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TECHNICAL PAPER

Geo-visual analytics for urban design in the context of future internet

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Abstract The internet, where much of the information has reference to location, together with the latest generation of geographical web services, represent a very large information space that can be used for planning and design. The wealth of information accessible, which requires new forms of interaction and management of the data available, has brought in recent year to the growth of the domain of visual analytics. In addition, the availability of 3D geobrowsers provides the technological means for interactive 3D environments which can be used to access large-scale geographical information. This technological scenario is paving the way to 3D web-based, geo-visual analytics tools for land planning and urban design tools. This paper illustrates the results of a research effort which has brought to the development of an interactive geo-visual analytics platform for land planning and urban design which makes use of procedural modelling algorithms.

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1 Introduction

The next years will bring a major evolution to the way we access data and reach services over the network. The availability of broad band networks, the growth of the so called "internet of things", are revolutionising the way information is created and distributed. Furthermore today we live in a mobile and distributed society. Because of this, most of the information flowing around has reference to location. It is widely acknowledged that the amount of geographical information (GI) existing, and the power that spatial data have, requires appropriate technologies to handle this [1].

Future internet technologies will have to deal with growing number of highly dynamic GI made ubiquitously available through a number of added value web-services.

Today typically (GI) is stored in databases, flat files or within geographic information systems (GIS). However the vast number of different formats, projection systems together with the fact that geographic resources are designed for many different purposes, makes it difficult to integrate GIS repositories. As a consequence of this in the last few years a number of international initiatives have brought to standardization efforts promoting the use of interoperable service-based geographical infrastructures.

The harmonization and standardization effort has been fuelled by the increasing success of 3D geobrowsers capable to view geospatial data from within a 3D scene. These tools have a great potential in that they are supporting user-friendly approach to geospatial information and services. Land planning and urban design can greatly benefit from the development of integrated 3D solutions providing fruition, editing and processing of geospatial information.

The scale of the issues tackled during land planning and urban design tasks in fact requires an integrated territorial approach which is naturally supported by the use of 3D visualization technologies. However when dealing with data at this scale new issues arise.

First the operator may require accessing a vast amount of information therefore new forms of data access, filtering and analysis capable to exploit the geographical nature of the information managed are required.

Secondly 3D modelling of urban layout at a vast scale requires automated processes. Modelling a large quantity of objects, even of relatively low complexity, would require several hours of work by a designer, CAD operator or 3D modeller. This precludes manual modelling in contexts such as cities where thousands of different geometries cannot reasonably all be created manually.

The latter issue can be solved through procedural modelling to create 3D models through the use of specific algorithms.

Procedural modelling can generate similar result to manual modelling in a small fraction of the time. Moreover, where slight modification to the models would require extensive works by the operator on every single object affected by the change, with the use of procedural modelling a change in the rules or in the input is sufficient to observe the change propagates in real time to all the objects.

The work presented in this paper tackles the aforementioned issue by presenting the results of an ongoing research work aiming at providing new visual analytical tools to provide administrators, professionals involved in the task of land planning and urban design. This is done through the development of a 3D web-based geospatial solution capable to provide design decision support functionalities. The articulated set of services, capable to provide access to a variety of data and services shows the how geo-visual analytics can be benefit from future internet scenarios.

2 State of the art

2.1 Geographical web services as information resources

Nowadays, the ever increasing number of people and institutions sharing GI is causing the deployment of distributed spatial web services (WS), capable to provide standardized access to GI via the web. This trend is stressing the importance of interoperability [2] and, together with it, the problem of visualizing such a vast and often heterogeneous wealth of complex data.

Many organizations and companies have provided services for accessing GI in the last years, however traditionally these systems have all been implemented according to different formats and protocols. Until recent years in fact vendors have tended to deliver closed systems [1]. This has lead to many users being bound to single vendor solutions, with web client applications being able to interact only with specific implementations. As a result wide access to information available has been strongly limited as each server had its own implementation and did not follow a published interface specification.

