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Infrastructure for 3D Modeling of Historical Fountains in Istanbul with GIS-Based Procedural Approach

Abstract: Along with the concepts of "smart city" and "digital twin," the 3D (three-dimensional) city models have started to be used as a basis for many studies that have been carried out in recent years. The most important and basic components of 3D city models are the structures that are located in the cities. However, some small structures of historical importance are within the category of the buildings in a city but are often not as large as a building. Historical fountains are some of these structures. For this reason, modeling with existing 3D city model-production methods is a little more complicated and requires local measurements and detailed modeling studies.

As a result, this study has designed a database scheme design in which the historical city wall fountains in Istanbul can be stored in a spatial database and modeled in three dimensions (with procedural modeling when necessary). In addition, the conveniences that this infrastructure will provide in the production of 3D structure models and some difficulties that were encountered during these studies are also discussed and examined.

Keywords: digital twin, 3D city model, 3D GIS, procedural modeling, historical fountains

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1. Introduction

The concept of "smart urbanism" is one of the most important issues in the world's agenda in recent years. Today, many public institutions closely follow the latest studies on this subject. On the other hand, the private sector develops new technologies to use new techniques that develop day-by-day in its studies in this field. One of the main issues that are mentioned in smart urbanism studies is the "digital-twin" concept, which is produced by creating a one-to-one scale three-dimensional (3D) model of cities in a computer environment. Three-dimensional web and mobile applications that started to emerge in this process have begun to be used effectively in almost every aspect of life, rapidly replacing the two-dimensional (2D) digital maps that have been widely used for many years [1–4].

Combining the spatial data of a city in a 3D environment and creating a 3D model of the city allows studies regarding the planning and management of the city to be carried out in a much more comprehensive and detailed manner. In addition to being used in studies on change analysis, urban transformation, and protecting the city's silhouette, it also allows many analyses such as flood, noise, wind, aspect, solar, and shadow analyses to be carried out in three dimensions [4–14]. In addition, it is possible to construct and simulate many situations that are likely to occur in daily life using 3D city models. In this way, it will be possible to prevent undesirable negative situations before they occur. Moreover, the locations of large projects that are planned to be built in the city can be tested within these simulations, and their possible effects on the environment can be determined before the projects are constructed. In this way, precautions can be taken against possible risks before an incident occurs. Also, more-effective decision support mechanisms and alternative solutions can be offered.

Especially in recent years, the use of spatial data science and 3D simulations in studies on disasters, crises, and environmental issues has become one of the most prominent research areas in the context of urban planning and urban management [15–17]. The use of 3D city models in city management has also increased. Today, 3D city models are used for dozens of purposes that are simply not possible with 2D data [18–19]. Researchers have also created sub-fields of study (such as the "remodeling of buildings") in order to solve the problem of the 3D modeling of a huge city due to the layered structure of the environment [13, 20].

In order to verify the great potential of 3D city models, high-quality building models must be produced at an affordable cost. An effective solution to the automation problem must be found first, as buildings are the most essential components of 3D city models and probably the most expensive to produce [3, 4, 21, 22]. Three-dimensional city model production is one of the most popular research areas today; however, there are still difficulties in accurately modeling and visualizing urban areas with dense buildings. Another important issue on which studies are focused is the investigation of 3D city model-production possibilities that offer fast and low-cost solutions [23].

Various techniques and algorithms have been proposed to detect buildings in two dimensions from images that are obtained from satellite and aerial photogrammetry studies and to automatically create 3D building models. However, those systems that have been developed for fully automatic building-model production from start to finish are not yet available [24]. Small structures and building attachments are difficult to detect from aerial images [25]. Using very-high-resolution satellite images can be a good data source for producing building models with basic roof details; however, aerial photographs or dense lidar data are required to model roofs at higher levels of detail [25]. Cities contain dense urban objects such as buildings, street furniture, and trees. For this reason, most of the measurement methods that are used for data collection are insufficient because the objects cover each other [26].

Moreover, high-detail models cannot be used directly in many applications because the data sets are too large. No matter how detailed that models are produced with new technological methods, these models must be generalized, diluted, and edited manually to be used effectively [3, 22, 27, 28]. Although these can be met to a certain level with developing technology and the many new applications that have been developed for this purpose, the 3D modeling of large-scale urban environments in the computer environment is still considered to be a challenging problem. It has some limitations [29–31].

Water has great importance in the Ottoman culture. It is believed that water is the basis of life, so Ottomans had fountains and wells built in many parts of the villages and cities in which they lived. Their belief that, as long as water continues to flow in the constructed fountains and dispensers, the charity work will permanently continue has supported this attitude for many years. The fountains that were built by the statesmen and sultans in the administrations as well as the wealthy reveal the importance that they gave to improving the existing waterways. "Istanbul Fountains" have a special importance in this area, because the city has served as the capital of the Ottoman Empire for more than 400 years. Each fountain, shaped according to different architectural fashions and tastes throughout the historical development and change of Ottoman architecture, has a special importance. For this reason, Istanbul Fountains are considered to be important historical documents that reflect the changing development process of Ottoman architecture over the centuries [32].

It is known that there are approximately 1200 monumental historical fountains in Istanbul. With some studies that were carried out in the past, many of these fountains have been personally examined in their locations, photographed, and registered with the conditions and techniques of that time. However, some of them have been destroyed by neglect and some other factors over the years; some of them were partially destroyed, and some were completely destroyed and have not survived to the present day.

