Towards Smart Urban Planning through Knowledge Infrastructure

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Abstract — **In companies, the use of the so-called business intelligence and knowledge engineering is more and more commonly found. By essence, companies are using computer tools, which tends to include them in the knowledge society; from a mathematical point of view, knowledge representation is made through rules and logics. And then comes the question: what could be done in this direction for urban planning? The big challenge is to deal with urban and environmental features which are usually described, stored and manipulated via computational geometry and spatial analysis. But those disciplines cannot easily be combined with logics. The goal of this position paper is to show how knowledge engineering can be the foundation of a new type of urban planning, *i.e.*, urban planning based on knowledge. Geographic knowledge bunches are usually described through geographic objects, relations, structures, ontologies, gazetteers, rules and mathematical models. After having explained those bunches of knowledge, the structure of a geographic inference engine is sketched so to renovate urban planning. Then beyond Spatial Data Infrastructure, we explain that some geographic knowledge infrastructure could be the basis of a new generation of tools for urban planning.**

Keywords — Smart City, Territorial Intelligence; Geographic Knowledge; Knowledge Infrastructure; Geographic Rules; Smart Planning; Geographic Reasoning.

I. INTRODUCTION

In many domains, it is more and more common to speak about knowledge and even the expression “knowledge society” was coined. Several definitions have been proposed to outline this new type of human society. According to a 2005 UNESCO report [21], “Knowledge societies are about capabilities to identify, produce, process, transform, disseminate and use information to build and apply knowledge for human development. They require an empowering social vision that encompasses plurality, inclusion, solidarity and participation”. Starting from this definition, it could be interesting to examine how knowledge can improve not only the management of a city but also urban planning at large. The goal of this position paper is to give a few directions for renovating urban planning through knowledge engineering especially by modeling geographic rules.

Of course, humans are at the center of smart city, but the use of knowledge technologies can help amplify human reasoning not only by studying alternatives of urban development, but also evaluating the consequences in various terms, human, societal, financial, etc. When we say humans, we do not only mean experts in urban planning but also lay-citizens who can influence decisions (public participation or participatory democracy).

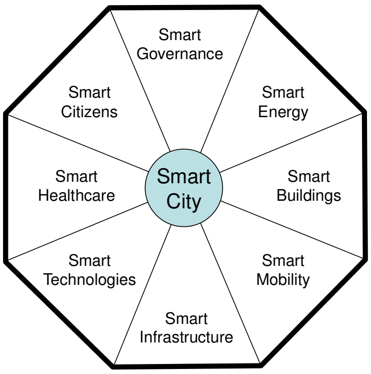


Figure 1. The Smart City components according to Mathew’s diamond (2013) [26].

From practically half a century, information technology has profoundly transformed urban planning. Initially, it was only for some statistics and mathematical modeling of cities [6] and then for map-making. During a few years, the expression “computer-assisted cartography” was used, emphasizing how computers could help the automatic creation of maps. At the end of 70s, it became obvious that automatic cartography must be seen differently, and geographic or urban data must be stored into databases. Then the expression “GIS” was coined for software systems able not only to store geographic data, to make maps but also integrating tools devoted to spatial analysis. As a consequence, urban planning has gradually been renovated [14], first by data then by information and now by knowledge [17].

The paper will by organized as follows; first, several definitions will be analyzed in order to sketch smart urban planning [7]. Then, we will examine the promises of knowledge engineering technologies for renovating urban planning.

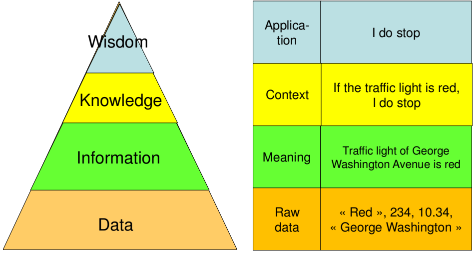
II. DEFINITIONS REGARDING SMART CITIES AND TERRITORIAL INTELLIGENCE

Many definitions have been proposed to define both smart cities and territorial intelligence. They have in common the integration of sustainable development.

