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# Approaching Healthy City Ontology: First-Level Classes Definition Using BFO

**Caterina Pietra *, Roberto De Lotto and Rakan Bahshwan**

Department of Civil Engineering and Architecture, University of Pavia, 27100 Pavia, Italy; roberto.delotto@unipv.it (R.D.L.); rakan.bahshwan01@universitadipavia.it (R.B.)
* Correspondence: caterina.pietra@unipv.it; Tel.: +39-0382-985743

**Abstract:** In recent decades, the concept of the healthy city (HC) has become more and more relevant in many fields, such as city administration and scientific environment, and has become a commonly understood concept in the general public. Due to the breakneck growth of people living in urban contexts, the subsequent necessity to guarantee good urban conditions for all kinds of citizens, and the general deterioration of the hearth environment caused by human activities (concentrated in urban settlements), this issue is increasing in its relevance. In this paper, the authors discuss the concept of the HC from an ontological point of view to organize the highly complex system of elements and the mutual relations that constitute the idea of HC. The main goals of an HC are quite intuitive, but the number of components that define and manage it is vast and related to different disciplines: sustainability, urban management, urban planning, and health and social studies. With the presented research, the authors intend to start an organizational definition of the HC using basic formal ontology (BFO). Considering the definition of HC, the authors focus on the ontology process and the different typologies of ontological structures. Then, the authors describe a first-level scheme of HC ontology and, finally, discuss possible applications of the presented study and next research steps.

**Keywords:** healthy city; urban ontologies; BFO; foundation ontology



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## 1. Introduction

The numerous urban transformations that have rapidly taken place over the last decade have captured the attention of many countries and related institutions at a global level. Cities, in particular, play a fundamental role in the process of change. Indeed, it has become essential to implement interactions between the specific environments describing the urban, physical, socioeconomic, and mental contexts in order to support cities as successful generators of good health. They represent a necessary resource for everyday life that cannot and must not be categorized as a single goal for a good existence or, simply, as the absence of disease [1]. The relationship between care for the health of inhabitants and care for the built environment is evident and has to be deepened [2].

Thus, the concept of health is strictly connected with the city's health, and discussions are various and of different nature. In 2015, Agenda 2030 made this clear with its 17 Sustainable Development Goals (SDGs), notably, goals 3 and 11: 'Ensure healthy lives and promote well-being for all at all ages' and 'Make cities inclusive, safe, resilient and sustainable' [3]. Overall, these goals, together with targets and indicators, aim to end poverty; improve economic growth, education, health, social protection, and job opportunities; prevent climate change; and protect the environment. The New Urban Agenda was adopted one year later, offering further insights into the mentioned topics. It has been proposed as the primary vehicle for the direct strengthening of the SDGs, in particular towards urban settlements.

However, it is not surprising that most current reflections on healthy cities result from re-elaborations, starting from the first official documents dating back to the 1980s. In fact, the 'Healthy Cities Project' was formally disseminated by the World Health Organization (WHO) between 1987 and 1988. The initiative aimed to develop and implement actions to promote urban health, design models and guidelines suitable for more contexts, hence replicable and subject to further modifications. In addition, in 1986, the first international conference on health promotion was held in Ottawa, Canada, which ended with the signing of the Ottawa Charter for Health Promotion [1]. It established that health promotion needs to be addressed by all the sectors of society, not only by the health one [4]. In this regard, the Healthy Cities Project represented a concrete opportunity to implement the Charter's strategy that ensured health for all at the local level. Since then, concepts have evolved, and dedicated programs have stimulated models' elaboration centered on the emerging issues. Hence, contemporary researchers and practitioners, both technical and medical, are looking to formulate interdisciplinary and trans-disciplinary approaches to face the city's main health problems. The focus is set on defining conditions for improved livability of cities' elements and processes, avoiding inhibiting possible future developments: individuals, households, communities, and local governments are all involved and should try to be healthy while carrying on with their everyday lives [5,6].

The presented contribution aims to transform such conceptual systems using a precise tool to define the main concepts related to the healthy city (HC) idea and the relations among them that could be easy to understand and sharable. The steps include constructing a dedicated basis ontology, going beyond its philosophical meaning, that expresses the need to manage and spread information through different domains and application areas by employing a common language and semantics. Ontologies are efficient instruments that allow for more accessible communication and integration of information among different sectors and actors. In the authors' case, applying ontology's principles within the urban domain becomes interesting and challenging since concepts are loosely defined and remain open to interpretation, raising questions about healthy practices and thoughts.

The main objectives consist of providing the thematic core of the general theory of an HC, based on official descriptions and formalizations, and subsequently implementing the concepts through a structured ontology basis. In particular, HC ontology employs the basic formal ontology (BFO) as upper-level ontology. The goal is to define and organize the essential set of first-level classes of universals referring to notions, relations, events, and processes that describe the conceptual models of the HC's structure [7].

This work is intended to lay the foundations for possible future additions and the harmonization of knowledge. Clarifying the connotations of the HC topic is a fundamental action for a practical application in the urban field at different scales of representation. The contribution starts with an overview of ontology, considering its leading definitions and classifications and focusing on urban planning applications. Then, HC's organization and brief evolution is presented and further implemented, explaining the architecture of BFO. HC ontology provides an initial framework that can describe the most important entities involved in healthy city urban planning that can be easily improved by extending coherent notions and relations following BFO's framework.

