Methodology for Integrating and Analyzing Environmental and Urban Data in 3D GIS

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Abstract. *This paper presents the conception of a tri-dimensional geographical information system applied to domains of architectural & urban planning, and introduces an approach to integrate the environmental urban data into this system. The development of this system aims at being able to store, manage, analyze and visualize urban objects (buildings, streets, external spaces, etc.), urban morphology (density, form, orientation, etc.) and environmental information (temperature, sunlight and sunshine duration, air movement, sound, etc.). This approach will help architects and urban designers to evaluating the environmental impacts of their urban projects (e.g., creation a new building block, renovation of housing, operation of urban renewal, etc).*

Keywords: *Environmental data, urban data, data integration, 3D GIS.*

INTRODUCTION

Sustainable urban and architectural design is an important issue in sustainable development (Leitmann, 1999). Moreover, the quality of urban environment is central to improve urban life and sustainability which is a main challenge in urban planning (Yao *et al*., 2006). Architects and urban designers play an important role in this aspect. Thus, they need a tool to evaluate and analyze the environmental impacts of their projects on urban microclimate, urban form and outdoor comfort before making the decisions. This task leads to the research of computer-based approaches for storing, manipulating, managing and visualizing urban data as well as environmental properties of urban space. The geographical information system (GIS) is an efficient tool for these works. In addition, 3D views of the city are key tools for increasing understanding and improving communication. 3D visualisation and analysis of environmental properties is an efficient way of assessing the impacts of urban projects. So, the tri-dimensional geographical information system (3D GIS) is well adapted to help in sustainable urban planning.

In this context, the aim of this work is to develop a 3D GIS for representing and managing urban data and also for integrating, analyzing and visualizing environmental data. This system makes it possible to have a better understanding of urban environment to help architects and urban designers to evaluate environmental impacts of their projects (e.g., creation of new building blocks, renovation of housing, operation of urban renewal, etc.).

In fact, the environmental data is related to physical phenomena (like thermals and aerodynamics, solar and luminous illumination, acoustics, etc.). They were the results of different simulation tools, or obtained by some terrain observations. The software used for simulations provides separated results of each type of environmental data and visualize them, but they cannot gather and visualize all environmental data. In this context, the role of GIS is to integrate results from environmental observations and numerical simulations. Because of the heterogeneity of environmental data, we propose an approach that integrates the environmental data into a same geo-database which is convenient for querying on all environmental conditions.

ENVIRONMENTAL URBAN DATA INTEGRATED IN THE SYSTEM

Urban comfort is in part related to environmental conditions. For example, the sound environment is interacting with the perception users have of the urban environment and thus with the comfort appreciation they have in public spaces. Thermal comfort is dependent on air temperature, radiant conditions and air movement. The study of urban morphology and microclimates had related to urban form is necessary for sustainable urban planning. The microclimate is mainly influenced by solar radiation, wind patterns, thermal exchanges with buildings, etc.

Thus, the use cases of the information system are:
- to integrate results from environmental observation and simulation results,
- to allow analysis of the properties of urban envelopes, public spaces and urban blocks,
- to query on the database for retrieving the information which satisfies some environmental indicators.

It means that the main sources to integrate are environmental data and data about urban objects.

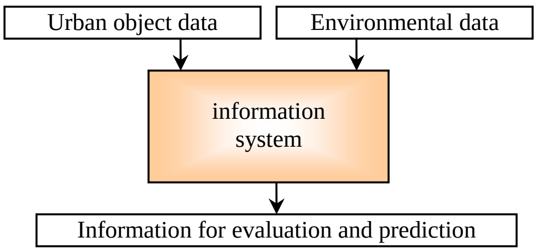

Figure 1: Main data sources of environmental urban information system.

In this section, we present the environmental factors and urban data which will be integrated in the system.

