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Exploring Feedforward Knowledge Management for Smart and Sustainable Cities

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Schopenhauer: *The motive is the internal cause of the action, the cause of the cause.*

Abstract—**As knowledge management is mainstream in business, few research activities have been carried out for governing and planning smart cities based on knowledge. The goal of this paper is to examine the case of feedforward knowledge to enlighten decision-making in sustainable cities. Indeed, for a lot of issues in urban planning, it is necessary not only to know the past, but overall to find mechanisms to extract knowledge and to organize it to solve urban problems for a better environment for citizens. Whereas feedback is reactive, adjusting inputs based on past performances, feedforward is proactive, adjusting inputs before problems occur. For that purpose, some conceptual rules (Feedforward rules) split into pre-rules and post-rules are exhibited for urban planning.**

Keywords—Knowledge Management; Smart Cities; Sustainable Cities; Feedforward Knowledge; Urban Planning; Geospatial Rule; Feedforward Rules.

I - INTRODUCTION

In the field of governance, two common sayings prevail: "*To govern is to provide*" and "*To govern is to choose*." While urban decision-makers handle routine events with ease, the complexity of governance intensifies when faced with unexpected situations. In such moments, reliance on information, knowledge, and intuition becomes paramount. In the context of city governance, knowledge – generally defined as information capable of solving problems – plays a crucial role. Knowledge can be sourced from various origins and takes the form of chunks and bundles. Its primary functions include aiding in city planning and driving economic development. To accomplish these dual missions, the significance of feedforward knowledge cannot be overstated. Remember that feedforward knowledge is a communication technique that focuses on the future and aims to provide suggestions and solutions for improvement whereas feedback provides observations on past actions.

After a previous paper [1] trying to extract the semantics of feedforward knowledge in regional planning, the scope of this paper will be to deepen those semantics for the special case of smart cities.

The ultimate objective is not only to define, collect, organize and index urban knowledge, but overall to extract and discover novel information which can be useful for cities, and to make computer tools to reason with the knowledge chunks and bundles. For that reason, the mechanism of rules can be a step towards automatic reasoning. And the preliminary steps are to examine their semantics, to find patterns which will lead to encode knowledge. Of course, since any model is a simplification of the reality, one must try to encompass a great number of situations.

This paper will be organized as follows: after the analysis of special cases of feedforward, we will try to explore some conceptual rules to shape the framework of a dedicated urban knowledge base.

II - GENERALITIES ABOUT URBAN KNOWLEDGE

After the rapid analysis of urban knowledge, some elements will be given to enlighten the mechanisms behind feedforward knowledge.

A. Urban Knowledge

As previously told, knowledge is defined as information potentially useful to solve a problem. Taking this definition into account, let mention that "geographic knowledge corresponds to information potentially useful to explain, manage, monitor, understand the past, plan a territory and innovate" [2]. In the perspective of urban knowledge, three directions can be given:

1 – to boost knowledge-based economy, that is to provide facilities at urban level to boost start-ups, industries, businesses dealing with any kind of activities;

2 – to boost education in order that citizens are more educated, and empowered vis-à-vis societal problems;

3 – knowledge and especially spatial knowledge can be the base of new instruments not only to analyze urban activities, but overall to assist policymakers not only in their daily work but also to help anticipate.

For more information regarding the management of knowledge for smart cities, please refer to some states of the art such as [3, 4, 5].

B. *Origins and Forms of Urban Knowledge*

Urban knowledge is in essence multi-disciplinary and multi-sectoral because it concerns several domains such as transportation, economy, agriculture, health organization, recreational activities, tourism, culture, folklore, education, natural resources, biotopes, infrastructures, flood and hazard mitigation, etc. Moreover, knowledge chunks and bundles come from various sources; among them we can mention:

- written documents such as books, expert reports, juridical documents, etc.;
- historic cartography, maps and images, including satellite images, aerial photos, and more recently, drone photos and videos;
- knowledge coming from experts, people, various stakeholders, activists, associations etc. as witnesses or participants recording their contribution in various formats such as forms, videos, audio,
- data and text mining from various repositories of big data and data streams (e.g., analyzing Twitter messages for obtaining recent event information);
- IoT data from cellular phones, Wi-Fi connections, and in situ sensors for climate and air pollution monitoring, and for traffic monitoring on board public transport and cars;
- dedicated components of knowledge collected for other smart cities, perhaps through technology watching;
- information and knowledge coming from the vicinity which can have an influence on the city itself;
- social media data, in many (often unorganized) forms; etc.