## 2. What Is Ontology?

The use of 'Ontology', as an uncountable noun with an uppercase initial, refers to the philosophical discipline. On the other hand, 'ontology', as a countable noun with a lowercase initial, refers to computer and information science. Regarding computer and information science, ontology reflects a formal description of knowledge as a set of concepts and the relationships between them in a specific domain [8]. The most widely well-known definition of ontology is stated by Gruber: 'An ontology is an explicit specification of a conceptualization' [9]. In 1997, Borst identified additional requirements: the conceptualization should express a shared view between several parties and should be expressed in a machine-readable environment. He defined ontology as a 'formal specification of a shared conceptualization' [10]. Later, in 1998, Studer et al. extracted a further illustration of an ontology by merging the two former definitions and stated that 'An ontology is a formal, explicit specification of a shared conceptualization' [11]. In 1998, Guarino formulated the other definition that should be considered. The definition emphasizes the role of logic theory as a tool in representing ontology. Guarino stated, 'An ontology is a set of logical axioms designed to account for the intended meaning of a vocabulary' [12]. Overall, ontologies represent a specification of a reality's (or domain) conceptualization which is a theoretical model describing the set of domain's entities in terms of concepts, relations, and other elements.

During the last three decades, ontologies development studies have shifted from theoretical models to practical implementation in real-world and large-scale applications. As a consequence, nowadays, the goals of ontological development have become wider. Ontologies development attempts to define machine-interpretable concepts and their relationships, share a common understanding of information structure between people and software agents, and enable experts to reuse domain knowledge. Moreover, ontologies allow researchers to analyze domains' knowledge easily and, in some cases, modify their assumptions. [13,14]. Therefore, several reasons have justified the demand for ontologies in different fields of science, such as archaeology, medicine, business, etc. [15–17].

### 2.1. Ontology in Urban Planning

The urban planning field is also concerned with ontologies and has published several studies. Since 2002, creating ontologies for urban planning has been employed, and it has attempted to accomplish one or more of the previously listed ontologies' benefits. In particular, it intends to facilitate the communication between planners, stakeholders, and information systems. The first steps were initiated by two European laboratories at INSA of Lyon and supported by the European Co-operation in Scientific and Technical Research. The project is called Towntology (also known as COST Action C21), aiming to define ontology in urban civil engineering projects (UCE) [18,19]. The project intended to define a taxonomy of ontologies in the UCE field, implement a UCE ontology and build a visual editor to update concepts, develop guidelines valid for the construction of ontologies, and then report the impacts on communication level between stakeholders belonging to UCE domain. Berdier describes in [18] three case studies discussing the construction of urban ontology using the Towntology prototype. Indeed, Towntology represents a valuable resource to define the urban space from a civil engineering perspective. However, it has limitations related to the urban space's representation with all its components [20]. Another ontology study was released by the American Planning Association in 2000 regarding land-based classification standards (LBCS) [21]. It was centered on compliance with federal and state needs to establish a land use classification standard. LBCS has been employed by several research projects related to urban ontologies. Montenegro describes [22] a land use planning ontology based on the LBCS classification standards that he named LBCS:OWL2. This ontology was a part of a research project called City Induction based on developing a tool for urban planning and design [23]. The goal was to provide a semantic description of land use using geospatial data and the LBCS dimensions as classes.

Otero-Caldeira et al., on the other hand, illustrated an ontology regarding smart cities and how smart objects for intelligent applications could support the interpretability between heterogeneous devices and embedded systems [24]. Similarly, regarding smart cities, Komninos et al. presented an ontology based on the definition of smart cities. This ontology identified the underlying causes of the low impact of transport application and smart energy [25]. From a different study, Km4City ontology was introduced as a knowledge model for the city and its services, which covered seven macro aspects concerning experiences in Florence and Tuscany in Italy. Two aspects deal with modeling of metadata and time, and the other five are specific for the city, such as street modeling, administration, and local public transportation [26]. Differently, Hellmund et al. concentrated on urban heat island mitigation strategies (UHIMS) and defined strategies to face increasing urban temperature, which generally impact air quality, human health, outdoor thermal comfort, and energy consumption [27]. Unlike other studies, Nandini et al. devoted the study to representing an ontology for the transportation system. This study aimed to provide information on transportation systems from a traveler's perspective [28].

The mentioned studies allow urban planning knowledge understanding by formally establishing concepts and relationships. They are related to various domains appointed in general to road systems, urban mobility, urban renewal, urban communication, land-use, smart city, the city and its services, cultural heritage management, and the transportation system.

Nevertheless, ontologies development has not covered all relevant urban planning issues since the latter are involved in a complex system. Urban planning ontologies require considering additional domains viewpoints by adopting a correct approach to promote a holistic ontology definition.

### *2.2. Ontology Components and Classification*

To benefit from the use of ontology and build a correct schema, it is essential to distinguish and clarify the differences between each type of ontology. 'Ontology designers have to make conscious and explicit choices of what they admit as referents in a particular system or language' [29]. Several authors introduced ontology classifications in the literature, such as Lassila and McGuinness in 2001, Gomez-Perez et al. in 2004, and Borgo in 2007 [30–32]. Each author considers different dimensions against which ontologies can be classified. The most common ontology components can be elaborated into concepts (classes), instances (individuals), properties (attributes, roles, or slots) of each concept, relations (between instances and concepts) such as is-a, related-to, part-of, has-part, etc., and axioms.

From a practical viewpoint, ontology development mainly focuses on defining concepts, the taxonomic hierarchy of concepts, the properties and their allowed values. Moreover, the focus is on identifying the instances and setting the values for each instance's properties. The taxonomy hierarchy term refers to the classification of sub-class and super-class of an ontology. There are three different approaches in developing class hierarchy [33,34]:

- Top-down approach: this approach begins with the most general classes in a domain, and then the sub-classes are defined. As stated by Gandon, 'This approach is prone to the reuse of ontologies and inclusion of high-level philosophical considerations which can be very interesting for coherence maintenance'.
- Bottom-up approach: this approach defines the most specific classes and groups the sub-classes, then generates the super-classes. 'This approach is prone to provide tailored and specific ontologies with fine detail grain concepts'.
- Middle-out approach: this approach blends both bottom-up and top-down approaches. It intends to identify the central classes in each selected domain and then specialize and generalize them to complete the ontology. 'This approach is prone to encourage the emergence of thematic fields and to enhance modularity and stability of the result'.

