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A 3D GIS FOR MANAGING BUILDING REHABILITATION PROCESS

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Abstract

Increase in energy efficiency and reduction of greenhouse gas emissions of buildings can be achieved through improvements made in the existing stock of buildings. Therefore, one of the objectives for incentive policies should be to promote environmental issues each time a rehabilitation process is engaged. Specific tools have to be developed for that purpose. In this paper, we present a 3D Geographical Information System (3D GIS) designed to evaluate the environmental properties of buildings envelopes, in order to assess their improvement potentials. The system offers a representation of the entities that compose the building, and its associated environmental data (solar data, energetic and sonic ones, architectural data, etc). These are obtained either by observation in situ or by simulation. The system facilitates data handling and data crossing to optimize analytical process. An evaluation of its functionalities is in progress in the city of Nantes (West of France).

INTRODUCTION

Geographical Information Systems (GIS) are common tools for urban planning, and many cities now have their own GIS. Most of them are 2D GIS that associate data to geographical urban entities like roads, building's footprints or squares. The third dimension within GIS is often used to offer impressive realistic 3D views, as an attractive means for communicating with non-expert public. Real 3D GIS still remains rare.

However, actual 3D modeling is a necessary step to manage complex and heterogeneous data that involve all dimensions of space. Environmental properties of buildings belong to this category. In fact, most physical phenomena such as sun, wind, sounds and so on, greatly modify environmental qualities of a same building, from the bottom to the top. Representing these phenomena by simplifying them in 2D is not satisfactory. An actual 3D representation of these data over all façades is needed.

In this paper we present a 3D GIS intended for managing rehabilitation process of buildings in an environmental-friendly way. This system is part of a campaign leaded by the French national environmental agency (ADEME) dedicated to the energetic improvement of existing buildings. The goal of the campaign is to greatly reduce energy consumption and greenhouse gas emissions for all kind of buildings (residential and services). During year 2001 in France, buildings were responsible for more than 40 % of the total energy consumption and about 19 % of the greenhouse gas emissions [MIES 2002]. Even if a recent thermal regulation (RT2000) intends to reduce these consumptions on new buildings, the situation of old buildings that are not concerned by RT2000 remains a problem.

The use of a 3D GIS in this context has four objectives:

- Merging with this tool the results of many observations and numerical simulations concerning the buildings envelopes. They include solar simulations, thermal analysis, sonic simulations and observations. Moreover, social data and architectural expertise are added to the database.
- Analyzing environmental properties of the envelopes of a given urban area in order to select the appropriate buildings in which a rehabilitation process could be (or must be) engaged.
- Improving dialogue with private owners by using 3D facilities that lead to a more intuitive and personalized communication.
- Monitoring the efficiency of the rehabilitation process for the long haul, in terms of economized tons of CO_2 and gain in energy efficiency.

The system is still under development. A prototype is evaluated through an actual rehabilitation process in Nantes, West of France (Figure 1). We present here its main characteristics, some of them are yet implemented and other just planned. After a general presentation of the system, we detail our data model. Then we introduce various solutions chosen to integrate solar, thermal, sonic and some other data within the system.

Figure 1. Part of the studied area : map of the area, examples of buildings and 3D reconstruction

GENERAL ORGANIZATION

Figure 2 presents the general organization of the system, which consists of three main modules:

- A simulation module constituted by simulation software developed or used at CERMA laboratory. These applications are dedicated to the evaluation of the environmental properties of building's envelopes (solar, energetic, aerodynamics, sonic evaluation and simulation).
- ArcGIS (ESRI Inc.) module, which is the commercial solution we have chosen to ensure interactive 3D visualization process and some specific data handling.

Furthemore, the ArcGIS framework provides an easy access to a wide range of possibilities related to geoprocessing and geodatabase management issues.

- GIS-CAR (Geographical Information System for Communication in Architectural rehabilitation) module includes the main part of our development. This module introduces several functionalities:
  - Supporting the data model and the associated architectural primitives.
  - Ensuring the communication process between the different entities of the system. Most of the communication is maintained by file exchange and file conversions.
  - Supplying complementary functionalities when those proposed by ESRI solution do not meet our needs.