Today's documentation studies generally include a large number of detailed measurements. Studies that have been carried out with classical terrestrial surveying methods take a lot of time. With the rapidly developing technologies in recent years, laser-scanning and digital-photogrammetry methods have begun to replace classical measurements. However, these methods require the intensive data-collection and processing of this dense data in a digital environment [33, 34]. In this study, some manual measurement values that were made in the past and measurement values that were taken from mobile lidar data that was taken for the purpose of creating a current street panorama were used. Using these values and procedural modeling algorithms, a method has been developed to model historical wall fountains with sub-centimetre precision and in three dimensions.

Two-dimensional GIS data that contains the necessary attribute information can be visualized in three dimensions with procedural modeling methods [9, 35–38]. In addition, there are no drawing or topological errors to be caused by operators and model production since pre-coded algorithms are used in the productions of the models [9]. Procedural modeling offers very effective modeling power; however, it is difficult to automatically reconstruct all of the buildings in the city. In fact, the procedural modeling method can be used to create a basic building model, but it is difficult to specifically adapt it to model something specific [26].

With this study, a database schema was designed in which the historical wall fountains in the province of Istanbul can be stored in a spatial database and, when necessary, can be modeled dynamically and 3Dly with the procedural modeling method. For this purpose, the components of the historical wall fountains were determined, and the advantages and disadvantages of storing them in a relational database that was designed for this purpose were evaluated.

2. Materials and Methods

Building objects in cities are the most important and basic components of 3D city models that are needed during the production of a digital twin. Different buildings in a city are not as large as a normal building; even though they are in the building category, they have historical importance. Since these structures are smaller than normal buildings, they can be modeled to the extent that is allowed by the measurement methods that are used and the precision of those methods. For this reason, building objects below a certain size may not always be modeled depending on the scope of the performed work. However, these landmark structures are urban symbols of significant importance for spatial cognition and route navigation [14, 39].

Since historical fountains are smaller than other structures that are commonly found in a city, it is a little more difficult to model them with existing 3D city model-production methods. However, another situation that should be considered is that, while the dynamic texture of the city is constantly changing, these objects remain unchanged. Therefore, there is no need to reproduce them in every study once they are modeled, as historical fountains do not actively change.

In its most basic terms, taxonomy describes the gradual categorization and classification of entities or objects from simple to complex – sometimes in a way that they can be defined as prerequisites for each other. Within the scope of the study, existing sources about the historical fountains in Istanbul were first researched, and detailed information was collected about these structures. Then, a comprehensive classification study was carried out to serve as a basis for the building model-production process.

A flow diagram that presents the methods and processes that are followed as a whole to create a 3D fountain model is shown in Figure 1. By applying the processes step by step, a detailed taxonomy study was first carried out on the historical fountains, and the basic fountain types and basic components and sub-forms that made up the fountains were determined. Later, procedural modeling algorithms were developed to produce 3D models using these sub-forms. With this method, 3D fountain models were created by taking the measurement values of the fountain components from existing photographs.

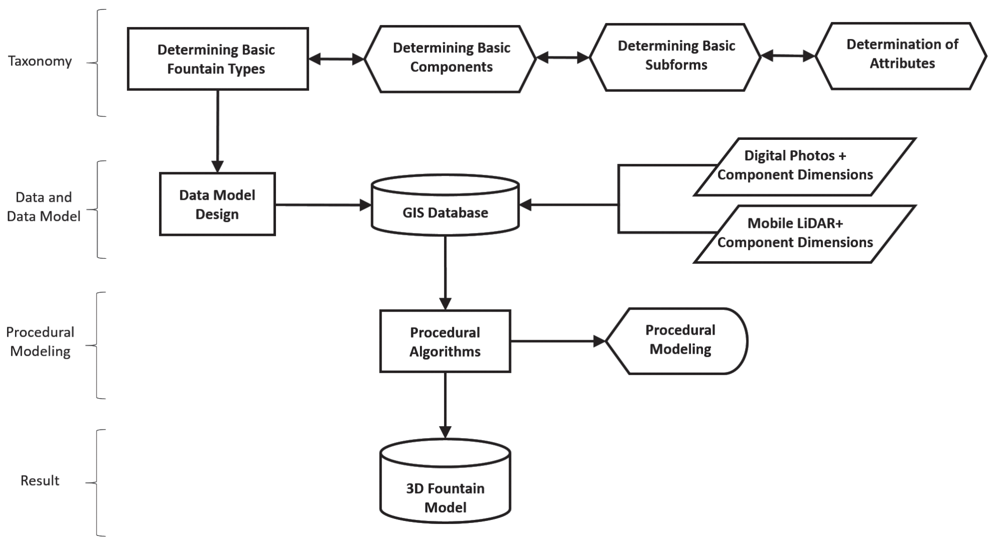

Fig. 1. Workflow diagram

In the second stage of the study, precise measurement values of the historical fountains were taken from the mobile lidar data of Istanbul's streets and panorama images. The 3D fountain models that were produced using this data were compared with the procedurally generated fountain models, and the results were analyzed.