According to Roussey et al., the classification of ontologies can be based on: (a) language formality and expressivity; and (b) the scope of the ontology [35]. Regarding language formality and expressivity, ontologies are classified into four types:

- Information ontology: this type aims to organize and clarify the ideas and plans in developing a project using visual languages such as sketches and diagrams. Humans only use this type of ontology, and it is considered an informal ontology.
- Terminological/linguistic ontology: this type mainly focuses on terms and their relationships. This can include dictionaries, glossaries, web metadata, or a lexical database, such as resource description framework (RDF). This linguistic ontology type is considered semi-informal.
- Software ontology: this type defines conceptual modeling languages that are used in database engineering and software. It aims to provide a schema for databases as well as data manipulation to guarantee their consistency. Usually, a conceptual modeling language such as unified modeling language (UML) is used during the software design procedure. This ontology type is considered semi-formal.

- Formal ontology: this type is defined by axioms. It is usually developed using precise semantics to describe the rules for defining the concepts and relationships. Different formal languages are used to describe formal ontology, such as the web ontology language (OWL), the most well-known formal language, and recommended by the World Wide Web Consortium (W3C).

The other classification of ontologies concerning the scope classifies them into five different categories [36,37]:

- Foundation/top-level or upper ontology: this category can be viewed as a meta-model of a conceptual schema. Foundation ontology consists of a wide range of generic concepts or primitives used to define other ontologies. It applies to various domains. Usually, every domain or core ontology (described in the following categories) includes a foundation ontology in its structure. There are different candidates for foundation ontologies, some recognized examples are: basic formal ontology (BFO), descriptive ontology for linguistic and cognitive engineering (DOLCE), and suggested upper merged ontology (SUMO).
- General ontology: this category contains the general knowledge of a vast area. It is not dedicated to a particular domain, describing concepts such as state, event, process, action, component, etc. Cyc ontology is considered as a general knowledge base that includes hundreds of thousand terms.
- Core ontology: this category defines a particular task and minimal concepts that are important for understanding other concepts in a domain and integrates many perspectives from different groups. This type of ontology integrates several domain ontologies or may be derived from a foundation ontology. Developing a core ontology about urban domain means considering generic concepts (for example, means of transport, construction, building, material, urban form, political action) related to a roadway system or urban renewal. The CityGML is an example of core ontology.
- Domain ontology: this category defines a specific domain by representing its concepts and relations to the real world, integrating and making available information pertinent to it. It shows how a group of users and experts perceive a specific domain. Again, this domain ontology may be based on the interpretation and the integration of foundation ontology. An example of domain ontology is the open biological and biomedical ontologies (OBO) foundry, which is related to biological sciences.
- Application/local ontology: this category is extracted from the core and domain ontologies to define a particular model. This model is presented from a single viewpoint of a user or a developer. One example of this type is the situational awareness and preparedness for public health incidents using reasoning engines (SAPPHIRE).

Indeed, no one can claim that there is a unique way to define the ontology of a domain. Instead, the best method to develop an ontology depends on the domain and application of ontology and the extent to which a domain overlaps with other fields of science.

## 3. The Paradigm of Healthy City

The paradigm expressed by healthy city became explicit during the conference entitled Beyond Health Care, which was held in Toronto in 1984, jointly sponsored by the Toronto Board of Health, the Canadian Public Health Association, and Health and Welfare Canada. On this occasion, the focus shifted from an individualistic interpretation of modifications in health to a common agreement about the necessity of public policies able to promote and ensure health [38]. The event produced two essential results: the notion of "healthy public policy", the notion of a "healthy city", and the related idea of "Healthy Cities Project" [39]. The program wanted to put at the center of its planning and design process a proper use of resources to reassemble all the spatial–temporal relations influencing the urban thinking of both specialists and society [40]. Three main issues were put at its basis:

1. The essential role reserved for local action in developing health issues;
2. The value of urban environments regarding health and well-being;
3. The responsibility given to local governments to work for developing beneficial environments for healthy living for all.

As the WHO expresses it: ‘A healthy city is one that is continually creating and improving those physical and social environments and strengthening those community resources which enable people to mutually support each other in performing all the functions of life and achieving their maximum potential’ [41]. The definition takes into consideration numerous intra- and interdisciplinary subjects, and it is founded on the following main steps:

- Building a solid wide-ranging structure;
- Involving community participation;
- Understanding and evaluating community needs;
- Accurately defining strategic and effective plans for healthy cities;
- Interacting with the political side;
- Acting at the local level.

Hence, the process depends on each cities’ actions that have to fulfill a set of requirements, including [42]:

- Engagement from both political and administrative sides;
- A joined contribution from different sectors and civil society about infrastructural and strategic development;
- Construction of a network working simultaneously at the local, national, and international level;
- Well-organized reporting activity able to evaluate progress and lessons learned.

Considering its overall structure, HC has been implemented as a concrete opportunity to nurture new hopes and experiment with further purposes and directions on the public health stage [43–48]. Policies and actions deriving from the HC vision need to be organized as a set of well-defined processes able to raise awareness among the different community levels by mobilizing it and enhancing local governments’ work in a matter of public health to implement the WHO Health for All strategy [49]. The latter was designed as a long-term vision requiring reforms and efforts regarding health from the WHO internal side, and intersectoral action and participation from others. The approach was integrated and developed in the HCs Project initiative by adopting five-year action plans starting from 1988. Participation in each phase is voluntary. However, it is strictly necessary to make an effort and produce suitable material that certifies the results achieved. Furthermore, the process’s layout through well-structured phases becomes essential to build a wide range of practical experiences on how to increase health and establish a benchmark that gives an adequate measure of the progress made. Moreover, during its evolution, the definition has become a-scalar to the processual characteristic, avoiding static results. As a direct consequence, any city can be healthy, despite its initial health status [50].

Activities and experiences in this regard have been flourishing for many years, and HC’s boundaries often appear challenging to identify and effectively analyze, moving well beyond the exclusive administrative level. Therefore, confusion is generated when trying to translate policies into efficient actions to evaluate benefits in terms of improved health. Overall, the HCs movement has consistently evidenced significant limitations affecting scale actions compared with early expectations [51–56]. The involvement is placed on a bigger scale, and a functional tool is necessary to make order within this context.

