Building resilience in complex cities: Ontological approaches for the case study of Taranto, Italy

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Abstract

This contribution describes the research path and identification of methods and tools for implementing strategic and urban planning aimed at enhancing the response of the Taranto city system in terms of resilience. We present here a reflection on planning, insights into the concept of resilience we are looking at, a diachronic analysis of the economic policies that have affected the city of Taranto, the description of the method of ontological analysis and applied ontology to manage and represent knowledge to develop a decision support tool that allows the empowerment of resilience itself. We close this reflection with perspectives of evolution and application of this path through the different tools and approaches for planning and resilience.

Introduction

Referring to the European project RMM (Resilience Maturity Model), the ReCity project focused on the political and administrative factors that can enhance the resilience of territorial and urban environmental systems. It specifically

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concentrated on three key variables: well-being, sustainability, and resilience.
Resilience can be understood as a characteristic of complex systems, but it can also be viewed as a quality that can be identified and assessed both qualitatively and quantitatively. We live in a constantly changing world, so it is crucial to coordinate the dynamics of natural and socio-technical systems. To achieve this, we need to employ forecasting techniques that provide reliable, albeit hypothetical, scenarios for consideration (Borgo, Guarino, 2022).
The objective of this research has been to lay the groundwork for developing knowledge collection and management models. These models aim to integrate the various levels and dynamics of the territory and environment, facilitating the creation of a territorial knowledge system for integrated and unified environmental planning. We based our methodology on applied ontology.
This work is part of a multi-year research initiative focused on ontological analysis and applied ontology, aiming to represent and manage the knowledge that emerges from complex systems (Stufano Melone, 2023). It includes reflections on future scenario construction, knowledge collection through participatory activities involving local inhabitants affected by research and planning, as well as addressing gaps in knowledge and potential management strategies related to territorial, urban, regional, and environmental planning actions (Stufano Melone, Camarda, 2023).
Decision-making in urban systems is responsible for choices that enhance resilience, often occurring in conditions of uncertainty and ambiguity—an enduring challenge in decision theory. This research specifically examined the tools and methods for planning that incorporate diverse interpretations, materials, and scenarios. This approach aims to broaden the inclusion and management of potential

knowledge through sharing, disambiguation, and exploration of future scenarios, while also increasing awareness of knowledge gaps to promote planning responses that support resilience, sustainability, and well-being.

What categories should be considered when requesting resilience enhancement for a city-environment-citizens system? What types of knowledge are essential? The territorial and environmental system of Taranto is both precious and complex. It serves as a paradigmatic example, reflecting the challenges of planned development strategies that have been implemented elsewhere, along with the consequences of significant environmental and health damage affecting the city, its residents, and its environment. Taranto, the only Spartan colony of Magna Graecia with a history spanning nearly three thousand years, sits on a geographically and environmentally unique terrain. Its advantages have historically been viewed as "gifts of the gods." However, the establishment of a steel mill, in the face of a national industrial policy disregarding the environmental context, has left the city grappling with contaminated sites and emerging economic difficulties.

Taranto exemplifies the consequences of short-sighted decisions that yield short-term benefits but lead to long-term repercussions that are challenging to rectify. The city's resilience lies in its desire to redeem itself socially and environmentally while addressing the impacts of decisions that create unknown challenges, often resulting in a negative feedback loop.

Why does a third way seem absent in the debate between environmental/health concerns and work/economic well-being? This situation is indicative of negative inertia within the system. A new commitment is required for alternative policies and organizational approaches to the urban system.

It is essential to untangle the Gordian knot that complicates this dichotomy and opens up new possibilities.

Reflections about planning

Planning for cities and territories involves normative elements and aims to control spatial development, which has significant social implications (Schubert, 2019). A paradox arises between planning and non-planning, as the interdependence of chaos and order becomes a crucial aspect of both planning and the ongoing debate about the future (Schubert, 2019). Often, planning procedures are vague and overly general, filled with ambiguities, and developed over time as responses to past conditions rather than to a future that is already in motion.