C. *Urban Knowledge Modeling*

For modeling knowledge, general several methodologies exist. In their survey, Bimba et al. (2016) [6] distinguished them into linguistic, expert, network/ontologies and cognitive categories. Now, regarding urban knowledge, graphs and rules are commonly used. For graphs refer to [7, 8, 9]. Figure 1 illustrates the case of the city of Martil in which a very small graph is given; with its kind of formalism, a query can be regarded as discovering a path within the graph or finding missing links.

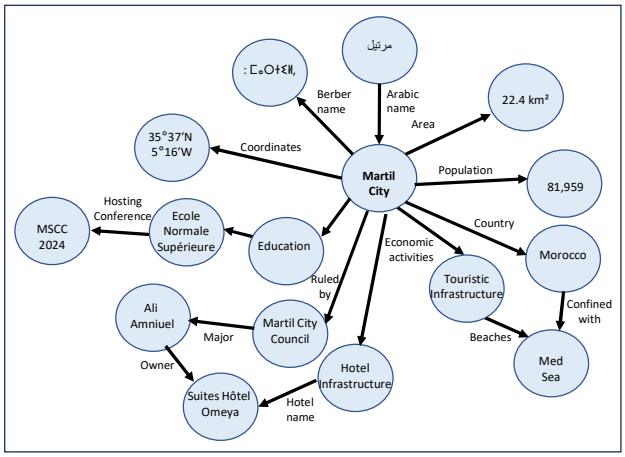

Figure 1. Rapid example for the graph representation of the city of Martil knowledge.

D. *Urban Rules in rule-based systems*

In business intelligence, this is common to use rules. Morgan [10] and Ross [11] have proposed two formalisms, `IF-THEN-Fact`, and `IF-THEN-Action` based on first-order logic, but problems with location are not handled efficiently. Facing this difficulty, in previous papers [12, 13, 14], a new formalism has been presented allowing to introduce location by means of topology and computational geometry, without forgetting the management of placenames thanks to a gazetteer.

So, following [2], concerning geoprocessing, new other types of rules can be distinguished:

- co-location rules the meaning of which is "*if something here, then another thing nearby*";
- `IF-THEN-Zone`, for the creation of a zone from scratch, for instance the administrative creation of a recreational park;
- Metarules such as "*IF some conditions hold, THEN apply RuleC*";
- among the latter a special case is located rules such as "*IF in the place A, THEN apply RuleB*", meaning that when we are in the place A, the *RuleB* holds;
- bi-location rules such as "*IF something holds in place P, then something else in place Q*"; in other domains, this rule is similar to the well-known butterfly effect. So possibly, the consequence can be set in several places.

The structure of the rule grammar is as follows (Figure 2), first antecedents split in context and some Boolean conditions, and then the consequents.

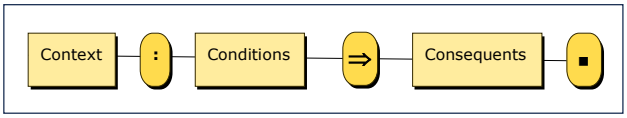

Figure 2. Structure of the rule grammar.

Consider the case of listed monuments in a city; generally, at the vicinity, to protect them, new constructions are forbidden (Figure 3).

