Integrating energy efficiency into urban design and management: a GIS for evaluating the environmental profile of cities

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1. ABSTRACT

The urban design process passes through a compromise search among prescriptive, functional and financial constraints that are extremely interactive. The environmental issues are often seen more as constraints than opportunities.

The objective of this research is therefore to develop a Geocoded Information System for sustainable urban development. This system, christened ZEIS for Zero Emission Information System, offers environmental opportunities to urban planers like:

- the integration of urban design through bridges between urban planning and environmental engineering, using simplified evaluation tools, and referential approaches of the urban design process,
- the co-operation between various different computer techniques (GIS, algorithmic procedures, hypermedia and graphical user interface).
- The ZEIS prototype has the three main characteristics:
- a description of the topological and geometrical information on the urban projects in a GIS, using a environmental oriented conceptual model of urban projects,
- the evaluation of an environmental *profile*, based on a system of environmental indicators ranking from energy and emissions, to community services…,
- the on-line access to multimedia resources presenting general environmental information about sustainable development, and the presentation of three reference sites environmental analysis (Toulouse, London and Berlin).

The ZEIS platform is using now «named selections» to perform inter-city comparisons or urban variations on the same site.

2. CONTEXT

The context of this work is the City as a framework with its own functions and decision making structures ; this system is highly constrained from its economical, political and natural environment. This intricate relations point out the danger of taking a decision related to only one dimension (energy, transport or emissions…) : by solving one problem, ones may often create another one.

To be efficient, urban environment management must be based on a global strategy where decision making process must be integrated in various key domains. The City is both a centre of resources consumption (like energy) and a centre of resources production (like services). Act for a sustainable urban development requires to tackle each of these topics, going beyond a domain related approach. It induces the analysis of the direct causes of the environment degradation, as well as the analysis of the social and economical options which are linked to environmental problems. But the social and ecological mechanism on which environment problems are rising, are also complex : to build a relevant system of indicators, physical models as well as social analysis must be available. Urban decision makers must then try to find a good compromise between these various dimensions to balance what we named, the Environmental *Profile* of the urban project.

The urban design process is a complex act relying on the transformation of constraints linked to heterogeneous knowledge and skills into shapes, spaces and flows. The early stages of design have a hegemony weight over the basic decisions. Paradoxically, it is during these stages that the available information on the project is the weakest, because it is impossible to directly apply all the constraints to satisfy, or to decide on eligible procedures to reach a goal ; the problem does not have a definitive expression [1].

The potential consequences of decision support tools are maximal during these stages. The traditional engineering tools requiring a practically total information on the urban objects are only applicable at the end of the design process, when the design freedom is the weakest. One family of computer tools is especially suitable to this context, namely Geographical Information Systems (GIS) mainly for their ability to manipulate and analyse objects located in the space (based on dimension, shape, location, distribution or proximity analysis).

Various ways of reasoning are involved in the urban design process like deductive, inductive or referential approaches. The last one are characterised by the fast emergence of possible solutions while the problem is not yet assimilated, and are using for example analogy between outstanding projects of urban design history and the current project. These projects could benefit from being embedded into hypermedia structures.

3. METHODOLOGY

Our work is aiming at building a tool for diagnosis of the urban environment at a scale ranging from the neighbourhood to the City, allowing urban design and planning, but also urban monitoring of the long term local politics according the environment, as well as the land and resources management. At this stage we want more to handle the qualitative inclination of the following concerns, building, services, transport, energy, emissions, urban pattern and landscape, milieu, than to define the urban environment.

The qualitative concerns are not absent from urban decisions, but they are very often translated in a quantitative way with an unclear signification. Emissions like for example the noise are a typical example where it is hard to list the sources and moreover the impacts on the physical and human environment.

So we decided to integrate a double approach in defining our system of indicators:
- a snapshot of the quantitative aspects of the urban environment based on gathering the information available on Toulouse, whose translation will be the objective indicators
- a subjective analysis taking into account individual aspects, users' perception, whose translation will be the subjective indicators.

The idea underlying to this system is to define a complete, non redundant and operational system of environmental indicators useful both for inter-city comparison (two urban projects in different sites), or for urban variations (two or more urban variations on the same site). So we purposely limited the number of indicators to somewhere under one hundred, in fact 83. This system of environmental indicators is the core of the ZEIS information system for sustainable urban development.