In recent years, at the international level, it has emerged a clear need for publicly documented interface specifications, accepted and adopted as standard by as many implementers as possible [3] capable to ensure interoperability between different products [1]. In this field the most noteworthy standardization effort has been carried on by the open geospatial consortium (OGC) which provides three programs, namely specification program, interoperability program and outreach and adoption program for planning, developing, reviewing, and last of all, officially adopting specifications in the domain of spatial information. OGC implementation specifications are sets of interfaces that specify the request and response protocols for the interaction between open web-based servers and clients [3]. As a result a number of OGC web services (OWS) [4–6] have been developed and adopted as standard form to provide access, editing and processing of GI.

2.2 Geo-visual analytics

Standardization is producing, as consequence, that a vast amount of information can be accessible in an interoperable form. The amount of GI available through web services has increased, in the last few years, at a staggering rate. A remarkable example of this is the recent data centre built by Microsoft for its 3D solution virtual earth which has been designed to accommodate up to 15 Petabyte (15 * 1,015 bytes) of data.

Interactive computer graphics can be extremely effective with such a vast range of *n*-dimensional information. With the correct design in terms of interface layout and information item, large amount of data can be quickly and easily comprehended by a human observer through the use of 3D graphics [7]. In fact it is well acknowledged that visualization provides an additional mental aid that enhances cognitive abilities [8]. When information is presented visually, efficient innate human capabilities can be used to perceive and process data. Information visualization techniques amplify cognition by increasing human mental resources, reducing search times, improving recognition of patterns, increasing inference making, and increasing monitoring scope [8].

For this reason in recent year the research community has focused on an emerging discipline called visual analytics (VA), capable to provide integrated visualization, filtering and reasoning solution to better support operators looking for design decision support. VA offers advantages to the user because it provides visual cues that can help the analyst formulate a set of viable models [9]. VA packages support multiple visual representations and computational techniques.

An ideal environment for analysis provides seamless integration of computational and visual techniques. For instance, the visual overview may be based on some preliminary data transformations appropriate to the data and task. Interactive focusing, selecting, and filtering could be used to isolate data associated with a hypothesis, which could then be passed to an analysis engine with informed parameter settings. Results could be superimposed on the original information to show the difference between the raw data and the computed model, with errors highlighted visually. This process could be iterated if the resulting model did not match the data with sufficient accuracy, or the analyst could refocus on a different subspace of information [9].

However many visualization techniques for analyzing complex event interactions only display information along a single dimension, typically one of time, geography or network connectivity. Each of these types of visualizations is common and well understood [10]. Actually, some systems are capable of using animation to display time. Time is played back, or scrolled, and the related spatial or other displays change to reflect the state of information at a moment in time. However this technique relies on limited human short term memory to retain temporal changes and patterns. One technique, called "small multiples" [11] uses repeated frames of a condition or chart, each capturing an incremental moment in time, much like looking at sequence of frames from a film laid side by side. Each image must be interpreted separately, and side-by-side comparisons made, to detect differences. This technique is expensive in terms of visual space since an image must be generated for each moment of interest, which can be problematic when trying to simultaneously display multiple images of adequate size that contain complex data content. One additional technique to mention is the use of linked views to support multivariate analysis, including time series data analysis in one view, and a map in another view [12]. Interactive linking of data selection across multiple, separate views improves the small multiples technique [10].

2.3 Procedural modelling for land planning and design

When dealing with large scale 3D environments it is however necessary to provide automatic forms of modelling of 3D features. Modelling of buildings on large scale, for instance in the case of cities, is a time and resource consuming task therefore, in this context, developing automatic approaches can bring significant added value to the process. Buildings come in all different kind of shapes and dimension, are built with the various types of material with different architectural features.

