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An architectural generative design process

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The paper discusses about architectural and urban design tools, and reports a prototype of parametric application that allows the designer to handle the architectural shape by using urban regulations. It is a Decision Support System (DSS), useful at the early stage of city planning as well as at the early stage of architectural design. The System integrates two different research topics: modelling in geo-referenced environment and modelling through constraints. Compared to the related works (Building Modelling on geo-referenced environment), our application is the first Generative System based on the urban regulation. Three case studies are presented to test the System.

Keywords: *generative design, urban design, architectural design, geo-referenced environment*

1 Introduction

In the last decades, digitals tools have an increasing role in the actual approach to design process. The latest enhancements of Computer Aided Design (CAD), Object Oriented Programming (OOP) and Geographic Information Systems (GIS) have opened new opportunity in architectural and urban design, with new software implementing complex algorithms based on parametric techniques, evolutionary systems, and shape grammars to model architecture. The current CAD technology, overcomes the traditional approach that utilizes computers as mere drafting and rendering tools. Several digital design software, enable the designers to manage an interactive architectural process generating one building or a very large urban context (City Modelling). They allow to bridge the gap between architectural shape and various forces or constraints emerging from the context. Some environmental constraints could be easily identified and encoded, for instance geometric components as height, floor number, area of building footprint and other aspects derived from general regulations. However, other types of environmental factors, such as social codes, economic factors and psychological aspects, are very often difficult to translate into generative rules. Specifically, many researchers see the constraints specification and satisfaction as the key issues in the design process, and they generally represent geometrical, physical and functional requirements. The constraints based approach is widely used in order to provide designers with powerful tools capable to strongly support the early stages of design activity. Among these, the systems based on urban regulation are particularly interesting. The study focuses specifically on this last issue.
The paper is organized as follows: the section 2 presents an overview on related works recently developed. The sections 3, 4, 5 and 6 describe the System, his ar-

chitecture, the generative process, the interoperability and the benefits for designer; the section 7 is dedicated to three simulations, that were especially developed to test the System. In section 8 we discuss some limits of the System and possible future developments leading to the conclusion section.

2 Overview on related works

The most interesting work for a designer is to find creative solutions for a given problem. Then he makes approximate estimations on dimensions and cost, and gives it to specialists for detailed analysis. After he interprets results and accordingly chooses the solution. There are many excellent tools capable to perform these tasks.

One of the most important examples is CityZoom.[1] It is a Decision Support System (DSS) to urban planning: the buildings are generated by applying urban regulations on plot geometry, according to input parameters. The system determines the geometrical features of the building which have to be assessed or optimised, such as number of floors, front or size width, and plot occupation. It is a powerful tool to evaluate the impact of urban regulations.

Urban Generator is a hybrid system integrating the generator of a large number of design solutions and the browser to search and structure the high-dimensional space of the design solutions, according to variable and customisable factors defined by the designer. It allows user to simulate different urban scenarios considering as input, total building volume, front and depth dimensions, floor number and height, number of buildings, minimal distance between buildings, minimal distance from the edge.[2] City Generator[3] is a tool for simulating urban scenarios. The central feature of the tool consists of a Genetic Evolution (GE) engine, which can quickly generate various urban forms, through the combination of L-System controlled procedural model and the GIS map controlled Spatial Occupancy (SO) model.

Prototype for Urban Code Constraints is a Decision Support Systems[4] that simulates several options for the building shape, according to the parameters required by the city zoning planning, such as ‘Buildable coefficient’, ‘Site coverage coefficient’, ‘Setback requirements’ and ‘Sky exposure plane’.

Another example is the Parametric Envelope,[5] which allows the designers to create prototypes in Revit©: the urban code is turned into computable data and theoretical volume is shown in real time.

ArchiGen[6] is a generative application that enables the designers to generate architectural shape, within a Building Information Modelling (BIM) environment like ArchiCAD©. It is based on GDL (Geometrical Description Language) and enables the designer to explore architectural shape, by changing the parameters such as ‘floors count’ and ‘floor height’.

High FAR[7] makes it possible to generate a high level residential district planning, with the focus of a layout of high ‘Floor Area Ratio’ (FAR). The tool is based on the principle of Multi Agent System (MAS) and simple genetic algorithms.

CityCAD[8] develops the automatic generation of buildings. This system allows analysis of urban master plans at the early design stages. It calculates floor areas, densities, costs, car parking spaces and a wide range of other planning, environmental and financial data.