This raises the question: How can we plan for resilient and sustainable cities in the long term? Alternatively, would a lack of planning, allowing market forces and private developers to take charge, yield the best solutions? (Schubert, 2019). Addressing spatial organization, planning, and design requires dealing with elements that do not currently exist (or may never exist). This is fundamentally a question of knowledge and knowledge management, concerning the future: thus, in knowledge management, the concept of non-knowledge also emerges.

Human beings tend to view their trajectories as linear paths through time, with the future as an open horizon of possibilities that often stems from what the future itself offers (Gumbrecht, 2014). The future, seen as the vast (unknown) present (Gumbrecht, 2014), is also understood as a complex global system filled with uncertainties, ambiguities, and profound unknowns that can significantly impact the outcomes of a strategic plan and, more broadly, the effectiveness of environmental and design choices.

Designing cities and territories has become an increasingly complex and nuanced activity. The wealth of information available, the variety of sources, and the numerous research methodologies have greatly enhanced our capacity for knowledge acquisition. Additionally, there is a growing awareness of the limitations of the rational-comprehensive planning approach, which is often viewed as rigid and divisive. This approach frequently leads to poorly informed decisions that neglect existing connections within the current and future urban system.

This increased awareness has shifted focus towards more appropriate, intuitive, and empathetic interventions in territories and cities, while still maintaining a technically valid and pragmatically oriented use of resources. Research has emphasized the need for a broader approach than merely manipulating surfaces, destinations, and values. New perspectives have emerged, including the need to read, interpret, extend, and integrate the dynamism and plurality of needs and viewpoints—beyond just human considerations—as well as the demand for sustainability and equitable resource sharing.

This awareness has enriched the objectives of designers and planners, offering them a multifaceted and visionary framework for action, allowing them to operate with new humility in the complex and challenging realm of "vast" choices. These choices influence large territories, affect extensive relationships, and impact both the present and future. Recently, this consciousness has expanded our field of knowledge and data, enabling us to analyze the layers of information embedded within data itself.

With the evolution of technology and information systems, we can rely on precise moments of direct interaction between stakeholders as well as socio-technical systems that enhance data collection and monitoring capabilities. This

enhances our ability to conduct increasingly detailed assessments of the status quo and its evolution.
There are two potential approaches to consider. The first involves using creativity in planning (through methodologies like C-K theory) (Hactuel et al., 2018) to construct scenarios for both desirable and undesirable outcomes, integrating a wide range of ideas and intuitions, even those that initially appear less "interesting." The second approach leans toward "apparent" non-action, crafting a future planning scenario where decisions and uses are separated from profit motives, focusing instead on the greater common good. This is where the concept of resilience plays a crucial role, defined as the system's quality, serving as a reference point for progress and evolution, which will be further elaborated in the next section.
The goal, aligned with the notion of happy de-growth, is to utilize new tools, devices, and awareness reflectively (Schön, 1983) and more constructively: observing natural trends and intervening only to avert foreseeable risks, while simultaneously implementing environmental mitigation efforts and environmental enhancements. This demands a questioning of the fundamental choices, policies, and intentions that shape prevailing global decisions, especially those entrenched in Western cultural approaches. At the core of these action options lies the essential participation of the inhabitants.
In the past twenty years, advancements in scientific and technological tools have led to a flourishing era of research, including Multi-Agent Systems, Space Syntax, CAD, GIS, E-Governance tools, and crowd-sourced initiatives, which rely on voluntary contributions from individuals. Alongside these modern tools, traditional methods like community walks, parish meetings, and street movements continue to play a significant role. Notably, artificial intelligence has rapidly emerged as a powerful and pervasive force, leading

to the development of tools that integrate modeling approaches with data collected from sensors deployed across various urban areas. This innovation has contributed to the creation of the Digital Twin concept for cities (Ferrè-Bigorra, 2022).
While defining a city remains a complex challenge (Borgo et al., 2021), cities can be viewed as the result of specific political, economic, and social organizations. However, understanding the social roles of urban artifacts continues to be a difficult task, making their representation even more challenging (Calafiore et al., 2017).