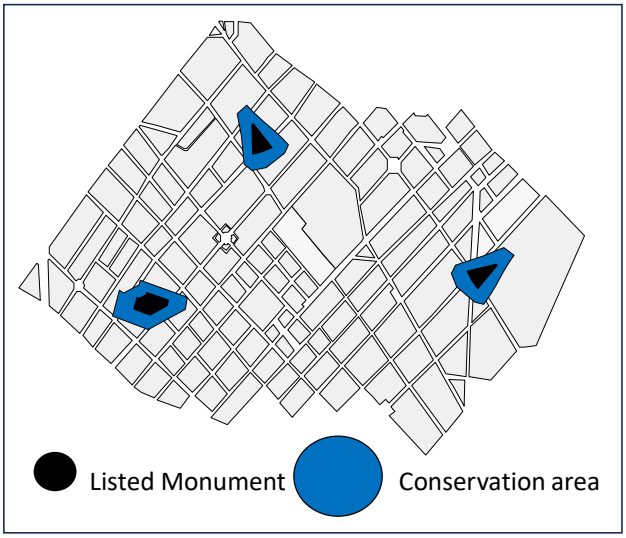

Figure 3. At the vicinity of listed monuments, new buildings are prohibited.

This example can be encoded (Rule 1) as follows (conservation area as a buffer zone of 100 m) in which the state of building *B* is in *PROJECT*, and not stayed already in reality, and will be approved only if it is located outside the buffer zone of a listed monument (*M*).

Rule 1
$\forall\ T \in Earth, \forall\ B \in PROJECT, \exists\ M \in Geo\text{-}Objects,$ Type (*B*) = "Building", Type (*M*) = "Listed_Monument", *Inside* (*Geom* (*B*), *T*), *Inside* (*Geom* (*M*), *T*) : *Disjoint* (Geom(*B*), *Union* (*Buffer* (*Geom* (*M*), 100))) $\Rightarrow$ *State* (*B*) = "LM_Approved"

To conclude this paragraph about rules, let's say that, by using many rules, deductive reasoning can be applied to generate novel information which can be used in decision-making for local authorities.

E. Differences between Feedback and Feedforward Rules.

As seminal example, let us compare two common rules, (i) "*if it rains, I get wet*", and (ii) "*if it rains, I take my umbrella*". The first one can be seen as a natural consequence, but the second is totally different. Indeed, knowing that rains can often occur, I can anticipate it by buying or borrowing an umbrella; and when the rain comes, since I have an umbrella, I can use it. In another domain, namely control engineering, two notions are central, feedback and feedforward. Feedback corresponds to (automatic) reactions as rules (i) and (ii), whereas feedforward corresponds to an anticipation, i.e., the rules to be mobilized not only to get the necessary resources, but also to design decisions and actions to make. In other words, feedback is reactive, adjusting inputs based on past performances, whereas feedforward is proactive, adjusting inputs before problems occur.

Rapidly said, by feedback, the city's behavior is based on the past, whereas by feedforward, its behavior is based on future, or more realistically of the projected future. But this statement must be immediately nuanced by several considerations.

- The past is only partly known; and regularly journalists, historians, and archeologists dig up new information.
- By definition, the future is unknown; according to the inertia of the urban systems, some projections can be carried out, perhaps with different scenarios. But several stakeholders can have different visions of the future (compare ecologists, chamber of commerce, etc.) and they each try to draw the evolution in conformance with their own vision and interests.
- Don't forget also all citizens who want to participate to decision have their own vision of the city. Some of them are called NIMBY (Not in my backyard) who are only interested in their nearby neighboring of their house, while others can have a more global vision of the future.
- For city's officials, the main concretization is done through plans and projects.

Generally speaking, feedforward knowledge can be acquired through several means [15]:

- Experience and Observation: Learning from past experiences and observing patterns can provide valuable insights. Decision-makers can draw upon their own experiences or learn from others who have faced similar situations.
- Expertise and Training: Seeking guidance from experts in relevant fields and undergoing specialized training can enhance feedforward knowledge. Experts possess domain-specific insights and can offer practical advice.
- Research and Data Analysis: Conducting research, analyzing data, and staying informed about trends contribute to feedforward knowledge. Access to reliable information helps decision-makers anticipate challenges and plan accordingly.
- Scenario-Based Learning: Simulating scenarios and understanding their implications can build feedforward knowledge. By exploring hypothetical situations, decision-makers can prepare for unexpected events.
- Collaboration and Networking: Engaging with peers, attending conferences, and participating in professional networks allow decision-makers to exchange knowledge. Collaborative efforts enhance feedforward capabilities.