*Identifying Core Elements and Relations*

A synthesis of the HC’s framework is provided through the proposed intuitive scheme in Figure 1. The intention is to clarify the primary actions and relations describing the HC’s overall structure, considering its formulation and description provided by the official document entitled ‘World Health Organization Healthy Cities Project: A Project Becomes a

Movement: review of progress from 1987 to 1990'. The latter is considered one of the most influential texts exploited globally in HCs development [57]. It analyzes the initial phases of the first five-year action plan (1988–1992) and draws attention to strategies, objectives, achievements, needs, and implications.

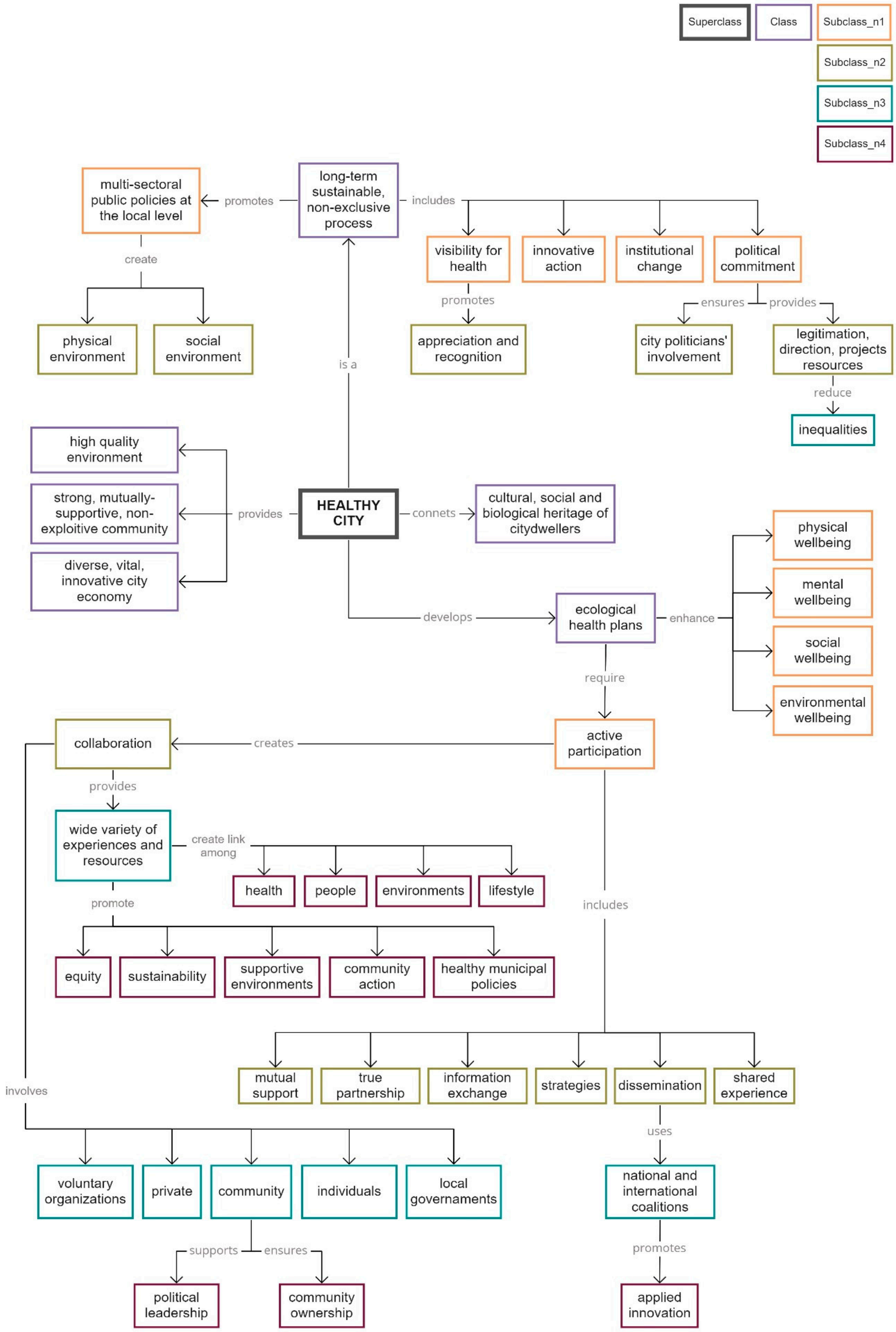


**Figure 1.** Logical structure of 'Healthy Cities Project' promoted by WHO.

Notions are linked through specific actions, and they are set into a hierarchy, identifying super-classes, classes, and sub-classes. The approach can be defined top-down since the general classes have been defined first, informally specifying more elements during the second stage (see Section 2.2). The logical structure collects the fundamental concepts related to HCs Project and it elaborates them into classes with different hierarchical levels. The step is essential since the represented concepts will help identify the ontology's components that will be implemented through the specific BFO's approach.

The system contributed evidence of the essential role played by the community resource in terms of collaboration and promotion. The community takes ownership of programs and initiatives proposed by the HC organizing body. It has legal or authorized right to participate in health issues. This action is fundamental since it can promote responsibility among people from the community and then arise co-operation and coordination with the stakeholders. To achieve it, involvement with programs has to start from their initial steps and be at the same level as the local governments' activity.

One crucial challenge is ensuring this process since it has to be long-term, sustainable, and non-exclusive. Political commitment is identified as one of the most important objectives, and it is connected to the proper exploitation of resources to reduce inequalities. Innovation in these terms will support a wide set of experiences connecting health, people, the physical and social environment, and lifestyle based on multi-sectoral healthy public policies implemented locally. Replicability and dissemination are other important elements; the project intends to build strong local networks and reach national and international coalitions.