ZEIS (for Zero Emission Information System) is characterised by two aspects as follows:

1. Integration into urban design through bridging urban planning and environmental engineering, with:
   - bottom-up approaches using evaluation tools compatible with the highly conceptual early stages of design and based on the system of indicators and their management in a multicriteria process,
   - top-down approaches of the urban design process embedded into hypermedia structures. These "hyperlinks" encodes therefore real-life reference urban design situations (in London, Berlin and Toulouse) into tools to improve the skills of designers, providing basic solutions of environmental engineering problems linked to the urban design.

2. Co-operation, through the use of different state-of-the-art advanced computer technologies necessary to match the complex problem solving context of urban design: GIS in MapInfo [2], analytical and heuristic algorithms developed in C++ and MapBasic [2], hypermedia structures in Hypercard, Graphical User Interface developed in MapBasic.

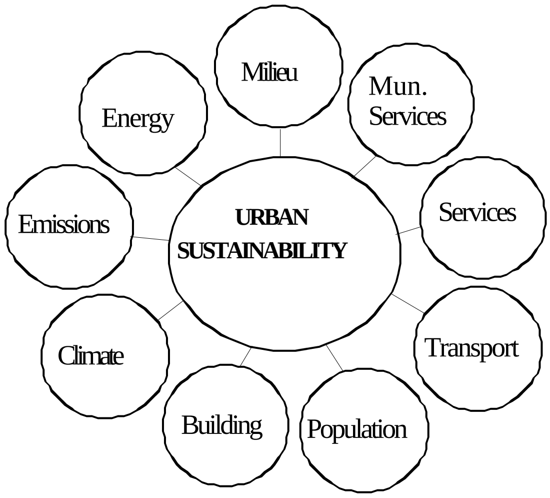
4. WORK COMPLETED

The system of environmental indicators

According to the methodology defined previously, we decided to gather the information available about the urban environment of the city of Toulouse, and to confront it to the goals and means available in the French municipalities, and to theoretical approaches of urban evaluation indicators at various scales (bottom-up approaches as ODCE [3], EC, CREDOC [4], ADEME [5]…).

This stage allowed to define nine domains and their relevant criteria to be integrated in our system. The nine domains are as follows: Milieu, population, Energy, Climate Emissions, Construction, Transport, Services, Municipal and Inter-municipal Services.

Figure 1. The nine domains involved in the system of indicators.



Two class of domains are available: **environmental domains** like energy, emissions or building, that allow a comparison between sites through reference values, and **key domains** like population and climate that do not allow a comparison but give an extra information about the physical, meteorological or social context of the urban project.

In each of these domains, we have defined some relevant criteria by a confrontation to available national and international systems of indicators. One of our constraint was to limit the number of indicators in each domain to 15, to be able to reach a total number under one hundred indicators (see figure 2).

Then the last step aimed at the definition of the system of objective and subjective indicators relevant of urban projects. The indicators defined may rely on an objective value derived from a calculation (Ex.: mean weighted compacity factor for buildings in a neighbourhood), or subjective values linked to the perception of the urban environment by inhabitant, (Ex.: percentage of people unsatisfied of the size of their flat) (see Table 1).

Figure 2. Domains and criteria.

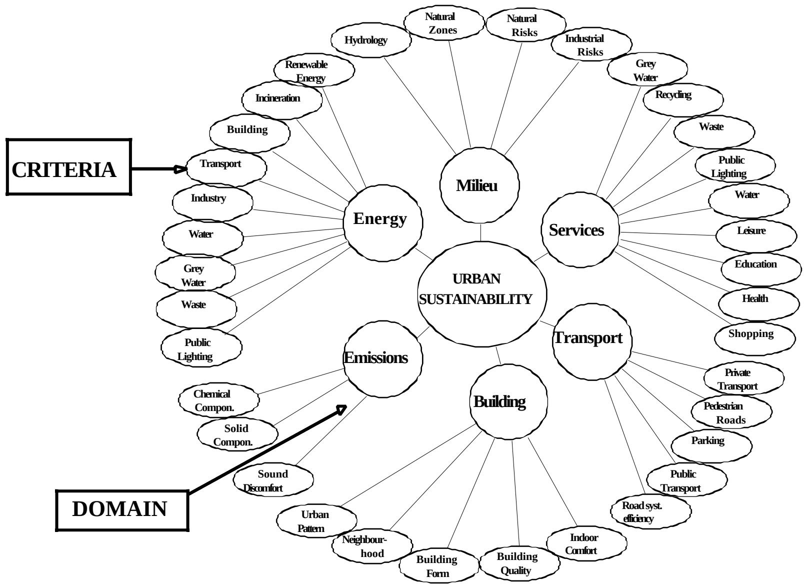


Table 1. An example of environmental indicators linked to Energy, Emissions and Facilities.