About Smart Cities

Carlo Ratti, director of the MIT Senseable City Lab, claims that an intelligent or smart city is technological, interconnected, clean, attractive, comforting, efficient, open, collaborative, creative, digital and green. The European Union considers six components: economy, mobility, environmental, people, living, governance to shape a Smart City. This latter definition was extended by Mathew [18] illustrated Fig. 1 as a form of a diamond connecting Smart Governance, Smart Citizens, Smart Healthcare, Smart Energy, Smart Buildings, Smart Technology, Smart Infrastructures and Smart Mobility.

According to [13], “Smart cities are the result of knowledge-intensive and creative strategies aiming at enhancing the socio-economic, ecological, logistic and competitive performance of cities. Such smart cities are based on a promising mix of human capital (e.g., skilled labor force), infrastructural capital (e.g., high-tech communication facilities), and social capital (e.g., intense and open network linkages) and entrepreneurial capital (e.g,. creative and risk-taking business activities”. Notice that the last definition stresses the importance of knowledge in a smart city. For other definitions and analysis, please refer to [1] for a very comprehensive review.



Applica-tion	I do stop
Context	If the traffic light is red, I do stop
Meaning	Traffic light of George Washington Avenue is red
Raw data	« Red », 234, 10.34, « George Washington »

Figure 2. Data, information, knowledge and wisdom.

In order to plan and manage a city, a novel way is through knowledge engineering [15] which require the design and implementation of a knowledge infrastructure. Remember (Fig. 2) that “data” are raw measures, “information” concerns data with their meaning and “knowledge” an information which can be useful to solve a problem. Moreover by applying knowledge, a sort of wisdom can be reached. Fig. 3 illustrates the role of this knowledge infrastructure in a smart city which is based on a physical layer integrating communications, sensors and data.

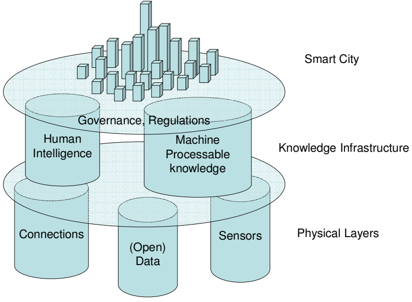


Figure 3. Position of a knowledge infrastructure in a smart city.

For years, in companies business rules are been a common way to encode knowledge. According to Graham [9] and Morgan [19], rules (business rules) should be considered as first-class citizens in computer science. In enterprises, the “craft” of expert know-how is capitalized in a computer system in the form of so-called “business rules”. These rules can then be explained and implemented in applications, such as business intelligence in software architectures often named ERP (Enterprise Resource Planning). Two forms are common IF-THEN-Fact or IF-THEN-Action. For instance, let us consider a newly-designed building. In order to check whether it must comply with the local Master Plan, several rules must be followed as exemplified Fig. 4.

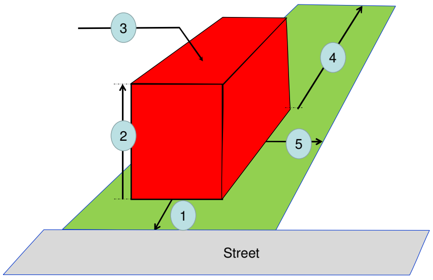


Figure 4. Example of building-related planning rules.

In Fig. 4, Rule 1 gives the minimum distance to the road, Rule 2, the maximum height of the building, Rule 3 the volume of the building, Rule 4 the distance to the end of plot and the 5, the distance with neighbors. Here, to be valid (accepted according to the meaning of the regulation), the building project must comply with this complete set of rules.

About Territorial Intelligence

As the concept of "Smart Cities" focuses on cities, "the concept of "Territorial Intelligence" has a larger meaning. Considering it, also several definitions can be quoted. According to [5], "Territorial Intelligence can be compared with the territoriality which results from the phenomenon of appropriation of resources of a territory; it consists in know-how transmissions between categories of local actors of different cultures." this definition was extended later [8] by specifying that territorial intelligence innovations must include: (*i*) use of multidisciplinary knowledge, (*ii*) dynamic vision of territories, (*iii*) involvement of communities and practitioners, (*iv*) sharing, co-constructing and (*v*) cooperating and participatory territorial governance.

For our part, let me propose the following definitions [17], "**Territorial intelligence can be defined as an approach regulating a territory (maybe a city) which is planned and managed by the cross-fertilization of human collective intelligence and artificial intelligence for its sustainable development**".