Environmental Data

The environmental data is related to physical phenomena such as thermals, aerodynamics, solar and luminous illumination and acoustic data. In our research, they are the results of terrain observations or obtained by simulation tools. Software used for simulations provides separated results of each type of environmental data and visualize them, but they cannot gather and visualize all data. To illustrate some kinds of environmental data in this work, we used part of the environmental data presented by (Musy *et al*., 2004).

Solar and luminous data was generated from the simulation software SOLENE[(1)] (developed by CERMA laboratory, (Miguet *et al*., 2002)). SOLENE performs solar, energetic and luminous simulations over 3D geometrical objects. It may calculate sunshine duration, incident solar energy, illuminance levels, whatever the scene complexity. The computation of the solar data in SOLENE was realised on the façades. For the geometric model, each façade was meshed by triangulation and results were computed for each element of meshing (triangular patch). The element size of meshing depends on the scale of analysis.

Wind data were obtained from simulations of airflow around buildings can be applied to predict wind conditions in outdoor areas or the building potential related to natural ventilation. To simulate

[1] SOLENE: http://www.cerma.archi.fr/CERMA/Expertise/solene/

wind, computational fluids dynamics (CFD) was used with the commercial code FLUENT(2). In practise, we model a wind tunnel in which we dip the studied district geometric model. Because of various turbulent and instable characteristic of wind, this kind of simulation constitutes very partial and approximate information. However, exceptional experimental studies the cost which is often dissuasive; it is till now the only means we have to obtain local wind information in urban context. For the design of the geometric model in FLUENT, in the first, air volume and inflow data was defined for the simulations. Next, an appropriate mesh size had to be determined with the outdoor areas was meshed by tetrahedron. The mesh size at near buildings was chosen to be fine. In each tetrahedron a wind speed (air velocity) and direction are calculated. When studying outdoor comfort, these values on a horizontal plane at pedestrian height can be exported from FLUENT. Each element of exportation was presented by the facet that resulted from the intersection of the plane and the cut tetrahedrons.

Energetic data were come from estimating of buildings' thermal loads (energy could be used to heating and cooling the building). A building was assumed as a well mixed zone ("monozonal approach") or devised into several well mixed zones ("multizonal approach").

Moreover, other important data concerning environmental impacts are visibility data (based on the visibility of façades from public spaces), sonic data (noise pollution), etc. Generally, environmental data is applied on buildings' envelope (e.g., solar data), interior of building (e.g., energetic data) or external space (e.g. wind data).

Remarks that urban climate may vary considerably within cities and being thus both complex and dynamic. So these simulations constitute information that always has to be referred to the hypotheses made to obtain them.

Based on data model of urban objects, other data concerning urban morphology are computed within the system such as orientation of frontage, density (ratio between total floor area and plot area), the mean surface area to volume ratio, directional porosity, etc.

In addition, the output files (result or extract of result) were based on ASCII text format. It is a very useful for 3D GIS to ensure the communication process between geo-database and the simulations. Nevertheless, environmental data are heterogeneous and it is difficult to foresee the common geometric forms for all the environmental data.

Each of these data may be presented in other ways such as averages, minimum, maximum, percentage, direction frequency of extreme values, etc.

Urban Data

Urban data was concerned to geometric and semantic data of urban entities. Each urban entity was represented by a discrete object. Urban objects are located directly by coordinates (geometric) and characterised by several properties (thematic). Often, geometric information of urban objects is foreseeable.

Data of 2D map of urban systems is available in some data layers and digital terrain model. Based on the 2D map, related data for third dimension will be manipulated. The 3D geometric information of urban objects is often available from the project designers that produce 3D CAD models.

In next section, data structure and model of environmental urban data will be presented. Based on this structure, the system will be organised.

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[2] FLUENT: http://www.fluent.com/

DATA STRUCTURE AND DATABASE ORGANISATION

As we presented in the introduction, the environmental data is coming from the result of simulations or terrain observations. The environmental objects are elements of simulation results. The urban objects are the entities in cities which have information of their localisation and shape information. Each urban object can be associated to elementary entities like points, lines, surfaces and volumes. It contains attributes (material, environmental information effect).