Monumental and registered historical wall fountains need to be separated into certain levels of detail so that they can be stored in a database, displayed, and produced as a 3D digital model in case it is needed for use. In this study, CityGML 3.0 building detail levels (widely used as a standard in the production and storage of 3D city models worldwide) were taken as reference. For the wall fountains, fountain-detail levels were determined specifically for this purpose following the existing CityGML data model structure. Determining the fountain-detail levels enabled the required parameters to keep the attribute data of the fountains in the database to be more easily determined and stored.

In the studies that have been carried out so far, it can be seen that the fountains of the Ottoman Period were classified from different angles and in different ways by different people. According to one approach, Ottoman fountains were divided into two categories: those that were related to architecture, and those that were independent of architecture. These fountains were divided into three subcategories: indoor, outdoor, and structures that were built as fountains. Rooms, sofas, kitchens, Turkish baths, and mosque fountains can be examples of indoor fountains, while courtyard, exterior wall, and portal fountains are examples of outdoor fountains. Structures that were built as fountains are gardens, meadows, streets, squares, and prayer fountains that were built independently of a building.

According to another approach, the fountains are classified according to their locations and purposes; these are walls, corners, squares, prayer places, rooms, columns, and fountains. According to Celâl Esat Arseven's classification of Ottoman fountains, they are classified as neighbors, mosques, fountains, rooms, taps, and monumental fountains; however, this approach is not considered to be correct by Prof. Semavi Eyice. According to him, chamber fountains and taps are water facilities that are outside the definition of a fountain in Turkish architecture [32].

According to some other approaches, a "Pit Fountain" is a type of wall fountain, as it is below ground level. Although two- and three-sided fountains are additionally called "fork fountains," they can actually be considered to be types of wall and square fountains according to still more approaches. As a result of the research, it has been determined that there is no consensus on the general classification of historical fountains that everyone accepts. For this reason, the classification study continued based on the four basic types that are the most general distinctions and are also mentioned in the three-volume work of Istanbul Historical Fountain Collection of Istanbul Water and Sewerage Administration (İstanbul Su ve Kanalizasyon İdaresi, İSKİ), as all work on historical fountains in Istanbul is officially carried out by İSKİ. These four basic fountain types are designated as Shadirvan fountains, wall fountains, square fountains, and column fountains. Since no examples of Shadirvan fountains exist in Istanbul, the classification continued with the other three fountain types.

Compared to classical 3D modeling methods, procedural modeling techniques involve processes and coding studies that take longer at the beginning. Despite this initial extensive work process, however, it is ultimately an effective modeling technique that was developed to produce much faster and more performant solutions. After a specific planning step, the coding process begins. Although this process may initially seem longer than normal modeling, the number of buildings to be modeled and all of the possible changes to the design can be instantly applied to the produced model. It is shortens the modeling process significantly when considering the entire study.

After determining the components of the historical fountains, 12 basic components and 73 sub-forms that belonged to these components were created. These basic components and their sub-forms are given in Table 1.

Table 1. Basic components and sub-forms

Basic components	Sub-forms
Floor	6
Base	6
Container	6
Eave	6
Cover system	8
Inscription	1
Arch	30
Tap stone	2
Bench	1
Bench top	1
Tub	4
Tub pod	2

All of the parameters that were required to reconstruct the basic components and sub-forms that are presented in Table 1 geometrically in a 3D digital environment were technically clear. In most modeling applications, geometric objects with known parameters can be easily created. While designing the data model, parameters such as “width, length, height, depth, diameter, and number of edges” were determined. In order to recreate the geometric form of a component, the relationships of these values with the relevant geometry were defined as attribute data. In this way, a basic “feature class” object that was stored as a “point” and 23 attribute tables were created in the data model where all of the parameters related to the sub-forms of this object were stored. As a result, all of the components that make up a fountain have a geometry object that corresponds to that object in the data model. In addition, the relationships among all of the components can be stored in the database as attribute tables.

Considering the need for the speed and up-to-dateness of our age (as well as the relatively high costs), it is not always possible to produce the required current 3D data at the required temporal and spatial resolution and on the entire city scale.

Since all created city models go through a certain data-production process, they always reflect the past [22, 40]. Even measurement techniques such as photogrammetry and lidar (which are among the most effective methods in measuring and modeling large areas as compared to traditional measurement methods and have become increasingly common in recent years) cannot deliver their products in a very short amount of time. Large city-scale studies can only yield results by waiting for certain processing times [36]. Even though the recent software that has been developed in this field and the automation of building-model production is used, the individual examinations, corrections, and improvements in the final products are processes that require human intervention and take a lot of time [41].

No matter which method is used, the data that is obtained after many studies quickly becomes old and out-of-date [42]. These situations have led to the need to quickly produce an entire city in 3D using spatial data that is produced by different methods (or is already available). For this reason, some procedural modeling techniques have also been developed that enable 2D spatial data to be quickly converted into a 3D city model.

In 3D city models, lidar can be produced by using many methods independently or together, such as photogrammetry, remote sensing, and terrestrial surveying [28]. Using procedural modeling techniques makes it possible to realistically visualize 2D geographic information system (GIS) data that contains the necessary attribute information in three dimensions. However, this requires a detailed and comprehensive database design.

By using procedural modeling techniques, it is possible to realistically visualize 2D GIS data that contains the necessary attribute information in 3D [9, 35–38]. The most significant advantage of the procedural modeling technique is that a 3D model can be re-derived whenever necessary by using the verbal attribute data that is stored in the vector data. In this way, a fundamental reference polygon is stored digitally instead of a comprehensive and detailed 3D model. Additionally, information on how to create this 3D model can be stored in the database when needed. This approach greatly reduces the data size. Since model production is created with pre-coded computer algorithms, it additionally prevents the drawing and topological errors that have been caused by operators and model production [9]. This way, the required models can be created with the minimum number of polygons and the most accurate drawing technique.