## 4. Implementing Basic Formal Ontology in the Healthy City Environment

The urban organism needs to be read and studied considering the set of complex independent entities, which includes built objects, contextual factors, visual sights, and temporal pauses that can, at the same time, influence healthiness conditions (positively or negatively) and generate new advantages of living in cities [6]. To have an exhaustive vision of the considered system, it is also necessary to evaluate the qualities deriving from the dependent components.

The authors have chosen the basic formal ontology as a primary tool to guide the design and description of the domain-specific ontology for HC. BFO is classified as a foundation ontology (also indicated as top-level or upper ontology). It describes a strict domain-neutral domain, and its use assumes relevance in terms of interoperability, rigor, and clearness.

The project was initiated in 2002 and developed at Saarland University by Barry Smith and his associates. It is designed to represent the entities in the world and their relations at a high level of generality. BFO is a beginning stage for categorizing entities and their relationships by more than 250 domain ontologies. It can be applied to various problem cases and support information retrieval, analysis, and integration in various domains. BFO is also easy to learn and use [37,58].

Several publications have already been produced discussing the main structure of BFO and its components [37,59,60]. In addition, attention has also been brought to its use in domains related to science and technology [61–64].

BFO represents consistent support for building domain ontologies by providing a pre-established top-level structure and a set of ready-made answers to facilitate and increase the possibility of sharing knowledge among multiple domain ontologies produced following its principles. The advantages become evident [37]:

- Ontology developers make their work and training extremely flexible by using a shared basis of top-level configuration;
- The overall process of governance becomes more effective, and it positively influences the ontology development;
- The number of ontology developers and users will increase since they will have suitable instruments to conduct overall and valuable revision work.

In addition to this, considering the already existing list of foundation ontologies coming from the research community, it is worth conducting some comparisons to demonstrate BFO potentialities with respect to other upper ontologies [65–67]. In this regard, the paper represents two other very common top-level ontologies: DOLCE and SUMO (Table 1) [68].

**Table 1.** The importance of using BFO for building and spreading ontologies compared to other top-level ontologies; elaboration by authors.

| | | **BFO** | **DOLCE** | **SUMO** |
|---|---|---|---|---|
| Top Level | | ● | ◑ | ● |
| Small | | ● | ● | ○ |
| Open | | ● | ● | ● |
| Documentation | User | ● | ○ | ● |
| | Technical | ● | ● | ● |
| External Community Review/Support | Users | ● | ○ | ○ |
| | Domain Ontology Developers | ● | ● | ◑ |

DOLCE, meaning domain ontology for linguistic and cognitive engineering, was developed by researchers from the Laboratory of Applied Ontology, headed by Nicola Guarino in 2002 in the context of the WonderWeb EU project. It is designed to capture ontological categories underlying natural language and human common sense. DOLCE is described as an 'ontology of particular', which means an ontology for instances rather than universals or properties. It intends to be descriptive of notions that support a formal specification of domain conceptualizations [69]. DOLCE and BFO share a common Aristotelian background and similar goals; they are built by following the same upper-level structure with the basic distinction between continuants and occurrents, and between independent entities and dependent entities ("qualities" in DOLCE) (see Section 4.1); and they have been employed in many projects. They are both small and open. One crucial difference is that DOLCE includes some human-specific terms, such as 'society', referring to social objects and social agents, that are not present in BFO. In fact, DOLCE shows a marked cognitive bias linked to a descriptive/multiplicative approach that generates multiple and simultaneous entities' locations. On the other hand, BFO endorses a completely realistic approach. Moreover, DOLCE provides poor user documentation and fails in organizing effective information hubs. It assists people who are using it and not people who want to use it. Instead, BFO supplies pretty good user and technical documentation, plus it supports ontology developers.

Additionally, DOLCE only focuses on describing particulars, while BFO is intended as an ontology including both particulars and universals [70]. In fact, according to BFO, the aspect of conceptualism, highlighted by Studer (see Section 2), is considered too ambiguous, and it proposes the use of a 'universal' for the ontology classes. Therefore, ontologies based on BFO also work with 'universals'. They correspond to what is treated as general in reality, rather than only with 'particulars' (or 'instances'). Finally, domain ontologies built on its basis will have a consistent and coherent structure expressing universals in their respective domains [37].

SUMO, which stands for suggested upper merged ontology, was released in 2000, and was created at the Teknowledge Corporation by the Institute of Electrical and Electronics Engineers (IEEE) (originally by Ian Niles and Adam Pease). SUMO is considered a mixed foundation ontology that contains both elements of realism and cognitive-specific categories. It has merged several existing upper ontologies that did not have licensing restrictions, such as Barry Smith's ontology of boundaries, John Sowa's foundation ontology, Guarino's formal mereotopology, and various formal representations of plans and processes. It has been used for research and applications in search as well as linguistics and reasoning [71]. Although SUMO is claimed to be an upper ontology describing both universals and particulars, it includes numerous specific domain terms referring to particular disciplines (for example, biology or physics). As a consequence, it is too big and dispersive in comparison with BFO and DOLCE.

As stated before, other upper ontologies exist that are possible candidates, such as BORGO, GFO, and Proton. However, they are exploited by few users or have not been maintained for several years.

The necessity of BFO comes from the fact that a certain number of researchers are putting effort in creating domain ontologies that, in the end, reveal to be incompatible with each other, only focusing on their local specific needs and objectives, then accumulating a set of inaccessible and non-sharable data. In the presented work, authors integrate information to propose a common structure valid for all the different actors involved during healthy cities' transformation processes (citizens, scientists, researchers, politicians, local administrators, urbanists, architects, etc.). The purpose is in line with the main ontology's principle of realism, and it is coherent with the one evidenced by BFO to give consistency [58]: "BFO's primary goal is to assist scientists and others in the development of practically useful, accurate, coherent, and interoperable domain ontologies by providing a starting point for downward population through the formulation of Aristotelian definitions" [60] (p. 111). In other words, BFO is based on ontological categories able to provide information-driven researchers with practical results, being far from more contentious metaphysics' questions.