Domain	Criteria	Indicator O. Objective S. Subjective	Unit
ENERGY	*Energy production of renewable energies*	O. Percentage of renewable energy / total consumption	%
	Energy production by incineration	O. Total energy produced by incineration per inhabitant	kWh/year.hab
	Energy consumption per inhabitant	O. Energy consumption	GJ/hab
	Percentage of energy consumption by source	O. Percentage of Solid Fuel+Petrol energy consumption	%
	Energy consumption for building sector	O. Energy within buildings per inhabitant	kWh/year.Hab
	Energy consumption for transportation sector	O. Energy for transport per inhabitant	kWh/year.Hab
	Energy for water distribution	O. Energy for water distribution per inhabitant and year	kWh/year.Hab
	Energy for public lighting	O. Energy for public lighting per inhabitant and year	kWh/year.Hab
	Energy for valorisation of waste	O. Energy for waste treatment	kWh/year.Hab
	Energy for valorisation of waste	O. Mean percentage of valorisation of waste	
	Energy consumption for waste water treatment	O. Energy for grey water treatment	kWh/ 10^3 m^3
EMISSIONS	*Dust concentration*	O. Mean annual emission of Pb particles	microg/m^3
	Estimated pollution	S. Percentage of population dissatisfied by pollution	%
	Concentration of chemical components	O. NO2 emission rate (Percent.98)	microg/m^3
	Concentration of chemical components	O. O3 emission rate (Nbr days with mean conc. > 65 microg/m3)	j
	Urban noise	O. Annual number noise complaints per 10000 inhabitants	Nbr/10^4 hab.
	Perception of Urban noise	S. Percentage of population dissatisfied by disturbing noise	%

Domain	Criteria	Indicator O. Objective S. Subjective	Unit
FACILITIES	*Quality of water distribution network*	O. Water consumption	m^3/ Hab.year
		O. Losses of water distribution	%
	Efficiency of public lighting	O. Number of public lighting points per roadway length	Nbr/km
	Waste production	O. Domestic waste production	kg/hab
		O. Incineration capacity of domestic waste	kg/hour. 10^3Hab
	Quality of recycling	O. Number of recuperation points for 10000 inhabitants	Nbr/10^4 hab.
		O. Mean distance to recuperation centre	km
		S. Percentage of population recycling	%
	Quality of grey water depollution	O. Depollution rate of urban unit	%

The values of the **objective indicators** have been calculated and gathered for three case studies, Toulouse, London and Berlin, at three levels when available (agglomeration, city and district), as well as reference values in France, Europe, and ODCE.

The **subjective indicators** are extremely important in a global appraisal of urban sustainability. The subjective indicators has been tested through a mini-survey on the inhabitants of a cross section of the case study district in Toulouse. The questionnaire was divided into six parts: urban livelihood, emissions, transports, leisure and culture, waste management, and shopping.

The ZEIS decision support tool for urban sustainability.

The ZEIS environment uses state-of-the-art advanced computer technologies necessary to match the complex problem solving context of urban design namely GIS, analytical and heuristic algorithms, and hypermedia structures. The ZEIS structure has been built around a neutral data framework involving geographical and environmental properties of urban objects. Around this data structure are gravitating the following components:

- The GIS, an ensemble of «modules» dedicated to the management and the representation of located information : the urban objects. We have used the neutral data framework to define object classes (building, route, parcel…), and their geometrical, topological and environmental attributes.

- The ensemble of environmental indicators devoted to the evaluation of an urban project according to different points of view. From the calculation (or the direct input) of an indicator, ZEIS is able to give a grade to this indicator, according to the comparison to a reference value, chosen as generic a possible.

- A «supervisor» of these components dedicated to decision making allows a multicriteria analysis of these indicators and leads to the definition of an *Environmental Profile* of the urban project. To do so, three global transitive methods (mean value, bonus and veto) are aggregating the grades chosen by the user on each domain, leading to a global grade or appreciation for each of them. This environmental profile helps orienting urban decision makers between different projects, or between variations on the same urban project.