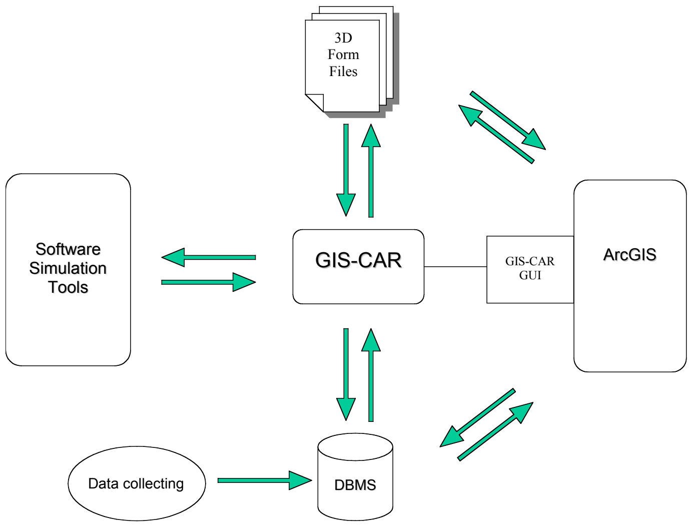

Figure 2. General organization of the system

We have implemented the specific modules concerning our purpose in C# language. Some of the developments depend on Geotools.net[1] library (GNU license). Geotools.net is the C# translation of JTS java library, which implements the Simple Feature Schema defined by Open GIS consortium. We also use ArcObject ESRI Inc. library that provides a way to handle ArcGIS objects (basically to incorporate our GUI in the ArcGIS architecture).

DATA MODEL

The system is based on a rather classical model, but accurate enough to handle different kinds of information linked to the buildings. In this data model, we distinguish the architectural modeling part from the geometrical modeling one. The architectural model organizes the scene in buildings, levels, surfaces (walls, grounds, roofs) and surface elements. The geometrical model joins a geometric form to architectural elements.

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[1] http://geotoolsnet.sourceforge.net/Index.html

Architectural Model

Buildings, associated to their cadastral footprint, contain general attribute characterizing the actual construction such as date of build, type of structure, height or conditions (Figure 3). Each building can be divided into levels (stories), described by their occupancy (dwelling, office, business, etc.). A level consists of several surfaces that delimit its envelope. There is no fundamental distinction to make between roof, wall and ground: all of them are boundaries between the inside and the outside of the level. Therefore, in our model, walls, grounds and roofs share the same architectural primitive but are differentiated by the value of some attributes. Common attributes for surface primitives are area, material, inertia, orientation, type of surface. For energetic issues, a distinction is made between external walls (parts of the envelope that communicate with the outdoor spaces) and shared walls (parts of the envelope that are shared with other buildings). Furthermore, when necessary, a surface may point to surface elements that describe specific objects like balconies, shadings or particular openings (Figure 4).

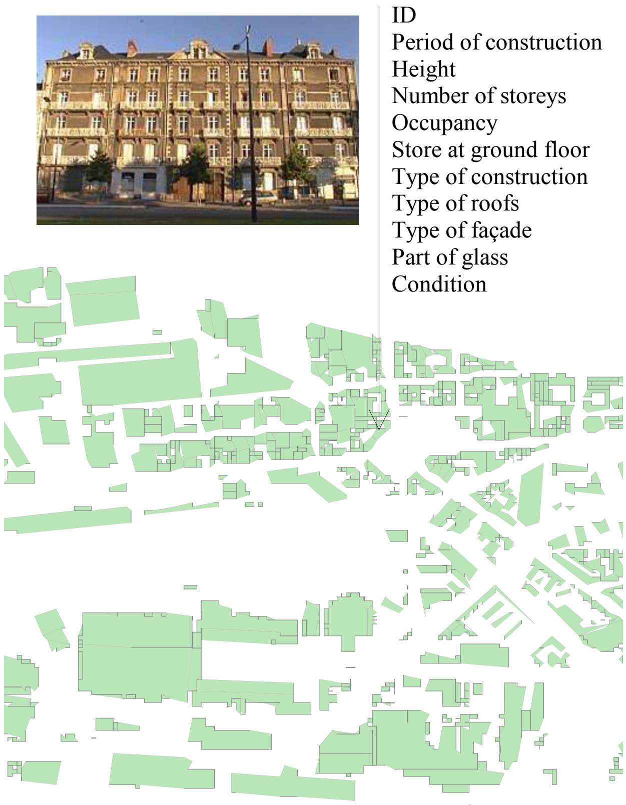


Figure 3. The 3D shapes of buildings are modelled according to their footprint and a set of attributes collected in situ