Generally, the fundamental primitive element of environmental urban information is the tuple <*x*, *y*, *z*, *t*, *G*> where G represents some thing present at some location (*x*, *y*, *z*, *t*) in space-time (Goodchild *et al.*, 1999). '*thing'* might be properties of urban objects or environmental objects.

The environmental impacts was applied on

- the building blocks (e.g. density, common indicators of block),
- the volumes of building (e.g. energetic)
- the façades (e.g. solar)
- and the outdoor spaces (e.g. sonic, visibility, wind).

The most important spatial objects in urban environments are buildings (Zhou *et al.*, 2004). Because the environmental data was affected on buildings blocks, building envelope and inferior entities of buildings, the city is decomposed into building blocks. A building is described by its cadastral footprint, its frontages, its various levels, the walls of these levels and eventually elements affixed on the walls. To each interior volume, that represents a level, is associated environmental information of the interior of level or building. Each wall can be characterised by its surface, its orientation, the materials which it is made with, etc. The façades have to represent the walls. They are associated to the semantic ones as the materials which make it up, and of environmental information (e.g. solar, energetic).

Thus, the structure of urban objects is described in Figure 2.

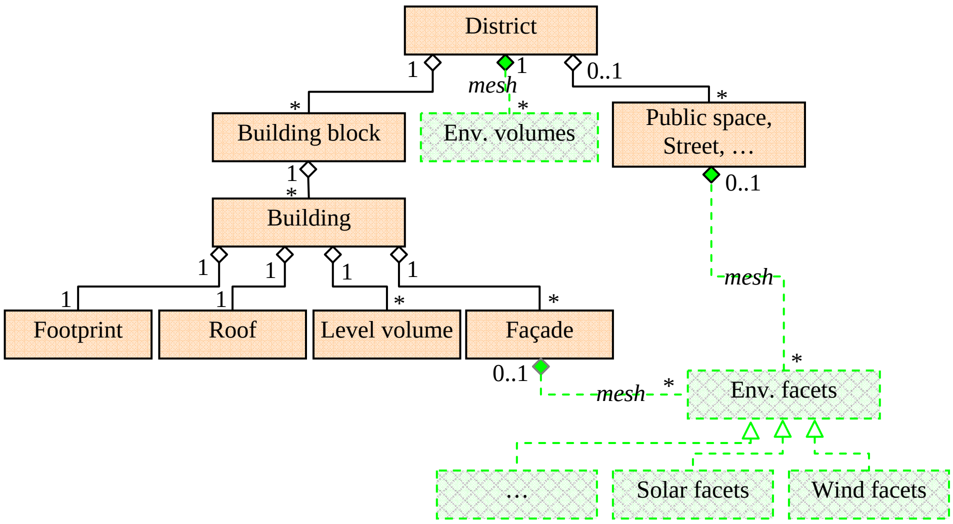


Figure 2: Composition of urban objects.

Before the realisation of simulations, urban objects are meshed: the façades are meshed by surface elements; the 3D urban space is meshed by volume elements. Alternative objects will be added into the system: the elements of surface mesh, called environmental facets or discrete patches; the elements of volume mesh, called environmental volumes. The points are also geometrical primitive elements of environmental facet and volume.

Among the important 3D data models for GIS applications belong:

- *3D FDS* ('Formal Data Structure') (Molenaar, 1990),
- *TEN* ('Tetrahedral Network') (Pilouk, 1996),
- Modèle Orienté-Objet 3D (De la Losa and Cervelle, 1999),
- *SSM* ('Simplified Spatial Model') (Zlatanova, 2000),
- *UDM* ('Urban Data Model') (Coors, 2003).

The 3D data model used in the system is similar to Urban Data Model (UDM) which is proposed in (Coors, 2003). But the role of line features is faint in our data model because we don't need to integrate the properties into line. Thus, the basic components are points, faces, and solids.