Procedural modelling provides a solution to this issue. Various techniques are reported in the literature to create 3D city models in a procedural way. Some of the most innovative allow relating the architectural form with the urban context, and are classified according to three different approaches: (1) parametric design, (2) shape grammars or (3) evolution algorithms.

So-called parametric design methodologies have been imported from other domains, such as mechanical engineering, and now are adopted in real-life praxis. An example of this is the design of "Bishopsgate Tower" [13], in the city of London by "Kohn Pedersen Fox Associates". The use of parametric design was adopted to address several environmental issue related to energy efficiency and natural ventilation.

With regard to shape grammars, significant are the methodologies developed by Wonka [14], who uses "Split Grammars" and "CGA shape" to generate buildings and massive urban models with unprecedented level of detail, based on the architectural characteristics of the context. Relevant is also the work carried out by Larive and Gaildrat [15], who uses "Wall Grammar" for automatically generating buildings from their footprints, heights and roof heights, inside a GIS. Finally Parish and Muller [16], uses "Lindenmayer system" to generate a huge number of buildings, and each building facade is rendered using a texture shader without any geometric details.

Last but not least as far as declarative programming and genetic algorithms are concerned, Plemenos et al. [17] make use of them for implementing an application which allows to generate building models, according to an optimization shape process, according to formal criteria, declared by the user.

3 The system developed

The application developed has been engineered to provide strong support to operators looking for decision support during land planning and urban design tasks. Typically operators have to refer to an extremely wide range of heterogeneous multi-source, multi-dimensional, time-varying information sources, for this reason a geo-visual analytical approach was preferred. The goal was to deliver a web-based 3D and OGC compliant solution capable to provide interoperable access to GI that was able to provide strong links between data transformation and visualization to provide more powerful analysis.

3.1 Access to information

To do so a client-server infrastructure has been developed. At the client side a 3D geobrowser allows the user to connect to geospatial repositories in a interoperable form through standard OGC web services (OWS). This allows accessing, editing and managing geographical repositories from a 3D interactive environment.

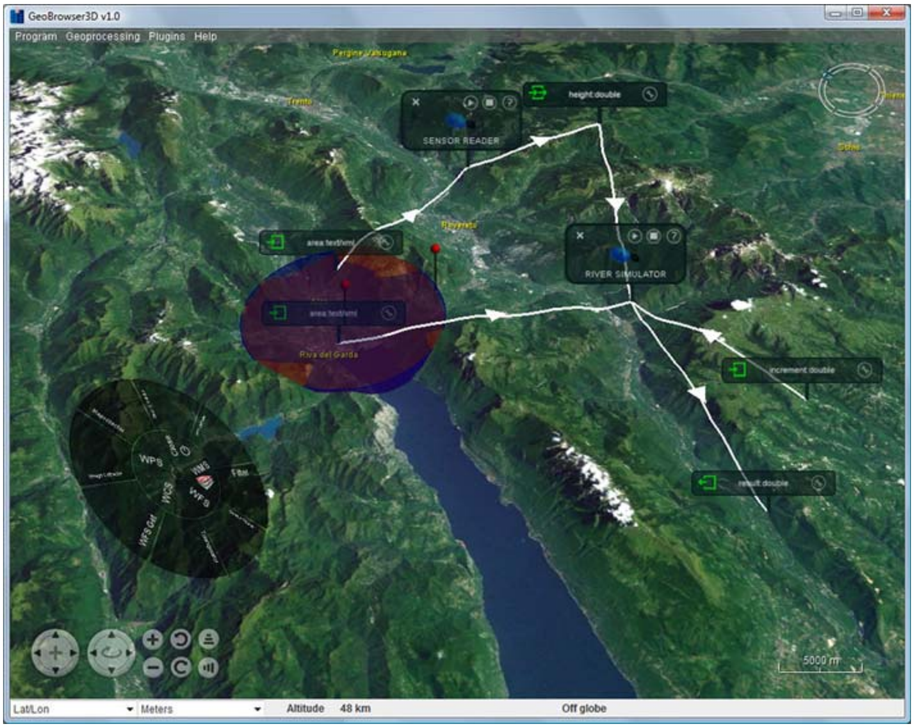

Fig. 1 An example of processing feature provided within the 3D environment

As detailed in previous works from the authors [18–20] the system allows to access, modify and process in an interactive form a vast range of GI from the 3D environment.

