J. Mt. Sci. (2020) 17(4): 973-991 e-mail: jms@imde.ac.cn http://jms.imde.ac.cn
https://doi.org/10.1007/s11629-019-5576-7

Augmented planning support system framework for mountainous urban master planning

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Citation: Sun XT, Xu JG, Wang ZB (2020) Augmented planning support system framework for mountainous urban master planning. Journal of Mountain Science 17(4). https://doi.org/10.1007/s11629-019-5576-7

Abstract: As a reflection of the relationship between human and mountainous environment, urban planning has an impact on the mountainous environment by changing the topography, landform and spatial layout. A good urban planning can mitigate and adapt to the mountainous environmental impact. Urban master planning involves the interrelationships and interactions of various components of urban complex systems. Planning Support System (PSS), as a technical means to assist planning decision-making, is mostly based on the construction mode of "user (stakeholder) - system". Its strong professional characteristics are not conducive to the consensus of diverse stakeholders on urban planning. The aim of this paper is therefore to build an augmented planning support system framework that is based on complex adaptive system theory, this framework is ontology-driven, and thus will enable the generation of a planning support prototype system for mountainous urban master planning founded on this framework. The framework fuses the urban planning ontology and the planning support system together, which helps different urban agents to reach a consensus based on a common understanding of urban planning. The defect is that the construction of the urban planning ontology is still manually constructed. The approach advocated here will enable a common understanding of mountainous urban master planning, support efficient and flexible decision in this area, and provide reference framework for future mountainous urban master PSS developments and application. The PSS prototype developed based on augmented planning support system framework has been applied to the urban master planning of Changting County in Fujian Province, China. Through the application of multi-scenario analysis, urban agents can deepen their understanding of the current situation and future development of the city, and ultimately helps to promote urban planning decisions and implementation.

Keywords: Urban planning Ontologies; Planning support systems; Complex adaptive system; Mountainous planning; Urban master planning; GIS

Received: 08-May-2019
Revised: 01-Jan-2020
Accepted: 17-Feb-2020

Introduction

Urban Planning, as a highly technical public policy to deal with a series of problems arising from urban disorderly development, has played an irreplaceable role in promoting the healthy development of the city. However, it seems that there is no good solution to the social, economic and environmental problems caused by urbanization. The main reason is that different stakeholders have different understandings of urban planning based on their own interests and knowledge structure, and it is difficult to reach a consensus. Planning support system, as a technical means to assist planning decision-making and promote public participation, can not solve the existing data and system island problem. Friedmann (1987, 2003), one of the earliest and most influential researchers in this field, defined urban planning as "the transformation of knowledge into action in the public domain" and considered that this process can (and should) provide a means to build the future. Planning knowledge is derived from a scientific understanding of cities and regional systems; thus, in light of the increasingly complex problems that are seen in this area, it is necessary to develop an enhanced scientific understanding of urban systems, viewing cities in particular as complex open forms of these entities (Byrne 2003; Batty 2007; Batty 2009; Portugali et al. 2012; Sengupta et al. 2016). Complexity theory provides a new holistic perspective for understanding and solving complex problems, observe the engagement with bottom-up phenomena, structural and functional co-evolution and resultant adaptable and self-organisational systems within complexity planning (Yamu et al. 2016); in this context, complex adaptive system (CAS) theory is a new level in the development of complexity science (Levin 1998; Holland 1995; Holland 2006) that view cities as amalgams of various adaptive agents (e.g., governments, citizens, enterprises) , these adaptive agents is self-organization and responsive to the dynamic environment (Rauws et al. 2016). Adaptive agents in these systems are continuously learning and accumulating experience as part of the interactive process and adjusting their own structures and behavior; local interactions between subjects therefore emerges as a complex global pattern with novel features that themselves contribute to the evolution of complex urban systems. The seven basic tenets of complex adaptive system theory include four distinct properties (i.e., aggregation, diversity, nonlinearity, and flow) alongside three mechanisms (i.e., tagging, internal models, and building blocks); these components provide a theoretical framework that can be applied to understanding urban complex systems (Holland 2006).