- Point features represent the most basic spatial primitive of façades, discrete patches, volumes of levels or buildings, external spaces, and plot of buildings.

- Face features are segregated portions of plane which define areas with common attributes. A convention of (Molenaar, 1990) is adopted: faces are planar. They are used to represent the façades (walls), environmental facet, external space.

- Solid features consist of a number of faces defining an enclosed boundary within which is a region of common attribute. They are used to represent the volume of levels ("multizonal approach") or buildings ("monozonal approach").

Based on data structure, the databases are organised. The extended relational formalisms (Laurini, 2001) were described in the following:

BuildingBlock(#block_ID, density, building, (x,y,z)*)*

Building(#building_ID, Block, height, compactness, thermal_comfort, acoustic_comfort, nbr_level, level)*

BuildingFootprint(#Footprint_ID, area, (x,y,z))*

BuildingLevel(#level_ID, volume, thermal_comfort, acoustic_comfort, façade)*

Façade(#facade_ID, area, orientation, horiz_verti, material, env_impact_average, (x,y,z)*)*

Env_Facet(#facet_ID, facade, area, env_impact, (x,y,z)*)*

Env_Volume(#Volume_ID, volume, env_impact, (x,y,z)*)*

Note that the star(*) means that the attribute is a list of values.

DATA IMPORTATION AND VISUALISATION

Currently, most GIS are available and can cope with 2D, 2.5D and 3D data. The ArcGIS (ESRI) is the commercial GIS software that we have chosen to ensure interactive 3D visualisation process and handle the 3D data. Moreover, ArcGIS allows the conversion of data between numerous formats from applications. Furthermore, in addition to the point, line and polygon feature types in their geo-database definition, ESRI provides a 'multipatch' geometry. Storing 3D features in the ESRI geo-database as a 'multipatch' geometry allows for a standard table structure with simple geometry field (Ford, 2004).

3D analyst and ArcScene (ArcGIS module) provided the ability to create and view 3D Objects. The data integration into geo-database based on data conversion from CAD files and addition ‘multipatch’ feature (e.g. elements of meshes, facades) into shapefile and geo-database. This data integration is composed of three main stages:

- *Converting 2D map* (in CAD format) presenting the footprints of multiple buildings into polygon shapefiles and geo-database. AutoCAD has the capacity to export drawings into shapefiles with an ID for linking to a database. ArcGIS can import a collection of CAD files and convert them into feature classes for use in ArcGIS. The polygon shapefiles representing the building footprint are completed by adding the polygons in 3rd dimension.

- *Inputting 3D urban objects*: the multipatch geometry is useful for defining the boundary and shape of 3D feature. Multipatch features can be created by converting 3D symbology to multipatch features or through other geoprocessing tools. One can also write ArcObjects code for generating complex multipatch geometries (Website ESRI). The 3D urban objects can be added into geo-database by using the ArcGIS editing environment for multipatch. Remark that the buildings consist in a number of faces (which define a boundary) which are multipatch features. Multipatch features can be created from existing data.

The input data used for creation of multipacth features is from of these ASCII text files. Often, ones create 3D CAD models during the design of the buildings. These 3D CAD models can be exported into ASCII text file representing features as a series of extremity points (*x*, *y*, *z*).

Figure 3 are showing the buildings and their footprint in ArcSene. The application from the Lyon Confluence project, an ambitious urban extension program (Figure 4). We have studied a part of the fist phase of this project that consist in a local 340,000 m^2 of usable floor space government-planning project (ZAC) situated along the Saône .

