. For instance, as a result, information should separate the road infrastructure and street furniture, which may change their position and type more frequently, from the topographic description of a building. This makes it possible to update the road infrastructure layer without considering many dependencies. During the fusion it is also conceivable to make necessary spatial corrections if road infrastructure etc. are not completely necessary to the road layout. The fact that this correction can usually be made on-the-fly and is not kept in the data makes the undoing of a correction in an outdated road description dataset obsolete during the update

process. Such fusion is essential when data sources need to be replaced. It could be the case that a data source (e.g. aerial imagery) may no longer be available, but a comprehensive cadastral survey becomes available and affordable.

Storing. The cleaned, processed and amalgamated data needs to be stored. For this purpose, simple and open description formats should be used. They are usually implemented in corresponding geographic information systems (GIS) or standards like OGC specified. In addition to geometry types (vector and raster), a distinction is also made in data types and forms of representation (discrete, continuous) [10]. Consequently, storing in the form of individual data sets merely creates a bundle of distributed databases arranged in a federated hierarchy. A crucial point is the linking of data. It is highly desirable to link as much information as possible directly across different database components. Therefore, domain-specific data formats should be avoided, as they are optimised for their specific use case and only contain the problem of implicitly representing certain features. Simple and open description formats that can be mapped to common geometric elements, with contextual information stored as attributes, should be preferred. The use of simple 3D features (Point, LineString and Polygon) for comprehensive modelling of, for example, a road environment, forms the basis for the versatile use of such a database [17]. The use of a simplified data model for objects enables detailed modelling of roads and buildings and their surroundings through relationships. With the help of mostly automated conversion, different and very specific output formats can be provided for domain-specific use, while simplified elements are translated into complex representations with the required spatial precision. Data storage is generally fully automatable. The data to be stored is known, as is the storage format. Once implemented, it can therefore be used again and again [10].

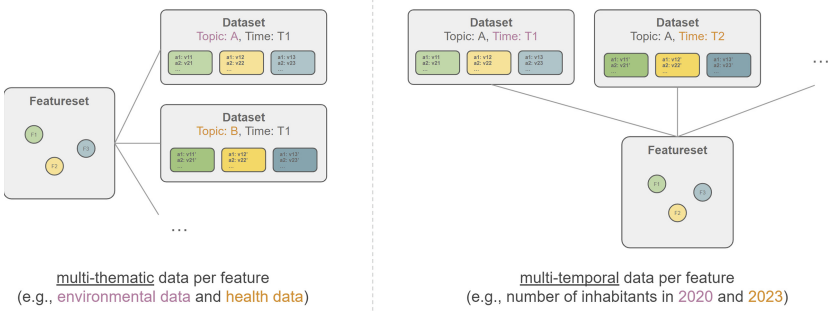


Fig. 3. Object-oriented modelling to enable multi-thematic and multi-temporal processing

Versioning of data also plays an important role, especially when it comes to data describing flows. They can be used later to analyse progress and can

be included in simulations to better assess the (temporary) impacts [10]. This is done either by storing different temporal versions of the same data layer as one consistent data set or by storing corresponding elements in multiple versions over time. They are further linked to related elements in different temporal versions. Object-oriented modelling then allows multi-thematic or multi-temporal processing of the features (objects) stored in the underlying databases, as shown in Fig. 3.

Referencing. Referencing is an important part of processing because there is no 'world format' for describing every piece of information. Meaningful references need to be made to meet the different requirements of stakeholders. An example could be the power infrastructure in the context of the building environment to assess the impact on the disturbance due to incidents. With regard to a Digital City Twin, other sensor data or Building Information Modelling (BIM) can also be linked without importing it into the database [3,4]. In this way, the actual data of the model can be accessed when needed and avoid dealing with complexity when it is not required. The linkage can be stored as additional attributes in a data set itself or as additional data layers in a specific description language. Based on the use case of the particular spatial data set, either only additional data is listed and linked in a catalogue service (CSW), or a federated database management system (FDBMS) is implemented, or a combination of both [10].

