**3D City Models in Planning Activities: From a Theoretical Study to an Innovative Practical Application**



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# Handbook of Digital Twins

Over the last two decades, Digital Twins (DTs) have become the intelligent representation of future development in industrial production and daily life. Consisting of over 50 chapters by more than 100 contributors, this comprehensive handbook explains the concept, architecture, design specification and application scenarios of DTs.

As a virtual model of a process, product or service to pair the virtual and physical worlds, DTs allow data analysis and system monitoring by using simulations. The fast-growing technology has been widely studied and developed in recent years. Featured with centralization, integrity and dynamics, it is cost-effective to drive innovation and performance. Many fields saw the adaptation and implementation across industrial production, healthcare, smart city, transportation and logistics. World-famous enterprises such as Siemens, Tesla, ANSYS and General Electric have built smart factories and pioneered digital production, heading towards Industry 4.0.

This book aims to provide an in-depth understanding and reference of DTs to technical personnel in the field, students and scholars of related majors, and general readers interested in intelligent industrial manufacturing.

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# Handbook of Digital Twins

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# 35

## *3D City Models in Planning Activities: From a Theoretical Study to an Innovative Practical Application*

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### 35.1 Introduction

During the last few years, digital 3D city models have achieved a high presence as valuable planning tools used by a large number of public administrations and private firms spread all over the world. Initially, the early use of 3D city models has been dominated by visualization only, and the main purpose was providing public access to users for an attractive view of the urban environment and all its geographic elements in a certain area, taking advantage of 3D models for tourism and marketing tasks. In recent times, by virtue of new software and new modeling technologies, 3D spatial and non-spatial information has been implemented in several cities. Consequently, 3D city models have become estimable for various domains beyond visualization and have been extended to larger number of tasks, such as urban planning, disaster simulation, virtual-heritage conservation and many others. However, on the one hand, the increasing number of different applications that employ 3D city models, where each of them requires its own specific LoD, and on the other hand, the complexity of 3D model generation process, have led to a fuzzy vision about the real possibilities of utilization that 3D city models have.

#### 35.1.1 Outline

In light of that, the first part of this chapter (Section 35.2) provides a comprehensive inventory of use cases, where specific 3D data requirements are

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classified for certain applications, hence delineating which 3D models with their specific LoDs fit-for-purpose. Since visualization seems to be the only criterion that is suitable and can cover almost all fields of application, a wide range of use cases that employ 3D city models has been chosen and categorized into two groups. The first regards non-visualization use cases, where the visualization of 3D city models is not required and the results of the spatial operations can be just stored in a database. The second group concerns visualization-based use cases, where the visualization of 3D city model is essential and without it the use cases part of this group would not make much sense. Successively, the use of 3D models as support tools throughout the planning process is investigated in-depth. Indeed, 3D city models are commonly used to display virtually existing cities as well as publicly divulge three-dimensional visualization about future developments, plans and projects in a 3D environment. Furthermore, these visualizations can be used in two-way communication where citizens can comment back and propose better alternatives after having inspected the plan, providing either positive or negative feedbacks to local authorities, information to citizens about hypothetical new developments in a 3D environment. Subsequently, to better understand how much attention the opinion of diverse actors deserves throughout the whole process, two different approaches widespread among municipalities are described, which use virtual city modeling to make engagement of different stakeholders faster and easier during the decisions-making process: the User-oriented approach and the E-participation technology.

The second part (Section 35.3) regards the description of a project developed at Vaxholms Stad, the municipality office of Vaxholm, a small town of the Stockholm County in Sweden. The project aimed to create a system that allows 3D visualizations of Vaxön's urban structure, which is the most populated island of the whole municipality chosen as the area of study. By virtue of the software FME, and the combination of data source with different formats, a geo database has been created to represent and manage a virtual LoD2 3D buildings model of Vaxholm, which has been visualized on Google Earth, allowing citizens to easily read and view the 3D model into a free web-based mapping platform as Google Earth. In addition, the detailed planning and project of Vauxhall are added to the three-dimensional model, and the planning work is still in progress. Indeed, citizens had the possibility not only to inspect the 3D city model of Vaxön on GE but also, from the plans mapped on the earth surface, to have access directly by the model to the interested area and to all the detailed information about a certain plan on the municipality web page. Furthermore, thanks to Google Earth functions, citizens can leave a feedback by e-mail to the city administration, claiming for their needs about a specific plan or just providing their points of view about what has been mapped on the 3D model. Finally, based on the results obtained, the possible improvements of the adopted program are predicted, and other applications of the 3D building model that may be extended in the future are prospected.