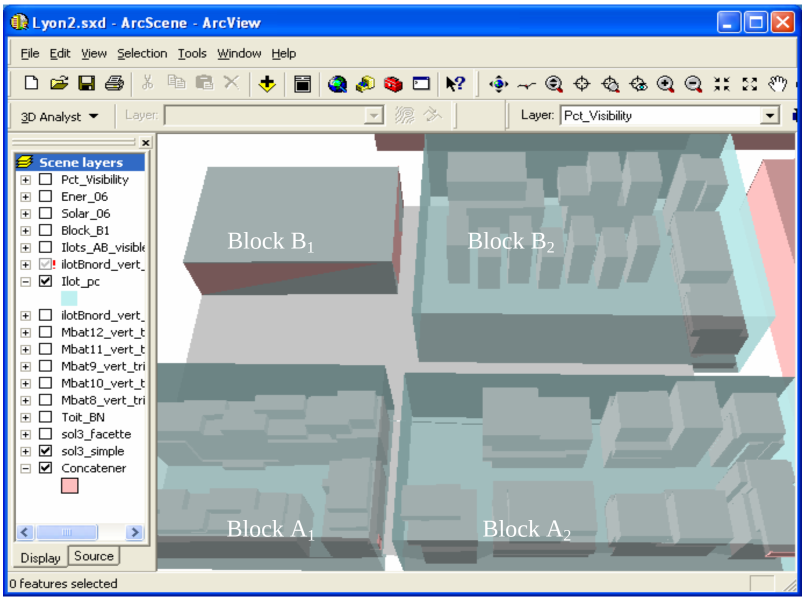


Figure 3: Visualisation of buildings and their footprint.

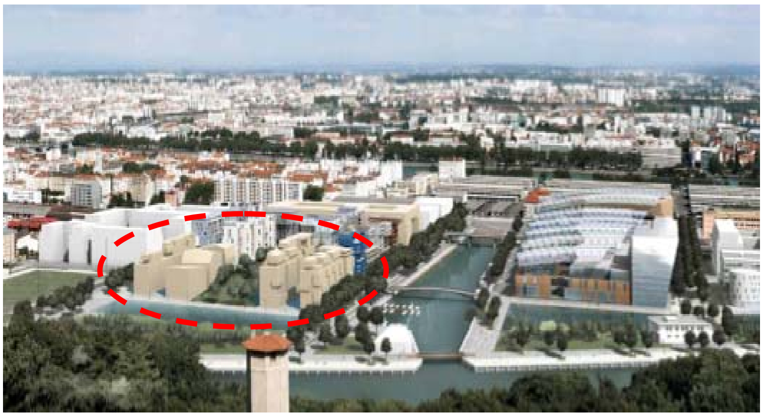
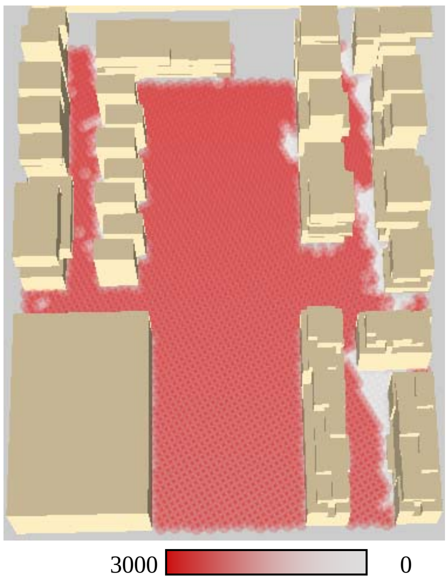


Figure 4**:** General view of Lyon Confluence project (www.lyon-business.org).