Reflections on the concept of resilience

Let's focus on one possible definition of a city: it can be described as a complex system that behaves accordingly. Like any complex system, an urban system lacks self-awareness and does not possess the ability to self-identify (Zimmermann et al., 2001; McPhearson et al., 2016; Tanza, 2020). Can such a system choose how to behave? No. It simply exists; it is not self-reflexive and does not make explicit decisions. An urban system, therefore, emerges as a complex entity that lacks awareness of its entirety. It manifests at specific times and places without consciously deciding its trajectory in the context of global and contemporary events. Its movement can be analogized to the principle of least resistance, such as how lightning strikes the ground following the shortest path.
Our discussion centers around an abstract concept of resilience, understood here as a property of the system. A complementary property that arises with resilience is inertia, which is often viewed as a physical property of negative resistance or passivity (Plein, 2019). In the context of Taranto, inertia seems to support the city's resilient

responses. For instance, the community's ongoing desire to live in and redeem the city exemplifies a key resilient trait (Stufano Melone, 2023).

Our objective is to apply these properties within an ontological analysis of the parts of the Taranto system, explaining the interactions across four layers (Stufano Melone et al., 2024): (i) the built environment and altered materials; (ii) the structure of agency (both anthropic and non-anthropic); (iii) the body of knowledge that informs the city's identity (Borgo et al., 2021); and (iv) the fourth layer of relationships and interrelations, which will be further explored.

Resilience, viewed both as a quality and property of the urban system, comes at a cost. Like any complex system, the properties and qualities of resilience do not come without impact on the system and its environment. According to the definitions proposed in deliverable 1.1.4 et al., when discussing resilience, we must account for the time and energy consumed by the system to return to a desired state, particularly following a shock or stress. It is crucial to recognize that recovery is not without expense; thus, we must be clear about the potential costs involved in choices or decisions that may induce shocks or exacerbate unfavorable conditions for the system's well-being.

For effective planning and design that enhance the city's resilience while promoting long-term sustainability, it is essential to act proactively in decision-making, taking into account known factors and the capacities of those in charge. This involves intercepting potential risks and stresses before they materialize. Resilience levels tend to be higher when the system has not exhausted its resources, allowing it to strive for greater resilience.

The accumulation of knowledge and the development of anticipated scenarios are integral to fostering a resilient decision-making framework. This framework should focus on modifying decisions based on potential scenarios rather than relying solely on reactive measures to address the consequences of poorly considered or automatic choices. Long-term sustainability decisions should be made within a framework that prioritizes the preservation and improvement of system conditions, rather than simply providing post hoc relief.

While a system should inherently possess resilience and resources to cope with unexpected and traumatic events, this resilience must be oriented towards addressing emergencies rather than becoming complacent in the face of recurring conditions that could diminish the overall quality of the system. Therefore, it is vital to implement strategies for data analysis and knowledge collection to create an environment that minimizes stress and reduces the likelihood of shocks, particularly in urban areas. The European resilience strategy established in 2018 (Smart Mature Resilience) emphasizes the importance of such proactive measures.

The city of Taranto: A case study in poor economic policies

In the theory of local economic development, several models have been studied, particularly aimed at regenerating declining or impoverished communities. The twentieth century, marked by two world wars and frequent periods of economic depression, prompted significant reflections on this topic (for instance, Keynes, 1936; Von Mises, 1949; Hirschman, 1958). One notable concept that emerged in the post-war era is the "growth pole model," developed to structurally restore local economies ravaged by major conflicts (Perroux, 1955).

In Europe, this model was operationally implemented in various paradigmatic cases during the 1950s and 1960s, with

Taranto often cited as the most historically significant example (Schachter, 1965; Pichierri, 1990; Masi, 2012; Camarda et al., 2014; Borri & Camarda, 2017). The Taranto growth hub was part of a strategic plan to regenerate some depressed areas of Italy, specifically aimed at accelerating the transition from an agricultural economy to an industrial one. This process involved building an industrial-production chain driven by the growing demand for certain goods projected to remain constant in the future.

The model utilized a concept known as "backward linkages," which entailed establishing a reliable consumption horizon around which a long-term production and development process could be formulated (Hirschman, 1958; Schachter & Pilloton, 1984). To initiate this hub, the basic steel industry was selected, which at the time required a large unskilled workforce, a significant energy supply, and a relatively low level of technology. Southern Italy, particularly Taranto, had a substantial post-war workforce available, making it an ideal candidate for this initiative.