### 35.1.2 Materials and Methodologies

The objective of this article is to investigate what the real potential of 3D city models can be for planning activities as well as for many other domains related to the city's development, in order to identify an efficient procedure to create 3D city models for municipalities, and which advantages they can get if equipped with this planning tool. To gather such information, the main methodology used in this essay was based on a survey and literature review of, mostly, online resources publicized in the last two decades, such as scientific journals, academic articles, theses and project reports. These documents were related in some cases, to the current application and utilization of 3D city models in diverse domains and in others, to the broad number of different approaches used today to create 3D city models at various levels of details. Most of the literature found about the topic debated includes cases of study taken as examples, in which cities were already equipped with 3D city models, and that were mainly chosen in Austria, Kenya and Sweden, where the 3D city model of Vaxholm has been developed. This study area was selected because it presents a mixture of historic and modern buildings with homogeneous architecture styles, which made easier the reconstruction of the 3D buildings, and where the highest building was about 20 m. Once all the documents were retrieved, a comprehensive and systematic synthesis was delineated through the sections of this essay, aiming to sort out the objectives aforementioned. First, an overview was reported about which application fields the use of 3D city models could be convenient for. Successively, a hypothetical procedure was proposed, already implemented in Sweden, to create a 3D city model, which in turn will be used as a tool for citizens' engagement throughout the decision-making process.

## 35.2 Theoretical Overview

### 35.2.1 Geometrics and Semantic Properties of 3D City Models

3D city models are digital representations of certain objects in the urban environment, which include earth surface, vegetation, infrastructure, landscape elements and buildings, created through a modeling process [1]. The third dimension indicates 3D GIS (Geographic Information System) data, where each dimension is geometrically defined. However, besides geometry, an important component of 3D city models is semantic information, which can be described as any information that is not visible as the geometry is, e.g., the land use of a building. Both geometric and semantic properties of 3D models are stored in diverse 'levels-of-detail' (LoD). The LoD approach, defined by the CityGML[1] standard, is a coherent modeling of geometric and topological properties at each level, where geometric objects get assigned to semantic objects. The LoD definition is mainly used for the details of the buildings, which are the most important items in a 3D city model, and it is a fundamental concept in 3D city modeling since it defines the degree of abstraction of real-world's elements [1].

### 35.2.2 Related Works

Nowadays, the development of new technologies has allowed the implementation of 3D geo-information data in several cities, which is rapidly growing and expanding in different research fields. The early use of 3D city models has been dominated by visualization only. However, by virtue of new software and new modeling methodologies, 3D city models have become estimable for several domains beyond visualization, and are currently used in a large number of purposes. During the past years, some researchers have studied the applicability of 3D geo-information, focusing on solving industrial and experimentation problems. For instance, Ross in 2010 [2], proposed a general taxonomy of 3D use cases, which relies on the type of data that each model contains: applications based on geometry (e.g. estimation of the shadow); applications based on geometry and semantic information (e.g. estimation of the solar potential); applications based on domain-specific extensions and external data (e.g. noise emission calculation). However, it is important to note that such categories are not 'exclusive' in all cases, but some applications might fit in more than one category. For example, to estimate the propagation of noise in an urban environment, only the geometry of buildings is needed. Furthermore, if hypothetically semantic information of geometries is also known, such as inhabitants or building's material, these data may represent important improvements for predictions and better assessment of noise consequences [3].

Biljecki et al. [3] conducted another study in 2015, where they argued that visualization might be considered as the only criterion that is suitable and can cover almost all categories of applications. Hence, the taxonomy of use cases mentioned above can be further categorized into two groups. The first concerns non-visualization use cases, where the visualization of the 3D model and the results of the 3D spatial operations can be visualized, but it is not essential to achieve the task of the use case since the results can be stored in a database. The second group regards visualization-based use cases, where instead, visualization is essential and the use cases would not make much sense without it. Based on these two groups, distinct use cases have been identified in several application domains.