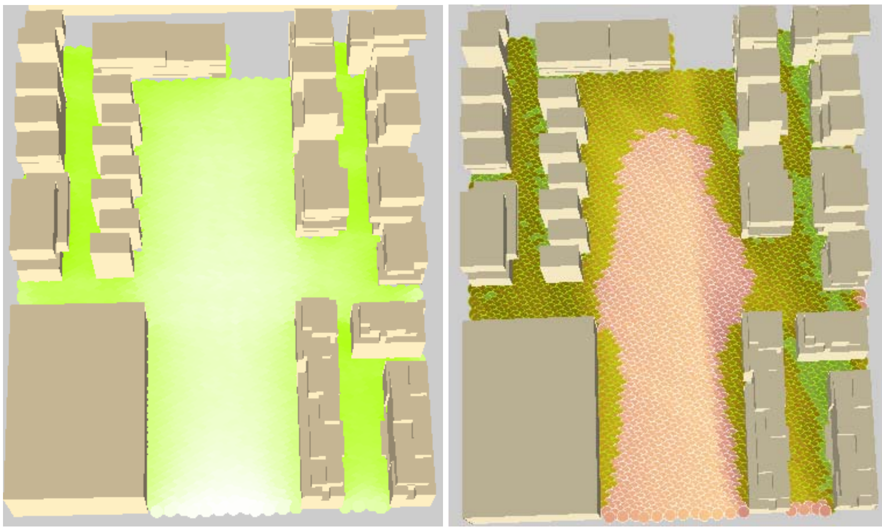
- *Inputting environmental data*: predicted data from a simulation process were stored in ASCII text files. Each element of meshes is associated to a series of extremity points (*x*, *y*, *z*) and environmental evaluation values (attribute). It is the same with integration of building faces, the elements of meshing can be represented by multipatch features. Multipatch features can be assigned to the geometry field of geo-database record.

The addition of attributes of discrete patch into geo-database is realised by VBA macro within the ArcGIS environment. The visualisation is showing in Figure 5.a. Figures 5.b and 5.c respectively shown the simulation of direct solar energy of surface in June and sky visibility percentage. Lastly, Figure 5.d. is showing the image of superposition of these simulations that allows seeing that a part of the public area (the central one) gathers luminous and energetically interesting properties.

a. Solar duration in June



b. Surface solar energy in June



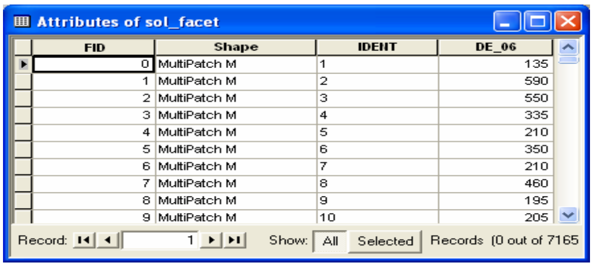
10% 80%

d. Superposition of visibility percentage, surface energy and solar duration

c. pct of visibility

***Figure 5*: Visualisations of environmental impacts on public area.**

A table of data importation of solar duration in June is in Figure 6. Figure 7 shows an example of integration of environmental data on façades.



Attributes of sol_facet

FID	Shape	IDENT	DE_06
0	MultiPatch M	1	135
1	MultiPatch M	2	590
2	MultiPatch M	3	550
3	MultiPatch M	4	335
4	MultiPatch M	5	210
5	MultiPatch M	6	350
6	MultiPatch M	7	210
7	MultiPatch M	8	460
8	MultiPatch M	9	195
9	MultiPatch M	10	205