Furthermore, the Italian state sought to finance steel production to support local industries, mainly for FIAT automobiles, and emphasized a "social" purpose alongside wage guarantees, including expectations for automatic on-the-job retraining of the workforce toward more entrepreneurial roles. In summary, the growth pole model applied to the "Mezzogiorno" envisioned a future free from the uncertainties of an agricultural economy, promising a stable industrial wage and the potential for entrepreneurial development.

However, the growth pole strategy ultimately lacked a well-articulated perspective, as evidenced by the social and economic trends discussed in the literature (Pichierri, 1990; Masi, 2012; Camarda et al., 2014). Additionally, the process was not without costs; it fostered aggressive and transformative rather than conservative attitudes toward local resources and natural environments, leading to serious health impacts on the local community (Banini & Palagiano, 2014; Greco, 2016; Maretti, 2014).

As we enter the 21st century, particularly in the context of Taranto, we can now reflect on the series of events and the significant knowledge gaps that contributed to the widespread failure of the growth pole model. For instance, the increase in energy prices, triggered by the Yom Kippur War in the 1970s, led to cuts in employment to offset rising energy costs. This was not an unforeseen outcome; the growing scarcity of environmental resources had been studied as early as the 1960s, with warnings that largely went unheeded (e.g., Odum, 1953; Carson, 1962; Boulding, 1966). The trend of job reduction continued structurally in the following decades, accompanied by increasing investments in technology to replace human labor—a scenario already anticipated by extensive scientific understanding of technological development over the last two centuries (Ricardo, 1817; Samuelson, 1989; Woirol, 1996).

Moreover, contrary to the model's predictions, the industrial economic transition proved incomplete and often maintained agriculture as a complementary source of income, leading to hybrid roles such as the "metalmezzadro," or steelworker/farmer (Romeo, 1989). This situation highlights that the local community's connection to its rural identity has never truly been severed over millennia—a sentiment expressed in numerous chronicles and testimonies of the period (Porsia & Scionti, 1989). Today, the most commonly recognized adverse legacies of this experience are the significant environmental and health issues faced by the local community. These problems are perhaps the most prominent negative outcomes of the growth pole experiment.

The ontological analysis and applied-ontology method

An ontology is a conceptual framework that provides a common and clear vocabulary for experts and practitioners. It is particularly suited for disambiguating and sharing knowledge among various agents, including humans, non-human animals, and artificial agents. Ontologies help navigate the nuances of natural and technical languages and their specificities (Guarino, 1998).

In this line of research, we based our analysis on the foundational ontology DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering), developed at the Applied Ontology Laboratory in Trento as part of the broader European project WonderWeb (Masolo et al., 2002). Ontological analysis aids in modeling the social content of the built environment as well as its planned characteristics (Searle, 2006; Lai & Zoppi, 2011). It supports the decision-making process and helps define patterns of use and life in urban places, such as urban squares, where local knowledge expressed through emerging social patterns is essential (Calafiore et al., 2017).

Previously, we conducted ontological analyses to identify the structural components of the city from this perspective (Borgo et al., 2021). A city is a complex and rich system composed of heterogeneous parts that interact in various ways and for different reasons. We identified and discussed three fundamental components of the city: (i) city-place; (ii) municipal agent; and (iii) knowledge of the city, as illustrated in the following scheme. Interactions determine the relationships within and between these components in the complex system that is the city (Billen et al., 2012).

The next step in our analysis is to explicitly outline this interaction network within the city. We propose to identify it as the fourth component of the city as a place. This relational component manifests itself structurally in both natural and artificial spaces. In the Leibnizian sense, relationships in the city can be seen as substances (Messina et al., 2009). As depicted in the following diagram, we have introduced a layer that pertains to the ‘substance’ of relationships, which should be incorporated into the processes of analysis, knowledge collection, ontology construction, and the drafting of management, decision, and planning documents.

In relation to resilience and long-term sustainability, the primary goal is to prepare and adapt to uncertain events by monitoring their evolution and normatively and effectively allowing adaptations to strategies and planning over time as new knowledge is acquired (Marchau et al., 2019). We have hypothesized using an architecture that relies on a knowledge base derived from applied ontological analysis and founded on the DOLCE ontology (Gangemi et al., 2002).