[1] *City GML:* Today, the number of cities that are representing their 3D city models according to the CityGML standard is growing. This standard has been issued by the OGC (Open Geospatial Consortium) to decompose articulated objects [1].

#### *35.2.2.1 Non-visualization Use Cases*

Environmental simulations part of this group are, for instance, the estimation of solar irradiation, where 3D data are used to evaluate the solar potential on rooftops in urban areas, and thus, to assess how much a building is exposed to the sunlight, in order to evaluate the suitability of a roof surface for installing photovoltaic panels above it. Another analysis concerns the energy demand estimation, where 3D city models are used to combine the data of the building's volume, number of floors, type of buildings, and other features to predict the energy demand for heating or cooling. A further estimation regards the distribution and shape of a building type in a neighborhood, which may help marketing and real estate management fields, forecasting its potential for taxation and valuation of buildings [3].

#### *35.2.2.2 Visualization-Based Use Cases*

Visualization is considered as one of the most used applications of 3D city models since it is able to provide panoramic views, web visualizations, profiling and other related works. Furthermore, it is generally used for an attractive presentation of the results from such analyses, which can be related to GIS, as in a visibility analysis, or which are not necessarily related to GIS, as economic activities [3]. Indeed, 3D city models are fundamental for various kinds of visibility analyses.

In light of the classification above mentioned, it is clear that 3D city models are currently used in a lot of domains for several purposes. The second group related to visualization-based applications is broader than the first one. This suggests that visualization is a fundamental feature of the contemporary workflows involving 3D city models. Therefore, this analysis has revealed some interesting patterns about the development and large utilization of 3D city models, and how a lot of use cases already prove the valuable role and their growth over time.

### 35.2.3 A Support Tool for Urban Planning and Facility Management

In recent times, 3D city models have been widely used by designer and urban planners as decision-making tools employed to explore, plan and actively act on cities. For instance, a visualization application of 3D city models can virtually display existing cities as well as may provide urban information to citizens about hypothetical developments in a 3D environment [4]. Furthermore, today's web technologies and availability of 3D city models, at different LoDs, enables local governments to communicate spatial plans to their citizens, but also it can be used in two-way communication where citizens can comment back and propose better alternatives, submitting either positive or negative feedbacks to local authorities [5]. This means that 3D city models can be useful to investigate local dynamics and best fitting urban indicators for a future enhancement [3].

#### *35.2.3.1 User-Oriented*

A useful method to achieve what is mentioned above might be a solution-oriented approach. This process starts with the collection of citizens' issues and needs, then understanding them carefully and subsequently, trying to figure out what the optimal solutions that solve citizens' problems might be. Therefore, user-oriented requirements may become helpful tools for a more transparent communication and a better decision-making process, which can improve the quality of the planning process. In Salzburg, Austria, a study has been accomplished thanks to the research project *Digital Cities*,[2] which Autodesk has conducted with Z_GIS and the City of Salzburg as a pilot city. The research was focused on the analysis of the impact that a future urban development could have in Salzburg. To do that, a combination of city data with realistic visualizations and simulation tools allowed Salzburg authorities to view and interact with the city landscape and analyze the impact of future urban planning, tourism, and economic development projects before they are built [6]. Successively, aiming to create an integrated tool for the working processes, a user-oriented approach was implemented. Indeed, users could express their needs that, in a second moment, have been structured in detailed requirements for digital cities. These requirements covered all the components of the digital cities working environment and aimed to embrace all the tasks that had value for the City of Salzburg [7]. Thus, this kind of analysis conducted, in order to be user-oriented, was context-oriented as well. At the end, two application areas have been selected: the first area concerns visual communication of planned development and navigation in the city model, considered at a different scale, from building modifications to planning the whole city districts, which represents the communication basis to involve stakeholders of different areas of expertise. The second application area regards the management of geographic objects that need to be represented in three-dimensions and that are spread over a big area of the city. In both application areas, respectively, planned modifications and geographic objects were integrated into their surroundings and could be analyzed by their spatial relations with other geographic elements [7]. In light of that, it can be argued that the digital cities environment may help cities like Salzburg to visualize and communicate proposed changes in urban areas to inhabitants. The data collected in Salzburg, especially about urban planning tasks, can be suitable for other urban contexts, such as cities with equal size, number of inhabitants, levels of development, social environment, and historical buildings structure.

