Chapter 1
Promises of Artificial Intelligence for Urban and Regional Planning and Policymaking

Robert Laurini

Abstract The design of regional plans is a difficult task combining political, economic, sociological and technological aspects. From decades, computers have been used for this task: at the beginning for mapping, then for spatial analysis and information systems, and now with artificial intelligence in the design of smart regions. The objective of this paper is to show some potentialities and promises of using artificial intelligence for regional planning, especially by using knowledge management, rule-based systems, case-based reasoning and machine learning. However, some limitations are still hindering its use, among them let us mention sociological acceptance and the existence of technological barriers.

Keywords Artificial intelligence · Smart regions · Knowledge management · Machine learning · Rule-based systems · Urban planning · Regional planning

1.1 Introduction

For half a century, computers have been used in urban and regional planning, first for cartography (Baxter 1976), then for information systems (Laurini 2001) and now with artificial intelligence (AI). Even if the inception of AI dated after WWII, after the long so-called "AI winter", now, not only the technology look mature, but also applications are mainstream in a lot of domains ranging from business to medicine and natural language processing. However, in regional studies, and especially in planning, few applications can be mentioned for several reasons which will be explained in this paper. Indeed, on one side, some technological barriers can be identified, and on the other side, promising applications are emerging.

The research questions of this paper can be stated as follows:

RQ1: what are the technological barriers which impediment the use of AI in regional planning?

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RQ2: what are the urban and regional problems for which AI can bring novel solutions?
RQ3: is there a difference between urban and regional planning in terms of actually produced research works?

In a generally agreed-upon definition, a smart region can be characterized as a region overlaid by a digital layer, which is used not only for storing region information but overall, for its governance. And in this digital layer, one can find GIS, big data analytics, 3D, AI, Internet of Things, etc.

An important aspect to mention is that in the literature, few have been done regarding AI in regional planning, except perhaps Zaborovskaia (2018) but only at economic levels to boost innovations, but many more in urban planning. That is the reason why several examples dealing with urban planning, are given in the text which can be a source of inspiration at the regional level.

Several studies have been made regarding AI and smart cities (Batty 2018). For instance, Bisen (2020) presents applications such as video-surveillance for helping the police monitor illegal activities, vehicle parking and traffic management systems, and waste and disposal management systems. Kumar (2019) declares that a smart city has various use cases for AI-driven technology, from maintaining a healthier environment to advancing public transport and safety. And she adds that by leveraging AI and machine learning algorithms, a city can plan for better smart traffic solutions making sure that inhabitants get from one point to another as safely and efficiently as possible. Thakker et al. (2020) apply AI for flood monitoring; indeed, monitoring gullies and drainage in crucial regional areas susceptible to flooding issues is an important aspect of any flood monitoring solution. More recently Gao (2021) has coined the expression "Geospatial Artificial Intelligence (GeoAI)" for regrouping all attempts to use AI not only in GIS domains but also in urban and regional planning.

In this paper, three important subdomains of AI will be examined, namely knowledge management, case-based reasoning and machine learning. For each of them, will be provided theoretical generalities, barriers to overcome and promising urban and regional applications.

1.2 Knowledge Management

In computing, this is common to distinguish between data, information, knowledge and wisdom (Ackoff 1989), in which knowledge can be defined as information helping to solve a problem, and wisdom, the use of accumulated knowledge. The so-called DIKW (Data, Information, Knowledge, Wisdom) pyramid can be seen as a key-concept in computing. Many authors asserted that a knowledge-based system is based on the assumptions that (adapted from Han and Kim 1990):

(a) the problem can be clearly specified and is well bounded;
(b) the relations between the factors or elements of the problem are known and can be expressed explicitly;

(c) problem-solving methods can be articulated; and
(d) experts agree on solutions, that is, the cause-effect relationships are clearly defined.

The pioneer of this approach is Sowa (1984) with his semantic networks, in which reasoning is like finding a path in a graph. Then followed by the seminal paper written by Davis et al. (1993) who examine "What is Knowledge Representation?" from a somewhat abstract, often philosophical viewpoint based on 5 different roles, (i) a surrogate or a substitute for the thing itself, (ii) a set of ontological commitments, (iii) a fragmentary theory of intelligent reasoning, (iv) a medium for pragmatically efficient computation, and (v) a medium of human expression, i.e. a language in which we say things about the world (Laurini 2017).

Regarding knowledge representation, presently, three directions can be defined, ontologies, knowledge networks and rule-based systems. See Soergel (2009) for more details.

1.2.1 Ontologies

The word "ontology" come from ancient Greek "οντος" (being) and "λογια" (discourse), i.e. the discourse about existing objects. This word, usually written with a capital "O" is overall used in philosophy and theology. Now, in computing, an ontology (with a lower case "o") refers to modeling things existing in the discourse which is a fundamental idea in data modeling: when something has no name, it is not existing in our mind, so not existing in our culture, so not existing in our world.

In information technology (Gruber 1993), the more used definition is "an ontology is a specification of a conceptualization", so ontology is an artifact created to describe the meaning of a vocabulary. Indeed Guarino (1998) said that in artificial intelligence, an ontology represents an artifact made with a vocabulary for building a reality, accompanied with a set of implicit assumptions concerning the meaning of words and of the vocabulary. So, an ontology is neither a catalogue of objects nor a taxonomy, but an ontology is not reducible to a purely cognitive analysis and represents the objective side of things. See Also Roussey et al. (2011) for ontology engineering. An example is given in Fig. 1.1.

Nothing prevents that some different ontologies can be used to describe the same reality. Therefore, two observers may have two different visions or two different understandings of the same reality, so giving two different classifications.