The field of ontology originated from philosophy and has been applied in artificial intelligence to support the processes of knowledge sharing and reuse as well as to promote a common understanding between stakeholders and interoperability between different systems (Gruber 1993). In earlier work, Studer et al. (1998) defined this concept such that "an ontology is a formal, explicit specification of a shared conceptualization". This means that ontology can be both a way to represent knowledge as well as the basis for building a system and managing information (Jurisica et al. 2004; Belleau et al. 2008; Stefik 2014; De Vasconcelos et al. 2016). In this context, Teller noted that knowledge sharing and reuse are key issues in urban areas that must be addressed to build consensus amongst experts, stakeholders, and decision-makers as interoperability between different information systems raises issues about communication between different domains, scales, purposes, and levels of data quality. Ontology can therefore be used as a tool to promote improvements in communication (Teller 2007).

Urban planning has recently evolved from the use of purely "rationalistic models" to the inclusion of more emphasis on negotiations amongst multiple stakeholders (Teller 2007). Thus, "coordinated planning" depends on a number of basic assumptions regarding stakeholders' understanding of relevant terms, concepts, and effective inferences within this field; conflicts between urban stakeholders often seem to be the result of differences in understanding these basic definitions. A series of themes have been developed to enhance communication, encompassing morphological process (Camacho-Hübner et al. 2007), public transportation (Houda et al. 2010), urban mobility (Berdier 2011), and urban regeneration ontologies (Rotondo et al. 2011), spatial data harmonisation for urban analytics (Chen et al. 2018), modeling spatial planning systems (Lazoglou et al. 2016), dynamic fine-grained Urban Indicators (Pileggi et al. 2017). There are few relevant concepts about urban planning ontology at present, urban planning ontology can therefore be used to regulate communication between stakeholders and reduce the likelihood of misunderstandings, promote stakeholders common understanding on systems, and interoperability between different systems. It is necessary to propose this concept. In earlier work in this area, Guarino discussed the role of ontology in building information systems and noted that an explicit approach should be at the center of architectures in this area (Guarino 1997); thus, ontology drives all aspects and components of information systems (i.e., ontology-driven information systems). This field therefore influences the construction of information systems from both temporal (i.e., development including requirement analysis and conceptual modeling as well as operation including communication facilitation) and structural (i.e., ontologies impact on information system components including databases, application programs, and user interfaces) dimensions.

The use of a planning support system (PSS) was first proposed by Harris who argued that this approach must incorporate elements including a professional model integrated into the planning process, geographical information system (GIS) spatial analysis capabilities, and a degree of user-friendliness to encourage constructive opinions and improve effectiveness (Harris 1989). These systems are therefore geo-information-based tools that provide planning professionals with technical support to complete specific tasks (Klosterman et al. 1997; Geertman et al. 2006). The volume of research in this area as well as the range of potential PSS applications has gradually increased since the 1990s (Brail et al. 2001; Brail et al. 2008; Geertman et al. 2009; Geertman et al. 2012; Geertman et al. 2013), Pettit et al developing an online planning support systems for land suitability analysis (Pettit et al. 2015), Goodspeed and Hackel developing a planning support system infrastructure about the Southern California's Scenario Planning Model (Goodspeed and Hackel 2017), Psyllidis et al develop a platform for urban analytics and semantic data integration in city planning (Psyllidis et al. 2015); significant progress has been made in support of urban planning which has enabled professionals in this area to more effectively handle complex problems they encounter, generate high-quality outputs, and save time and money, and even decreasing sense of responsibility of users (Kazak and Van Hoof 2018). In a review, Geertman (2013) provided some advice regarding future PSS research directions in an article entitled "Planning support: From system to science", noting that more effort will be required in the future with regard to the theory and conceptual framework of these systems. The existing planning support system for urban planning practice is highly specialized, mainly for professional people in the field of urban planning, and does not integrate well with the urban planning ontology that represents the knowledge system in the urban planning field. There is also a clear need for more effective communication between different users (stakeholders) in terms of a common PSS "language" in order to reach a consensus.