To our information, there is no previous work concerning the modeling of feedforward knowledge for smart cities.

Back to the seminal example of umbrella and rain, one can observe that the rule "*if it rains, I take my umbrella*" has a sort of hidden rule "*since it often rains, I will buy an umbrella*". Let's call the first-mentioned rule a post-rule (`Whenever/Then`) whereas the hidden one, a pre-rule (`Since/Consequently`). The conceptual framework can therefore be formalized as follows (F1):

Pre-rule	`Since` it often rains, `Consequently` I will buy an umbrella. ■	F1
Post-rule	`Whenever` it rains, `Then` I get my umbrella. ■	

III - ANALYSIS OF FEEDFORWARD URBAN KNOWLEDGE

Now that the conceptual framework is set, let us examine a few examples of feedforward control. First, fighting pollution and harbingers will rapidly be analyzed, followed by the important problems of disaster management. Then, urban planning, technology watch and public participation will be explored.

A. Fighting pollution and harbingers

Environmental regulations impose to monitor several physical, biological and chemical pollutants in air, water and soils [16]. To monitor the city's safety, sensors are

placed throughout the city and whenever a certain threshold is exceeded, an alert is triggered (F2).

Of course, this kind of feedforward rule can be instantiated by every pollutant for which specific actions must be taken. For instance, regarding the Covid-19 crisis [17] have shown that traces of the virus can be extracted from wastewater a few days before leading to a higher risk of disease spread.

Pre-rule	`Since` pollution must be monitored, `Consequently` adequate sensors are distributed throughout the city. ■	F2
Post-rule	`Whenever` a threshold is exceeded, `Then` an alert is triggered. ■	

B. Rapid Analysis of Disaster Management

As another preliminary analysis let's examine the case of disaster management such as floods, tsunamis, hurricanes, volcano eruption, big fires, bridge collapse or nuclear plant explosion, etc. Disaster management systems are characterized by information and knowledge required to support decision making in all chronological phases of a disaster – mitigation, preparedness, response and recovery – as defined by the Federal Emergency Management Emergency, (FEMA) [18] (Figure 4), (i) Mitigation concerns long term feedforward; (ii) Preparedness, short term feedforward; (iii) Response, short term feedback; (iv) and Recovery, long term feedback. But now, the question is: "what are the information and knowledge necessary to manage those phases?". In reality, there is a link between recovery to mitigation, because the issue of recovery is to transfer knowledge to better mitigation.

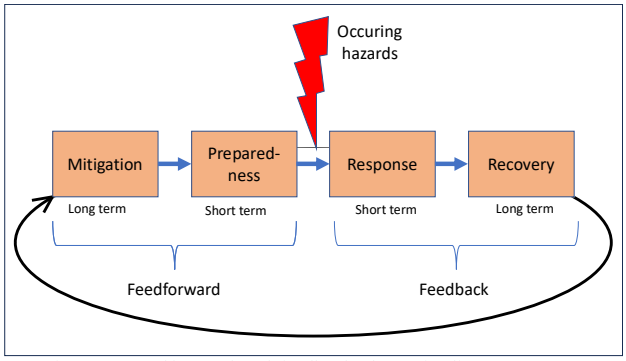

Figure 4. Feedforward and feedback phases in disaster management (FEMA 1998 with modifications).

The rapid analysis of the phases of disaster management shows that, by knowing the past, it is necessary to define actions adapted to the context, in other words, the necessity of planning. As a consequence, from a knowledge point of view, the conceptual rule can be modeled as given in Figure 5 in two parts: (i) when facing recurrent events, we can plan some procurement actions, and (ii) when the city is facing the kind of events, it is ready to deal with it.

So, this feedforward rule can be split into a pre-rule for the preparation, and a post-rule for the decision (F3).

Pre-rule	`Since` a risky event is recurring, `Consequently` define actions to mitigate it and to be prepared. ■	F3
Post-rule	`Whenever` the risky event occurs, `Then` organize response and recovery. ■	

In addition, evacuation and shelter management are critical issues in disaster management. The rule (F4) is as follows to ensure that the shelters are safe and accessible for the people who will be using them.