### *4.1. BFO Main Architecture and Entities Organization*

BFO can describe reality as a top-level division of it, which means dividing all particular entities, 'anything that exists', into two dissociated categories of continuant and occurrent [72]. The organization proposed is valid considering any domain, and it works along two dimensions (namely time and scale). The time dimension refers to the subdivision of reality between continuant and occurrent, while the scale classification is based on entities' granularity.

The continuant classification incorporates objects, attributes, and locations, and it is opposed to the occurrent one, which refers to processes and temporal regions. Processes exist over time since they happen or occur. They have temporal parts and always depend on some (at least one) material entity (for example, the process including the life of this organism, that meiosis process, etc.). Nevertheless, the life process cannot be considered thoroughly, but it is made of temporal parts characterized by different levels of granularity (childhood, adolescence, adult life, old age). A human being can keep living as a continuant entity (even without a limb). However, his or her life process is unique; when a human being changes, his or her life process is not the same anymore. Contrarily, continuants exist entirely at any time of their existence. More specifically, this category includes [37] (p. 87) (Figure 2):

- Independent objects, divided into material and immaterial entities (such as human beings, a building and its constructive components, communities, Piazza del Duomo, the North Pole, the Greenwich meridian, any surface of a material object);
- Dependent continuants that incorporate qualities (for example, the weight of a person, the color of the façade of that building); roles (such as the role of engineer or doctor); dispositions (an element X has the predisposition to evolve in Y; some people have the predisposition to develop colon cancer); and functions (the function of a window to open);
- Spatial regions are occupied by the entities at any given time.

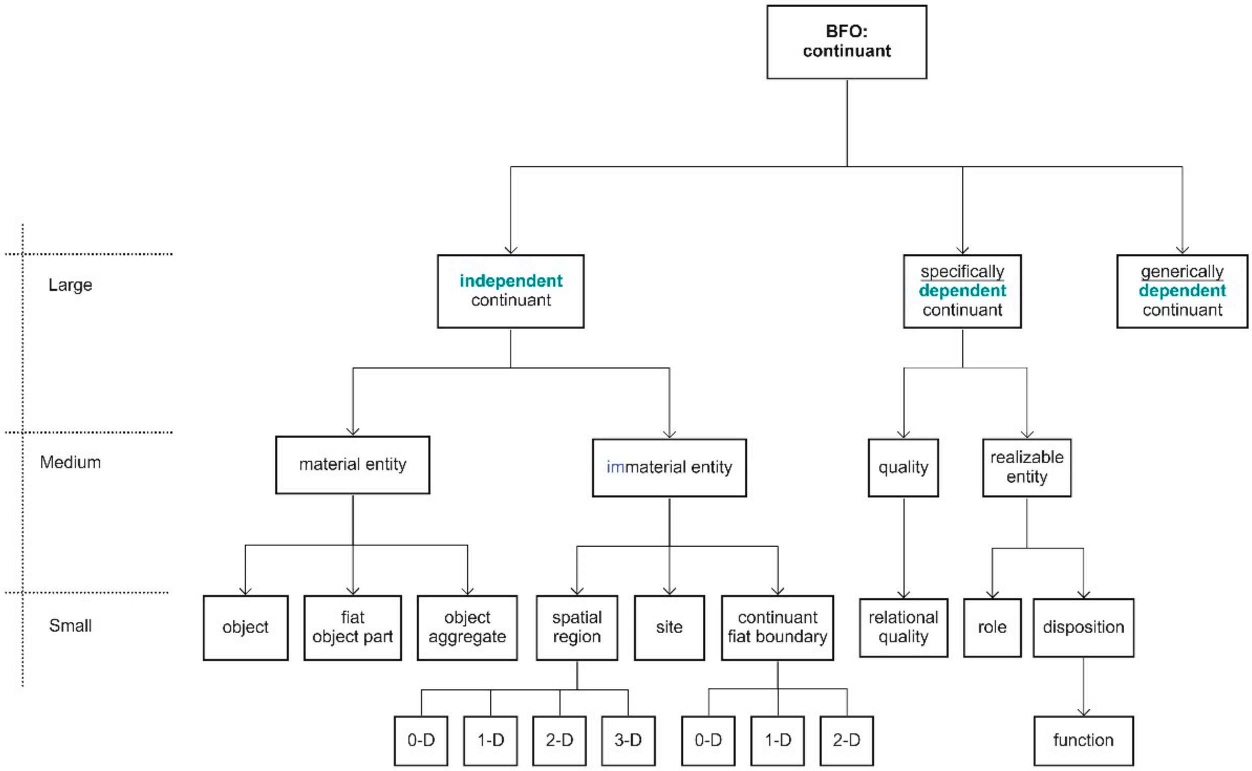


**Figure 2.** The hierarchy of BFO continuant category.

Meanwhile, the occurrent category comprises (Figure 3):

- Processes made of different phases, as stated before;
- Boundaries, meaning the processual limits that represent the beginning and the end of such processes; they refer to instantaneous changes rather than to results due to those changes (the creation of a synapsis, the starting of REM sleep);
- Temporal and spatiotemporal regions, where the processes can happen.