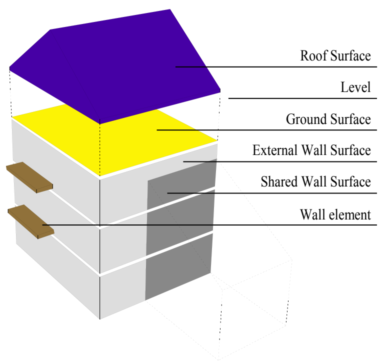


Figure 4. Entities representing a typical building within the GIS data model

Geometrical Model

Figure 5 presents the relation between the architectural model and the geometrical model. Each primitive of the architectural model (i.e. buildings, levels, surfaces and surface elements) is associated to a geometrical 3D form in a boundary representation (B-REP) [Ramos 2003]. We use the Geotools.net library to describe and manipulate 3D forms of objects.

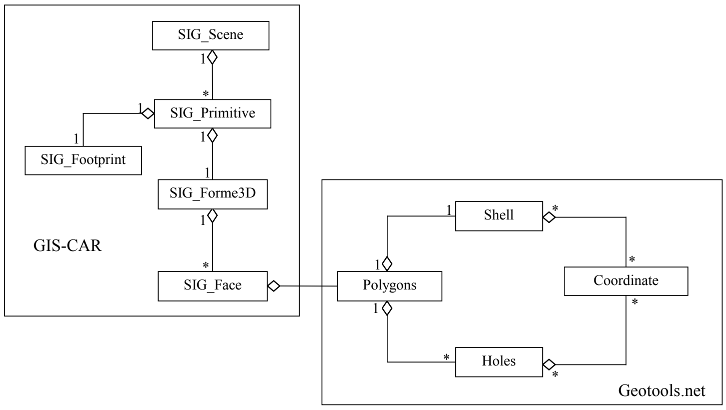


Figure 5. Architectural primitives used in order to describe a building

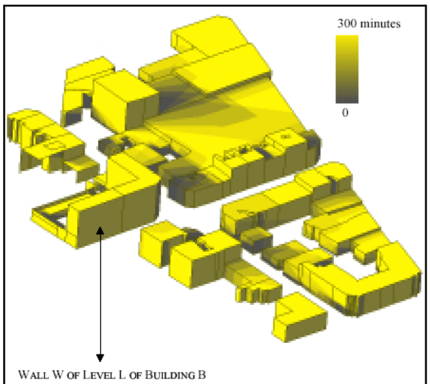
INTEGRATION OF ENVIRONMENTAL DATA

Solar data

Our laboratory has developed a solar simulation software so-called SOLENE. SOLENE performs solar, energetic and luminous simulation over 3D geometrical object [Miguet and Groleau 2002]. It may compute sunshine duration, incident solar energy, illuminance levels, indoor and outdoor, whatever the scene complexity, taking into account exact 3D geometry, shading effects, multiples transparencies, specific sky models and light exchanges.

SOLENE is devoted to produce exhaustive data in order to perform both qualitative and quantitative analysis. Each facet is meshed and results are computed for each point of the meshing. The amount of computed data may be considerable for a large urban area. It is obviously meaningless and unproductive to manage all these data within the GIS.

To solve this problem, we have chosen to integrate solar data into two forms. The first one is numeric. For our application, the interesting issues are the sunshine duration and the incident energy on each surface of each level of each building. We compute these factors for each facet, for the morning and the afternoon of three typical dates (December 21, mars 21 and June 21). Then we integrate the results in order to produce a set of 48 values that successively describe the average, standard deviation, minimum and maximum of sunshine duration and incident solar energy, for the six considered periods. These values are added to the database as attributes of surfaces and they are used for solar queries.