Regarding spatial knowledge, tools developed on an ontological basis enable the utilization of “form” and “relation” objects as terms incorporated within the ontological structure. Among the foundational ontologies that have yielded notable and widespread practical results, DOLCE stands out as it captures the ontological categories that emerge in natural language and common sense. The ontological categories of DOLCE are designed to reflect the structures of human language and cognition (Gaio et al., 2010). DOLCE has served as a starting point for developing ontologies in our chosen domain, adding concepts specific to that domain to the DOLCE categories when appropriate (Gaio et al., 2010; Borgo et al., 2009).

Ontologies offer common vocabularies or terms, as well as their relationships, allowing for the formal representation of domain-specific knowledge (Noy & McGuinness, 2001; Ru Wang et al., 2019). This capability makes ontologies an excellent candidate for managing the vast amounts of data and interactions among various agents (both human and non-human). Over the past few decades, there has been a progressive application of ontologies across different fields relevant to the humanities, medicine, social sciences, archaeology, environmental planning, geography, urban studies, and architecture. As McKeague noted, "Spatial information is increasingly used to guide heritage management policies, from urban design to rural planning and tourism" (McKeague, 2019).

In our research, we propose applying ontological analysis and ontologies to support decision-making in the creative processes of architecture and planning (focusing on the imaginative and reflective aspects), as well as to clarify and share knowledge during planning processes based on the foundational ontology DOLCE. The goal is to effectively manage uncertainties and utilize the knowledge obtained through this process.

Artificial intelligence and decision support in planning: the urban digital twin between opportunities and critical issues

Artificial Intelligence (AI) has made notable progress over the past decade, achieving success in a variety of applications. This advancement has sparked increased interest in utilizing AI to manage and represent knowledge in complex systems such as cities and in broader areas like land use, environmental planning, and resource management. Our research seeks to refine AI methodologies by integrating techniques from the dynamic field of applied ontology.

The primary aim of this research is to design and develop an efficient decision-support system tailored for urban environments. Smart cities, as highly intricate systems, generate and exchange substantial volumes of data and knowledge. Over the past 15 years, the concept of a Digital Twin (DT) has gained prominence in academic discussions, driven by technological advancements that enable the creation of virtual counterparts for physical entities.

Smart cities have paved the way for decision-making systems powered by data collected through distributed sensors and personal devices such as smartphones and tablets. This information helps construct virtual representations of real-world environments, facilitating the simulation and prediction of future scenarios. These models often uncover potential outcomes of decisions that might otherwise remain hidden. For traditional urban infrastructure, Digital Twins are indispensable tools for informed decision-making, though the unique nature of cities necessitates specialized adaptations of this technology.

An Urban Digital Twin, designed to assess conditions and explore resilience strategies, must effectively represent critical urban elements, including the population and built environment. Additionally, it must capture and interpret the intentions, needs, strategies, and visions unique to each city.

The Digital Twin concept, originally developed in industrial contexts to model structural, procedural, and functional aspects of products, allows real-time simulation by integrating these models with physical and material systems. Such simulations can anticipate potential issues like system failures and optimize performance (Stufano Melone et al., 2024a).

Digital Twins offer valuable advantages, such as identifying problems before they occur and enabling proactive adjustments to operational parameters or maintenance schedules. While they require relatively affordable computational systems, advanced simulations often demand significant investments in specialized hardware, software, and human expertise.

In urban studies, Digital Twin applications provide opportunities for optimizing infrastructure (e.g., energy and water distribution) and enhancing service delivery (e.g., managing traffic flow and monitoring charging stations, as demonstrated by the Snap4City initiative). However, even before implementation, urban Digital Twins must address the complex and hybrid nature of cities, which encompass natural and artificial, organic and inorganic, and anthropogenic and non-anthropogenic elements. Cities are shaped by the intricate interplay of mechanical and social dynamics, necessitating a systematic approach to simplify and codify this complexity.

Applied ontology and ontological analysis contribute to structuring knowledge by formalizing data gathered through sensors and incorporating insights derived from the cognitive interactions of people within the urban environment. While intelligent devices and AI play an increasingly significant role in managing cities, a city cannot be reduced to a digital system or automated mechanism.