1 **Turkienicz, B.** et al (2008). Cityzoom: A tool for the Assessment of Planning Regulations, International Journal of Architectural Computing, 6:1, pp 79-95

2 **Caneparo, L.** et al (2007). Urban Generator, Agent-based simulation of urban dynamics. In: Dong, A. et al eds, *12th CAAD Futures Conference*, Springer, Sydney, pp 347-360

3 **Tang, M.** (2008). City Generator: GIS Driven Genetic Evolution in Urban Simulation. In: *Proceedings of the 96th* ACSA Conference, Houston, pp 366–377

4 **Donath, D.** & **Lobos, D.** (2008). Massing Study Support. In: Muylle, M. ed, Architecture ‘in computro’- Integrating methods and techniques, 26th eCAADe Conference, Antilope Printing, Lier, pp 101-108

5 **Mellantoni, G.** (2006). Sólido Capaz: Modelamiento Parametrico de Distanciamientos. In: *Proceedings of the SIGraDi Conference*, Santiago de Chile, pp 127-130

6 **Mallasi, Z.** (2007). Applyng generative modeling procedure to explore architectural forms. In: Okeil, A. et al eds, Em‘body’ing Virtual Architecture, 3rd ASCAAD Conference, Publisher ASCAAD, Alexandria, pp 335-342

7 **Biao, L.** et al (2008). A generative tool base on Multi-Agent System: Algorithm of HighFAR and its Computer Programming. In: Nakapan, W. et al eds, *CAADRIA 2008-Beyond Computer Aided Disign*, Pimniyom Press.Co.Ltd, Chiang Mai, pp 335-342

Besides, formal local planning codes, patterns of movement, social codes, and other interventions, which affect the architectural shape, can be included in the process to obtain a new modelling technique. These patterns may be used to explore the emergent properties of different types of the urban settlement.[9] Moreover, they can suggest ways in which the planners could beneficially influence the development processes that are otherwise beyond their control.

In the architectural design process, the designers are able to handle other constraints such as architectural features of the envelope, types of facade as well as types of windows and roofs. An interesting example is Split Grammars.[10] It is a technique derived from shape grammar, which generates many configuration alternatives of the building facade.

The morphogenesis of architectural shape could be performed by using climatic or physical features, such as solar radiation[11] and solar passive evaluation,[12] based on the Unified Day Degree (UDD) method. They lead to the optimisation of architectural envelopes through a Genetic Algorithm to minimise HVAC and lighting energy, in the first case, and solar passive qualities in the second case.

CityEngine is a tool based on 'Procedural Modeling of Cities'. It was developed in order to enable designers to generate many digital models of buildings and cities, changing a set of specific rules.[13]

The Wall Grammar is Technique used to automatically generate building facade.[14] The tool imports GIS data such as '.dxf' and '.vmap', containing the building footprints. The building outlines and heights can be either obtained automatically or defined in a GIS environment. Then the system uses such data to create 3D building models.

The modern GIS technologies are used extensively in many 3D applications, as practical means to aid decision making. The most recent development of Geo-Visual Analytics offers to designers and city planners new opportunities. Some systems, such as World Wind© (NASA), Google Earth™ (Google), Virtual Earth® (Microsoft), provide three dimensional models of earth surface. The information available through geographical services can be employed to create 3D representations at territorial scale that are useful to land planning and urban design.

3 Description of the System

Recent developments of our research propose a prototype of parametric application that allows the designer to generate 3D digital models of buildings and urban scenarios by using the main constraints based on urban regulation, directly within a 3D geobrowser such as Google Earth™.

The urban planning regulation establishes some parameters and constraints in order to control urban configuration, shape of the buildings and their geometrical features, such as height (H), number of storeys (SN), storey height (hi), area of the floor (A_{floor}), area of the building footprint ($A_{footprint}$), distance from boundaries plot (d_i), with i = 1, 2… SN. At present we take into account the following set of parameters:

- Building Index (BI): multiplied by the area of the plot, determines the maximum volume of the building (1).
- Coverage Ratio (CR): multiplied by the area plot, determines the maximum area footprints (2).