Another advantage of procedural 3D model generation is that the created models can be coated automatically. These textures can be real photographs of buildings or can be called from symbolically prepared covering libraries.

This study used CityEngine software as the modeling environment and the computer-generated architecture (CGA) scripting language that was supported by the same software in the development and coding of the procedural algorithms. Actual photographs of the fountains were used in all of the fountain models that were created, and the facade coverings were carried out procedurally and automatically.

3. Results

Traditional 3D geometric models are used for visualization purposes only. However, 3D city models nowadays contain abundant detailed information such as location, classification, and functional aspects; this semantic information also needs to be integrated into the geometric model. CityGML is quite effective in this sense [43]. Studies in the field of 3D modeling and the digital storage of a city have been continuing for many years. The most critical achievement that has been obtained as a result of these studies is CityGML standards. CityGML standards are the most fundamental data model that is widely used in many ongoing studies in this field and is accepted by many researchers worldwide [22].

Buildings are some of the most essential elements when modeling a city. CityGML standards allow buildings to be stored at different detail levels and allow us to access the model at the required level of detail when necessary. During this study, similar detail levels were determined for historical fountains, taking the CityGML 3.0 building detail levels as a reference (widely used worldwide). Just like buildings, historical fountains need to be divided into certain levels of detail in order to produce 3D digital models. In this way, performance and quality are added to the study using the appropriate models during the imaging and various analyses. The different detail levels that were determined for Wall, Square, and Column Fountains are shown in Figure 2. The basic components and sub-forms are also shown in the figure.

Basic components such as "footprint, base, container, cover system, eave, arch, tap stone, inscription, bench, and tub" are common in all basic fountain types. In this context, a basic object library was created by determining the geometric sub-forms for the basic components. Thus, a data model was created to recreate all possible component combinations of historical wall fountains using these basic geometries.

The attribute data that is determined according to this design and the relational structures with each other is also defined. In this way, a relational database scheme has been developed to store a historical fountain in a digital environment without being modeled in three dimensions. This database schema creates the infrastructure for the 3D modeling of the relevant fountains using the necessary attribute data and procedural modeling method. Figure 3 shows the UML diagram of this database schema and the relationships among the tables.

In this study, "historical wall fountains" (a subclass of structures that represent the most important components of 3D city models) were discussed and examined in detail in this context. Thus, the components and sub-forms that make up the historical wall fountains were determined. An approach is presented on how information about these determined components and sub-forms can be stored in a relational database that is designed for this purpose.

After designing the system and developing the procedural codes, the 3D model of a fountain can be produced quickly and easily using the available data. The accuracy of the models that were obtained from the study is related to the accuracy and precision of the data that was used. Two different studies were carried out using two different data sources, and models of some relevant historical fountains were produced instantly and at the desired level of detail.

In the first stage of the study, ten historical wall fountains that were photographed and recorded by the Foundation Waters Branch Directorate (a sub-directorate of İSKİ) in the 2000s were selected. Within the scope of the Fountain Information System studies, the dimensions of the fountains were also measured and recorded by the Foundation Waters Branch Directorate in the 2000s.