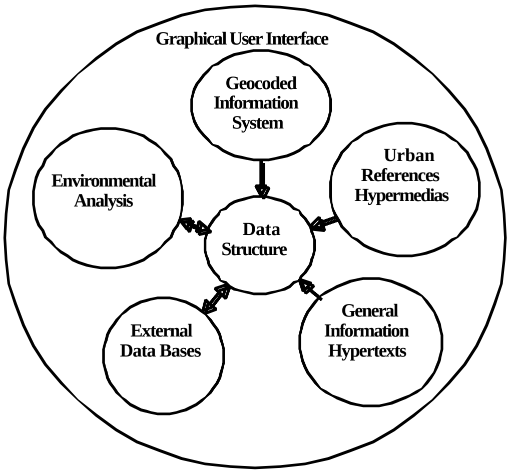
- An ensemble of hypertextual links allows the access to general information about urban sustainability or to presentation of three reference projects in Toulouse, London and Berlin, and their environmental analysis.

All these modules are using various collaborative computer techniques in an integrated graphical user interface (see Figure 3).

A **conceptual data model** has first been developed allowing optimal representation of urban projects and their environmental properties. This model is based on the system of environmental indicators presented and the definition of the geometrical, topological, or environmental attributes of the urban objects necessary for their calculation.

This conceptual model allows the definition of the system of objects classes as well as their relations. We use the NIAM modelisation method [6] based on the definition of non semantically reducible sentences, as well as on a graphical display of objects and their relations (hierarchy, inheritance and association).

Figure 3. The architecture of the ZEIS platform.



The **knowledge structure** in ZEIS is derived from the definition of the system of environmental indicators. This structure is common to the procedural knowledge defined in the GIS , and to declarative knowledge defined in the hypertext structures.

Three various types of **procedural knowledge** are involved in the ZEIS platform: qualitative, geographical and analytical knowledge:

- Qualitative knowledge are non calculable and non geographical knowledge (Ex.: Percentage of population dissatisfied by green space area).
- Geographical knowledge are knowledge obtained through geometrical or topological evaluation from objects located in the space (Ex.: Mean distance between home and bus stop).
- Analytical knowledge are obtained by analytical methods involving not only geometrical, topological or heuristic methods (Ex.: Pollution due to transport per inhabitant) (see Figure 4).

A specific type of analytical knowledge is linked to **multicriteria decision making** analysis, and based on a comparison between reference values and the current urban project, using a linear variation of each index. These reference values are chosen as generic as possible, but can be update by the user. This allows to proceed from absolute values to relative grades. A grade is given on a five levels scale ranging from worst to excellent (see Figure 5).The user is able to define on which indicator he wants the aggregation to be done. Then the user can choose between the three aggregation methods available: the mean value, the bonus / malus and the veto methods.

New developments have been performed on «named selections»: complex geographical areas, like urban islands or districts, or non contiguous islands defined from union or intersection of islands. ZEIS offers now the opportunity to display objects that are responsible of a selection bad grade, on a thematic map.

Through either index or key-words access, the concept you want explanations about can be reached and you can have direct access to illustrations of this concept in the Urban References hypertext.

Figure 4. Environmental indicator linked to the pollution due to traffic and thematic map displaying the most polluted roadways of the selection.