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[2] Digital Cities: 'The Digital City initiative is Autodesk's unique technology designed to provide a collaborative environment for visualizing, analyzing and simulating the future impact of urban design and development at a city-wide scale'. http://www.autodesk.com/digitalcities.

#### 35.2.3.2 E-Participation

During the past years, E-participation has been frequently used to involve citizens in urban planning and management [5]. Indeed, web technologies, today, facilitate the communication of citizens' feedbacks about development plans promoted by authorities in order to eliminate the need for citizens to gather together in a certain place and in a specific moment. Through these technologies, a citizen may choose how, when and where to take part, even anonymously if he wants, to the decision-making process simply using a web portal. Aiming to prove the feasibility of the E-participation approach in developing countries, a 3D model with a web portal access has been created for the city of Kismu, in Kenya. Experiments have been held to measure the ability of groups of people from different backgrounds. The 3D model created was visualized in a web portal, provided by ArcGIS online, and each participant had the possibility to take part remotely, without meetings to take part in the whole process. Essentially, each citizen could easily create an account, log in, view, navigate through and leave comments in the portal. Subsequently, opinions, proposals and various alternatives gathered have been discussed throughout plenary workshops [5]. To verify participants' abilities coping with the designed 3D model, two tasks have been identified: the first regards 2D maps on A3 sheets with road networks and a list of feature names, where each participant had to pick the name of a feature in the list, locate it and mark it in the 2D map within a time limit. The second task had the same process, but with a 3D city model stored in a web-based portal. The participants' performance has been measured calculating the time needed to complete the tasks and counting the number of correct objects identified. Considering these factors, the results have shown that for all groups, the 3D task has taken less time than the first one and also appeared in more correct answers than the 2D task [5].

## 35.3 A Practical Application of 3D City Models

### 35.3.1 Public Use of the 3D City Models in the Swedish Environment

Since 1970 in Sweden, after a decentralization process that has brought about a considerable power transition to counties and especially to municipalities, the fields of territorial and urban planning are managed by the public sector and municipalities, who are considered the main actors [8]. In light of that, the 3D industry in Sweden is increasingly developing thanks to the recurring employment of 3D models in public use and particularly in city planning applications widespread in many municipalities. Indeed, many Swedish cities are currently engaged in projects that aim to reinvent the

**FIGURE 35.1**
From the left: Stockholm Royal Sea Port; *Min Stad* in Gothenburg; touchscreen of Linköping's 3D city model [10].

use of 3D city models for the promotion of the city development and public participation [9].

As shown in Figure 35.1, in projects like Stockholm Royal Sea Port, *Min Stad* and the Linköping's touch screen, the digital dialogue's structure consists essentially of a web portal or a touch screen, which uses an interactive 3D city model as background and encourages citizens to post ideas, according to their needs, that can be useful for the development and enhancement of several projects in certain contexts [10]. Therefore, the recent broad employment of 3D city models for public uses and stakeholders engagement have allowed many cities in Sweden to digitally promote the implementation of new projects in their territory as well as inviting an increasing number of citizens to take part in the decision-making process.

### 35.3.2 Study Area

The generation of a 3D city model for the city of Vaxholm will be carried out throughout this chapter as a case study to get firsthand experience with some of the available methods to create 3D city models. The whole process to create the model, the results obtained and the potential future applications and improvements that the model may reach will be presented in this chapter as well. The geographic area used in this case study, as aforesaid, is the municipality of Vaxholm, which is located in northwest of Stockholm and is often referred as the capital of its Archipelago [11].

### 35.3.3 The Generation Process

Throughout the next paragraphs will be presented the workflow generated to reconstruct a 3D building model with textured roofs at LoD2. The project developed aimed to create a system that allows 3D visualizations of Vaxön's urban structure, the main and most populated island of the whole municipality chosen as study area. Through the use of the software FME, and the combination of different data formats, LIDAR point clouds, 2D footprints in shapefiles and ortho images in ECW (Enhanced Compression Wavelet), a geo database handled in a FME workflow has been created to represent and manage the virtual 3D building models of Vaxholm, as shown in Figure 35.2.