8 www.holisticcity.co.uk/index.php

9 Erickson, B. & **Lloyd-Jones, T.** (1997). Experiments with settlement aggregation models, Environment and Planning B: Planning and Design, 24:6, pp 903-928

10 Müller, P. et al (2006). Procedural Modelling of Buildings, ACM Transactions on Graphics, 25:3, pp 614-623

11 Caldas, L.G. (2005). Three-Dimensional Shape Generation of Low-Energy Architectural Solutions using Pareto Genetic Algorithms. In: Duarte, P.J. et al eds, Digital Design: The Quest for New Paradigms, 23th CAADe Conference, Lier, Belgium, pp 647-654

12 Marin, P. et al (2008). Integral Evolutionary Design, Integrated to Early Stage of Architectural. In: Muylle, M. ed, Architecture 'in computro'- Integrating methods and techniques, 26th eCAADe Conference, Antilope Printing, Lier, pp 19-26

13 Parish, Y. & **Muller, P.** (2001). Procedural modelling of cities. In: Siggraph 01, *Proceedings of the 28th conference on Computer graphics and interactive techniques*, New York, pp 301-308

14 Larive, M. & **Galdrat, V.** (2006). Wall Grammar for Building Generation. In: Graphite 2006: Proceedings of the 4th International Conference on Computer Graphics and Interactive Techniques in Australasia and Southeast Asia, pp 429-437

- Maximum building height (H_{max}): the maximum vertical distance between the ground level and the highest point of the building (3).
- Maximum storeys number (SN_{max}), (4).
- Setback requirements (DB_{min}): the minimum distance between the sides of building footprint and the plot boundaries (5).
- Minimum storey height (h_{s-min}): the minimum vertical distance between the floor and the ceiling of an inhabitable room (6); this parameter is generally influenced by hygienic and lighting requirements.

The workflow consists of two main steps:

- Converting the geometrical and urban constraints to mathematical form.
- Implementing an efficient generative code.

Each of these parameters affects the volume and all geometrical features of the buildings (Figure 1), by means of specific geometrical and topological relationship, closely connected each other:

$$BI \geq \Sigma(h_i A_{floor}) / A_{plot} \quad (1)$$

$$CR \geq A_{footprint} / A_{plot} \quad (2)$$

$$H_{max} \geq \Sigma(h_i) \quad (3)$$

$$SN_{max} \geq SN \quad (4)$$

$$DB_{min} \geq di \quad (5)$$

$$h_{s-max} \geq h_i \geq h_{s-min} \quad (6)$$

$$A = (\Sigma (x_i y_{i+1}) - \Sigma (x_{i+1} y_i))1/2 \quad (7)$$

$$P = \Sigma ((x_{i+1} - x_i)^2 + \Sigma (y_{i+1} - y_i)^2)^{0,5} \quad (8)$$

$$\pm[P-(P^2 -4 \cdot A \cdot (1- CR) \cdot \Sigma (P \cdot tg(\alpha_i/2)))] / 2 = 0 \quad (9)$$

$$\alpha_i = \arccos((\square x_{i+1} - x_{i-1})^2 + (y_{i+1} - y_{i-1})^2 - 1) / (L_N^2+L_P^2) \quad (10)$$

The maximum storey height (h_{s-max}) is an important parameter for the generative process and it is not indicated in urban planning regulation, being set by the designer according to specific architectural requirements. The equation 7 gives us the area of the building footprint, building plot and all floors (x_i and y_i, are the Cartesian coordinates of the vertices); the parameter 'P' (8) is the perimeter calculated according to the vertices of building plot; the parameter 'di' is the equidistance between the sides of the building footprint and the boundaries of the building plot. The parameter 'α_i' (10) is the angle at each vertex of the polygon that representing the building plot; 'L_N' and 'L_P' represent the lengths of next and previous segment of the plot, converging at the generic vertex. The 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 are important components of the System; this set of relations duly codified through an object oriented method, become generative rules and enable the designer to create the 3D models of buildings. The designer can access and modify some of the mentioned above parameters, but he cannot change the algebraic framework of the relations. The combined use of relations 8, 9 and 10, allows to calculate the optimized distance between all the boundaries of building plot and footprint: this parameter allows to locate the footprint vertices, so that the ratio between footprint and building plot area, corresponds to the coverage ratio (CR), established by urban regulations.

4 The architecture

The architecture (Figure 2, left) of the System was conceived especially to ensure interoperability between several commercial software. It has been developed using Java Enterprise Edition Environment and XML mark-up language and consists of five main components: *Graphical User Interface* (GUI), *Data Processor*, *Model Generator*, *Texture Library* and *Displayer*.