3.2 Processing of information

Furthermore complex processing functionalities, essential for land management and planning are also provided [21]. As illustrated in Fig. 1, the user can interactively define processing units (represented by icons within the 3D scene) related to specific information present at the territorial level. The input required by each processing unit can be interactively provided by the user. As illustrated in Fig. 1, the user for instance can select a line (while line in foreground at the bottom of the picture) to request the profile of the terrain.

This information is sent through a standardized interface, based on web processing service (WPS) [6], to a server that in the example illustrated has performed the calculation over a very high-resolution dataset. In this case the calculation has been performed over a digital model of the terrain acquired through airborne laser imaging detection and ranging (LIDAR) technology with resolution of 50 cm for a total extension of 6.212 km^2. For such a datasets, which easily scale up the order of Gigabytes, calculation must to be performed at the server side in order to avoid massive network traffic and to optimise system performances.

Through this approaches processing functionalities are off-loaded to remote servers, with a number of advantages among which scalability, safety, data integrity and performance.

3.3 Interaction process and workflow

The interaction process approached is based upon the workflow of operators in the environmental planning field. Traditionally the operator needs to use a number of different software suites in order to perform different simulations upon the environmental data. In the typical workflow the operator uses a GIS platform to manage the different data sets, to structure them in layers. This information becomes the basis for a number of simulations, often performed through different software. This process is extremely time consuming, it requires a number of different software packages, file format conversion and it is not interactive. The interaction metaphor proposed instead allows the user to create, in a fully interactive manner, the entire workflow by authoring the information available within the environment, and by programming a sequence of different processing steps in a very visual manner. Such high level of interactivity, that in fact allows visual programming of geo-processing units, yields great flexibility, shorter execution times and it is less prone to errors as no conversion to/from different packages is required.

3.4 Interaction and complexity reduction

This architecture described (see Fig. 2) gives to the client the power to make use of geographical data and services

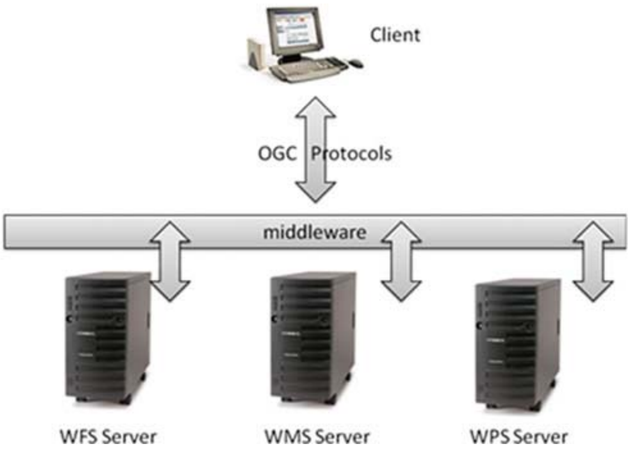

Fig. 2 The overview of the architecture

coming from multiple sources in multiple formats and process it, if necessary, by using distributed processing over an infinite number of scenarios.

Complex analytical functions, such as processing functionalities, essential to provide the necessary complexity reduction, can be performed very interactively. In fact as illustrated in Fig. 1, processing units can be chained to provide complex processes. Output fields from one building block can be used as input of a further building block creating processing chains directly within the 3D scene. In turn, input and output of each process, as well as the overall chain of process, can be directly related to the 3D scene. For instance, where applicable, results can be visualized as 3D representations or as images mapped over the territory.