Export. The collected and processed data shall be exported in different data formats so that they can be used e.g. as 3D visualisation for decision making. It is important that each export based on the same data set does not export ambiguities [15]. Accordingly, each target format requires the implementation of its own exporter to avoid information and accuracy losses along the conversion chain that follows. Specific requirements for the target format should be implemented in the export and not in the prior data processing. Conversion between domain-specific, complex data formats is almost always lossy, introduces numerical challenges and leads to limited flexibility in incorporating future requirements. This makes a solid, simplified database model and design all the more important. Export can be fully automated, as can data storage, as the data and formats used are usually clearly defined. Besides the export functionalities, this section also includes the provision of interfaces to access data from the database in modules and components of the system. This includes database adapters and interfaces.

Analytics. However, the comprehensive, harmonised database in the form of a common database serves as an input for analyses. Furthermore, the challenges related to data harmonisation and fusion in some ways favour another approach [6]. In addition to the already existing spatial reference of each datum, another independent spatial reference such as a grid cell (for example, a square or hexagonal shape) allows the neutral calculation and processing of each datum for

analysis purposes. Such spatial references can be hierarchically structured, thus also allowing an efficient implementation as well as application of spatial functionalities and queries (select, filter) or processing procedures (filter, intersect, compute). Furthermore, the choice of a grid as spatial reference allows a transfer of analysis results and calculations across, for instance, variable administrative units. It is therefore a generic approach.

Visualisation. Visualisation is the graphic representation of information, visual elements such as diagrams, graphs or maps. Visualisation is essential for analysing information and making data-related decisions. When it comes to spatial elements, it is also cartography, the art and science of graphically representing a geographical area [11]. This usually involves a flat surface, such as a map or diagram. Political, cultural or other non-geographical subdivisions may be superimposed on the representation of a geographical area. This is then referred to as a thematic map. With the increased emergence and availability of the third dimension or more, visualisation and cartography are conditionally reinventing themselves. The effective and efficient representation of multidimensional objects and relations is therefore also part of this complex. Interactive and dynamic visualisations compared to static variants can have advantages, but also many disadvantages. Similar to the visual representation of uncertainty, 3D visualisation raises the important question of whether it is useful. The answer is usually that it depends. In general, it turns out that people prefer to use 3D maps than their 2D counterparts. However, it also shows that people perform tasks less efficiently with 3D graphics than with simpler 2D visualisations. There is no scientific consensus on whether 3D visualisations are helpful to users, and due to the contextual nature of such a question, it is unlikely that there will be an answer in the foreseeable future. The current state of research suggests that 3D visualisations should be used with caution. In contexts where seconds matter (e.g. emergency management, disaster response), 3D visualisation tools could be a risky option. In contexts where the user's pleasure is paramount (e.g. a university campus map), on the other hand, they could be an excellent choice [11].

Applications. The applications of a digital city model are as versatile as they are limited. The availability of data and the degree of abstraction of the model usually limit many applications right from the start. Nevertheless, the spatial representation of a digital city model or twin touches on many areas, just like in reality. Energy supply, solar potential, traffic engineering, traffic flow analysis, civil engineering, municipal planning and analysis or tourism, to name just a few, show the versatility given appropriate data availability [3]. At the same time, in combination with the spatial and temporal dimension, an experience and analysis space can be created that makes planning or results tangible; for example, through augmented or virtual reality. Applications can be differentiated in terms of their taxonomy, such as semantics, the minimum level of detail, the

level of spatial granularity, the spatio-semantic coherence, the nature of the output of the use case or the 'human-style' visualisation itself.