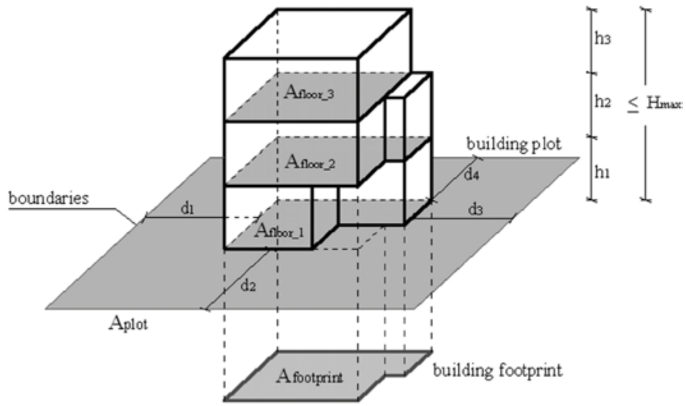

Figure 1 The geometrical features of a building generated according to urban planning regulation, duly codified through an object-oriented method

The *Graphical User Interface* (Figure 2, right) is a parametric component which allows to manage the interactive generative process ; it is based on 'JFormDesigner™' technology and implements the Java classes 'awt', 'swing', and 'jgoodies.forms.factories'. As computer systems become more complex, the GUI is an important component to deal with the increasing complexity of design process. The GUI allows to enter and load the following specific data:

- The *Parameters* defined by urban planning regulation, such as aforementioned building index, coverage ratio, maximum building height, maximum storeys number, setback requirements, minimum storey height, and other required parameters such as maximum storey height and texture of façade.
- *Geometry file*, with '.dxf', '.shp' and the '.kml' file formats, which contains polygons. The file can consist of an urban plan, a simple sketch or drawing of the designer; the polygons represent building plots or building footprint.

The *Data Processor* consists of three sub-components. The first implements the 'buffered-reader' in order to read the *Geometry file*, and it consists of three parser; each of these is based on three different Java libraries, such as 'Kabeja' to read dxf file, 'Geotools' to elaborate respectively ESRI Shapefile ('.shp') and '.kml' (Keyhole Markup Language) file. The second sub-component implements the generative rules describing the urban regulations, the geometrical and topological relations. The third sub-component is based on the well known free NASA WorldWind package called 'gov.nasa.worldwind.geom'. The two last sub-components are able to carry out specific computational tasks, including determination of geometrical attributes of the building models and conversion of coordinates vertices; in fact, as planning parameters which are expressed in meters, all geographic data must be converted to meters.

The *Model Generator* implements the known Java pachages 'BufferedWriter' and 'javax.media.j3d.Shape3D'. The first pachage allows to generate three files according to ASCII and XML syntax; the first syntax constitute the base of '.dxf' files, the second, is the base of ' COLLADA' (COLLAborative Design Activity) and '.kmz' files. The 'model.kmz' consists of a compressed file, which contains much information about the digital models, not only the geometrical attributes but also the texture of facades and his location on the earth surface. The second pachage provides a function template to built a complex triangulation algorithm; it takes as input a set of points wich represent the coordinates of vertices of the

3D model, to be meshed. The algorithm allows to perform two mesh process, involving respectively the development of 3D surface and the texture to apply on the model.

The *Texture Library* is the only component which is not a java class; it consists of a container folder and contains several data images characterised by various extension ('.jpg', '.bmp', '.gif' and '.png'). Each image represents a texture to apply on the 'model.dae'. The System allows the designer to access the *Texture Library*, in order to update and add new items to it.

The *Displayer* connects our System to external 3D viewers, by means of the well known Java class 'Runtime', able to run Google Earth™ and place the 'model.kmz' on the earth surface. This component makes it possible to use the advanced Virtual Reality Environment (VRE), and the other features provided by 3D Geobrowser.

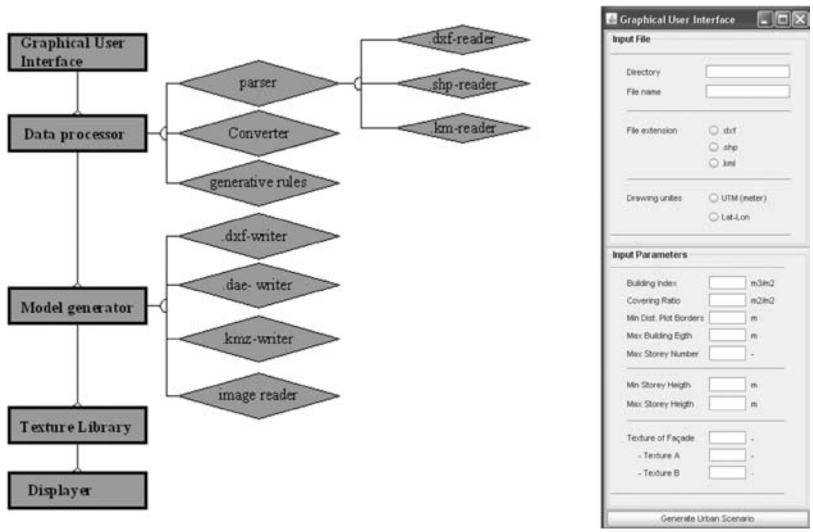

Figure 2 Left: architecture of the system, Right: parametric graphical user interface

This section addresses the generative process and his three main stages (Figure 3): *Input*, *Processing* and *Output*.