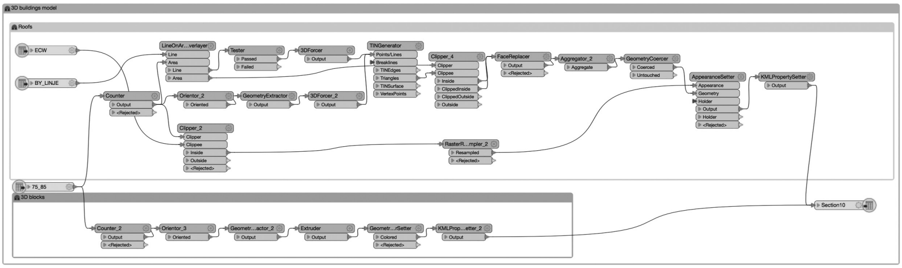


**FIGURE 35.2**
Workspace assembled to shape integrated 3D buildings models (Own elaboration from FMEDesktop).

The KML format was chosen because it is compatible with GE, and thus, allowing citizens to easily read and view the 3D model in a free widespread web-based mapping application as GE. Furthermore, the KML model has been spread out on the earth surface in GE, which, as in reality, presents the earth slopes according to the sea level, as shown in Figure 35.3.

Furthermore, *Detaljplaner* (Detailed plans) and *Projekt* (Projects) *pågående planarbeten* (with an ongoing plan work) have been added to the 3D buildings model, representing a zoning spread on the island of Vaxön in proximity to those buildings' part of the plans. Therefore, adding these plans has improved the usability of the 3D model, not only as a mere 3D visualization of the municipality, but rather as an effective urban planning tool. Indeed,

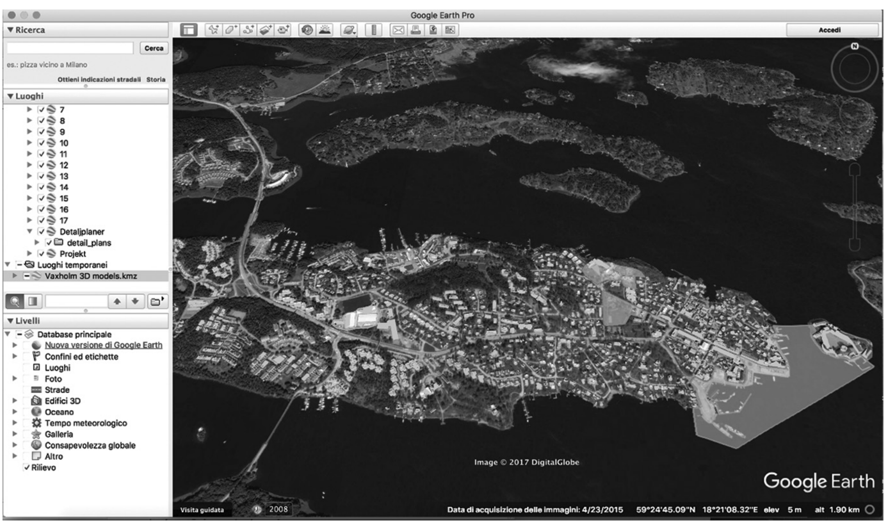


**FIGURE 35.3**
Visualization on Google Earth of the 3D models, detailed plans and projects (Own elaboration from GE).

these types of plans are legally binding in Sweden and thus, considered as the most incisive ones at the local level. They are planned for specific areas of the municipality where particular development process makes such plans fundamental. For instance, they can be adopted for: new buildings of an urban settlement; evaluation of the potential development in an urban area; and identifying a building with significant impact on the surrounding area and others cases [8].

### 35.3.4 Results Achieved

As aforementioned, only the plans where the planning process was still ongoing have been selected and added to the 3D model. The reason was to allow the municipality of Vaxholm, throughout the *iter* of approval, to take into consideration different alternatives proposed by citizens about those plans, and eventually, modifying some features before the approval of a certain plan. Indeed the plans mapped on GE can be easily switched on and switched off from the legend on the left side, according to the users' interest, and also present an URL link in the attributes content that from a clickable pop-up window connects each user directly to the plan information, published on Vaxholm municipality's webpage, as shown in Figure 35.4. In this way, citizens have the possibility not only to inspect the 3D city model of Vaxön on a GE but also to have access directly from the model, specifically on the interested area, to all the documents about analysis and studies conducted before drawing up the plan, planimetries and different types of maps about measures and quantities about the construction of new buildings and any other information about the area of interest, which are available on the webpage. In light of that, the integration between the 3D building models and the plans with pending approval may represent a helpful planning tool for those citizens who are not familiar with a web-GIS portal. For this reason, a free widespread program with an easy interface as GE has been chosen for the visualization of an interactive 3D building model.