And now the question is "how artificial intelligence and especially knowledge engineering can help not only local decision-makers to plan city but also lay citizens to give their opinion about the future of their city [15], [17]?"

Smart Urban Planning

Smart Urban Planning can be seen as a possible answer. Similarly several visions are possible, among others [2] and [7], by having all three facets, sustainable development, greater involvement of citizens and major use of technologies. By examining the difference between the words smart and intelligent, the authors of [7] explain that the adjective intelligent seems to imply the capability of developing actions in order to solve a problem by using methods and information contained into a knowledge base whereas the word smart seems to have, apart from the cognitive heritage (even if not organized in analytical way), also the power of solving the problem “operatively”, showing which are the “tools” to be used for the specific purpose. Summing up, while the intelligent thinks, works out and suggests the models to adopt in order to find a solution, the smart shows also the operative way and the devices to use.

Let us examine rapidly an introductory example. In [22], an example of rule encoding is given concerning road naming in Australia in order to automate the process. Rules are defined in the form of ontological vocabularies using SWRL. However they have some limitations. For instance in one rule, the road length which must be taken into account, is given as an attribute, not computed from road coordinates. In another, a panoramic view is also given as an attribute, not calculated taken terrain morphology into account by 3D computational geometry.

III. PROMISES OF GEOGRAPHIC KNOWLEDGE

As previously told, geographic knowledge must be multidisciplinary. One of the ways to represent knowledge is by using rules. In planning, the rules have the following origins, physical (water, floods, vegetation, landslides, etc.), societal (economy, etc.), administrative (laws, decrees, etc.) or even from best practices. In addition, other rules can be extracted from spatial data mining [17], [18].

One of the difficulties is the fact that among the urban actors, some have different “logics”. With regard to industry creation, an environmentalist or an industrialist may have different ideas on the possible implications of this or that choice. Similarly, some groups may have different priorities: before an empty space, athletes imagine a stadium; pupil’s parents a school; and a realtor a building, etc. From a formal point of view, these aspects will occur in multi-actor and multi-criteria decision support systems.

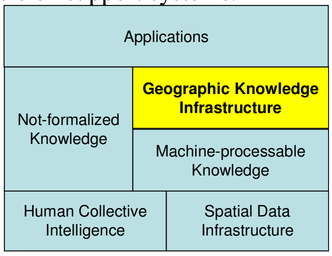


Figure 5. Geographic Knowledge Infrastructure.

After the book edited by Kim *et al.* (1989) [12], in their paper, Batty and Yeh (1991) [3] exposed the promises of so-called expert systems for urban planning. In that period, those systems were only built on logics characterized by the difficulty to use them and by limited interfaces. Now, 25 years after, with the evolutions of information technologies, artificial intelligence and geovisualization, new approaches can be integrated to design new kinds of intelligent systems especially devoted to geographic applications and overall urban planning. Let us call them geographic inference engine which will be able to make reasoning about geographic knowledge. Whereas a conventional inference engine is only based on logics, such a system must integrate topology, computational geometry, statistics and spatial analysis because geographic rules necessitate those aspects to be modeled.

Advocacy for Geographic Knowledge Infrastructure

Based on this background, it is possible to define a Geographic Knowledge Infrastructure l17]. From decades, governments, national or local, have developed spatial data infrastructures. Similarly, it is possible to envision geographic knowledge infrastructure (Fig. 5) as bunches of knowledge necessary to developed higher level applications, those bunches coming either from data mining over the spatial data infrastructure or from human collective intelligence able to be formalized in a machine-processable format. Of course, many bunches cannot be yet formalized.

Chunks of low level knowledge will be directly detailed into chapters dealing with geographic objects and relations whereas high level knowledge more studied in the geographic rule chapter as a basis for territorial intelligence, and smart city planning and governance.

Requirements for Geographic Knowledge Systems

In order to get a well-done geographic system, there are some requirements to follow: (*i*) offering a relevant and complete representation of reality, (*ii*) offering a robust and accurate representation for any granularity of interest, (*iii*) storing consistent and validated knowledge, (*iv*) updating regularly, (*v*) supporting geographic reasoning, (*vi*) representing any shareholder’s logics, (*vii*) combining GKB coming from different sources, and (*vii*) defining planning projects and assessing them.