3.5 Land planning and urban design through force fields

Furthermore information available through geographical services can be used to create 3D representations at territorial scale, especially useful for land planning and urban design. The 3D client in fact is capable of creating 3D models of buildings at urban scale, directly into a three-dimensional scene, by taking into account a number of geographical as well as urban features, modelled from the mathematical point of view, based on the concept of geographical "forces" and "constraints".

In this context forces and constraint are considered as those emerging from the urban context, as factors that model the urban space. The urban space is the result of the interaction of a large number of environmental constraints such as urban factors, natural and monumental emergencies, buildings, road infrastructures, climatic features, flows of vehicles and people. Each of these constraints and their reciprocal relationships, influence each other and have a profound effect at the land management and urban design level.

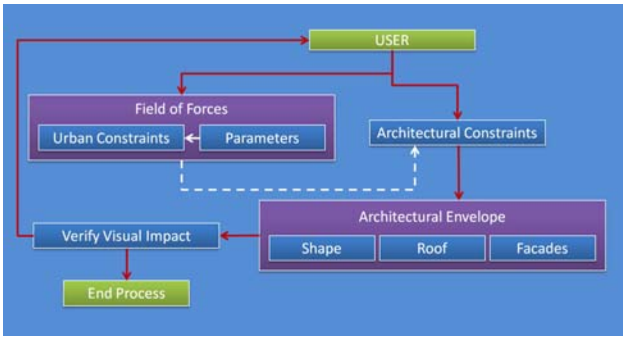

Fig. 3 The overview of the generative process

From the mathematical point of view those factors may be regarded as force fields with a specific spatial dimension. For this reason we have proposed a mathematical modelling which takes into account the spatial dimension when formulating the concept of force field. This way it becomes possible to formulate the variation that one or more design parameters are subject to according to their positions in the real space.

An example helps better illustrate this concept. When the system has to create a 3D model of a residential area it takes into account a wider geographical context. Let us suppose that this area is found to be located next to the city centre and to a commercial area. Those buildings close to the city centre or to the shopping areas will be affected, in terms of design choices, by the presence of the neighbouring areas. The result of the influence can be either in terms of height of each storey, in the average dimensions of the windows as well as in terms of a number of urban-related factors which influence the design of a building. The modelling must then take into account the geographical proximities of the "centres of the forces" as the effect of each force, on the urban layout, decreases with the distance according to specific relationships which have to be modelled from the mathematical point of view.

When defining the model of force fields the most complex factors to identify are: (1) the relationships between the components that often are of different nature, (2) the main variables characterizing the urban context (3) the relations between the architectural envelope and components of the force field.

To do so the system we have made use of generative procedures to manage the designed shape in an interactive way through the process illustrated in Fig. 3.

3.6 The generative process

Specifically modelled forces have been coded through two classes called urban constraints and parameters. The urban constraints class comprehends the most important dimensions linked to the urban law, these are:

- building index (*Ie*),
- coverage ratio (*Rc*),
- maximum building height (Hmax),
- maximum number of stories (*SN*max),
- minimum distance of terrain borders (*DB*min),
- minimum distance from the generic urban elements (Dmin), such as roads and nearby buildings.

The class urban constraints is therefore characteristic of the urban context and it is common to all buildings generated and it defines the constraints set by the national and local laws.

Within this class, typical architectural elements are also found, which characterize the typology of façade and windows inside the local context of reference.

Additionally the parameters class comprehends factors that allow regulating the influence of the constraints present in the urban constraints class onto each building. The parameters class, is linked to a single building and is constituted by factors over which the designer has decisional power. Through the coefficients of the parameters class, the designer decides the influence of the force field on the geometric features, and consequently the final design choice.