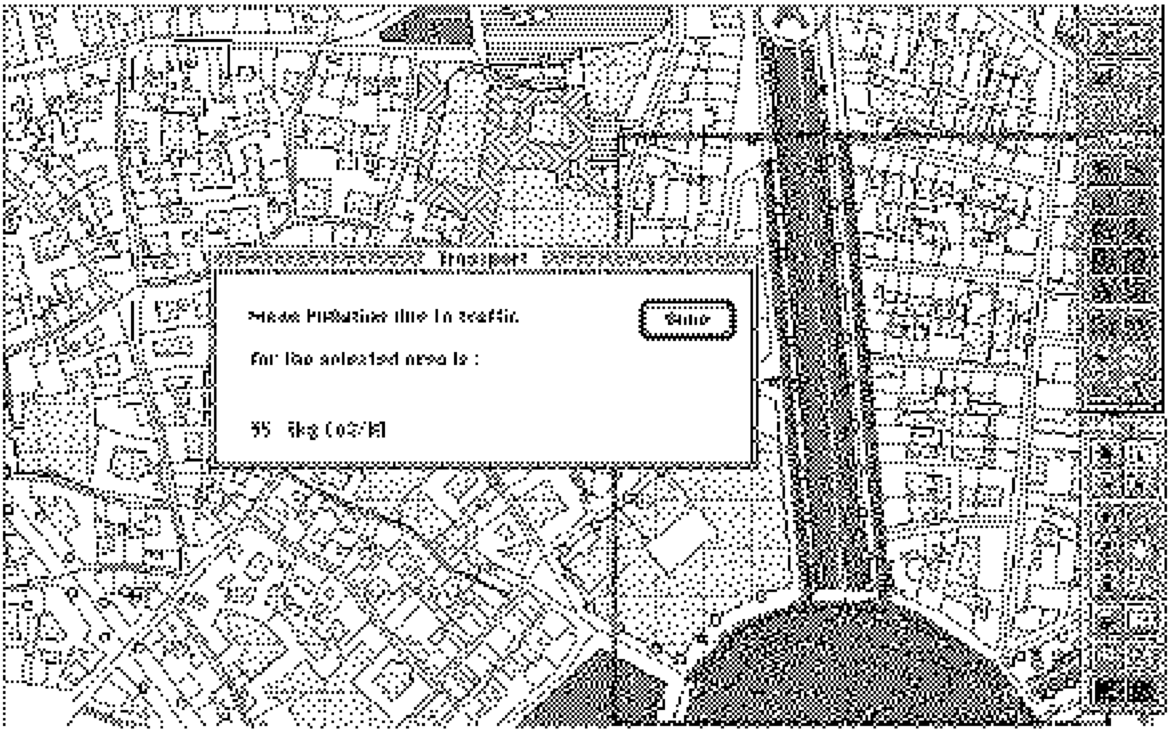
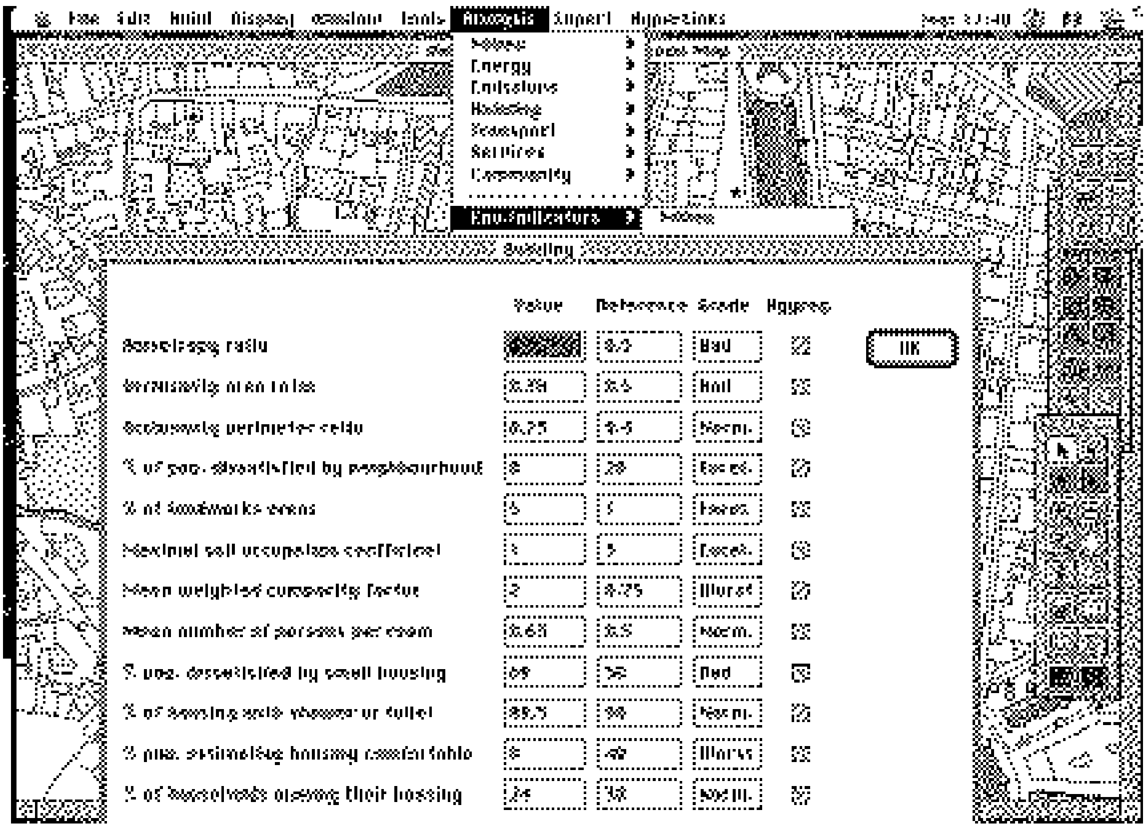
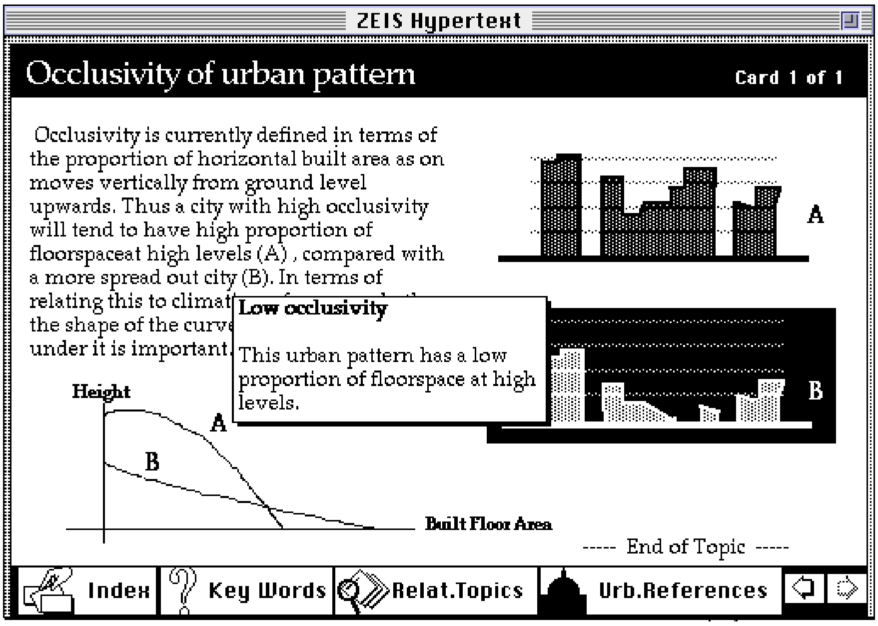