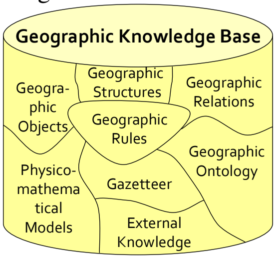


Figure 6. Contents of a geographic knowledge base

GKS Components

In consequence, any geographic knowledge base will consist of Fig. 6 a set of geographic objects, a set of geographic relations, an ontology, a gazetteer, a set of geographic structures, a set of physico-mathematical models and a set of rules; in addition, external knowledge can also be very useful; let us explain those components. For more details, please refer to [17].

Geographic Objects: Features existing in the real world (rivers, roads, parcels, buildings, engineering networks, etc.) can be modeled with types, names, attributes and geometric coordinates by points, lines and areas. Often 3D information can be taken into account. Often fuzzy sets can be invoked to model objects with undefined boundaries, such as mountains or deserts. One of the big problems is that the same geographic object can have different geometric representations (Fig. 7).

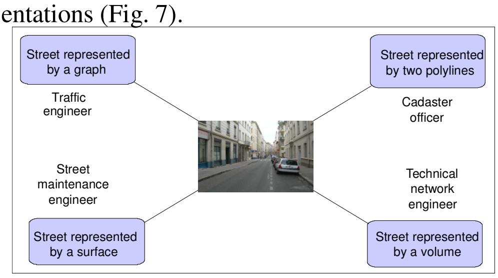


Figure 7. Various geometric representations of a street.

Geographic Relations: Between geographic objects, the majority of relations can be defined based to topological relations (overlapping, etc.) such as Egenhofer relations [6]. But some others can be defined (administrative relations, twinning relations, etc.).

Geographic ontologies: An ontology is a semantic network or a graph between concepts. For us, essentially, geographic ontologies are organizing geographic types. More and more geographic ontologies integrate geographic relations; for instance, an example in urban planning integrates 254 concepts organized into five levels [20].

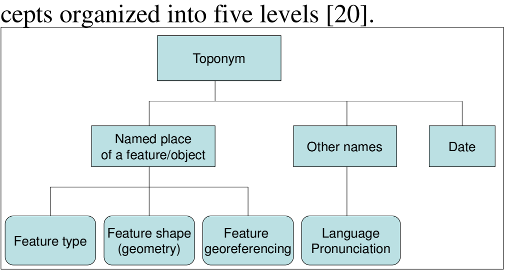


Figure 8. Example of structure of a gazetteer after [10].

Gazetteers: Initially a gazetteer is a dictionary of placenames (toponyms). Since there are complex many-to-many relationships between names and places, since places can change names over time, can change their shape (compare Rome in Romulus' time and now), can absorb other places, etc. And the same name can be assigned to different places. See Fig.8 for an example of gazetteer's structure [10]. Now gazetteers tend to become databases of names with links with ontologies. See [11] for more details concerning gazetteers.

Sets of geographic structures: Two types of structures are common, tessellations and networks, which have specific relations between their components. A country is divided in regions, provinces, etc. which form a tessellation and city into quarters. Often hierarchical tessellations must be considered. The structure of networks is very common. Among them, let mention, road networks, river networks and engineering networks such as for electricity, gas, telephone, sewerage and for the management of traffic lights. In addition, several urban structures can derived from shape grammars such as the organization of city blocks, allotments, etc.

Physico-mathematical models: A lot of knowledge regarding environmental planning, transportation planning and demography is encapsulated into models. It is important to use this already-existing knowledge into this novel system. In addition, there could be added more sophisticated models for multi-criteria decision-making and spatial analysis.