Acting on the class urban constraints or parameters yields different design results. Changing the formers equals to changing the territorial reference context, with its own laws and with the elements that characterize the architecture. Modifying the later equals to changing the shape of the building, leaving unchanged the field of forces and therefore, the effects on the architectural envelopes previously generated. Finally a further class called architectural constraints takes into account the most important geometric parameters, to generate the building and to locate it within its context. For this the area of the terrain At (1) and the its perimeters Pt are calculated according to the vertexes of the terrain (x_i, y_i) as follows:

$$At = \sum_{i=1}^{N} x_i \cdot y_{i+1} - \sum_{i=1}^{N} x_{i+1} \cdot y_i \tag{1}$$

$$Pt = \left[\sum_{i=1}^{N} (x_{i+1} - x_i)^2 + \sum_{i=1}^{N} (y_{i+1} - y_i)^2 \right]^{0,5} \tag{2}$$

Furthermore through (3) we calculate the value of α_i that is the angle at each vertex of the polygon that represents the shape of the building:

$$\alpha_i = ar\ \cos \left\{ \frac{(x_{i+1} - x_{i-1})^2 + (y_{i+1} - y_{i-1})^2}{[L_p^2 + L_n^2]} - 1 \right\} \tag{3}$$

where L_n (4) and L_p (5) are the lengths of next and previously segment of the shape defining the terrain, converging at the generic vertices "i". These are, respectively, defined as:

$$L_n^2 = \left\{ (x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2 \right\}^{0,5} \tag{4}$$

$$L_p^2 = \left\{ (x_{i-1} - x_i)^2 + (y_{i-1} - y_i)^2 \right\}^{0,5} \tag{5}$$

The values found through Eqs. 3, 4 and 5 are used to calculate D (6) a distance between all the boundaries of the building and boundaries of the terrain it is located within, so that the ratio between the area of the building and the area of the terrain corresponds to the coverage ratio (Rc), defined within urban constraints.

$$D^2 \cdot \left[\sum_{i=1}^{N} \tan\left(\frac{\alpha_i}{2}\right) \right] - D \cdot Pt + At \cdot (1 - Rc) = 0 \tag{6}$$

In other words D is the distance necessary for the building to have the correct Rc (defined within urban constraints class) ratio between the area of the building and the area of the terrain.

Through the value of D (6), taking into account the values set for DBmin and Dmin as defined in the Urban Constraints class through Eq. 7 we calculate d as:

$$d = \max \{DB\text{min}, D, D\text{min}\} \tag{7}$$

that yields the distance from the terrain edges at which the building must be placed.

Then as far as the creation of the building shape is concerned we calculate the parameter Final_*Ab*:

$$\text{Final\_}Ab = At - d \cdot \left[Pt - S \cdot \sum_{i=1}^{N} \tan\left(\frac{\alpha_i}{2}\right) \right] \tag{8}$$

that is the final value for the area of the base's building, which optimizes all three values of the distance between building and boundaries of terrain, that are "*Db*min", "*D*min", "*D*". The value of Final_*Ab* is used then to calculate *Hb* (9) and *SN* (10) that are the height of the building and the number of storeys according to:

$$Hb = \min \left\{ \frac{At \cdot Ie}{\text{Final\_}Ab}; H\max \right\} \tag{9}$$

$$SN = \min \left\{ SN\max, \text{int}\left(\frac{Hb}{Hs}\right) \right\} \tag{10}$$

In this way it has been possible to formulate a mathematical relation between force fields and the architectural envelope, which are implemented in the system. Some of the most important environmental issues, duly modelled, can therefore become generative elements that can be managed by the user.

4 Technological details

The architecture of the entire client-server system developed is based on Java and Java Enterprise Edition. Specifically the client has been developed on top of Nasa WorldWindJava libraries while each component at the server side is developed as Enterprise JavaBean (EJB) in line with component-based distributed business applications. Applications written using the EJB architecture are scalable, transactional, and multi-user secure. These applications may be written once, and then deployed on any server platform that supports the EJB specifications (e.g., JBoss, Glassfish, etc).

In the EJB container we implement the processing of all the client's requests. For that it may be necessary to access multiple local or remote flat files, database or other types of data storage, containing shape files, styles and other types of data that can be used if necessary.