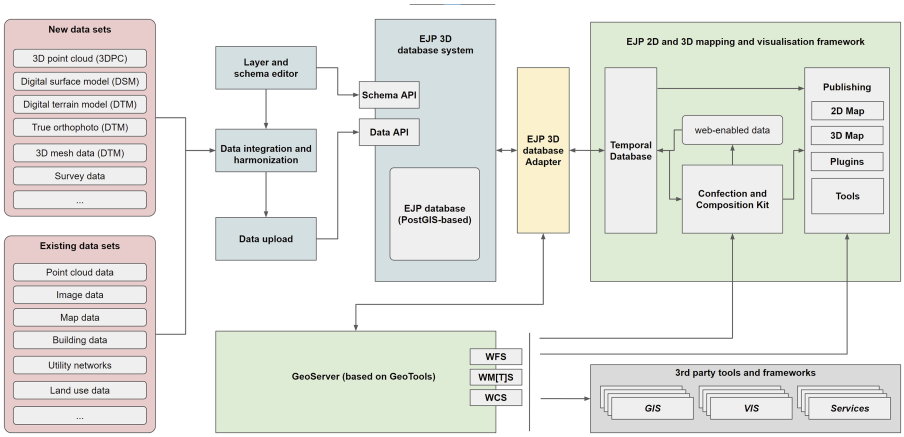
3 Implementation

Based on the described methodology, the construction of a georeferenced virtual city model from unstructured 3D point clouds is implemented. The realisation consists of the development and application of a component-based and modular comprehensive workflow from data acquisition to web-based dissemination of the content.

3.1 System Design

The system design is essentially based on open-source components. The system components are shown in Fig. 4 for an applied overview. For storage and management, a specially developed data model is implemented in a PostgreSQL, which, as described, is object-based. It allows, for example, to link and store changes in the state of an object (e.g. a building) over time. Individual modules and segments allow for targeted integration and harmonisation when importing data into or exporting data from the database. For the management of the database, a management system was developed that allows the administration and modification of the contained data via a graphical user interface. As the database is object-based, only vector data can be stored, which is why another module for raster data is an essential part of the system in supplement to the database. This is the software module 'GeoServer', which is open-source and provides additional management functionalities. Various self-developed data adapters or already existing standardised ones of the GeoServer form interfaces to further modules and third-party services or GIS and VIS systems. A large, still proprietary module (VC Map, VC Publisher) of the workflow represents the mapping and visualisation framework that makes the data available on a web-based platform. This system also serves to package the virtual representation of the East Jerusalem region. It allows for compilation and presentation in 3D using Cesium technology with extensibility through tools.

In addition to the dedicated component overview in Fig. 4, Fig. 5 illustrates an abstracted and genericised variant, which is, however, extended by the user types. Thus, in addition to the main modules 1) database, 2) mapping tools, 3) visualisation tools and 4) management tools, the respective user role is also shown. As an example, a tourism application is provided in the system, which only includes read rights and does not allow any changes to the data stock. The user role of the tourism operator, on the other hand, allows changes to the database via a graphical user interface after authentication. Furthermore, various standardised interfaces, such as WMTS or WFS, allow data integration into third-party tools and services for in-depth analyses, provided the corresponding user role and expert knowledge are available.