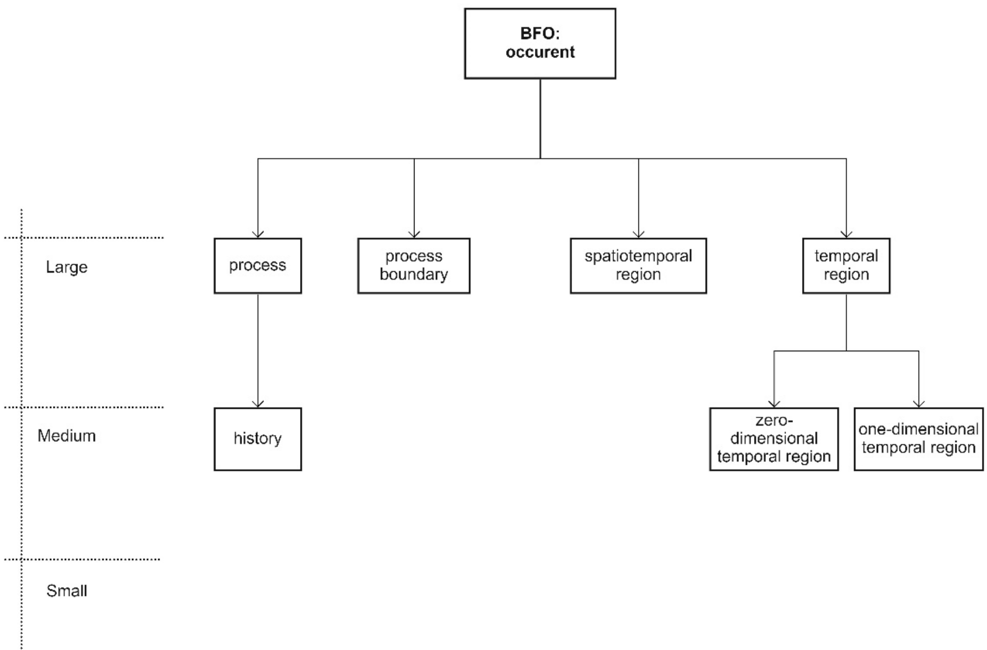


**Figure 3.** The hierarchy of BFO occurrent category.

According to BFO, continuant and occurrent entities do not exist side by side in a simple environment. They both have a specific character, and they look at the same reality with different and complementary perspectives. The result is that none of the two have the power to intervene in the reality described by the other.

## 5. Proposing a Framework for Healthy City First-Level Universals

Once the elements characterizing an HC have been identified, and in the light of BFO structure, it is possible to define some steps to provide evidence of the set of universals composing the specific urban domain, the object of this paper. The scale dimension is divided into healthy city, healthy city component, and healthy city element, while the time dimension is divided into continuant and occurrent entities (Table 2).

**Table 2.** Healthy city first-level classes organized through BFO.

| Support / Surface | Continuaut | | Occurrent | |
|---|---|---|---|---|
| | **Granularity** | **Independent** | | |
| HC | Citizen<br>Local government | Local public administrative role | Healthy municipal policy<br>Multi-sectoral public policy<br>Local initiative | Intersectoral action<br>• Urban planning<br>Innovative action |
| HC Component | Community<br>Neighborhood | Information<br>Support | | |
| HC Element | Individual Subsystem<br>• Physical<br>• Socio-economic<br>• Mental | Lifestyle<br>• Physical well-being<br>• Mental well-being<br>• Social well-being<br>• Environmental well-being<br>HC impact indicator | Process indicator | |

### 5.1. Continuant Entities

An HC keeps transforming and improving its physical and social environment, considering all the sets of material entities and immaterial entities composing the independent category explained by BFO. The entities describe the lowest level of granularity, and they can be related to three main layers. One is represented by the physical subsystem of the city, to which all the structures, networks, and artifacts belong, and where all human activities are carried out. These activities are part of the socioeconomic level, including interactions among individuals. The third layer is connected to ethics and aesthetics, then to urban design and housing that generate mental objects and relations following architects or urban designers' thoughts on planning healthy cities. Together the different layers are essential to explain a city's complex organism by establishing more viewpoints. Moreover, a similar organization of the city derives from the large body of theories discussing urban systems that have been encoded and shared over time [73].

The elements put together by the physical system are, for example, houses, buildings, streets, squares, green areas, and monuments. Generally, both natural and anthropic areas or volumes of the city where healthy activities can be located. Under BFO classification, the mentioned entities can be 'object', 'fiat object part', 'object aggregate', 'spatial region', 'site', and 'fiat boundary' (see Figure 2).

Creating connections between community and neighborhood components constitutes a fundamental step that can help reduce morbidity and mortality and positively transform the city into a healthier place to live [74]. The action, to be effective, requires active participation, and from the HC's perspective, citizens have a significant impact on the whole process. They participate firsthand in health issues when interacting with HC elements, which means choosing their lifestyle, health care services, and even their beliefs about health.

Today's lifestyle is mainly affected by the worldwide spread of so-called non-communicable diseases, mainly due to sedentary lifestyle, improper nutrition, and unhealthy habits (smoking, alcohol, drugs, etc.), accounting for about 2/3 of the total burden of these pathologies. Most of them are cardiovascular and respiratory diseases, cancers, obesity, allergies, diabetes, stress, anxiety, sleep disorders, cognitive development, and social exclusion. Additional causes affecting lifestyle depend on road accidents and crime, which, in many cases, involve entire urban areas (slums, outskirts, isolated areas) that generate high levels of perceived insecurity and related psychological health problems. Therefore, lifestyle depends on HC's elements and can significantly affect people's physical, mental, social, and environmental well-being.

Furthermore, lifestyle can be considered an internal dependent factor, being linked, in part, to each individual's behavior. However, HC's elements also cause external dependent entities. These entities are mostly connected to the extended set of indicators evaluating the potential positive or negative impacts on health, medical services, environment, and socioeconomic system [75].

Those living in the city every day are strictly involved and, under the HC vision, they can directly influence local governments' decisions. Following a very simple and intuitive way, it will be the latter, through their actions, who decide whether to stay or move to a city that they consider 'healthy' or abandon or keep away from one they consider 'unhealthy'. The collaboration between the urban and administrative sides aims to produce many examples and resources freely available to other network members. Indeed, citizens and local governments are two substantial universals together with community and neighborhood. The term community, in the discussion, is intended as a bond among individuals, from which the spatial definition and implementation of a healthy neighborhood arise.

The analysis regarding the dependent class of entities focuses, in particular, on the role. The latter represents a realizable entity owned by its bearer due to external circumstances (the role is always optional since the bearer does not necessarily have to be in those circumstances). The existence of the role thus depends on whether some qualities' bearer exists in some physical, social, or institutional condition.