At least two protocols can be used to remotely access the EJB container from the client, HTTP and RMI/IIOP. By using HTTP, it is possible to meet the requirements of a number of specifications for OGC web services such as web map service (WMS) [5], web feature service (WFS) [3] and WPS [6]. Servlets are then used to provide the bridge between the client and the EJB container.

All spatial information are stored on a PostGIS database including information such as unique building ID, number of storeys and facades, height and the geometry that define the outline of the building on the ground (Fig. 4).

As illustrated in the previous figure, upon request from the client, an Enterprise Java Bean downloads the entries representing the building from the database and pre-processes them to produce an instance of an utility class, called BuildingData, that is nothing more than a wrapper for the features store.

The rule engine, responsible for the formulation detailed in previous sections, is thrown in the loop to modify the features of the building, such as position or height, and generate additional ones, for example the texture to be applied on the wall based on the position of the building in the city. At this stage the force fields, described in previous sections are applied.This way, as far as the client software is concerned, this receives only a list of the descriptions of the buildings figuring in the scene which is used to generate the 3D scene.

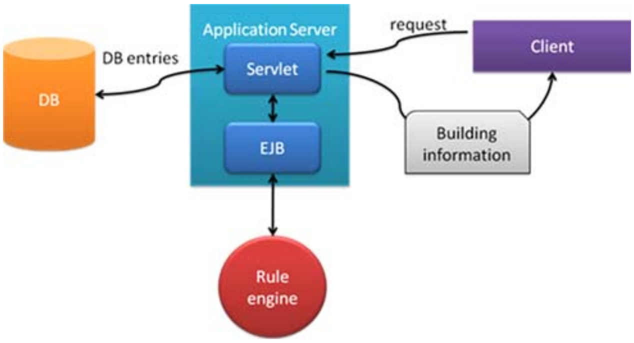

Fig. 4 Diagram of the modelling process

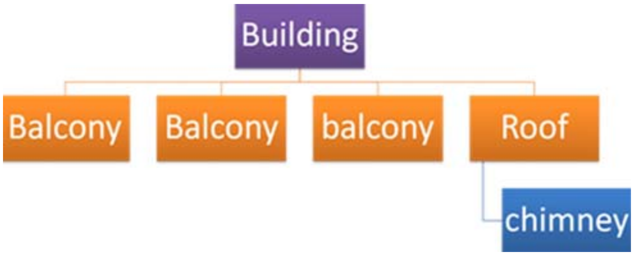

Fig. 5 The typical logical structure of a building

The first step would be generating the basic building shape starting from the plan of the building. At this stage it is required a conversion from coordinate pairs of the perimeter of the building, as stored within the geographical database, to a list of Cartesian space coordinates that describes the outline of the base of the building, more suited to a 3D representation.

In fact all information present within the geo-database is stored relative to the world origin located at the center of the Earth.

From the outline is rather trivial creating the building's walls through a simple extrusion process. Then the roof is laid onto the upper outline of the walls. Once the main structural elements of the buildings are laid off, system passes to the texture mapping. The textures to be used are known, thanks to the pre-processing task performed by the EJB together with texture coordinates for each texture. As a result a multi-pass texture creation process delivers the optimal texture, representing the most suitable material combination according to the force field applied to the area. A similar approach can be used to calculate the texture coordinates for the textures used to represents openings. Additional features, such as size and style of balconies, signs or even draining pipes, are always created through the use of the rule engine and therefore reflect the style, urban constrains and overall appearance typical of each area. All additional features are defined relative to the parent object and its local axis. In the case of a balcony this is a wall while in the case of a chimney this is the roof that in turn is referring to the position of the structure of the building. This approach reflects a logical hierarchical structure used to create a scene-graph representation at the graphical level as illustrated in Fig. 5.