Cumulated Sunshine Duration

	Average	Std Dev.	Min	Max
December 21 - AM				
PM				
March 21 - AM				
PM				
June 21 - AM				
PM				

Figure 6. Integrating solar computation within the GIS, as numerical data and simulation textures

The second form of integration of solar data is as building textures. SOLENE is able to produce 3D representations of the computed data, offering many options for the graphic display. The idea is to keep a trace of the qualitative distribution of the solar insolation by computing the corresponding image on the wall. This image is kept separate as a texture. Within the GIS, this texture can be mapped on the wall, giving instantaneously both quantitative values and qualitative information of solar insolation. We call this process "mapping of simulation textures" (Figure 6).

Energetic data

When estimating building thermal loads (energy necessary for heating and cooling the building), two ways of modeling the building can be envisaged: it can be considered as a single thermally homogenous zone (we call this approach "monozonal approach"), or it can be divided into zones, levels in our case ("multizonal approach"), depending on the study's objectives. Indeed, complete estimation of the total building load (magnitude only) may be obtained by monozonal approach and it will not be significantly different from the total building load calculated using a multizonal approach, but the distribution of the load within the building cannot be estimated with the monozonal approach.
We have retained EnergyPlus[2] that allows performing energy analysis and thermal load simulations using both of these approaches. Some key features of this simulation tool are its applicability to various simulation situations, its modularity that allows developing our own modules and its ASCII text based input and output files. This ASCII based interface is

2 http://www.eere.energy.gov

helpful for GIS-CAR to ensure the communication process between geodatabase and EnergyPlus. This is crucial because the data necessary to carry out a building energy simulation are numerous and should have already been supplied to the geodatabase, In return, the energy analysis will enrich the geodatabase for further analysis.

Moreover, architect associated to the rehabilitation program will conduct a survey on energetic efficiencies. This information will be confronted to simulation results in order to validate the data model applied to energetic issues.

Sonic data

From a quantitative point of view, simulation tools like SoundPlan[3] or Mithra[4] evaluate noise pollution within complex 3D scenes, given specificities of road traffic and other sources of noise. Horizontal noise maps can be computed at several elevations, and then imported within the 3D GIS. A geometrical process detects the values of the map close to a given wall of a given level of a building. The computed average of these values is added to the database as the noise level of the wall, this process being is repeated for all building's levels.

To this quantitative approach, we join a qualitative one, which consists in identifying the sonic identity of considered area. Measurement added to surveys and sound records allow to establish the main characteristics of this sonic identity. In situ location researchings enable to draw up a typology of representative buildings (according to envelope's types, and noise exposure).

Patrimonial data and visibility

The collection of patrimonial data is the responsibility of an architect specialized in architectural heritage. The objective is not to get an exhaustive and precise analysis of the architectural value of the buildings. We just want to know if a given façade or a wall element may be easily transformed or not, according to existing patrimonial regulations.

Another important data concerning architectural protection is the visual impact of a façade. Existing regulations on old urban areas are based on the viewshed of the façades from public spaces. As a consequence, integration of solar devices or other environmental systems on a façade is often impossible according to architectural protection regulations, even if the concerned building is not actually visible from a large part of the public open spaces. Establishing the part of a façade that is visible from the surrounding public spaces is a way to overcome these difficulties. The visual impact of a given installation is precisely evaluated and this prevents unnecessary debate and systematic opposition.

[3] http://www.soundplan.com
[4] http://www.cstb.fr

CONCLUSION

The system we have shown is a prototype of a 3D GIS intended to aid the environmental assessment of buildings for rehabilitation of old urban areas. We have presented the general organization of the system and its 3D data model. We have also emphasized the ways to integrate the most significant environmental data within the system: solar data, energetic and sonic ones. The system takes a central place to manage both entries for simulation tools (geometrical descriptions, material properties) and physical results of the simulations. It provides a means to present these results using numerical data (associated to 3D forms) or what we called “simulation textures” that are superimposed to 3D buildings shapes in order to take into account the qualitative forms of the studied phenomenon. We do not only use 3D to provide impressive realistic view. We integrate 3D issues in the analytical process and we offer a new 3D approach that enables environmental data crossing on buildings.

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