Input: The first stage is managed by the designer through the special GUI, according to the following steps:

- load the *Geometry file*; this operation is done by specifying the file path and specifing his type ('.dxf', '.shp' or '.kml')
- enter the *Parameters*
- select an appropriate texture to be applied on the digital model
- select the digital model in output ('.dae', '.dxf', '.kmz')

The designer defines different polygons ('polyline' command), such as convex, concave, regular or irregular ones, by using the commercial CAD software or GIS systems. The *Geometry file* must be geo-referenced, in order to achieve a correct visualization of the building models within the 3D Geobrowser. The System supports geo-referenced files, not only in latitude/longitude units, but also in UTM (Universal Transverse Mercator) units. The UTM coordinates are more preferred than latitude and longitude, because the System runs very quickly and efficiently. Coordinates must be referred to a Cartesian system with origin at the centre of Earth.

Processing: From this stage onwards, the control of the process is shifted from the Designer to the System. This is a computational stage performed by *Data Processor* and *Model Generator*, aiming to generate architectural envelope features, according to steps below:

- reading geometrical data from the *Geometry file*, and extraction of the building plots coordinates
- converting coordinates from longitude and latitude to meter; this is an optional step which will be performed only if the *Geometry file* is geo-referenced in latitude and longitude
- calculating geometrical data of the building plots, such as area, perimeter and angles at vertex.
- determining building footprints; this step involves especially two of the aforementioned planning parameters, such as Covering Ratio (RC) and minimum distance from plot boundaries
- determining geometrical attributes of the building models, more especially building height, storeys number, storeys height; this step involves especially two of the aforementioned planning parameters
- calculating vertices (x, y, z) of both building footprint and floors. The outcome consists of a list of vertices to triangulate, and arranged into an associated array
- generating 3D models. On this step three file formats are developed; they represent the building models called respectively 'model.dae', 'model.dxf' and 'model.kmz'
- texture-mapping. After the main elements of the buildings are generated, the System works on texture mapping, which represents the most suitable material selected by the designer. As a result, a multi-pass texture creation process produces the optimal texture

Output: In this last stage, the three dimensional building models are automatically displayed and they are shown on the three dimensional geo-referenced environment.

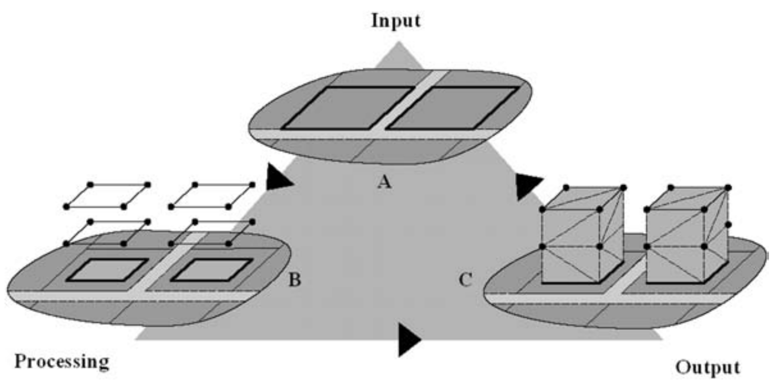

Figure 3 The generative process: building plots (A); the System calculates the vertices of the floors according to the generative rules (B); 3D building shape is generated and consisting of triangular mesh (C)

5 Compatibility with other software

The possibilities of data exchange in real-time between the System and the main software used in the field of architectural and urban design, were the significant

issue on which the work has been focused. It is important in order to achieve an integrate design process, and take into account the import and export of data. Detail about to import capabilities (input stage):
the System is able to interface itself with many kinds of software supporting three widely used file formats, such as:
- CAD applications supporting the '.dxf' format: AutoCAD®, ArchiCAD©, Microstation®, Autodesk Map 3D®. It is especially important in order to enable the designer to interactively manage the *Geometry file*, during the generative process.
- GIS systems, supporting the '.shp' format: ArcGis®, fGIS®, PostGis®, GrassGis®, gvGIS®, OpenStreetMap®.
- 3D Geobrowsers, supporting the '.kml' format, such as Google Earth™.