The first important project to design urban ontologies was Towntology. In fact, under this name, there were two projects; the first one was developed in Lyon, France, from yours truly (Keita 2007; Teller et al. 2005). A second was a European COST project, the outcomes of which were published in Teller et al. (2007); the idea was to design a unified ontology for urban planning. But due to several objectives, geographic and juridical contexts, are not unique, but several were designed. One of the conflicts was the scope of designing ontologies; for computer scientists,

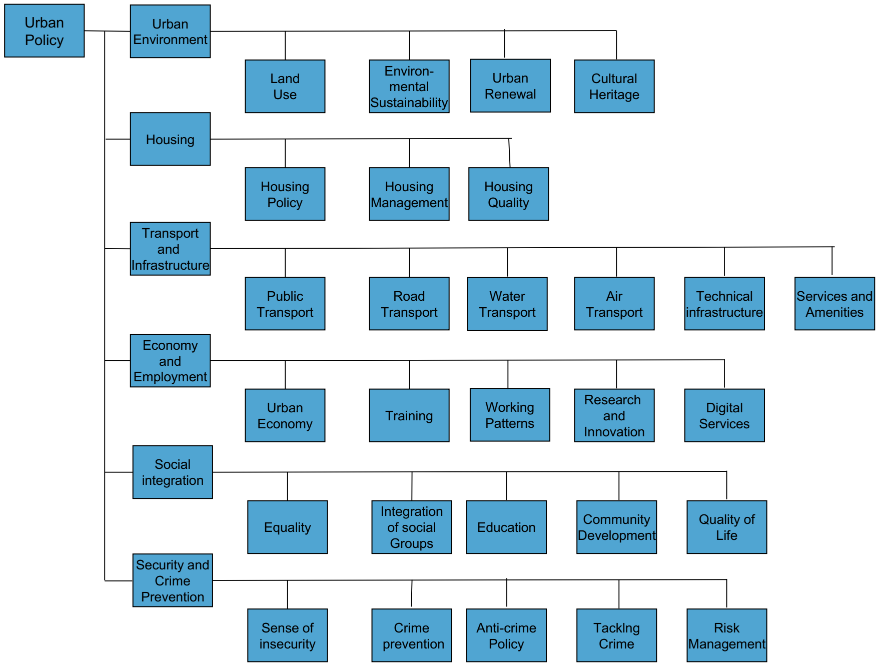


Fig. 1.1 The European Urban Knowledge Network (EUKN) top-level ontology. The thesaurus is composed of 254 concepts organized into five levels. Quoted by Teller (2007)

it was a key for urban information systems interoperability, for region planners, a way to clarify vocabulary and for decision-makers, an assistance for governance.

Further, Komninos et al. (2015) try to improve effectiveness in several urban issues by using ontologies (Fig. 1.2). However, they conclude that region intelligence is a product of citizen engagement rather than smart region technology. See also (Laurini and Kazar 2016) for a survey on geographic ontologies.

Regarding regional ontologies, let us mention Sewchurran et al. (2010) who wrote an interesting paper, but too much philosophy-oriented than practical experimentations.

To conclude this section on urban and regional ontologies, let us say that the design of ontologies is something difficult needing first the consensus of several actors for the definition of terms and concepts. And an expected issue has been the clarification of the vocabulary in regional planning. But the main limitation resides in the fact that if ontologies can be used to help reason on this discipline, direct applications to a precise town or district are not so easy. But with knowledge networks, it looks possible.

In this category, one can add folksonomies (Soergel 2009; Mocnik et al. 2017) which are taxonomies made by people's contributions.

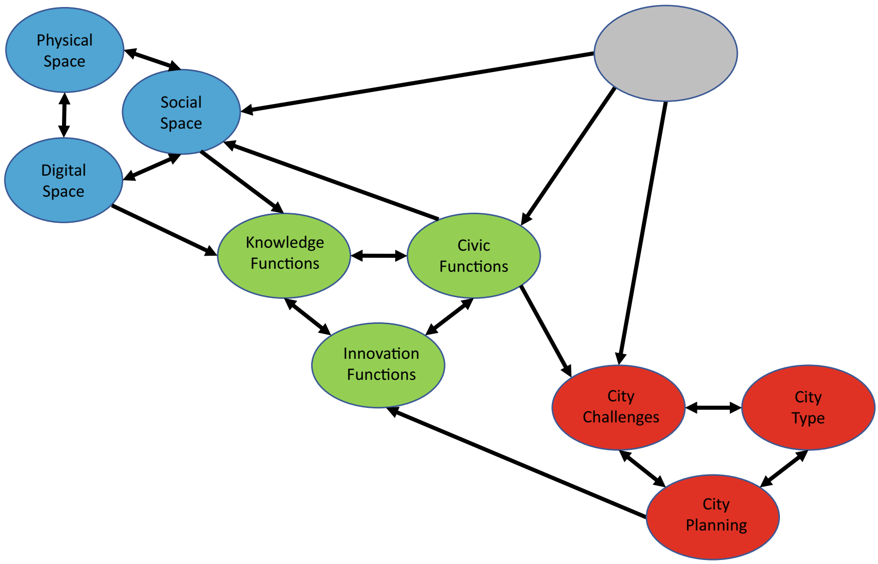


Fig. 1.2 Smart city ontology superclasses After Komninos et al. (2015)

1.2.2 Knowledge Networks

Another direction of knowledge management is based on networks or graphs. To start the presentation, let us take an example. In crime movies, it is common to see detectives utilizing an investigation board. On this board, they usually pin pictures of possible suspects, of witnesses if any, of exhibits of evidence, together with arrows showing the relationships, sometimes complemented by names and maps. In other words, they try to collect all information concerning the crime into a network. From a certain point of view, a crime novel or movie can be seen as the construction and filling of this network. Of course, there are missing pieces or missing arrows. By human reasoning, detectives try to answer questions concerning the motive, the used weapon, the opportunity, etc. As in the beginning, it looks like an incomplete puzzle, but at the end, the board is fully completed and the solution is clear.

Back to artificial intelligence, this is a case of knowledge management, or more exactly the construction of a knowledge graph or network against which queries can be put in order to solve a problem. In essence, a knowledge network is composed of two items, objects and relationships possibly with attributes as exemplified in Fig. 1.3.

With this mechanism, it is possible to describe a situation, a context or a city; see for example Fig. 1.4 issued from Qiu et al. (2019), in which we can mention various relationships such as `has_junction_with`, `country`, `twin_city`, etc. Of course, for any city, this description in terms of knowledge network can easily be made by adding other objects and relationships.