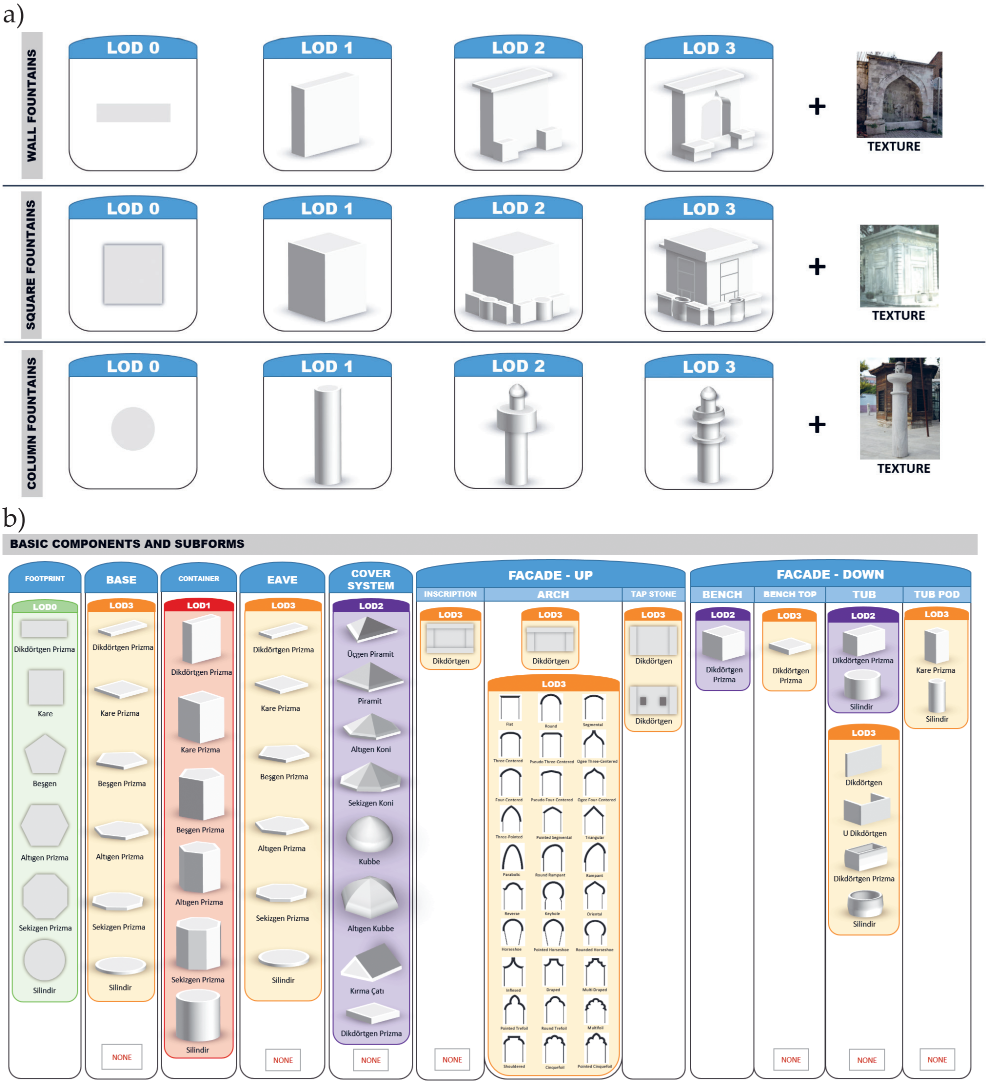

Fig. 2. Detail levels determined for historical fountains (a) and basic components that are determined for fountains (b)

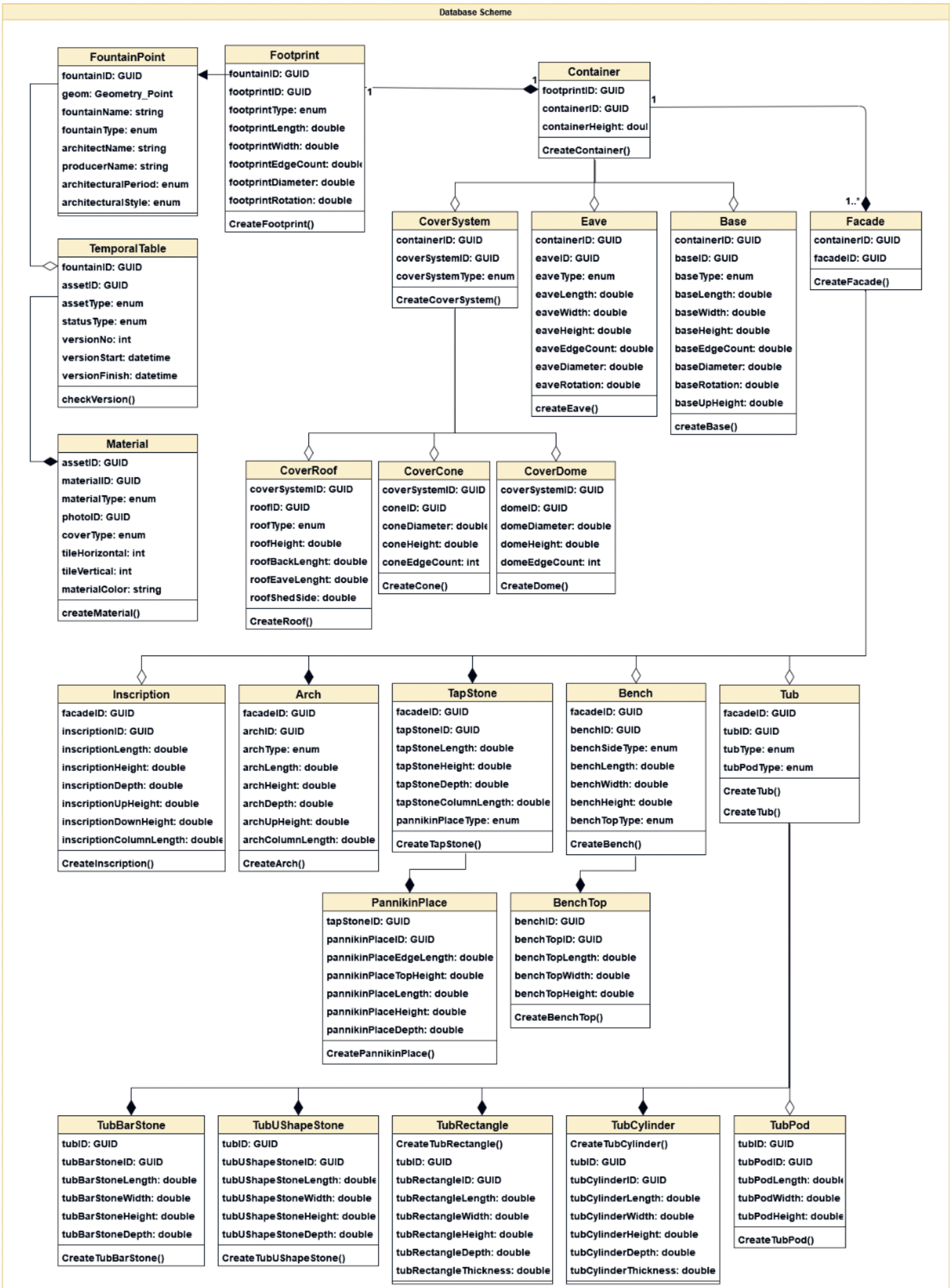

Fig. 3. 3D historical fountain data model
design with GIS-based procedural modeling support

All ten of the selected fountains were chosen within the borders of the Üsküdar district; the locations of the selected fountains in the study area are given in Figure 4. Within the scope of the fountain-information system, there is no information about the methods that were used in the fountain-measurement studies that were carried out in the 2000s.