The aim of this paper is attempts to understand and deconstruct the urban complex system through the complex adaptive system theory. On this basis, the urban planning ontology concept term is extracted to construct the urban planning ontologies, the urban planning ontology provides support for the construction of the urban master planning knowledge system and the planning analysis model system, thus promoting the common understanding of urban master planning by different urban agents (stakeholders). The urban planning ontologies supports the construction of the planning support system in temporal (development including requirement analysis and conceptual modeling as well as operation including communication facilitation) and structural (ontologies impact on information system components including databases, application programs, and user interfaces dimensions), this urban planning ontologies driven augmented planning support system framework is established to construct a planning support prototype system for county-level urban master planning formulation.

1 Research Rationale and Method

1.1 Theory and methodology

The theoretical and methodological foundations that underpin this study are shown in

Figure 1. First, urban complex systems can be divided into material subsystem and non-material subsystem based on physical form. Material subsystem can be further divided into five subsystems: landuse, transport, buildings, municipal infrastructure and landscape (Sun et al. 2016; Xu et al. 2017). Non-material subsystem can be divided into five subsystems: social, economic, cultural, ecological and management (Sun et al. 2016; Xu et al. 2017). Then understand and deconstruct the urban complex system through the complex adaptive system, the concepts and terminology systems reflecting the characteristics of urban complex systems are extracted to support the construction of urban planning ontology, and identify the adaptive agents that drive the development and evolution of cities. Secondly, using ontology method to define and construct urban planning ontology, ontology-based modeling provides support for urban planning analysis model construction, and semantic relationship between ontologies can provide support for UML modeling of planning support system. Thirdly, an ontology-driven urban planning analysis model and a prototype of planning support system are constructed. Finally, the prototype of the planning support system is applied to the practice of urban master planning.

1.2 A complex adaptive system

The concept of a complex adaptive system (CAS) was first proposed by John Holland in his book "Hidden Order: How Adaptation Builds Complexity" (Holland 1995). In this thesis, Holland discussed the operation of highly complex urban systems like the cities of New York and Tokyo, and outlined the adaptive agents that enable the normal