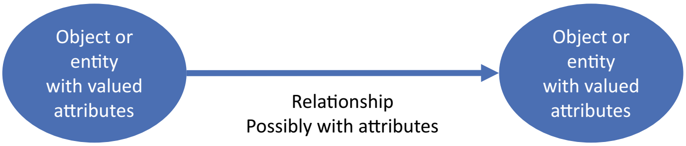


Fig. 1.3 Basic items of a knowledge network

This formalization was extended by Wang et al. (2019) into the Geographic Knowledge Graph (GeoKG) with the following representation (Fig. 1.5). In their paper, they have successfully applied this methodology to represent several cases in regional planning and management. However, in a neighboring domain, namely surveying and remote sensing, Hao et al. (2021) have proposed a methodology for designing a knowledge graph based on an ontology (Fig. 1.6) which could be used, maybe with modification in regional planning and management.

Another interesting study of knowledge graphs for disaster prediction, see Ge et al. (2022).

As a conclusion for knowledge networks, they can give an appropriate model of the town or the district desired not only to understand but overall to sketch its future. The main advantage is the flexibility i.e. the possibility to create new relations and to be very flexible in portraying novel or complex situations. In this context, reasoning can be seen as finding a path in a graph.

1.2.3 Rule-Based Systems

According to Graham (2006) and Morgan (2008), rules must be considered as first-class citizens in information technologies, meaning first that several computer-based activities must be revisited. By definition, a rule is a sequence of antecedents-implication-consequents which can be noted by $(A) \Rightarrow (B)$, in which A is a conjunction of conditions. Instead of antecedents, sometimes the expression 'premise' is used. In logic, B can be either a disjunction of conditions or a set of assertions.

In Business Intelligence, generally, their implementation is based on two grammatical structures IF-THEN-Fact and IF-THEN-Action (Ross 2011). The first serves above all to involve new facts, that is new objects, attribute values and new relationships between objects. As to the second, it is to involve new actions. However, in regional planning, rules are essentially coming from laws and by-laws. Moreover, some experts can use other rules in their daily practice, sometimes called best practices. In addition to that more and more specialists in spatial data mining can discover what they call associative rules. But the main problem is to take geometry and topology into account. For instance, consider the following rules (Fig. 1.7):

- If a lane is narrow, make it one-way, except if it is a cul-de-sac (dead end);
- When planning a metro, move underground networks;

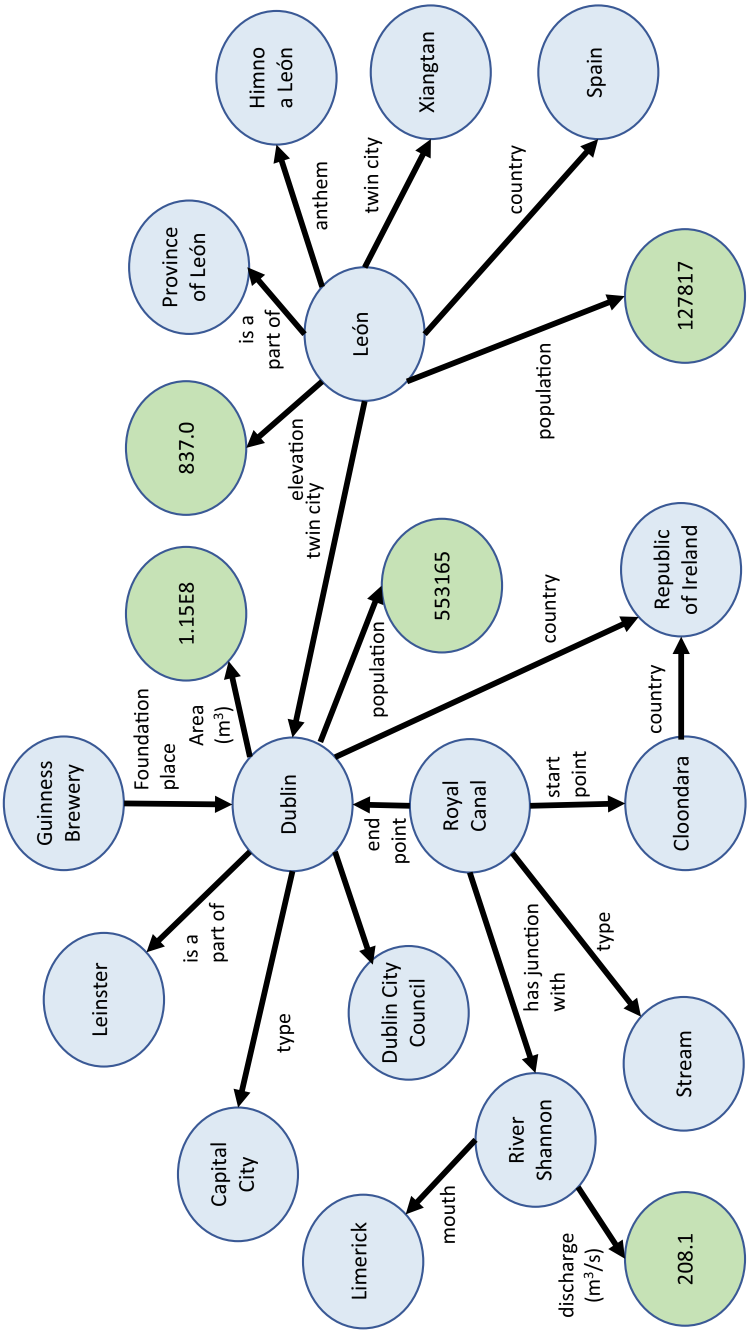


Fig. 1.4 Knowledge network for the description of Dublin, Ireland After Qiu et al. (2019)