Refined system architecture - including the acquired software

Fig. 4. Overview of system components and their linkages

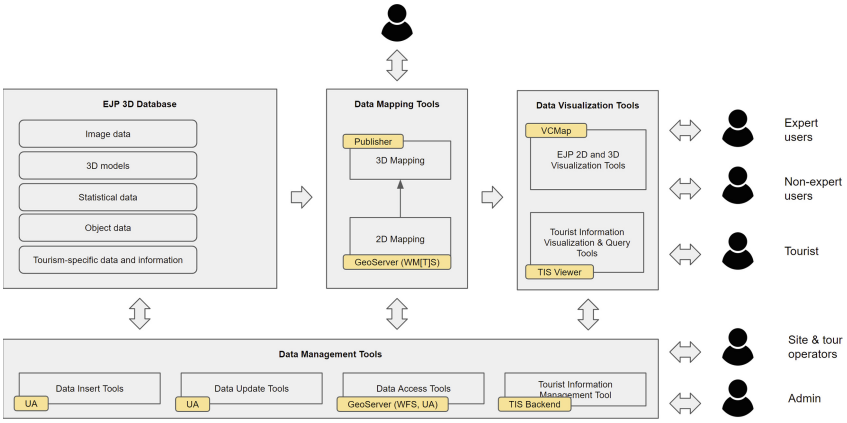


Fig. 5. Abstracted system overview including user types

3.2 Data Acquisition

For the region of East Jerusalem, there are no reference data available, neither for the whole area nor in a certain quality, in order to derive a digital model of the region. Consequently, valid and usable reference data must be acquired. As already described in [6,7], nadir stereo aerial images could be obtained during a flight campaign, which were processed photogrammetrically. An overview is shown in Fig. 6. This acquisition represents the geometric corpus respectively the

geometric reference, which is enriched and extended by means of further object-based data. Further data include, for example, statistical parameters and data from a comprehensive household survey of the region, which was geo-referenced.

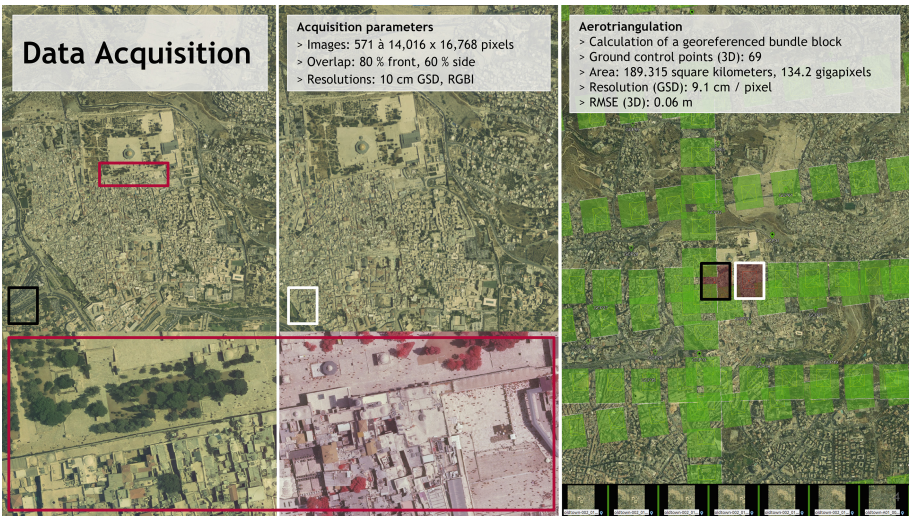


Fig. 6. Exemplary illustration of data acquisition using stereo aerial images (left) and calculation of a bundle block (right)

3.3 Data Processing

The processing of this massive amount of imagery photogrammetrically into point clouds (over 21 billion points, mean point density 119 pts/sqm), allows a very accurate representation of the entire status quo in East Jerusalem with an area-wide resolution of less than 10 cm Ground Sampling Distance (GSD). Using proprietary software, point clouds and 3D meshes could be derived and generated with unprecedented accuracy. This is a novelty for this region. Furthermore, due to the encapsulated and modularised process sections, the massive dataset could be analysed to detect, extract and reconstruct objects (such as buildings) geometrically. Details can be found in [7]. Semantics and thematic could then be assigned or linked to these objects in the database by means of harmonisation and integration modules as illustrated in Fig. 7.