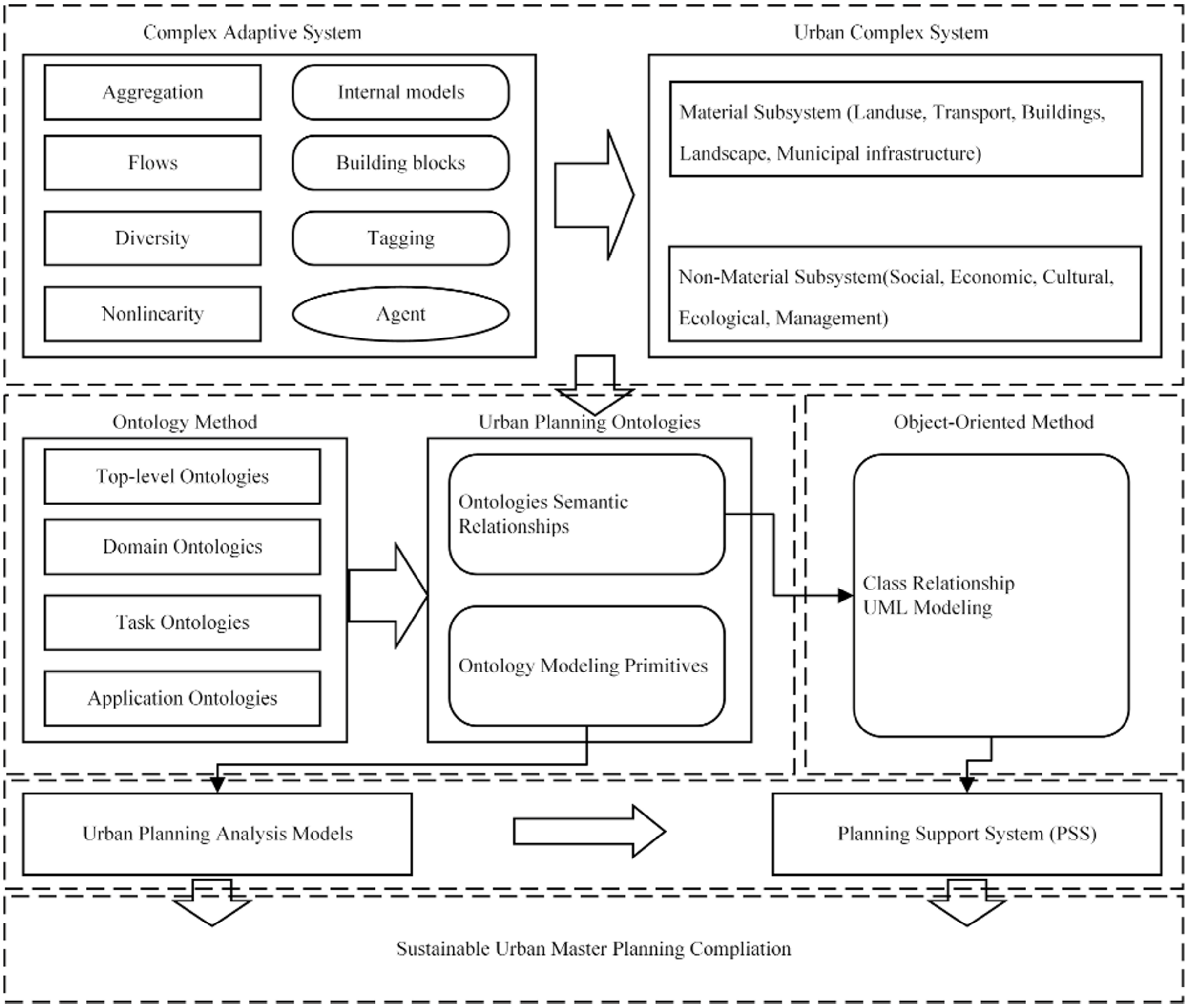

Figure 1 An outline of the theoretical and methodological foundations underpinning this research.

operation of these agglomerations via mutual interactions and learning as well as how local interactions between these factors lead to the emergence of complex global patterns with novel features (i.e., innovation network, industrial clusters) (Holland 1995). Complex adaptive systems (CAS) consist of both rule-based and interacting agents; these adapt to others as well as to their environments by changing their rules of operation, leading to the development of complex dynamic patterns. A complex adaptive system contains seven basic components which can be used as a theoretical framework to understand urban complex systems (Table 1). In another key study in this field, Levin argued that the key to research on complex adaptive systems is an understanding of the interrelationships between micro-processes and macro-patterns as well as the forces that drive and shape the evolution of the whole system (Levin et al. 2003). As these concepts are especially important with regard to ecosystems and urban socioeconomic systems, current research is focused on features such as diversity and resilience as systematic evolution occurs mainly at the level of interactions between agents in different echelons.

The urban planning process involves mainly four kinds of adaptive agents within a city,

Table 1 Detailed description of the basic characteristics that comprise an urban complex adaptive system.

Characteristics		Key role	Description	Example in urban master planning
Properties	Aggregation	Emergence of macro behavior	Building from primitive settlements to towns, cities, and urban agglomerations, the impetus for the development of an urban complex system is the spatial agglomeration of economy and people. The clustering effect of industrial development therefore promotes urbanization	Functional districts promotes the agglomeration of features.
	Nonlinearity	Causes a complex state	As a city is a multi-agent driven self-organizing system, its spatial interactions are nonlinear. Uncertain factors to do with urban and regional development therefore lead to highly complex urban evolution.	Mechanical functional districts causes traffic problems, social problems, etc.
	Flow	Enhances the system effect	Cities can be regarded as interactions between different flows (i.e., people, information, resources, traffic, biology). Multiplier and recycling effects caused by the superimposition of different flows inject new vitality into city development	Urban infrastructure planning promotes the interaction of different flows and enhances rrban vitality
	Diversity	Promote system stability	Diversity is an intuitive feature of urban complex systems and different social groups comprise different city agents. The interactions and influences of different agents promote the coordination of urban systems	Public participation promotes the maximization of public interest and maintains urban stability
Mechanisms	Tagging	Influences boundary generation	The boundaries, roads, regions, nodes, and landmarks within a city comprise different urban image spaces that facilitate the aggregation of different population groups and enable people entering urban spaces to access information efficiently	Space control zoing helps to protect ecological environment
	Internal models	Enhances system resilience	Urban planning requires an understanding of the laws governing the evolution of such complex systems. Predictive models for the development of different elements (i.e., population, land use, transportation) are key internal models	Prediction population and land use helps to develop appropriate measures to enhance urban resilience.
	Building blocks	Generates adaptive patterns	The combination of different functional areas within urban systems, planning hierarchies, and multi-level schemes are different manifestations of urban building blocks	Residential district, industrial district, Central Business District (CBD), commercial district is the building blocks of the city.