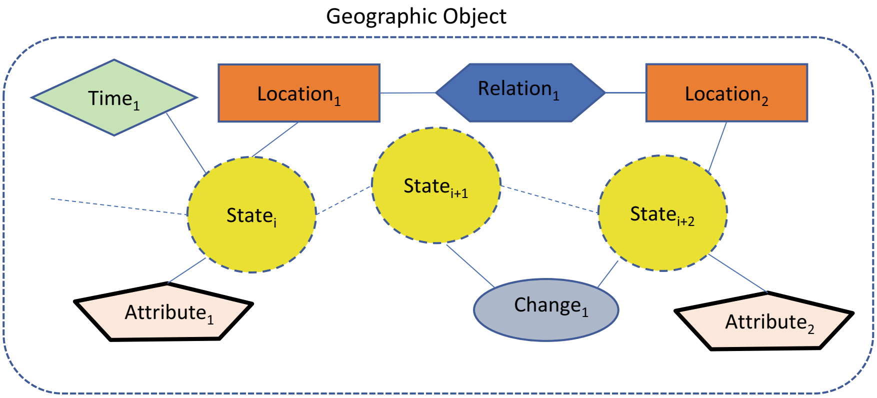


Fig. 1.5 A conceptualized model of GeoKG based on the basic elements. From Wang et al. (2019)

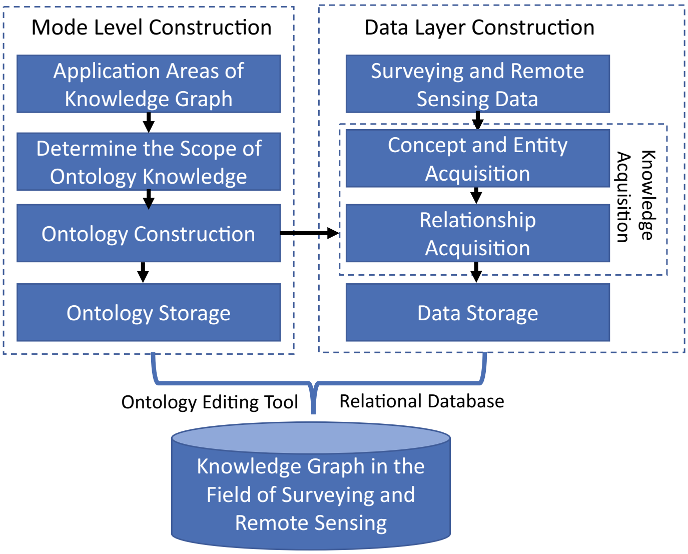
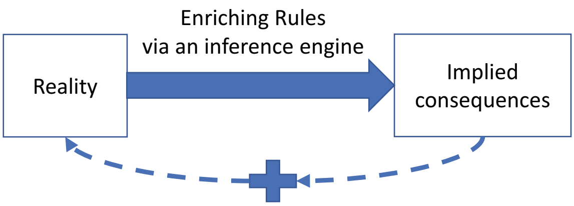


Fig. 1.6 Framework of the knowledge graph in the fields of surveying and remote sensing as proposed by Hao et al. (2021)

Fig. 1.7 More knowledge chunks are produced by rules enriching through an inference engine



- No parking, no business;
- Each building must be connected to utility networks (water, electricity, gas, telephone, internet, etc.);
- If a crossroad is dangerous, install traffic lights;
- In city centers, transform streets into pedestrian precincts;
- When a commercial mall is planned in the neighborhood of a city, shops located in the city center will be in jeopardy.

As a consequence, several types of rules must be considered in addition to `IF-THEN-Fact` and `IF-THEN-Action rules` (Laurini 2019a):

- Rule of zone creation; "`IF-THEN-Zone`";
- Co-location rules: "IF something here, THEN another thing nearby";
- Metarule: "IF some conditions hold, THEN apply RuleA";
- Located rule: "IF in a place B, THEN apply RuleB";
- Bi-location rule: "IF something holds in place P, THEN something else in place Q".

According to Klosterman (2015), the first to use a rule-based system in urban planning was Landis (1994). Varadharajulu et al. (2016) were using a rule-based system to assign names to roads. In their survey of using rule-based systems in regional design, Pisano et al. (2020) give a few examples, but no instance of rules is given.

Sometimes rules are positioned in small places, for example in urban planning zones. Figure 1.8 illustrates the case in which there are three zones in which five rules can be applied, those zones being delimited by the list of surrounding streets. Two solutions are possible:

1. for each zone, give the list of applicable rules,

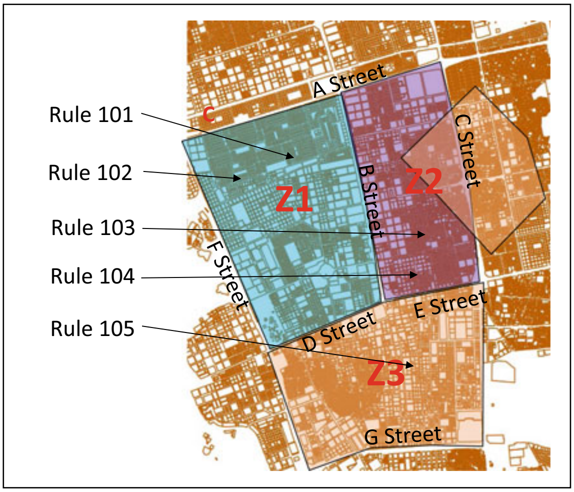


Fig. 1.8 Rules and zones

2. for each rule, give the list of zones in which they apply.

In Laurini (2019b) a mathematical language was presented integrating geometry and topological aspects in addition to logic. With this ruleoriented language, let us detail take the option that, for each zone, will give the rules to be applied. For zone *Z1*, the following rule can be written:

$$\exists C \in City, \forall B \in Project, \exists\, ZoneZ1 \in Terr,$$
$$Geom(ZoneZ1) \equiv SurroundedByStreet(A\_Street,\ B\_Street,\ D\_Street,\ F\_Street)$$
$$:$$
$$Contains(Geom(ZoneA), Geom(B))$$
$$\Rightarrow$$
$$\{AppliedRule(101);\ AppliedRule(102)\} \quad \blacksquare$$

1.3 Case-Based Reasoning

Case-Based Reasoning (CBR) is a subset of knowledge management which tries to solve new problems by retrieving stored 'cases' describing similar prior problem-solving episodes and adapting their solutions or outcomes to fit new needs (Kolodner 1993). This framework can be stated as follows:

$$(Description(A) \Rightarrow Outcome(A)) \wedge Resemble(Description(B), Description(A))$$
$$\Rightarrow$$
$$Resemble(Outcome(B), Outcome(A)) \quad \blacksquare$$

To simplify this mechanism, suppose that the cases are stored according to the following schema in which the set of attributes are split into two categories, the first for the description of the case and the remaining the characteristics of the solution:

$$K\,(k_{\#}, k_1, k_2, k_3,\ \ldots, k_i, k_{i+1}, k_{i+2}, \ldots k_{i+n})$$

The first step to get a solution is to find the stored cases the most resembling to our new case. For that, usually, an n-dimensional distance between cases is defined. The nearest case according to this distance is the most interesting. Sometimes some k-nearest algorithms are launched to find other neighbors.