About to export capabilities, the System generates not only '.kmz' file, but also '.dxf' and '.dae' file formats, that allows to export the three dimensional models of buldings, even within following software:
- CAD applications supporting the especially '.dae' format, but also '.dxf': AutoCAD®, Revit®, 3D Studio Max®, Blender®, Maya®, Catia®, MicroStation®, Poser®, Cinema4D®, Softimage XSI®, MeshLab®, CityEngine, SketchUpPro®, Simlab Composer v2®, Arc2Earth®.
- 3D Geobrowsers, the System was designed to display the outcome in Google Earth™ and Nasa WorlWind©, in order to make it possible to navigate through the three dimensional virtual environment, which represents the city modeled, with the blocks, plots, buildings. The interactive environment enables the designer to get better decisions.
- CFD (Computational Fluid Dynamics) systems, integrated with the architectural digital model, allow to predict temperatures, direction and velocity of air flow, pollution dispersion, inside the urban space during the early design stage. The designer is able to make architectural changes, i.e. modify architectural shape or urban configuration until to get desired results. Two considerable CFD packages are CFX® and Fluent®. The New Fluent releases enable the designer to use directly the existing native CAD geometry, without translation to '.iges' or other intermediate geometrical formats. Both CAD and CFD systems allow the user to achieve a complete simulation, and to take in account many constraints, not only urban regulations but also climatic features.

6 Benefits for the designer

In a previous section we have seen the state of the art in CAD technology. We have discussed about a lot of different tools which provide a range of software and methodologies to support urban and architectural design. From this extensive literature, emerge two important research topics, especially, modelling in geo-referenced environment and modelling constraints. The aforementioned topics have not been incorporated into integrated processes. Our research seeks to overcome this limitation.
The objective is to provide the architectural designers a Decision Support System (DSS), useful at the early stage of urban planning as well as architectural design. It combines the modelling ability of the CAD systems with the numerous opportunities offered by a geo-referenced environment, like geo-visualizations and 3D GIS technologies. Compared to existing works about the building modelling in a

GIS, our application is the first Generative System based on urban regulations. The benefits at present offered by our tool are:

In the city planning process, the System allows the designers to evaluate the impact of the urban regulations and therefore to choose the best set of rules and parameters in order to achieve the desired environmental goals.

In the architectural design process, it also enables the designer to generate 3D model of buildings according to the most significant urban parameters:

- optimizing volumetric and formal requirements of each building, on the base of parameters entered by the designer
- optimizing the facade configuration, defining the most important local architectural features, also codified within the System. This issue depends on the quantity and the type of pictures stored into the *Texture Library*

The designer can quickly explore many urban scenarios and various possible alternatives of the architectural shape; he can change the value of selected parameters and visualize in real time the results of the changes.

Additional advantages for the designer derive from the advanced features of 3D GIS technologies, such as:

- interoperable access to planning and more generally to the geographical information, available at the level of public administration
- access to processing functionalities necessary for land management and urban design
- 3D GIS is used to corroborate information independently collected using traditional observation methods. The way 3D GIS supports urban and architectural design process through its spatial database. Its main function is to store urban information in digital format for further GIS processes, which involve queries, analysis, visualizations and simulations.

The System might be not only a DSS, but also an useful tool to help didactic activities. The teaching design process is not an easy task, in a complex field like the architecture; nowadays there are not adequate tools capable to help teachers and educators to overcome some their teaching difficulties and to achieve desired didactic goals. At academic level our System can also efficiently support the processes of educating and teaching architectural and urban design. It helps students to explore design scenarios, acquire knowledge and awareness of urban constraints and design parameters, and know their effects on the architectural and urban configuration. The general framework and the intuitive *Graphical User Interface* of the System, make it accessible to teachers and every student, and they can help to overcome the limits of the traditional teaching methods.

7 Examples of parametric generative design

We present three case studies concerning the design of buildings in a peripheral area of Palermo (Italy). Each of these allows to generate a range of possible formal solutions and evaluate the results of their spatial organizations. In order to facilitate the simulations and to make these more concrete, we have avoided forms totally invented, without any reference to spatial aggregations really possible and with shapes of uncertain feasibility. While the projects used in the proposed case studies, even if they refer to different urban context, having the same typological and architectural shapes, will be certainly appreciable and still compatible with the considered sites. So we have referred to projects done in three

15 **Cambi, E.** et al (1992). Tipologie Residenziali in linea, BE-MA

different European cities: Zaandam and Rotterdam (Netherlands) and Berlin (Germany), which however have had relationship with an environment very similar to those taken into account. We have also chosen very different configurations, referred to three different types of buildings: tower, courtyard and terraced houses.