including urban residents, managers, developers, and experts. These agents all exert impacts on decision-making and the results of urban planning. Thus, the concept of urban residents refers to all citizens affected by a planned area, as well as organizations encompassing different domains such as society, economy, and culture. The concept of urban managers refers to members of the administrative departments involved in the formulation, preparation, approval, implementation, supervision, and management of planning policies in this area, while the concept of urban developers encompasses all entities that participate in planning and construction processes, including real estate developers and builders who create infrastructure. Finally, the concept of urban experts mainly refers to individuals who participate in the formation, approval, and supervision of planning, including planners, professionals from other fields, and PSS system developers.

1.3 Urban planning ontologies

Drawing on Giaretta and Guarino's (Giaretta and Guarino 1995) definition of ontology, we define the urban planning ontology as “a formal, explicit specification of a shared urban planning domain conceptualization”. In an earlier study, Guarino noted that in terms of the accuracy and level of detail (i.e., coarse or fine-grained ontology) that comprise representative domain knowledge, a fine-grained approach should be referred to as reference ontology while a coarse-grained approach can be viewed as a shared ontology (Pileggi et al. 2017). Similarly, this field can be divided into top-level, domain, task, and application ontologies according to generalization level and domain knowledge. Urban planning ontologies can therefore be divided into three categories that deal with domains, tasks, and applications.

The terminology system that constitutes the urban planning ontology mainly comes from the understanding of urban complex systems based on complex adaptive system theory, urban planning standards system, urban planning texts and urban planning expert knowledge. Describe and analyze the urban complex system characteristics based on the theory of complex adaptive systems, extract the related terms and concepts of urban material subsystem and non-material subsystem are extracted to support the construction of urban planning ontology, Table 2 shows the material subsystem as an example.

Urban planning domain ontologies therefore encompass a specific generic vocabulary as this field is closely related to entities that include urban material subsystems (i.e., land use, transport, building, municipal infrastructure, landscaping) and non-material subsystems (i.e., social, economic, cultural, ecological, and managerial). Ontologies within this domain can also be subdivided into ten distinct categories.

The urban planning task ontologies represent common tasks in the field of urban planning. The planning compilation, approval, implementation, management, and supervision involved in the urban planning process are all urban planning task ontologies. Urban planning tasks include: master planning, near-term construction planning, detailed planning, and non-statutory planning; urban planning approval tasks include: overall planning approval, near-term construction planning approval, detailed planning approval, and non-statutory planning approval. There are two cases of urban planning implementation tasks, one is the implementation of major engineering and infrastructure construction projects, and the other is the implementation of general construction projects; urban planning evaluation tasks mainly include: evaluation of planning plans, evaluation of planning implementation processes, and evaluation of the effects of planning implementation; planning management and supervision mainly include: planning preparation management, planning approval management, planning implementation management, and planning supervision. The contents of the urban master planning task mainly include: preliminary basic data collection, determination of urban functions and urban nature, urban development strategies, urban scale, urban system planning, overall urban layout, urban ecological protection and space control, urban fourth-line delineation, Protection of historical and cultural cities, multi-regulation integration and recent construction planning. Detailed planning is mainly divided into regulatory detailed planning and constructive detailed planning. Regulatory detailed planning proposes control indicators and control guidelines for urban land use and development and