By the way, "wall fountains" are generally built adjacent to or embedded in a wall. For this reason, the standard length information for wall fountains was taken as 30 cm during the procedural modeling study. Also, basic information about the selected fountains is presented in Table 2.

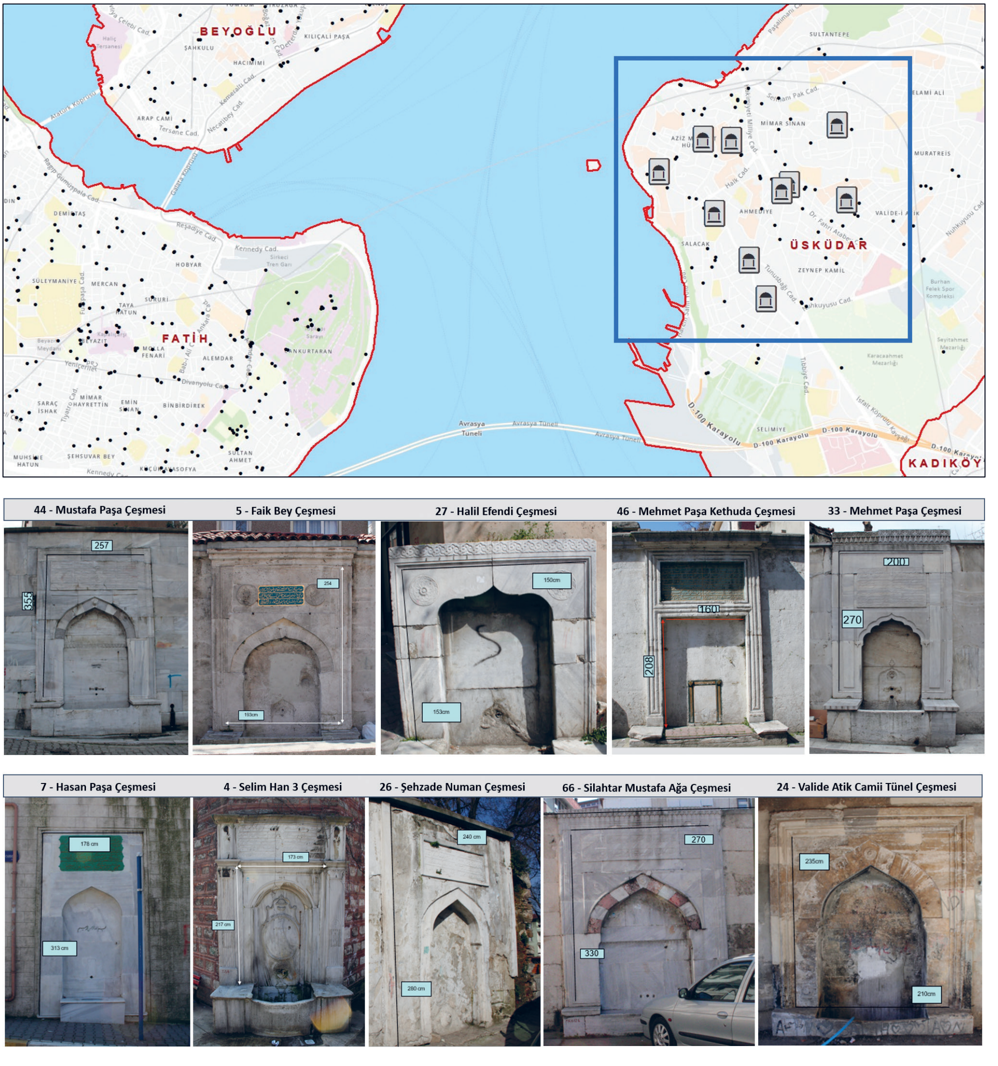

Fig. 4. Study area and ten fountains selected from Üsküdar district

Table 2. Basic information about ten selected fountains

Fountain name	ID	Inventory no.	Length [m]	Width [m]	Height [m]
Mustafa Paşa Çeşmesi	44	210	0.3	2.57	3.55
Selim Han III Çeşmesi	4	166	0.3	1.93	2.54
Halil Efendi Çeşmesi	27	96	0.3	1.50	1.53
Mehmet Paşa Kethüda Çeşmesi	46	214	0.3	1.60	2.08
Mehmet Paşa Çeşmesi	33	194	0.3	2.00	2.70
Hasan Paşa Çeşmesi	7	171	0.3	1.78	3.13
Faik Bey Çeşmesi	5	167	0.3	1.73	2.17
Şehzade Numan Çeşmesi	26	190	0.3	2.40	2.80
Silahtar Mustafa Ağa Çeşmesi	66	106	0.3	2.70	3.30
Valide Atik Camii Tünel Çeşmesi	24	188	0.3	2.10	2.35

In order to make visual comparisons easier during the study, the point data of these selected fountains were temporarily moved side-by-side in the CityEngine modeling environment (Fig. 5).