In our publications (Stufano Melone et al., 2024a; Stufano Melone et al., 2024b), we examine the Urban Digital Twin concept and the challenges of modeling urban systems. Building on an ontological perspective, we discuss the essence of cities, informed by our prior research, and highlight the importance of Digital Twin technology. A city, therefore, can be understood as a multifaceted, open, dynamic, and diverse entity.

Conclusions

The research conducted on the resilience of complex urban systems aims to support long-term sustainable planning, specifically focusing on the city of Taranto. This effort seeks to integrate various theories and methods while exploring the latest possibilities presented by advancements in technology and research. We propose a new paradigm for urban, territorial, and environmental planning that dynamically combines diverse insights and methodologies available to planners and managers, drawn from multiple disciplines in a truly interdisciplinary and trans disciplinary approach.

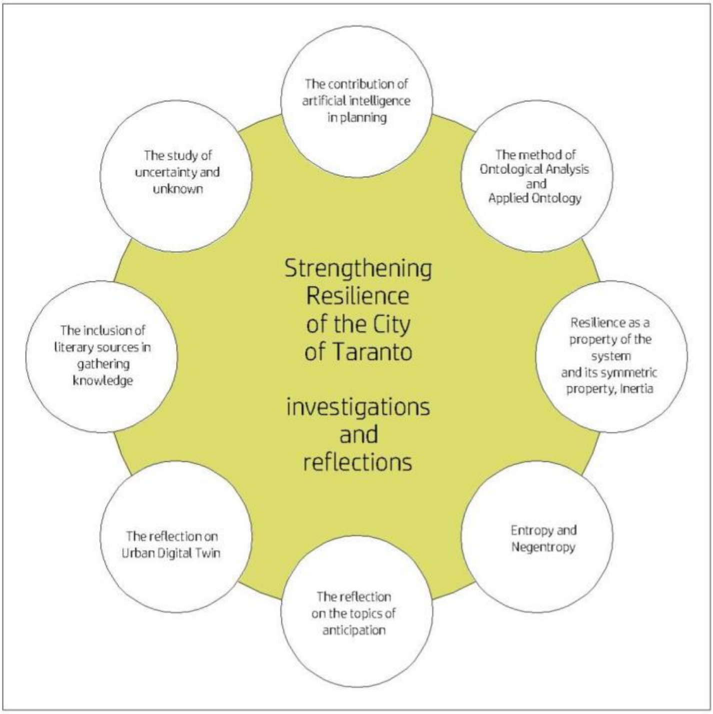

Figure 1 – Collection of approaches

As illustrated in the accompanying graphic representation (fig. 1), we have examined the potential contributions of artificial intelligence in planning, including distinct approaches such as:

- Semantic-Based Approach: Understanding the semantic meaning of data through ontological analysis.
- Data-Driven Approach: Utilizing data from sensors and other sources.
- Hybrid Approach: Integrating the above two methodologies.
- Ontological analysis and applied ontology promote human-machine interoperability.
- Studying uncertainty and gaps in knowledge emphasizes the importance of 'humble,' robust, and 'adaptive' planning (Marchau, 2019). This approach enables us to collect disparate clues and construct scenarios for the 'impossible' or unexpected, ensuring resilience and preparedness (Stufano Melone et Camarda, 2021; Stufano Melone et Camarda, 2022). This is related to the concept of anticipation (Poli, 2020) and includes an awareness of the rebound effect (Pigosso, 2023).
- Incorporating literary sources into our knowledge collection enhances the historical and descriptive narrative, capturing nuances and values that go beyond mere economic or political considerations (Stufano Melone et al.).
- The exploration of urban digital twins offers techniques and tools for modeling scenarios and monitoring urban dynamics in real-time.
- Data lakes that collect and manage data from various sources, enabling them to 'speak' to one another.

The theoretical foundations supporting these listed techniques include the theory of roles, the theory of relationships, and reflections on collaborative knowledge construction. Our aim is to create a system that effectively manages this knowledge, integrating insights from interviews, questionnaires, and continuous participation to enhance the resilience, well-being, and sustainability of the urban system., and diverse entity.

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