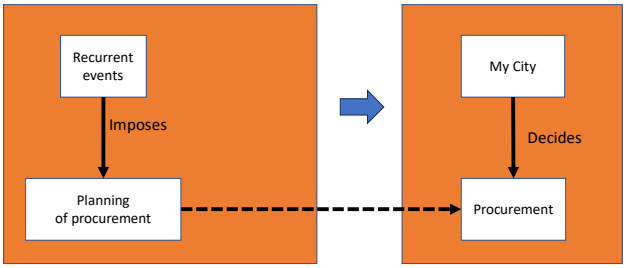

Figure 5. Conceptual rule regarding recurrent events needing some actions.

Pre-rule	`Since` many people can be affected by various disasters `Consequently` create shelters and design evacuation plans. ■	F4
Post-rule	`Whenever` the risky event occurs, `Then` alert people to go to the nearby shelters in accordance with the evacuation plan. ■	

C. Fundamentals of planning

Urban planning is a technical and political process that focuses on the development and design of land use and the built environment [19, 20]). This includes considerations related to air, water, and the infrastructure within and around urban areas, such as transportation, communications, and distribution networks. Traditionally, urban planning followed a top-down approach, involving master planning for the physical layout of human settlements. The primary concern was public welfare, which encompassed efficiency, sanitation, environmental protection, and the impact of master plans on social and economic activities.

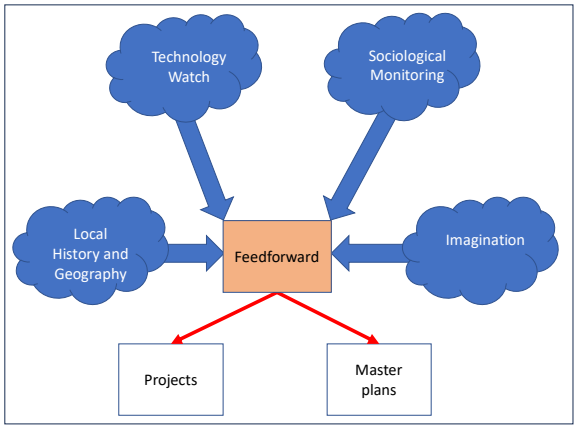

Figure 6. Urban plans and projects as feedforward mechanisms.

Several so-called urban development models have been written not only to understand its dynamics, but also to try to project its future [21, 22, 23, 24]. This kind of models could be a path for feedforward control of cities essentially by what-if simulations.

Figure 6 depicts the main abstract components of feedforward in urban contexts; as input, local history and geography, technology watch, sociological monitoring together with imagination; as outputs, urban master plans and development projects.

Figure 7 shows the feedforward rule (F5) concerning planning as a result of electoral promises based on an analysis of problems to be solved, or on some existing land opportunities and sometimes ideology.

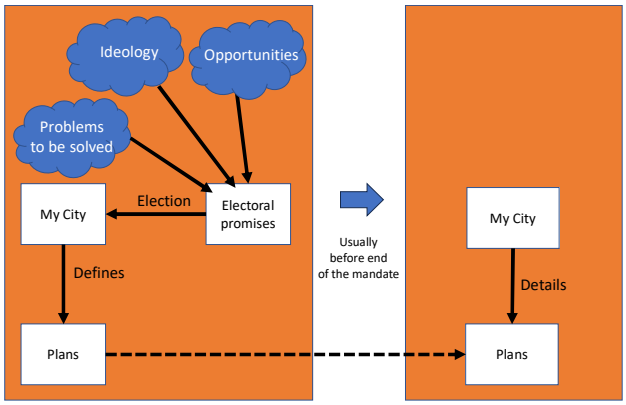

Figure 7. Feedforward conceptual rule concerning urban plans.