Geographic Rules: As rapidly explained, rules are the key-element for knowledge management since due to rules, new objects can be created, new values can be assigned to attributes, new relationships can be set, etc. Moreover, since often rules can be applied successively, they can represent a sort of chain of causality ($A \Rightarrow B$, $B \Rightarrow C$, etc.). More details can be found in [24, 25]. In fact, let us look at some of them:

- in the United Kingdom, we drive on the left;
- in Canada, the majority of the population lives along the border with the United States;
- each capital city has an international airport nearby;
- between the two capital cities, in general, there are direct flights;
- in the Northern Hemisphere, the more you are going to the north, the colder (but locally this is not always true);
- the more you climb a mountain, the colder;
- heavy rain upstream, downstream flooding;
- mosques are oriented towards Mecca;
- if a zone is a swamp, it is necessary to prohibit construction;
- if there is unemployment, the creation of companies or industrial areas must be encouraged;
- if a plot is adjacent to an airport, it is necessary to limit the height of buildings;
- it is forbidden to open a new tobacco shop within 500 meters of an another already existing;
- when you want to install a metro-line under a street, please move underground networks to another place;
- a good practice in Mexico is to use a bus to go from Puebla to Oaxaca City.

$\forall B \in PROJECT, \exists P \in GO$ $\Omega\text{-}Type(B) = \text{“Building”},$ $\Omega\text{-}Type(P) = \text{“Parcels”},$ $Contains\ (Geom(P), Geom(B)) :$ $Height(B) < 10$ $\wedge Street\_distance(B, P) > 3$ $\wedge Neighbor\_distance(B, P) > 3$ $\Rightarrow$ $UP\text{-}Allowed\ (B, P)$	Rule 1

Back to Fig. 5, the following [Rule 1) rule can be written. For instance, suppose that the building in project is described with BIM (Building Information Management) language from which procedures can be applied to compute *Height*, *Street_distance* and *Neighbor_distance*. In this rule, *GO* means the set of stored geographic objects with the knowledge base, and *PROJECT*, the set of currents projects.

Ω-*Type* means the ontological type and *Contains* corresponds to the Egenhofer relation [6].

Another example of rule is given in Fig. 9 illustrating the case of a city in a country in which a rule stipulates that it is forbidden to open a new tobacco shop within less than 500 meters from another one. In this case, some buffer zones around the existing tobacco shop must be defined. And the places where it is possible to open a new pharmacy are given via a set of geometric operations.

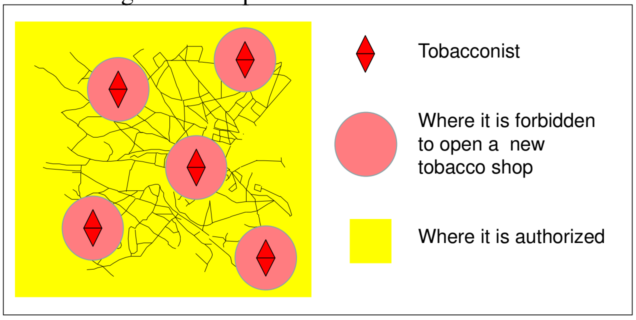


Figure 9. Example of administrative rule: "it is forbidden to open a new tobacco shop within 500 meters from another existing one".

This rule can be formalized as follows:

$\forall F_i \in OG, \exists Z \in Terr,$ $G\text{-}Type(F_i)=Point,\ G\text{-}Type(Z)=Area,$ $\Omega\text{-}Type(F_i)$ = "Tobacco_Shop", $Geom\ (F_i) \in Terr$ $\Rightarrow$ $Geom(Z) = Terr - Union(Buffer(F_i, 500))$	Rule 3

In which in addition, *Terr* is a territory; G-*Type* is the geometric type; *Geom* the geometry of an object; *Union* and *Buffer* respectively geometric operations for determining union and buffer; and *Z*, the zone in which it is allowed to open a new tobacco shop.

The rules can have several origins; the more important are given by experts and some of them can be extracted from spatial data mining under the name of association rules. Various categories can be distinguished: (*i*) Geodetic rules relative to North, South, East and West; (*ii*) Physical geography (sun, flood, winds, vegetation, etc.); (*iii*) Rules coming from laws (see building example given Figure 5, or such as "in UK, one drives left"); (*iv*) Rules coming from sociology or economy such as "along the edges of sea, the greater the distance from the sea, the lower are prices of homes", "the more children, the more schools", or "all big cities have an international airport"; (*v*) Rules relative to flows (transportation of humans, freight); (*vi*) Rules coming from best practices; (*vii*) Rules linked to quality control, mutation of topological relations due to scales (for instance, depending of the scale, a road touches or not a lake); (*viii*) Facing the same situation, some shareholders can have different rules; see an example in Rule 4; (*ix*) Some local rules can supersede global rules, for instance when municipal level rules different from state rules, Etc.