Figure 5. The grades given to each indicator of the building domain according to a comparison with reference values, and the user-defined choice for the aggregation



Declarative knowledge are based on the integration of referential top-down strategies through on-line access to hypermedia presenting both general information about urban sustainability, and urban references. These hypermedia are using the neutral data framework structuration. Each page corresponds to a concept (environmental criteria), for example the urban pattern occlusivity (figure 6).

Figure 6. The concept of occlusivity of urban pattern explained in the ZEIS hypertext



5. CONCLUSION

The construction of a system of urban environment indicators is a difficult task because of the qualification of the concept of urban environment involved, the clear definition of the goals and methods involved, and the mix between quantitative and subjective approaches as well. To obtain information about urban environment, we had to work in close contact with municipalities : for all the scales and sites studied, the global information about the urban environment has never been gathered. This means that decisions and community action have been undertaken without knowing their global impact on the short and long term urban environment. In this context, we do think that the use of this system has a very pedagogical value, especially in a computer tool tackling to the complex context of urban design.

The outcome of the project is therefore a prototype of GIS environment available on PowerPC platforms which can be readily licensed to educational institutions. Initial or continuing education institutions could benefit from the use of this package.

For us, this work is a first step towards a prototype of computer aided urban design tool that need now to be tested and validated on various real-life situations. Energy, emissions, transport or services indicators could benefit from this expertise. These test cases could be then embedded in the hypertext reference structure.

The integration of inductive approaches could also be embedded in ZEIS through heuristic algorithms or expert systems, and would be able to directly answer to a question like "What happens if I modify the urban pattern this way…?".

6. ACKNOWLEDGEMENTS

This research has been possible through funding of the APAS program (EC- DGXII) in the project «Towards Zero Emissions Urban Development» [7], and of the Midi-Pyrénnées district [8].

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