Record: 1 Show: All Selected Records (0 out of 7165

***Figure 6*: A table of integration of solar duration in June 21.**

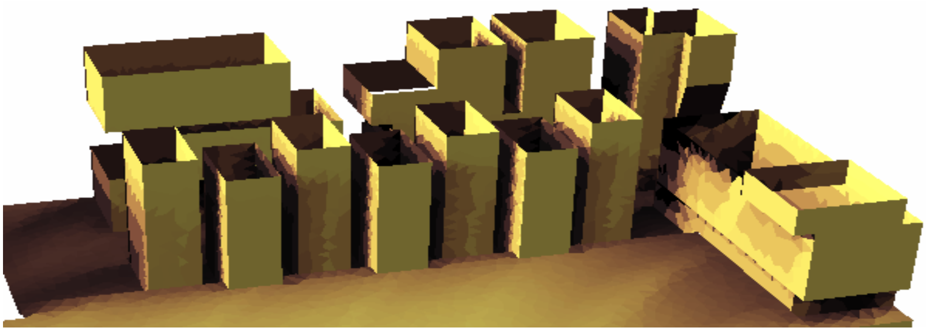


***Figure 7*: Visualisation of solar data of buildings block B2 (without roof).**

INTEGRATION STRATEGIES FOR QUERIES ON ENVIRONMENTAL DATA

We introduce the notion of partition of space (both 2D and 3D). The partition of surface (respectively volume) S is a covering $\{e_1, e_2, \ldots, e_n\}$ of S such that each e_i is a facet (respectively volume) and for any e_i and e_j, $1 \leq i, j \leq n$, $i \neq j$, the area (respectively volume) of $(e_i \cap e_j)$ is zero.

Remarks that, the mesh of each simulation is a partition of space on it the environmental impact is affected. The elements of each simulation are geometrically discrete. The data of each simulation can be inputted in same geo-database. In this case, the records in each geo-database are geometrically discrete. The queries on this environmental data can be realised.

In addition, the use of different simulations leads in different meshes that can be different in form (e.g. rectangular and triangular for the surface; cube and tetrahedron for the volume). Even when the form of mesh elements is the same, for physical reason, the refinement of the meshes generally differs, so that the size of elements may be different.

These geo-databases can also be combined by union or join operator into a same database. However, in these two cases, some queries based on many environmental conditions can't be applied.

2D example: The element form of solar simulation is triangle; the element form of wind export is rectangle (see figure 8). $\{r_1, r_2, r_3, r_4\}$ and $\{t_1, t_2, t_3, t_4\}$ are two partition of space S. The results of simulations can be inputted into two different tables. The union of these tables contains the set of elements $\{r_1, r_2, r_3, r_4, t_1, t_2, t_3, t_4\}$ which isn't a partition of S. The query for looking for the area where the wind speed is a_i and the solar duration is b_j is not realisable.

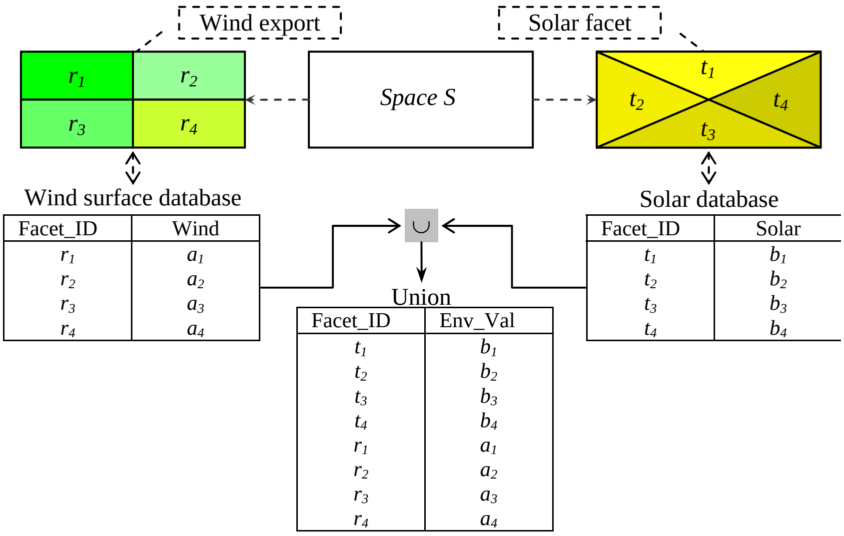


Figure 8: Different form of environmental facet.

It is necessary to integrate the environmental data in a same database which contains same geometry field. The computation of intersection of the mesh elements can be considered as solution. Most 2D GIS currently available support for this operator. Meanwhile, the intersection in third dimension is complex and is not available in 3D GIS.

One of solutions to solve this problem is the use of a new partition of space S in which environmental data is added. Some approaches are the following: i) using the partition of one of these meshes, ii) creating a new mesh which is a compromise between different given meshes.