Furthermore, the inhabitants of Vaxholm, besides the visualization of the 3D models and the connection that detailed plans have with the municipality's webpage, have also the possibility to login in GE with their private e-mail account and leave opinions, complaints and proposals about a building or a whole area, In order to attach a screenshot or KML of the subject they are interested in to the email, an email was sent to the Vauxhall Municipality.

Therefore, Google Earth, besides a simple visualization of the 3D model generated, provides a user-friendly tool to the citizens of Vaxholm, which allows them to have a clear and quick access to all the information about what is going to happen in certain areas, in order to give them a chance to have voice within the planning process of those plans with pending approval.

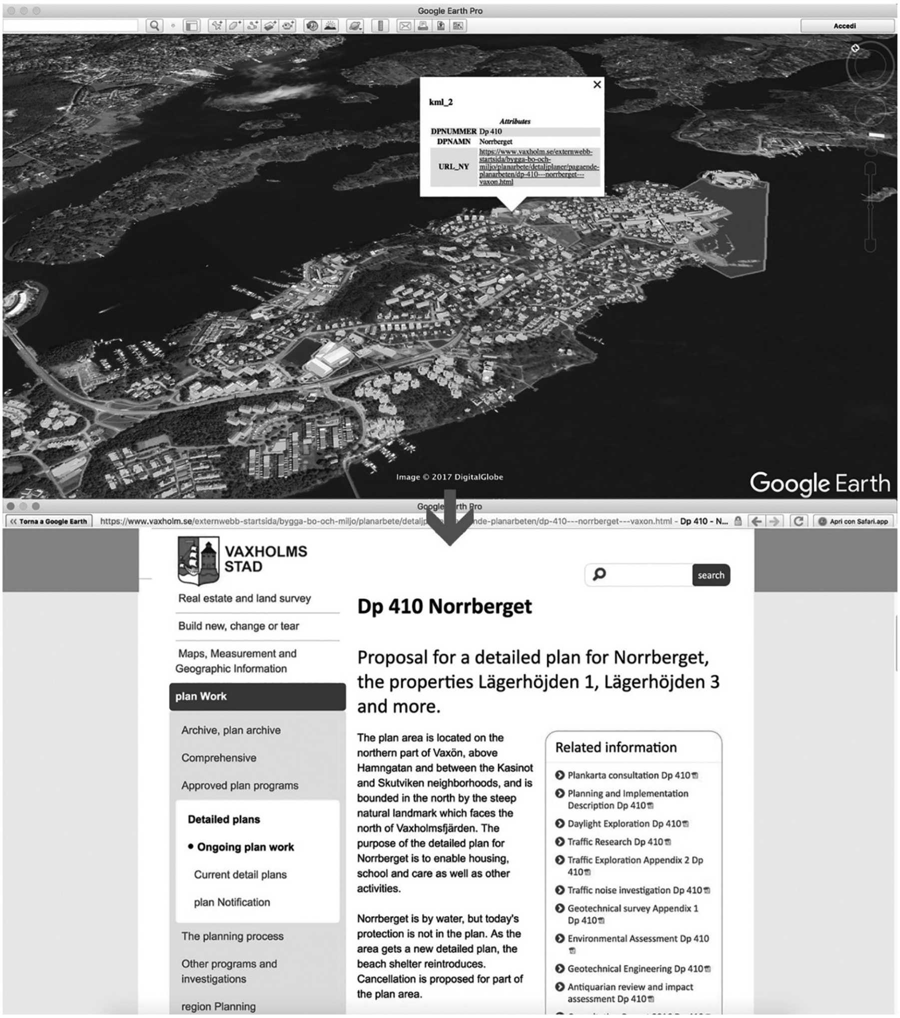


**FIGURE 35.4**
On the top: the pop-up window with the URL link (Own elaboration from GE) that connects users directly to the detailed plan information on the municipality's website, on the bottom [11].