According to Sànchez-Marrè (2001), the description of the case is as follows:

- an identifier of the case,
- the description of the case,

- the diagnostic of the case,
- the solution of the case,
- the derivation of the case, i.e. from where the case has been derived/adapted,
- the solution result, information indicating whether the proposed case solution has been a successful one or not,
- a utility measure of the case in solving past cases when it was used,
- other relevant information about the case.

According to Holt and Benwell (1999), the procedure is as follows (Holt and Benwell 1999):

- Build a repository of cases.
- Retrieve the most similar case(s).
- Reuse the information and knowledge in that case to solve the problem.
- Revise the proposed solution.
- Retain the parts of this solved problem (experience) which are likely to be useful for future problem-solving.

The generic rule can be stated as "If a MyTown resembles to OtherTown which has successfully completed a realization, then MyTown may create a project to adapt this realization". See Fig. 1.9.

As many applications are found in business, few can be found in geoprocessing. However, we can mention the pioneering work made by Holt and Benwell (1999) for soil classification, for digital terrain analysis, in particular to extracting drainage networks by Qin et al. (2016), and in logistics by Belyakov et al. (2018). For regional planning, the work by Yeh and Xun (2001) is interesting to be mentioned in Hong Kong.

But the more complete approach is given by Anthony (2020) by applying CBR for sustainable smart region development and planning.

However, by using previous cases, this methodology can be seen as a preliminary example of the machine learning experience.

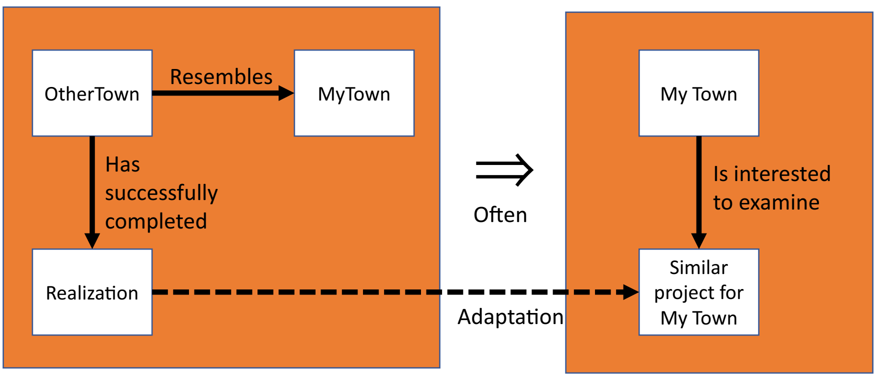


Fig. 1.9 Regional project inspired from an interesting realization elsewhere

1.4 Machine Learning

Essentially, machine learning is a method of teaching computers to make and improve predictions or behaviors based on some data. Data depend entirely on the problem. On the other hand, neural networks reflect the behavior of the human brain, allowing computer programs to recognize patterns and solve common problems in the fields of AI, machine learning, and deep learning. Artificial neurons are very simple linear systems with one output and several inputs in which w_i are weights as depicted in Fig. 1.10. Of course, more complex functions can be used.

Those neurons can be combined to give a network, generally with several layers (Fig. 1.11). To train this network, we present together several inputs and outputs. A special algorithm is run in order to evaluate the weights of all constituting neurons (see, for instance, Rumelhart et al. 1986). Once those weights are stabilized, the network can function by presenting new cases.

Deep learning is an evolution of neural layers in which many layers with many neurons are used, but there is no agreement regarding the threshold. However, applications run from natural language processing to image recognition. According to Murphy (2021), neural networks are performing tools for sequences and images.

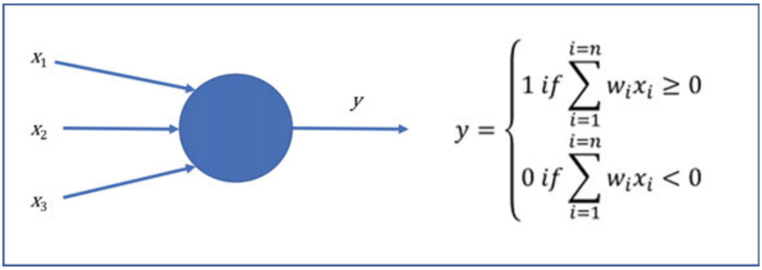


Fig. 1.10 A simple artificial neuron

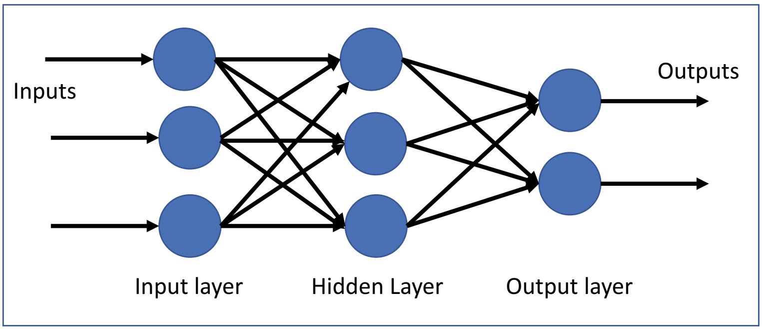


Fig. 1.11 Example of a simple neural network with one hidden layer

By a search over the Internet, a query with "machine learning" and "satellite images" will return more than one million answers: so, it could be difficult to make a synthesis. Nevertheless, the main applications run from land use and vegetation detection to terrain analysis. However, this aspect is more important for regional studies than for regional studies because now aerial and drone photos are more interesting. For a state-of-the-art survey of drone imagery, refer to (Taha and Shoufan 2019).