Figure 4 The building 'De Ruyter' by F. van Dongen, Müllerpier, Rotterdam, Netherlands, 2005-2008. Its 3D model was generated aggregating several buildings within the same area

In the first case we have referred to the building called 'De Ruyter', one of the 13 blocks of apartments designed by F. van Dongen and Architecten CIE for 'Müllerpier', near Maas River, between downtown and Rotterdam - West. The shape of the building has been derived combining two different types of houses, courtyard and tower. The scenario was generated aggregating several buildings properly arranged, forming a whole block in the neighbourhood in accordance with the urban regulations of Palermo (Figure 4).

The second case concerns the project known as 'Salamander' designed by M.A. Miguel and L.B. Mastenbroek and realized in Zaandam (1999-2006). The building consists of 79 apartments with a courtyard, with a free public space, 14 service apartments and community facilities. The outline of the building and its height have been deliberately opposed to the urban context, which is a neighbourhood with terraced houses and multi-storey row houses. The scenario of the planning allowed the simulation to assess the inclusion of the building in the urban context of the Palermo's periphery (Figure 5).

The third case deals with terraced houses designed by architect K. Müller - Rehen,[15] and built in Berlin, Germany (1956). The generated scenario shows that the buildings have been arranged in groups of four units following the inclination of the area chosen for simulation (Figure 6).

The case studies consist only of three simulated scenarios; however it is possible to generate more scenarios by changing the building plots, parameters and type of buildings, until the architectural shape and urban configuration satisfy specific formal and spatial requirements. Different design solutions can be defined and verified, in relation to the specific factors of each urban context where the buildings are located. Operating directly inside a geo-referenced environment, it is possible to verify, in real time, the results of the variations and to explore the different scenarios. Various possible alternatives can be directly evaluated, considering the buildings within the urban context and their environmental impact, through an analytical process and more and more visualizations.

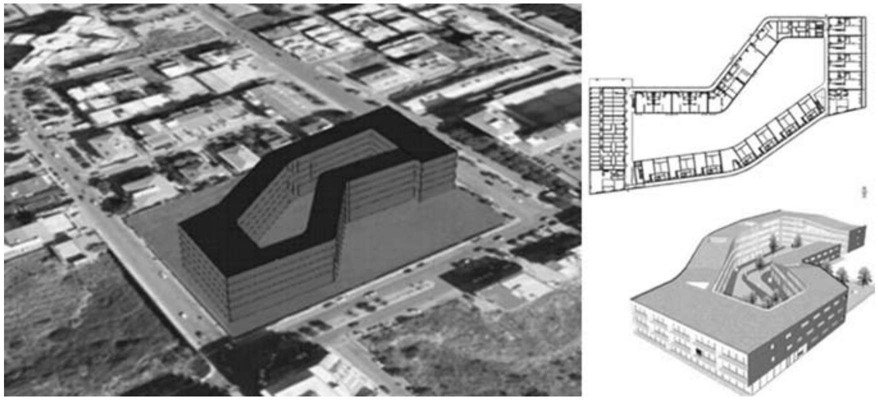

Figure 5 The 'Salamander' building by M. Loosand and B. Mastenbroek, Zaandam, Netherlands, 1999-2006. The 3D model was used to simulate an urban scenario in an peripheral area of Palermo, Italy (Google Earth™)

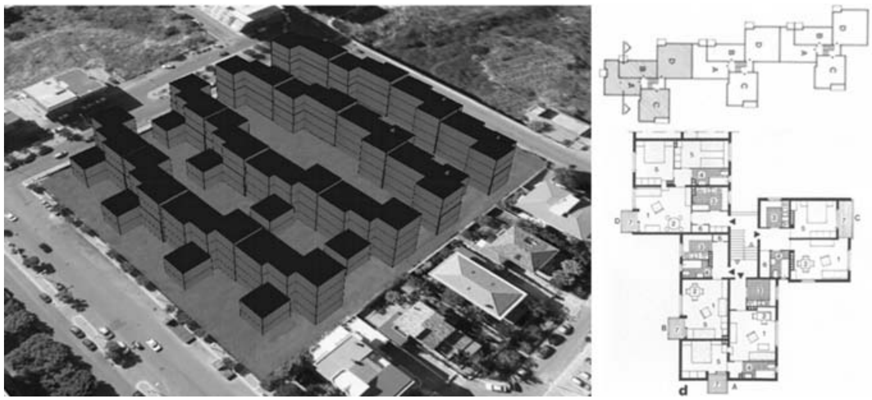

Figure 6 The 'Row houses' by K. Müller-Rehen, Berlin, Germany, 1956. The 3D building models generated and displayed in the same area