## 35.4 Conclusions and Future Improvements

The evidence presented in this article clearly indicates that 3D city models have proved to be estimable for a large number of domains during the last few years and thus have been recently used in large number of application ambits and for diverse purposes related to cities' development that, throughout this chapter, have been classified according diverse criteria. These principles can regard the geometry of the building, if the task, for example, is the estimation of shadow; or semantic information stored in each building, if we refer to the estimation of solar irradiation. However, the most relevant criterion followed to individuate two main groups, concerns the visualization or non-visualization of 3D models. Indeed, besides being the first early-use domain of application for 3D city models, visualization is arguably an indivisible part of the workflows that involve 3D city models and it can be considered as the only criterion that is adaptable to almost all categories of applications mentioned in the last chapters. Successively, in examining how the utilization of 3D city models in purposes related to urban analyses is growing, some interesting patterns have been delineated. For instance, it has been revealed that, by virtue of new technologies and methods for data acquisition and processing that have enhanced the efficiency of 3D city models, the requirements of 3D city models have changed direction: from a mere realistic geographical representation of cities that provides to users public access for the exploration of 3D elements, currently, the goals that a city administration wants to achieve using a 3D city model go toward the realization of a detailed and attractive representation of the urban environment that, thanks to specific interactive functions, enables users to retrieve from buildings spatial and non-spatial attributes data when they interact with the model. As it has been shown in some case studies aforementioned, this information stored in the 3D model may regard the building features about its structure (e.g. height and number of households that live in the building), or on the other hand, may concern a future development plan drawn up for the area of interest that shows how the area would look like in the future, or as in the case of Vaxholm, the model visualized in a web-mapping platform can present some clickable pop-up windows that connect users directly to the municipality's webpage where all the documents related to the plans of interest are published and open for inspection. Another pattern emerged, regarding the recent increasing spread of 3D city models toward a larger number of public and private institutions, such as city administrations, mapping agencies, private firms, universities research departments and many others [12]. Most of the research papers and articles available on the web, documenting uses of 3D city models and integration of them as planning tools employed by several municipalities, have been published during the last decade. Hence, this fundamental support tool has been already adopted by every municipality that has a dense urban structure and a copious population or, for the cities where it is not yet, they are in the process of setting up 3D city models as part of their planning tools [13].

Given the results achieved, this research might be helpful for all stakeholders involved in 3D city modeling community with different level of decision-making, in the way that they may use it to make improvements to their product or at least understand the range of applications that 3D geo-information can offer today. Also, it might be beneficial as a reference that provides a detailed insight defining use case scenarios and then according to the purposes that have to be achieved, setting the suitable requirements when procuring the 3D datasets. Even though the large number of cases of study that have been mentioned proves already the estimable role and the high demand of 3D city models, further technologies' improvements, new scenarios and cases of application, are expected in the following years. One of the biggest tasks related to the field of 3D city models is to find cost-effective and avoid time-consuming approaches to create models rich in semantic information. For instance, improvements toward the integration of computer graphics, GIS and BIM would allow on the one side, the realization of more detailed 3D city models, and on the other side, rich information stored in the model would allow new types of applications to be planned thereby increasing the possibilities associated with 3D city models.

The integration of 3D modeling with dynamic visibility analysis is being developed in order to allow users (citizens, planners, members of landscape commissions, ... up to students) to analyze the urban proposals presented using this key [14,15].

In conclusion, in light of the all above-mentioned considerations, it can be asserted that virtual city modeling for many municipalities is a new approach to manage cities' development and to encourage participation of the public within the planning process. A 3D city model can help cities, both similar to and different from Vaxholm, to visualize, inspect, and communicate proposed developments and changes of their urban environment. The approach followed to generate the model can be applicable in other contexts with similar characteristics, such as equal size, number of inhabitants, historical background and building structure, as a support tool for more transparent communication with the citizens that have the potentiality to improve the quality of the planning process. However, there is a lot more to investigate in this field that unluckily is outside the scope of this dissertation, but it is clear that the more detailed is the model and rich of semantic information, the greater are the possibilities to include additional applications with the model as a basis.

The tools developed are used in academic activities and represent a significant example to be promoted as best practices at various administrative levels.

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