One domain in which many deep learning experimentations is the analysis of satellite images. For example, remote sensing can be used for the prediction of crop yield, military surveillance, precipitation estimation, size estimation of oil spills, monitoring ice caps, natural disaster assessment, freshwater estimation, etc. For a survey, please refer to Goswami et al. (2020) or Mohanty et al. (2020).

For applications of machine learning for some regions, let us cite two interesting studies by Badar and Rahman (2020), and Ullah et al. (2020). Some examples can be mentioned, health, transportation and especially real-time traffic control, energy consumption, combating pollution, public safety, waste management, telecommunication, etc. See also Boucetta et al. (2021) for road repair, and Alfarrarjeh et al. (2018) for images based on smartphone images.

However, the paper written by Varshney et al. (2021), even if they claim to present a critical review for smart cities, more focuses on civil engineering than urban planning. An application was made by Meeran and Joyce (2020) concerning airports in the US: the initial and a more general trend identified was that more congested airports tend to cause a greater negative impact on the surrounding regional context. We can add some studies for wind direction and speed prediction in Germany and in The Netherlands (Harbola and Coors 2021, Ibrahim et al. 2021) and for pollution prediction (Petry et al. 2021). See also Öncevarlıkl et al. (2019) for parking spot detection.

Fyleris et al. (2022) have recently presented an excellent study on urban change detection by using aerial photos at certain dates and machine learning.

But the more promising study was developed by Wang et al. (2020) by reimagining city configuration with a kind of automated urban planning based on deep learning: they developed a learning framework to generate effective land-use configurations by learning from regional geography, human mobility, and socioeconomic data. In particular, they first characterize the contexts of surrounding areas of an unplanned area by learning representations from spatial graphs using geographic and human mobility data. Then, they develop an adversarial land-use configuration approach, where the surrounding context representation is fed into a generator to generate a land-use configuration, and a discriminator learns to distinguish among positive and negative samples. And they apply this methodology to plan virgin areas. For that, they develop a system based on Points of Interest (e.g., latitudes and longitudes) and regional functionality categories (e.g., shopping, banks, education, entertainment, residential, and administrations). The structure of their system is depicted in Fig. 1.12.

Finally, very recently, Wang and Cao (2021) have mentioned overall regional planning, transportation, safety, and environment monitoring in their study in addition to remote sensing. See also Mehta et al. (2022) for a survey for applications in smart cities.

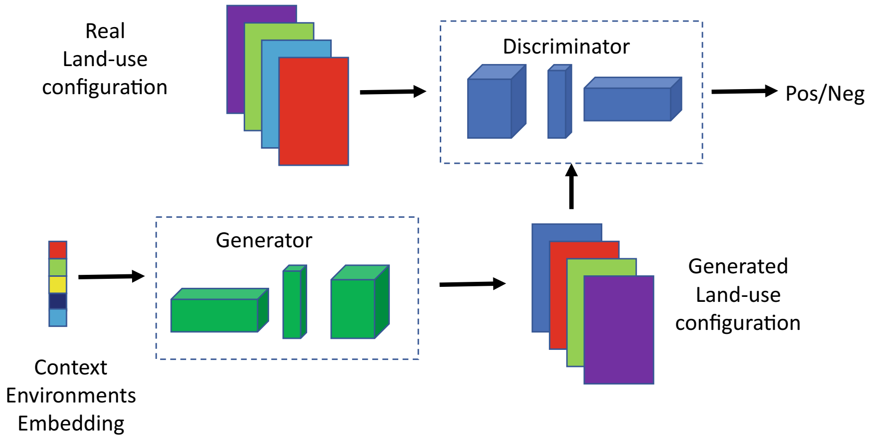


Fig. 1.12 Automatic land-use configuration planner From Wang et al. (2020)

1.5 Final Remarks

The goal of this paper was not to give an exhaustive survey of using AI in urban and regional planning, but rather to sketch some potentialities. Now, outside the domain of sensing, few developments have been made when practicing regional planning. To reach this objective, several barriers must be overcome.

Indeed, among technological barriers, let us mention an adequate and performing representation of space which can be useful and practical both in knowledge management and deep learning: the classical OGC model used in geomatics must be adapted for those novel directions.

But the more important barrier seems to be sociological, namely the sociological acceptance of using AI in regional planning; it does not mean that future regions must be governed by AI, but the way humans can use AI to enlighten their decision. In other words, AI must be seemed like a sort of assistance in human decision-making in designing the region of the future by generating possible schemes of solution (Meza et al. 2021) paving the way to territorial intelligence by combining artificial intelligence and human collective intelligence, by involving not only practitioners and elected officials, but also citizens.

As it was told in the introduction, the majority of experimentations were made at the urban planning level, but too few at the regional level: so, it looks interesting to constitute a research agenda for smart region policymaking.

References

Ackoff RL (1989) From data to wisdom. Journal of Applies Systems Analysis 16:3–9

Alfarrarjeh A, Dweep Trivedi D, Seon Ho Kim SH, Cyrus Shahabi C (2018) A deep learning approach for road damage detection from smartphone images. In: 2018 IEEE international conference on big data, 10–13 Dec, Seattle, Washington, pp 5201–5204. https://doi.org/10.1109/BigData.2018.8621899

Anthony BJ (2020) A case-based reasoning recommender system for sustainable smart city development. AI & Soc. https://doi.org/10.1007/s00146-020-00984-2

Badar M, Rahman S (2020) Machine learning approaches in smart cities. In: Studies in computational intelligence, MIDATASMART 2020. Springer (in press)

Batty M (2018) Artificial intelligence and smart cities. Environment and Planning b: Urban Analytics and City Science. 45:3–6. https://doi.org/10.1177/2399808317751169

Baxter RS (1976) Computer and statistical techniques for planners. Methuen Press, 336 p