$\forall P \in GO, \forall B \in PROJECT,$ $\Omega\text{-}Type(P)$ = "Parcels", $P.Landuse$ = "Vacant": $Area(P) > 1000$	Rule 4
For an environmentalist	$\Rightarrow \Omega\text{-}Type(B)$ = "Recreational_Park"
For a sportsman	$\Rightarrow \Omega\text{-}Type(B)$ = "Stadium"
For parents of pupils	$\Rightarrow \Omega\text{-}Type(B)$ = "School"
For The Chamber of Commerce	$\Rightarrow \Omega\text{-}Type(B)$ = "Start_up_Facility"
For a land developer	$\Rightarrow \Omega\text{-}Type(B)$ = "Residence"

All those geographic rules use the vocabulary of the ontology and place names described in the gazetteer and sometimes some mathematical models.

External knowledge: In practically all GIS, only data inside the jurisdiction of the entity in charge of planning activities are stored. But often "external knowledge" or "*extra muros* knowledge" could be of importance, in contrast with "internal knowledge" or "*intra muros* knowledge". External geographic knowledge means knowledge the location of which is outside the jurisdiction: it includes neighboring knowledge located at the vicinity of the jurisdiction and outside knowledge coming from everywhere else. For instance outside knowledge can model experiments and good practices in other cities.

Neighboring knowledge represents knowledge located at the vicinity of the jurisdiction, for instance within an out-buffer. It must include main geographic objects, relationships between those objects and the objects located inside the jurisdiction and especially cross-border rules if any.

Especially from technology and urban sociological watching, interesting experiments made in other territories or cities can be modeled and stored as external good practices. Let us call those bunches of knowledge, external outside knowledge. However, the primary step will be to analyze the semantics of this knowledge and to propose a way or a language to be machine-processable, for instance by a variant of case-based reasoning.

Other types of knowledge: In this list, we can add documents which can be considered as storing geographic information giving in natural language.

IV. CONCLUSION: RESEARCH AGENDA TOWARDS URBAN KNOWLEDGE BASES

The benefit of this novel approach will be to simplify the study of consequences and the assessment of urban projects by means of rules and inference engines.

The knowledge society will shape the city of the future. Now that the background of a knowledge infrastructure for smart urban planning is sketched, several questions emerge. Let us precise some of them.

The main question is not to create a smart city from scratch, but rather to "smartify" a city, *i.e.*, to define a methodology to pass from an existing city (whatever is its level of development) to a real living smart city. And knowledge engineering and infrastructure could be considered as the key issue for this transformation.

In the previous section, even if a model of knowledge infrastructure was argued and presented, some validation must be launched by creating operational systems of urban planning based on knowledge engineering. Among the key-problems we have to solve is the discovery of socio-economic rules.

The second aspect concerns citizen participation. Since each citizen or groups of citizens have different interests, this issue has two sides. The first side concerns nimbies who can have divergent interests. But there are citizens who are aware of global interest; but what is general interest and what could be the entity really in charge of global interests? Nevertheless from a computing point of view, we need a robust model to describe citizen's opinions, to analyze them and to synthetize them. Existing multi-actor multi-criteria decision support systems are often very naïve and cannot integrate various forms of knowledge.

Supposing that such a system exists, an important issue is to evaluate the efficiency of generated smart urban plans. But this is a very long task since the efficiency or limitations can often be discovered decades after.

From the knowledge engineering side, various problems must be solved. Among them, let us mention urban and environmental rule encoding, robustness vis-à-vis measurement errors and scaling effects, the combination of knowledge coming from different sources, encoded with different languages and different levels of trust. Do not forget also the integration of external knowledge. And finally, we have to give the complete specifications of a future geographic inference engine.

As those research topics will be carried out and implemented in robust systems, real experiences of knowledge-based smart urban planning will be launched. Indeed, in our society, knowledge is THE infrastructure as the philosopher Michel Serres recently told. Now, since knowledge-based economy is common in businesses, why not in local authorities?

However the main barrier is not technological, but rather political: are politicians really ready to empower citizens?

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