Pre-rule	`Since` an election is scheduled, `Consequently` prepare electoral promises and plans. ■	F5
Post-rule	`Whenever` the election is won, `Then` prepare the implementation of the plan. ■	

D. About technology watch

In technology watch, as soon as one knows that a new device is applied successfully in another similar city, it could be interesting to examine to apply it. So, the feedforward rule could be formalized as follows (F6).

Pre-rule	`Since` another city puts in place a clever device, and this one is a success `Consequently` examine it carefully. ■	F6
Post-rule	`Whenever` the context is favorable `then` it can be imported into my city. ■	

Of course, a similar mechanism can be provided for any interesting social innovation made in another place.

F. About lessons learned from abandoned projects

In urban areas, some development projects are abandoned due to various reasons. However, some of these projects have given rise to interesting design ideas that can be repurposed in other projects. In essence, the lessons learned from these projects can be compiled into a sort of idea repository, which can be used as a special case for feedforward knowledge.

Remember that often during the design of any urban project or plan, several alternatives are considered. For instance, for the design of a streetcar route, several possibilities are considered, and finally, only one of them is selected and decided. The lessons learned concerning the rejected alternatives can be also stored into that repository (F7).

Pre-rule	`Since` learned lessons from abandoned projects can be interesting `Consequently` a special organization storing those lessons must be designed. ■	F7
Post-rule	`Whenever` during the design of a novel project, some lessons could be re-used `Then` study how to adapt them in the project. ■	

F. For more sustainable cities

Combating climate change requires packages of special actions to be taken in energy saving, industry, mobility, tourism, health, waste management, housing, security, etc. So, a very general rule can be formulated (F8).

Pre-rule	`Since` public combating climate change is compulsory `Consequently` list appropriate potential actions. ■	F8
Post-rule	`Whenever` a novel project is proposed, `Then` modify it towards more sustainability. ■	

Of course, many other specific rules can be developed, for instance regarding house insulation, tree planting, green façades, bike paths, electric vehicles, pollution, safety, etc. So, we can observe same the same pre-rule can induce several post-rules.

G. Public participation in urban planning

In many countries, public participation is an important issue in the design of plans and projects for sustainable city planning [25, 26]. For that purpose, the following mechanism can be used (F9).

Pre-rule	`Since` public participation is mandatory for any urban plan or project, `Consequently` organize it to be efficient. ■	F9
Post-rule	`Whenever` a plan or a project is designed, `Then` collect public opinions and synthesize them. ■	

To generalize this aspect, let us mention that this is one of the main components of territorial intelligence [2, 26]

which can be defined as the combination of artificial intelligence and human collective intelligence toward the design and the planning of smart and sustainable territories. By human collective intelligence, one means that several stakeholders, whatever their interests, must try to converge to the choice of actions for the mutual interests, not only for them but overall, for the benefit of the planet.

IV - Conclusions

The paper aimed to explore the concept of feedforward knowledge in the context of smart and sustainable cities. After briefly examining the semantics of a few cases, a formalism was presented using conceptual feedforward rules that were divided into two parts, pre-rules (`Since/Consequently`) and post-rules (`Whenever/Then`).

Back to the seminal rule about rain and umbrella, another rule can be easily written "*If it rains, my take my umbrella*". In other words, from a pre-rule, several post-rules can be induced, so opening the possibility to consider several alternatives to decision-makers. For example, considering decarbonization of mobility, a unique pre-rule can be linked to many post-rules, which leads to specific rules for decision-making or organizing priorities in connection with financing and other constraints.

So, the articulations between pre-rules and post-rules must be examine carefully, and this is not a mere deduction. In other words, each pre-rule determines a sort of context, maybe consisting of a set of documents or generic plans, from which several specific post-rules can derive by means of a congruence mechanism to be identified.

The next step will be to examine other cases in order to validate the presented formalism, knowing that the ultimate goal will be to instantiate the feedforward rules in several contexts and to implement a reasoning system. This will check the validity of the presented theoretical model.

Concerning encoding, as the grammar [13] presented in Figure 2 can easily be used for post-rules, another dedicated grammar must be developed to integrate new concepts issued from the modeling of pre-rules. Among those concepts, the integration of documents such as written reports, maps, etc. must be introduced.

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