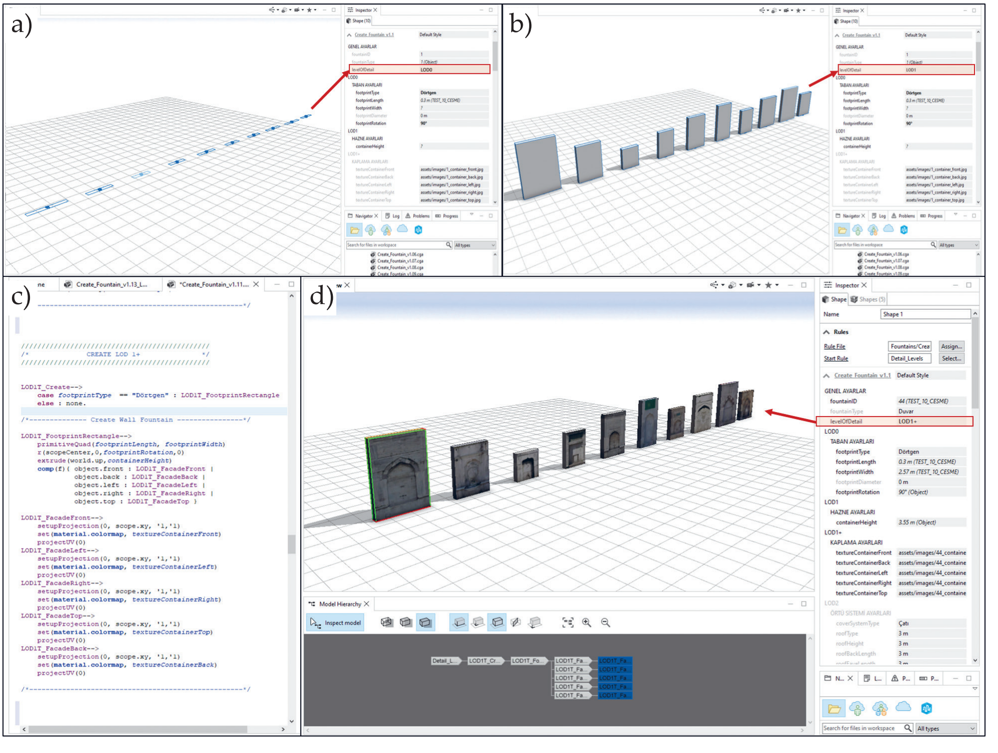

Fig. 5. Procedurally generated LOD0-level fountain footprints (a); procedurally generated LOD1-level solid model for fountains (b); procedurally algorithm for LOD1+ fountain models (c); procedurally produced LOD1+-level fountain models with facade textures (d)

During the study work that was carried out, seven basic detail level functions were defined: LOD0, LOD1, LOD1+, LOD2, LOD2+, LOD3, and LOD3+. Within each function; the CGA coding that was required for the modeling and primitive-object creation from the point data to the relevant detail level was carried out.

The maximum modeling level in the ten fountains that were selected for the sample study was determined to be LOD1+. The parameter values that were necessary to create this level of detail were entered into the designed data model.

The developed procedural modeling algorithm first created the footprint polygon of the fountain using the "width" and "length" values. Then, it created the fountain container as a solid model with the "height" value (Fig. 5). The images of the relevant fountain components were recorded (along with their IDs) through the photographs that were archived within the scope of the Fountain Information System. In this way, all of the textures were automatically loaded and assigned to the facades of the fountain models when creating the procedural model. In this way, the LOD1+-level fountain models could be created dynamically at the time of a viewing by simply giving the relevant parameter values. In addition, it was possible to produce the fountain model at the desired level of detail as soon as the LOD0, LOD1, and LOD1+ values were selected through the developed interface (Fig. 5).

The procedural model generation was run on a machine with a 64-bit Windows 10 operating system, an Intel Core i7-6700K CPU, 4.00 GHz, 32 GB RAM and NVIDIA GeForce GTX 970 graphics card configuration. The production times are presented in Table 3.

Table 3. Information on time spent to create 3D fountain models with procedural modeling technique

Type	Study 1		Study 2	
	Quantity	Time [s]	Quantity	Time [s]
Solid model	10	<1	10	<1
Textured model	10	<1	10	<1

In the second stage of the study, the Ahmed Pasha Fountain (located on 44th Street in the Fatih district) was chosen. During the study, we took data regarding the Ahmed Pasha Fountain from two different sources.

First data set consisted of the photographs and measurement values that were collected within the scope of the Foundation Waters Branch Directorate Fountain Information System studies. Because of the oblique perspective and lack of georeferences, this style of photography is not generally used in quantitative studies [44]; however, the photographs contained measurement information that was created during the information-system studies. These measurement values were taken as the basis in this study.

The second data set consisted of the mobile lidar data that was collected during the Street Panorama studies that were carried out by Istanbul Metropolitan Municipality IMM (İstanbul Büyükşehir Belediyesi, İBB) in 2018 (this data can be accessed publicly and free of charge within the IMM City Map web application). The 3D fountain models that were obtained with the designed data model and developed procedural modeling algorithms are presented in Figure 6.