8 Goals and future developments

The architectural design process, is nowadays characterized by a high degree of complexity and interdisciplinary. The processes involved are sophisticated, and they need the knowledge of most important mechanism and constraints that occur at urban level. We have been encoded many relationship, in order to obtain an extensive Java code which is very difficult to represent. Because the System is very complex, we cannot show all relationship, such as those between the vertices of the building plot and its base. On the whole the System has some limitations, more specifically:

- the designer can manage geometrical solids with a polygon base; other geometrical entities cannot be treated, such as nurbs surface or curves and non planar roofs
- the *Geometry file* can be loaded only by writing his path on relative GUI
- there is not relationship between architectural envelope and functional/distributive factors of internals space
- the System does not take into account the structural aspects and all elements related to mass distribution of the building
- the creation of *Geometry file* requires specific procedures: for instance the geometrical objects treated are only polylines, and they must be placed on a specific layer named 'Polyline'

The future work aspires to improve the System, such as to increase the efficiency and interactivity, in order to enable the designer to explore more scenarios and more complex architectural shapes. This goal will be achieved through several meta-goals, such as:

- enhancing the *Graphical User Interface* and the process of *Geometry file* loading
- achieve a better interoperability between our System and the different applications software. These are the problems that can only be solved by using an Object Oriented Programming
- introducing other kinds of features, especially typological and formal, that constraint the shape to urban local conditions or to specific needs
- developing an algorithm capable to dividing the interior space of a building into functional units, connected and related between them. We will take into account a constraint based approach, linked to shape grammar, according to suggestions emerging from existing literature
- implementing a code that allows to manage *Geometry file* characterized by image file formats such as '.jpg', '.bmp' and the 'tif'. At present, the System is able to work out only the three file formats discusses in previous sections
- improving the export capabilities, so that take into account many file formats, such as '.obj' and '.dwf'

Besides, other environmental features will be added to better simulate the effects of the context. For instance:

- type of urban zone (trade, industrial, housing)
- presence of significant architectural works (monuments and historic buildings); elements of natural landscape (rivers, lakes, parks, mountains, vegetation)

We will include geometric rules in order to generate streets, building plots, land-use on a small scale, and to represent functional relationships based on flow systems such as traffic movements, vehicles, people and information flux.

Finally, a study is being carried out to automate the generative process of the scenarios by means of evolutionary algorithms. The conceptual work is done by the computer, which finds the global optimal solution and speeds up the solution searching process. We will examine Genetic Algorithm (GA) and the Bee Colony Optimization Algorithm.

We will focus on the development of a more specific formalism in order to defining rules and constraints; physical and climatic factors such as solar radiation, intensity and direction of dominant winds that may be included in the generative process. We take into account XML syntax, specifically engineered to encode the urban planning relationship and laws. The outlined problems therefore demand to seek innovative solutions which allow to improving design efficiency by favouring the development of creative ideas. The final goal of the research is to provide designers innovative design tools which bring inside an integrated process many factors traditionally belonging to different planning stages, so that they can efficiently support the design activity for a sustainable architecture.

9 Conclusions

The paper reflects on design methodology and discusses the latest innovations in CAD technology. The new techniques open new fields for the development and exploration of more complex as well as architectural shapes, where complexity is considered not only in the sense of geometric and topological properties of the shapes, but also in the relationship that links architecture to the elements of the surrounding environment. The results show that using specific information and tools, in the early stages of the architectural design or the city planning, reduces the time of work, and allows to explore many alternatives in a short time. Most of the examples described in the paper, concerns a constraint based approach; we have showed how this method is applicable to different design problems. This approach is an ideal candidate to help the designer, but it requires specific skill, especially the knowledge of hierarchical blocks.

Many difficulties have arisen when collecting information. The most complex problem dealt with finding and implementing relationship between various types of elements, as well as defining significant parameters that characterise the architectural shape and environmental context. Many actions limiting the shape, derive from considerations that cannot be immediately translated and represented according to predefined codes, therefore giving origin to qualitative natural evaluations. Aside from the complexity itself bound to concepts that rule a planning process, these difficulties sometimes also impose a partial behaviour to coping with the planning aspects. Then we have to leave out some of it that may be at times necessary, in order to research simplifications that the complexity of the system requires. The work presented in this paper is an ideal candidate for architectural and urban design specifically in the context of the evaluation of the impact on the environment of new buildings.

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