Table 2 The list of terminology of urban material subsystem

Complex Adaptive System		Material subsystem				
		Landuse	Transport	Buildings	Municipal infrastructure	Landscape
Properties	Aggregation	Town, urban, urban network, functional districts, industrial cluster ...	Transport network, transportation hub, station, airport ...	Block, school, Central Business District(CBD), place, urban structure, urban texture ...	Infrastructure network, power plant, sewage plant, destructor plant ...	Park, wet land, green infrastructure, ecological network ...
	Nonlinearity	Urban sprawl, landuse structure, landuse capacity ...	Traffic capacity, traffic flow, commuting ...	City image, positive space, negative space ...	Demands, supplies, interaction	Human activities, capacity ...
	Flow	Resource flow, energy flow, information flow	Resource flow, human flow, mobility ...	Resource flow, energy flow ...	Material flow, energy flow, information flow ...	Material flow, energy flow, information flow ...
	Diversity	Landuse types, landuse structure, urban morphology ...	Trip modes, traffic subjects, traffic networks ...	Building type, architectural style and texture ...	Electricity, logistics, water supply and drainage ...	Parks, wetland, scenic regions ...
Mechanisms	Tagging	Location, landuse policy, landuse planning ...	Railway station, transportation hub, transportation planning	Public space, sacred buildings, detailed urban planning	Power plant, sewage treatment plant, infrastructure planning	Parks, scenic regions, landscape planning ...
	Internal models	Eco-sensitivity analysis and delimitation of urban growth boundary ...	Traffic network evaluation, traffic development model ...	Hybrid residential, urban affordable housing ...	Equalization of Basic Public Service ...	Construction of Urban Ecological Network ...
	Building blocks	Slope, altitude, geological disasters, rivers, farmland ...	Traffic subjects, vehicle, city road classification ...	Residential type, building type, building quality ...	Infrastructure type, urban resident subject	Patches, matrices, corridors ...

construction. It is the legal basis of administrative and guides construction detailed planning. The main content is the determination of prescriptive and guiding control indicators. The construction detailed planning is based on the master plan and the control detailed planning, and the main content is the specific planning and design of various buildings and engineering facilities. Figure 2 shows the contents of the urban master planning ontologies (created by using the software Protégé 5.2.0).

Urban planning application ontologies refers to the planning analysis model rely on domain ontology and task ontology. Take ecological sensitivity analysis model for example(Figure 3), urban master plan needs to take the regional ecological background as the premise of urban development, ecological sensitivity analysis is mainly related to ecological subsystem and land subsystem. By identifying the ecological limiting factors (elevation, slope, geological hazards, water system, forest, basic farmland, ecological protection area, construction land, etc.) which affect the sustainable development of cities, ecological sensitive areas are delineated to provide support for the division of main functional areas and spatial control zoning.