HC formulation discusses the importance of developing the role of local governments, thus the roles of people who can effectively find new ways to promote HC projects and propose a real change for the community. They can be mayors, city councilors, municipal technicians, senior executives in city departments responsible for the environment, urban planning, housing, education, social services, or health care professionals. An HC initiative enhances more active roles for people belonging to these administrative fields. Academics with valuable training in social policy, public health, urban development, and ecology also have a role to play.

Information and support play a unique role by helping projects and initiatives bring new and interesting perspectives from community groups. Subjective insights are vital since they give form to a dense set of information and data regarding livability in the city: when a positive opinion is expressed, a judgment is made in holistic terms. They help provide the correct focal point able to induce local government actors to re-examine their policies. Once all of the selected stakeholders have agreed about the necessity to intervene and have acquired enough knowledge, the development process can start.

### *5.2. Occurrent Entities*

HC concept necessarily implies a process, not just an outcome. Therefore, the processual quality of HC directly refers to the occurrent class of BFO. The processes arising are consequences of citizens' and local governments' decisions converted into multi-sectoral policies and initiatives. In many cases, actions are targeted at reducing environmental risk factors connected with impacts on health concerning lifestyle. At present, numerous strategies have been designed and enforced focusing, in particular on the following: green/blue/grey infrastructures, biodiversity protection, adverse meteoric events management, public transport systems, vehicular traffic reduction, pedestrian and cycling paths, social/functional mixitè, urban solid waste management, renewable energy and efficiency, outdoor spaces lighting, and design for all [76].

Facing this, identifying process indicators assessing the health status of an urban conglomerate is essential from the point of view of the implementation and monitoring of the process of change. Evaluation of projects is valid when process indicators instead of impact indicators are employed; they constitute the most important component displaying activities and interacting with the community [77]. The goal is to develop a set of comprehensive indicators both qualitatively and quantitatively, subjective and objective, that are analytical and holistic and that, above all, consider the social context [49].

Analyzing the overall scale, intersectoral action represents the process through which more organizations and bodies can actively participate and be protagonists at the same level of the health sector. This process is necessarily implemented by another process (that is, the one of innovation). The constant and diligent search for new ideas and methods is required to create valid opportunities and experiment with new policies and programs, encouraging knowledge acquisition.

## 6. Discussion and Conclusions

Nowadays, HC embodies a clear idea in general terms. However, specific technical definitions are still vague. This paper has highlighted HC's first character, which is its intrinsic multi-disciplinarity and inter-disciplinarity. Urban and health studies must interact to create a well-structured system of objects, subjects, actions, policies, and related results toward an urban environment that can improve human health. Considering city operations' specific nature, disciplines such as sociology, economy, psychology, modeling, and decision-making processes are necessarily involved. Therefore, the HC logical structure can be considered as an example of a multilayer complex system.

One of the ontology's main characteristics concerns the particular perspective from which every phenomenon is studied. The authors can affirm that a HC involves the study of the elements that compose the city and the related causes of diseases affecting people. Moreover, the complete process of conceiving, planning, designing, and managing the city involves multiple subjects with different roles (from technicians to politicians and from scholars to all citizens, as all classic urban planning manuals describe). Hence, HC ontology must be understandable to different types of people, with different cultures, multiple visions of the city itself, and individual goals; the organizational scheme must also be clear and simple to be represented.

To organize the hierarchy and mutual interactions among all the elements that compose an HC's system, which corresponds to the first step of the ontology creation, the authors decided to choose a specific ontological approach, one that is followed by the basic formal ontology (BFO).

BFO's approach applied to the study of the HC gives consistent support in defining the first hierarchy of elements. BFO's structure and interpretation of reality are built coherently and intuitively, and it has been chosen by the authors as a means of clarification and facilitation. At the same time, the work is not intended to establish a pre-eminence of one tool for others. Considering such an ample domain, the perspective becomes flexible, and, starting from the same considerations, it is possible to provide more ontological schemes.

In this specific context, ontology is employed to read the complex city system by intuitively defining HC vision's main entities. The latter are described and connected to the overall system following BFO's subdivision. The effort is also made concerning the dissemination and interoperation opportunities offered by ontologies and their related editing tools. One of the most well-known and freely available is the Protégé editor. It is described as a 'free, open-source ontology editor and framework for building intelligent systems.' [78]. Ontologies edited using Protégé, built with BFO, are considered interoperable with other domains with a similar foundation [79]. Using BFO is a premeditated decision taken by the authors derived from comparing the existing approaches in ontology building.

After creating an ontology, authors and scholars are called to use this logical scheme to build representation tools, simulation models, and decision support systems. Representation tools are helpful for policies' implementation and communication to citizens, who must accept or adapt to the rules defined by a public administration. Furthermore, representation also constitutes an essential step in scientific fields, particularly when different disciplines are involved. In this sense, the ontology can create a common basic language indispensable for making scholars with different backgrounds interact.

Simulation models can be divided into two main categories, namely descriptive models and predictive models. Ontology is the basis for a general descriptive model of HC, and it can also be implemented as a predictive one, knowing that, in complex systems, previsions are infected by the surprise creation of the system itself. Moreover, according to the history of urban modeling and use of data, it is well known that forecasts are credible when they define 'possible scenarios', which is what is necessary to improve urban policies [80,81].

Decision support systems are growing faster and faster in urban management mainly since they have a continuous interaction between planners (or designers, politicians, and scholars) and automatic systems. The ontology is fundamental to providing users with a scheme of all implications involved in specific decisions or issues. Of course, in this last case, the ontology should be flexible in letting users modify interactions between the elements according to their specific objectives.

In conclusion, the present contribution represents a preliminary phase of research that aims to improve the understanding of what already exists in HC planning to design and structure new formalizations using ontology tools. It will then be possible to choose the most suitable approach for developing a complete ontological structure intended to define the entire domain of an HC.

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