The advantage of such representation is that the modification of an upper level node propagates itself down the tree: for example, if the building is moved, the roof with its chimney and the balconies will be moved too. As illustrated in the following pictures the resulting environment is created according to a visual appearance that is typical of each

Fig. 6 Screenshot showing the virtual city

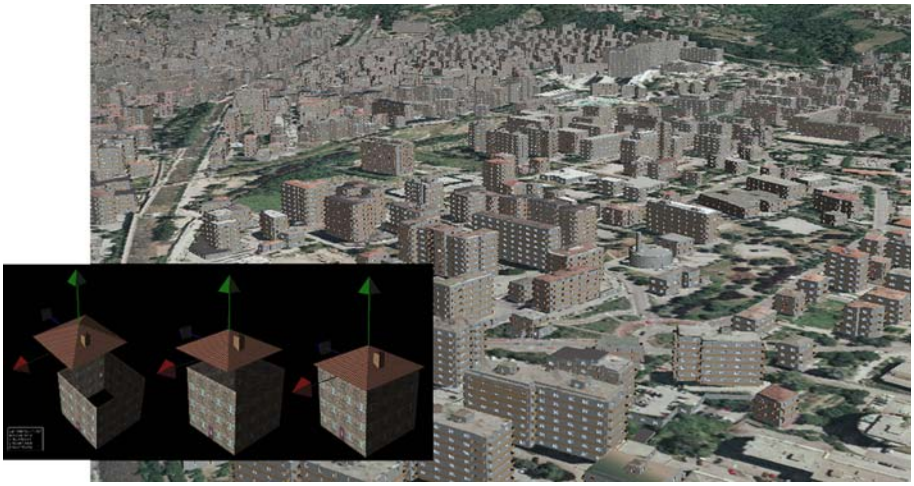

Fig. 7 Different screenshots showing how the city is automatically modeled according to a set of rules which define the different force fields

different part of the city. That means that if an operator wants to move a building from a part of the city to the adjoining area its appearance will change while this is moving, taking in account the effects of the force field modelled within the system (Figs. 6, 7).

5 Results

As illustrated in the pictures the system proposed brings together a generation process, with factors that traditionally belong to different planning and territorial management stages.

Operators can access spatial information available from public administration repositories, perform complex analysis related to the territory and provide consequent design choice in a fully interactive way, within a web-based interactive application that always provides very high realistic rendering. Problems related to optimization of the formal and volumetric properties of an area of a town, with respect to urban parameters and architectural styles can be tackled through the definition of constraints. Any variation to one or more parametric variables is applied to all the components of the buildings, providing a new configuration, which is visualized in real time. The user is able to interactively operate within a design process, by changing the parameters values and by verifying in real time, the results of the changes, he/she is able to evaluate all possible infinite scenarios.

The major contributions of this system are as follows:

- Interoperable access to planning and more generally to GI available at the public administration level.
- Access to processing functionalities necessary for land management and urban design.
- Optimization of volumetric and formal properties of the envelope of each building on the base of parameters given by the system, in terms of volume constraints.
- Optimization of the façade configuration defining the most important local architectural features, also codified within the force fields.

6 Conclusions and further developments

The work presented in this paper is an ideal candidate for land management and urban design specifically in the context of the evaluation of the impact on the environment of new buildings. The paper has illustrated how different design solutions can be defined and verified in relation to the factors proper of each urban context where they are located. Operating directly inside a geo-referenced context, it allows the user to verify, in real time, the results of the variations and to explore the different scenarios and the various possible alternatives, directly evaluating the introduction of the building within the context and its environmental impact through a true analytical process.

Further development will focus on two main issues, first the support to other design-related activities, such as public infrastructure (roads, railways, etc.) design and maintenance according to the specific context. Secondly we will focus on the development of a more specific formalism for defining rules and constrains. For this we will consider the development of a mark-up, based on XML syntax, specifically engineered to define urban-planning relationships and laws. This could be particularly useful to create a formal representation of urban-related laws.

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