Belyakov SL, Bozhenyuk AV, Belyakova ML, Zubkov SA (2018) Case based reasoning in intelligent geographic information systems for the management of logistics projects. In: Moshkin V, Yarushkina N, Afanasyeva T, Sosnin P (eds) FTI 2018, fuzzy technologies in the industry, held in Ulyanovsk, Russia, 23–25 Oct 2018, Ulyanovsk State Technical University, Ulyanovsk, Russia, pp 1–10. http://ceur-ws.org/Vol-2258/paper1.pdf

Bisen VS (2020) How AI can be used in smart cities: applications role & challenge. https://medium.com/vsinghbisen/how-ai-can-be-used-in-smart-cities-applications-role-challenge-8641fb52a1dd

Boucetta Z, El Fazziki A, El Adnani M (2021) A deep-learning-based road deterioration notification and road condition monitoring framework. International Journal of Intelligent Engineering and Systems 14(3). https://doi.org/10.22266/ijies2021.0630.42

Davis R, Shrobe H, Szolovits P (1993) What is a knowledge representation? AI Mag 14(1):17–33

Fyleris T, Kriščiūnas A, Gružauskas V, Čalnerytė D, Barauskas R (2022) Urban change detection from aerial images using convolutional neural networks and transfer learning. Int J Geo-Inf 11(4):246

Gao S (2021) Geospatial artificial intelligence (GeoAI). https://doi.org/10.1093/OBO/9780199874002-0228. https://geods.geography.wisc.edu/song/papers/2020_OxfordBibliographies_GeoAI.pdf

Ge X, Yang Y, Chen J, Li WC, Huang ZS, Zhang W, Peng L (2022) Disaster prediction knowledge graph based on multi-source spatio-temporal information. Remote Sens MDPI 14, 1214. https://doi.org/10.3390/rs14051214

Goswami N, Kathiriya K, Yadav S, Bhatt J, Degadwala S (2020) Satellite imagery classification with deep learning: a survey. International Journal of Scientific Research in Computer Science, Engineering and Information Technology 6(6):36–46. https://doi.org/10.32628/CSEIT2065124

Graham I (2006) Business rules management and service oriented architecture: a pattern language. Wiley, London

Gruber TR (1993) A translation approach to portable ontologies. Knowl Acquis 5(2):199–220

Guarino N (1998) Formal ontology and information systems. In: Guarino N (ed) Formal ontology in information systems. IOS Press, Amsterdam, pp 3–15

Han SY, Kim TJ (1990) Intelligent urban information systems: review and prospects. In: Kim TJ, Wiggins LL, Wright JR (eds) Expert systems: applications to urban planning. Springer, New York, pp 241–261

Hao X, Ji Z, Li X, Yin L, Liu L, Sun M, Liu Q, Yang R (2021) Construction and application of a knowledge graph. Remote Sensing (in press)

Harbola S, Coors V (2021) Deep learning ensemble model for wind forecasting. PFG—Journal of Photogrammetry, Remote Sensing and Geoinformation Science

Holt A, Benwell GL (1999) Applying case-based reasoning techniques in GIS. Int Journal of Geographical Information Science 13(1):9–25

Ibrahim A, Mirjalili S, El-Said M, Ghoneim SSM, Alharthi M, Ibrahim TF, El-kenawy ESM (2021) Wind speed ensemble forecasting based on deep learning using adaptive dynamic optimization algorithm. IEEE Access 9:125787–125804. https://doi.org/10.1109/ACCESS.2021.3111408

Keita AK (2007) Conception Coopérative d'Ontologies Pré-Consensuelles: Application au domaine de l'Urbanisme. PhD, INSA-Lyon, University of Lyon, France, 6 June 2007

Klosterman RE (2015) Urban planning: methods and technologies. In: Wright JD (editor-in-chief) International encyclopedia of the social & behavioral sciences, 2nd edn, vol 24. Elsevier, Oxford, pp 889–893

Kolodner J (1993) Case-based reasoning. Morgan Kaufmann Publishers, San Mateo

Komninos N Bratsas C, Kakderi C et al. (2015) Smart city ontologies: improving the effectiveness of smart city applications. Journal of Smart Cities 1(1):31–46. https://doi.org/10.18063/JSC.2015.01.001.

Kumar V (2019) What AI and machine learning can do for a smart city? 7 Dec 2019. https://www.analyticsinsight.net/ai-machine-learning-can-smart-city/

Landis JD (1994) The California urban futures model: a new generation of metropolitan simulation models. Environment and Planning B 21:399–420

Laurini R (2001) Information systems for urban planning: a hypermedia cooperative approach. Taylor and Francis, Feb 2010, 308 p

Laurini R (2017) Geographic knowledge infrastructure for territorial intelligence and smart cities. ISTE-Wiley. 250 p

Laurini R (2019a) Towards knowledge-based spatial planning. In: Voghera A, La Riccia L (eds) Spatial planning in the big data revolution. IGI Global, March 2019, pp 1–15

Laurini R (2019b) A mathematical language for the modeling of geospatial static rules. Journal of Visual Language and Computing 2019(1):1–13

Laurini R, Kazar O (2016) Geographic ontologies: survey and challenges. Journal for Theoretical Cartography 9:1–13. ISSN 1868-1387

Meeran A, Joyce SC (2020) Machine learning for comparative urban planning at scale: an aviation case study. Online conference: ACADIA 2020. https://proximities.acadia.org/

Mehta S, Bhushan B, Kumar R (2022) Machine learning approaches for smart city applications: emergence, challenges and opportunities. Comput Sci Intel Syst. Corpus ID: 246833918. https://doi.org/10.1007/978-3-030-90119-6_12

Meza J, Vaca-Cardenas L, Vaca-Cardenas L, Teran L, Portmann E (2021) A human-machine collaboration model for urban planning in smart cities. Computer 54(6):24–35. https://doi.org/10.1109/MC.2021.3050664

Mocnik F-B, Zipf A, Raifer M (2017) The OpenStreetMap folksonomy and its evolution. Geo-Spatial Information Science 20(3):219–230. https://doi.org/10.1080/10095020.2017.1368193

Mohanty SP, Czakon J, Kaczmarek KA, Pyskir A, Tarasiewicz P, Kunwar S, Rohrbach J, Luo D, Prasad M, Fleer S, Göpfert JP, Tandon A, Mollard G, Rayaprolu N, Salathe M, Schilling M (2020) Deep learning for understanding satellite imagery: an experimental survey. Frontiers of Artificial Intelligence. https://doi.org/10.3389/frai.2020.534696