Fig. 6. İSKİ Fountain Information System Project data (a);
IMM City Map Street Panorama Web Application screen (b);
mobile lidar data accessed through Street Panorama application (c);
measurement operations via Street Panorama application (d);
3D fountain model produced procedurally using designed data model (e)

When the data from the Ahmed Pasha Fountain was evaluated based on these two sources, the mean errors of the fountain's dimensions were found to be 0.5 cm. Table 4 compares the measurement values between the İSKİ Fountain Information System data and the IMM Mobile Lidar data. The measurement values of these two data sets, which were obtained at different times and in different years, were very similar to each other. The mean errors between the values were calculated to be 0.5 cm. The measurement values and mean errors are given in Table 4.

Table 4. Measurement values and mean errors
taken from data sources used for procedural modeling

Data source	Width [cm]	Height [cm]	Mean error [cm]
İSKİ Fountain Information System	200	260	0.5
IMM Mobile Lidar	199	259	0.5

4. Discussion

In the continuation of the study, the procedural modeling algorithms of the "square" and "column" fountains that are located throughout the city of Istanbul can be developed in the CGA language and be included in this design. Thus, it will be possible to store these important structures, which can be considered "landmarks" for 3D city-model applications in a database in such a way that will take up less space and allow one to produce them quickly with a procedural method when necessary.

With this study, it has been revealed that fountains need to be generalized in three dimensions in order to be modeled procedurally. Although the designed data model applies to most of the historical fountains in Istanbul, some fountains whose architectural designs included much higher-level artistic relief motifs and decorations were excluded from these generalization studies, as they could not be reduced to simple geometric forms. In the event that the study continues, those fountains that cannot be generalized should also be reconsidered and evaluated separately.

One of the most important aims of the study is to integrate some spatial data that can be produced procedurally within the scope of smart urbanism studies with the Turkish National Geographic Information System (Türkiye Ulusal Coğrafi Bilgi Sistemi, TUCBS). The TUCBS project aims to establish the Turkish National Geographic Information System infrastructure, prepared in accordance with the INSPIRE directive that was put forward by the European Parliament, in order to create a common spatial data infrastructure [45]. Within the scope of the TUCBS project, a web portal is planned to be created so that all of the relevant institutions and organizations can present the spatial information for which they are responsible to all of the relevant users on a common platform. Thus, it is planned to establish content standards and determine data-exchange standards to meet the data needs of all users.

It has been observed that a high level of integration can be achieved by matching the relevant data classes of the TUCBS data infrastructure and the data that is stored in these classes with any data that is produced from different sources and via different methods. Some of the data that is included in the TUCBS data model but not directly in the Historical Istanbul Fountains Data Model can be generated from the relevant geometries. In this way, 2D and 3D data will experience no obstacles in terms of their integration with TUCBS.

In the TUCBS data model, structural objects other than “buildings” (such as “barns, warehouses, garages, pool, and ATMs”) are stored in the “other structures” layer. So, after the fountain data is stored in the “other buildings” layer, the “fountain” information is stored by selecting it from the “other building types” category.

For this reason, fountains are not seen as city furniture but rather as different and smaller types of structures. Therefore, the fountains were integrated with the “other building type” data during the integration with TUCBS in the study that was carried out. The most comprehensive basic standard in terms of geographical data standards in Türkiye is TUCBS; this is considered to be the main reference in all studies. The CityGML data model and CityDB structure do not meet this goal exactly yet; however, the opportunity of the use of CityDB in this field can be evaluated with the further development of TUCBS in the near future.

As a result, it has been observed that it is possible to integrate the two-dimensional geometries and related attribute data that is used in the procedural model production stages with TUCBS, which was created in certain standards and used at the national level. For this reason, the fact that all of the spatial data that is produced can be integrated into TUCBS at the last stage is of great importance in the common use and sharing of all spatial data.

5. Conclusions

It is possible to dynamically produce 3D models of historical wall fountains with the database schema and procedural modeling algorithms that were designed within the scope of the study. With the development of these procedural algorithms and database schema, it will be possible to use this system for other buildings and structures in a city.

It is very important to record cultural assets such as archaeological objects and historical buildings with digital documentation methods. In case the building is partially or completely damaged by earthquakes, floods, or similar natural disasters or other human causes, recording the 3D models and architectural surveys of these buildings in the digital environment will provide the basis for the restoration and restitution processes that can be subsequently carried out.

Structures with monumental features, historical buildings, and some examples of civil architecture are now considered to be immovable cultural assets that need to be protected. These works shed light on the past from the present and carry the traces of the past to the present and, therefore, to the future. Thus, it is of great importance to digitally document these structures using various methods.

In this study, some manual measurement values that were made in the past and measurement values that were taken from the mobile lidar data that was taken for the purpose of creating a current street panorama were used. Using these values and procedural modeling algorithms, a method has been developed to model historical wall fountains with sub-centimeter precision and in three dimensions.

Thus, a method has been developed that will enable the digital documentation and recording of certain cultural assets by reevaluating the data from different studies that were carried out in the past for different purposes.

Moreover, it will be possible to model a new fountain design in three dimensions and integrate it into the 3D city model by giving the required attribute values as parameters for a new fountain that is planned to be built in any part of the city with the further developments of these database schema and procedural modeling algorithms.

In addition, it will be possible to use this infrastructure for other objects such as buildings, other structures, city furniture, and vegetation layers in 3D city models with the further developments of these database schema and procedural modeling algorithms.

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