Note that the result of simulation is a set of (*p*, *v*) where *p* is the set of points use to constitute an element of mesh, *v* is the environmental data of this element.

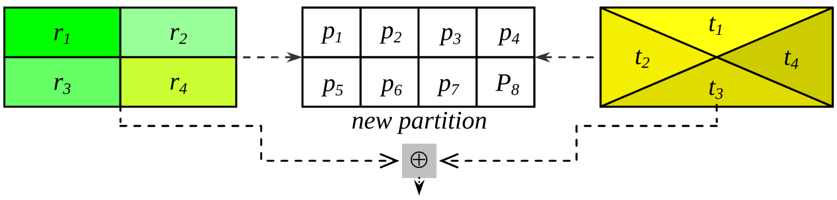
In the two cases i) and ii), one needs a set of elements *p* (from either new mesh or existing mesh) to aggregate environmental data. The integration of data may be realised by similar way for these approaches. We propose an algorithm for integrating data of two meshes of same space (either surface or volume).

Input:
  $\{p_1, p_2, \ldots, p_n\}$ *new partition of space S.*
  S_1 *set of couples (x', v') of first simulation on space S.*
  S_2 *set of couples (x", v") of second simulation on space S.*

Output:
  L list of tuples (p, v', v").

Method:
  Create new list $L = \emptyset$;
  For (*each p of new partition*) do
    For (*each couple* (*x', v'*) *of first simulation*) do
      If (*inertia center of p is in the polygon x'*) then *add* (*p, v'*) *into L;*
    Endfor
    For (*each couple (x", v") of second simulation*) do
      If (*inertia center of p is in the polygon x"*) then *replace* (*p, v'*) *by* (*p,v',v"*)*;*
    Endfor
  Endfor
  Return *L;*

The quality data depends on the size of polygon *p*. The advantage of the second solution (creation of a new partition) is that varying the scale of mesh is possible. In the second case, using the more refined mesh should to a better precision. For creating the new mesh, the discrete rectangular mesh is easier to use and manage the topology relation between the elements. Figure 9 shows an example of creation of new mesh and the result of integration



Integration

Facet_ID	Wind	Solar
p_1	a_1	b_2
p_2	a_1	b_1
p_3	a_2	b_1
p_4	a_2	b_4
p_5	a_3	b_2
p_6	a_3	b_3
p_7	a_4	b_3
p_8	a_4	b_4

Figure 9**:** Different form of environmental facet.

This approach applied to a field values for a group of buildings leads to a unique table regrouping all the information for all kind of surfaces (vertical, horizontal) and a unique table regrouping all the information for all kind of outside volume.

From these tables, the query on different environmental conditions is realisable. For example, query for looking for the comfortable areas in summer (area which receive more than 10 hours of sunshine (600') and which have sky view factor higher than 50%) was resulted in Figure 10.

Select From TOTAL_ENVDATA
Where (solar_June > 600) and (Pct_Visibility > 50)

Figure 10: areas receive more than 10 hours of sunshine and sky view factor higher than 50%.

CONCLUSION AND FUTURE WORKS

In this paper, an approach to integrate environmental urban data into a 3D GIS was discussed. This approach allowed the integrating heterogeneous environmental data into the same database, on this the queries on many characteristics of the environment may be easily applied. This approach was suggested for integrating environmental data in plane surface or in 3D volume. This integration permits gathering data that are difficult to cross other way, imagining new analysis and developing new sustainable planning indicators. It is also a useful tool in research tasks, it also can be used to estimate different fields of indicators, to research correlations between them, etc.

Integration of heterogeneous data in term of geometry and semantic from different sources is a difficult problem. The semantic accuracy of data in the result is not only depending on the size of new mesh but also integrating a great amount of data, it would be consuming to use more sophisticated methods. However, the error implied by the use of this method will be studied further.

The integration of other environmental data will leads to other problematic: it is sometimes difficult to analyze the 3D data, in particular in the case of densely built area and we will have to imagine new way of visualizing them.

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