Analyses on hierarchical grid reference allow versatile correlations and are very precisely available or referenceable due to the spatial resolution of the source data (10 cm GSD). The spatial 3D data visualisation and on-the-fly analysis is carried out using CesiumJS. The system components allow a transformation of necessary formats. CesiumJS is an open source JavaScript library for the creation of 3D globes and maps as well as interactive web applications with the sharing of dynamic geodata and is the 'de facto standard' in terms of performance, precision, visual quality and usability today. CesiumJS is based on open formats

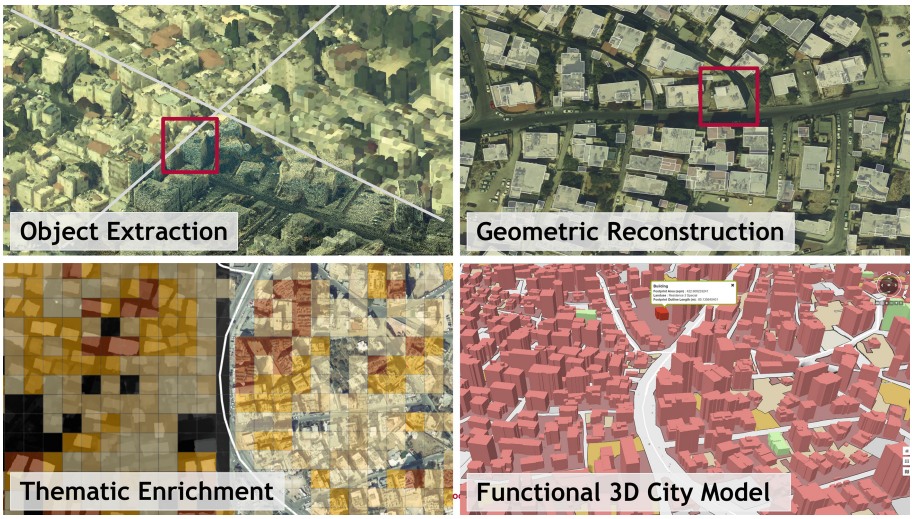


Fig. 7. Exemplary illustration of consecutive data processing, object reconstruction, semantic enrichment towards a feature-rich 3D city model

and designed for robust interoperability and scaling for large datasets. The final result is a 3D spatial virtual model of the East Jerusalem region that is usable and can add value through simple functionalities such as spatial selection or spatial queries.

4 Conclusion and Discussion

In summary, the comprehensive workflow presented can be applied to create a virtual city model in case of a lack of adequate or valid reference data. The encapsulated and independent modules allow the realisation of a feature-rich virtual city model of the East Jerusalem region. Another point to note is that this has generated the development and compilation of a comprehensive geodatabase, including up-to-date 3D geodata and thematic data of unprecedented breadth and depth. The choice of the grid for analysis purposes demonstrates independence and objectivity especially in regions where boundaries are changeable (administratively or by uncertainty). With hierarchical handling, it also allows efficient and effective processing of integrated and harmonised geodata in a common geodatabase. The interconnection of the modules in the overall system are appropriate as a documentation, information and dissemination platform for research, education and decision-making by civil society, municipal stakeholders and the general public. The sustainability and outlook of the contents of this contribution lie, among other things, in the maintenance and expansion of the existing database and the improvement and expansion of the dissemination tools. Furthermore, in the spirit of the VGI, the extension of crowd-sourcing tools to all user groups and sectors can be considered [13]. This includes providing specific

access to the database and data processing functions for specific target groups. Moreover, this also includes the development of a mapping and visualisation system for the general public and the use of the collected data for the development of decision support functions and planning tools [3]. Hence, the field of the digital twin is clearly already touched upon, as it can act as a communication medium for versatile applications. It can be seen that a combination of 2D and 3D - regardless of the temporal dimensions - requires further research, given that added value can only arise in combination when it comes to effective forms of visualisation. The accuracy provided by the point cloud reference data is an excellent starting point. It can be assumed that in future developments point cloud processing will allow object-based representation forms to be derived on-the-fly, which can be used for monitoring or modelling purposes in the future [5,7]. Since the approach is detached from the spatial region, it is important to check whether it is transferable to other oriental cities (for example Cairo or Damascus) that are faced with similar data availability. However, due to the requirements and few limitations of the process, it can be assumed that this is possible and that adjustments may only be necessary within individual modules or segments.

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