Morgan T (2008) Business rules and information systems: aligning IT with business goals. Addison-Wesley, Reading

Murphy KP (2021) Probabilistic machine learning: an introduction. MIT Press, Cambridge. https://probml.ai. 5 April 2021

Öncevarlıkl DF, Yıldız KD, Gören S (2019) Deep learning based on-street parking spot detection for smart cities. In: 2019, 4th international conference on computer science and engineering (UBMK). pp 177–182. https://doi.org/10.1109/UBMK.2019.8907006

Petry L, Meiers T, Reuschenberg D, Mirzavand Borujeni S, Arndt J, Odenthal L, Erbertseder T, Taubenböck H, Müller I, Kalusche E, Weber B, Käflein J, Mayer C, Meinel G, Gengenbach C, Herold H (2021) Design and results of an AI-based forecasting of air pollutants for smart cities. In: 6th international conference smart data and smart cities, 15–17 Sept 2021, Stuttgart, Germany; ISPRS Ann Photogramm Remote Sens Spatial Inf Sci VIII-4/W1-2021:89–96. https://doi.org/10.5194/isprs-annals-VIII-4-W1-2021-89-2021

Pisano C, De Luca G, Shirvani DA (2020) Smart techniques in urban planning: an insight to ruled-based design. Sustainability 12:114. https://doi.org/10.3390/su12010114
Qin CZ, Wu XW, Jiang JC, Zhu AX (2016) Case-based knowledge formalization and reasoning method for digital terrain analysis—application to extracting drainage networks. Hydrol Earth Syst Sci 20:3379–3392. https://doi.org/10.5194/hess-20-3379-2016
Qiu P, Gao J, Yu L, Lu F (2019) Knowledge embedding with geospatial distance restriction for geographic knowledge graph completion. ISPRS Int J Geo-Inf 8:254. https://doi.org/10.3390/ijgi8060254
Ross RG (2011) More on the if-then format for expressing business rules: questions and answers. Business Rules Journal 12(4). http://www.BRCommun2002ity.com/a2011/b588.html
Roussey C, Pinet F, Kang MA, Corcho O (2011) An introduction to ontologies and ontology engineering. In: Ontologies in urban development projects. Advanced information and knowledge processing, vol 1. Springer, London. https://doi.org/10.1007/978-0-85729-724-2_2
Rumelhart DE, Hinton GE, Williams RJ (1986) Learning internal representations by error propagation. In: Rumelhart DE, McClelland JL (eds) Parallel distributed processing: explorations in the microstructure of cognition, vol 1. MIT Press, Cambridge. ISBN 0-262-18120-7
Sànchez-Marrè M (2001) Principles of case-based reasoning. https://www.cs.upc.edu/~miquel/sel/CBR-intro.pdf
Sewchurran K, Smith D, Roode D (2010) Toward a regional ontology for information systems project management. Int J Manag Proj Bus. https://doi.org/10.1108/17538371011076118
Soergel D (2009) Knowledge organization systems. Overview. https://www.dsoergel.com/UBLIS514DS-08.2a-1Reading4SoergelKOSOverview.pdf
Sowa JF (1984) Conceptual structures: information processing in mind and machine. Addison-Wesley, Reading
Taha B, Shoufan A (2019) Machine learning-based drone detection and classification: state-of-the-art in research. IEEE Access. https://doi.org/10.1109/ACCESS.2019.2942944
Teller J, Keita AK, Roussey C, Laurini R (2005) Urban ontologies for an improved communication in urban civil engineering projects. Cybergeo: European Journal of Geography. http://journals.openedition.org/cybergeo/8322. https://doi.org/10.4000/cybergeo.83220
Teller J, Lee JR, Roussey C (2007) Ontologies for urban development. Springer, Berlin. 212 p. https://doi.org/10.1007/978-3-540-71976-2
Thakker D, Mishra BM, Abdullatif A, Mazumdar S, Simpson S (2020) Explainable artificial intelligence for developing smart cities solutions. Smart Cities 3:1353–1382. https://doi.org/10.3390/smartcities3040065
Ullah Z, Al-Turjman F, Mostarda L, Gagliardi R (2020) Applications of artificial intelligence and machine learning in smart cities. Comput Commun 154:313–323
Varadharajulu P, West G, Mcmeekin D, Moncrieff S, Arnold L (2016) Automating government spatial transactions. In: Gustavo Rocha J, Grueau C (eds) Proceedings of the 2nd international conference on geographical information systems theory, applications and management (GISTAM), held in April 2016, Rome, Italy, Scitepress, pp 157–167. ISBN: 978-989-758–188-5
Varshney H, Khan RA, Khan U, Verma R (2021) Approaches of artificial intelligence and machine learning in smart cities: critical review. IOP Conf Ser: Mater Sci Eng 1022:012019
Wang S, Cao J (2021) AI and deep learning for urban computing. In: Shi W et al (eds) Urban informatics, the urban book series, pp 815–844. https://doi.org/10.1007/978-981-15-8983-6_43
Wang S, Zhang X, Ye P, Dun M, Lu Y, Xue H (2019) Geographic knowledge graph (GeoKG): a formalized geographic knowledge representation. ISPRS Int J Geo-Inf 8:184. https://doi.org/10.3390/ijgi8040184
Wang D, Fu Y, Wang P, Huang B, Lu CT (2020) Reimagining city configuration: automated urban planning via adversarial learning. In: 28th international conference on advances in geographic information systems (SIGSPATIAL '20), 3–6 Nov 2020, Seattle, WA, USA. ACM, New York, 10 p. https://doi.org/10.1145/3397536.3422268

Yeh AGO, Xun S (2001) Case-based reasoning (CBR) in development control. International Journal of Applied Earth Observations and Geoinformation 3(3):238–251

Zaborovskaia O (2018) The concept of knowledge management in the region as a basis of estimation of conditions of innovative activity. International Scientific Journal Machines Technologies Materials Year XII I(9):355–357