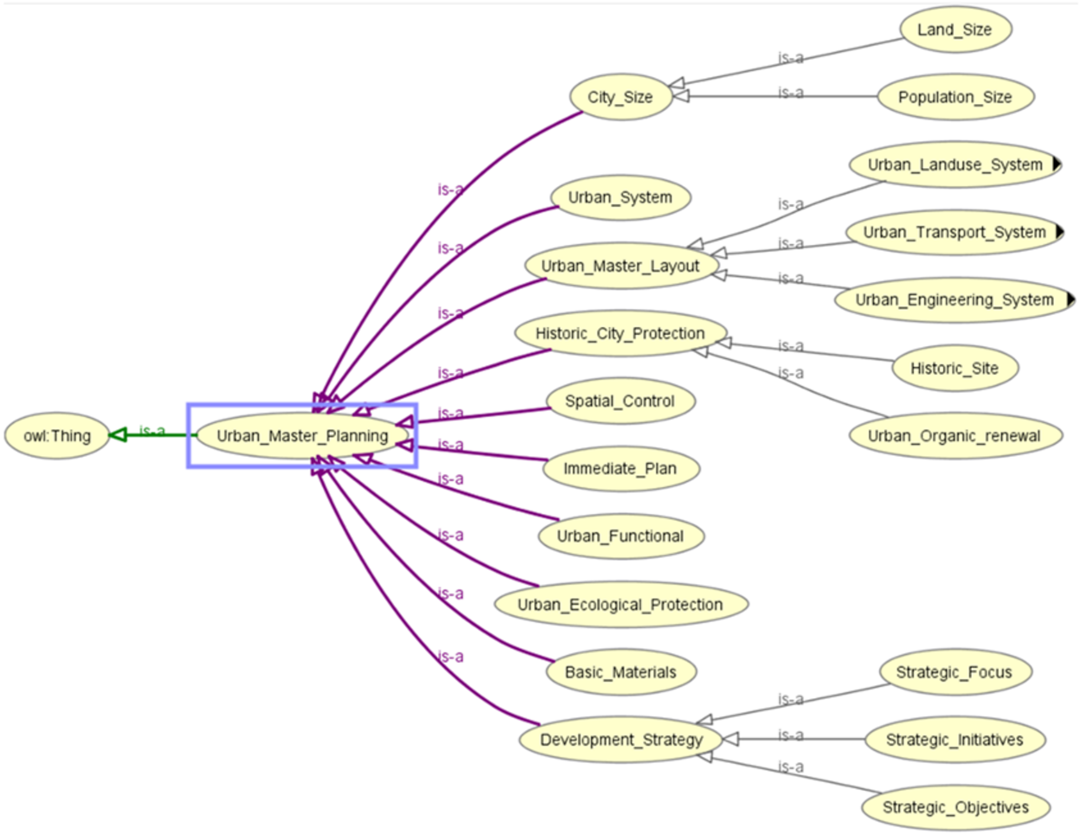

Figure 2 Summary of urban master planning ontologies. This figure is created by software Protégé 5.2.0. The "is-a" in this figure represents the relationship between concepts. The black triangle to the right of the yellow ellipse indicates that there are some subclasses of this concept that are not expanded.

1.4 Relationships between urban planning agents and ontologies, urban planning ontologies and PSS

As mentioned earlier, there are mainly four adaptive agents are involved in the urban planning process: urban residents, managers, developers, and experts. Thus, as a standardized expression of knowledge in this field, urban planning ontologies provide a common semantic basis that enable different agents to reach consensus. In this context, a PSS can be utilized as part of the auxiliary decision-making process to enhance scientific content and to ensure that the overall urban planning process is ontology-driven. The inter-relationships between urban planning agents, ontologies, and the use of a PSS are summarized in Figure 4; in this context, the level to which different city agents (stakeholders) are concerned, or master, knowledge concepts in urban planning (urban planning ontologies) will differ from one another. The main concern of urban residents is obviously how planning measures will affect their lives and work; these stakeholders are therefore mainly concerned with urban planning domain ontologies including the convenience of transportation from home to their workplace and the level of public facilities adjacent to their families. In contrast, urban managers and developers are likely to be more familiar with planning domain ontologies (economic, social, municipal infrastructure etc.) that include the influence of system elements on development as well as urban planning task ontologies that include formulation, implementation, and management components. As urban experts actually participate in the planning process, it is necessary for them to be familiar with top-level, domain, task, and application ontologies; urban domain, task, and application ontologies comprise the knowledge base that supports decision-making, approval, implementation, and the supervision of urban planning and necessitate the development of a planning analysis model system based on shared ontologies. The organization of multi-source

Figure 3 An example of urban planning application ontologies - ecological sensitivity analysis application ontology. This figure is created by software Protégé 5.2.0. The "is-a" in this figure represents the relationship between concepts. The black triangle to the right of the yellow ellipse indicates that there are some subclasses of this concept that are not expanded.

heterogeneous data into a subject-oriented data warehouse (As mentioned earlier, the urban complex system is divided into ten subsystems. Accordingly, the data will be organized according to ten subjects: landuse, transport, buildings, municipal infrastructure, landscape, social, economic, cultural, ecological and management. These ten subjects are also urban planning domain ontologies mentioned earlier.) , the urban planning domain ontology in the knowledge base provides support for the construction of the data warehouse. The data warehouse provides data support for the analysis of the model base and the knowledge base. Data warehouse, knowledge base and model base can enable the development of a planning support system and can also be structured visually for display to urban planning agents.

2 Augmented PSS Framework for Urban Master Planning

2.1 Technology framework

The technical methods used in this study mainly encompass ontology approach and software engineering approaches which themselves correspond with the construction of urban planning ontology and ontology-driven planning support systems (Figure 5). The ontology approach

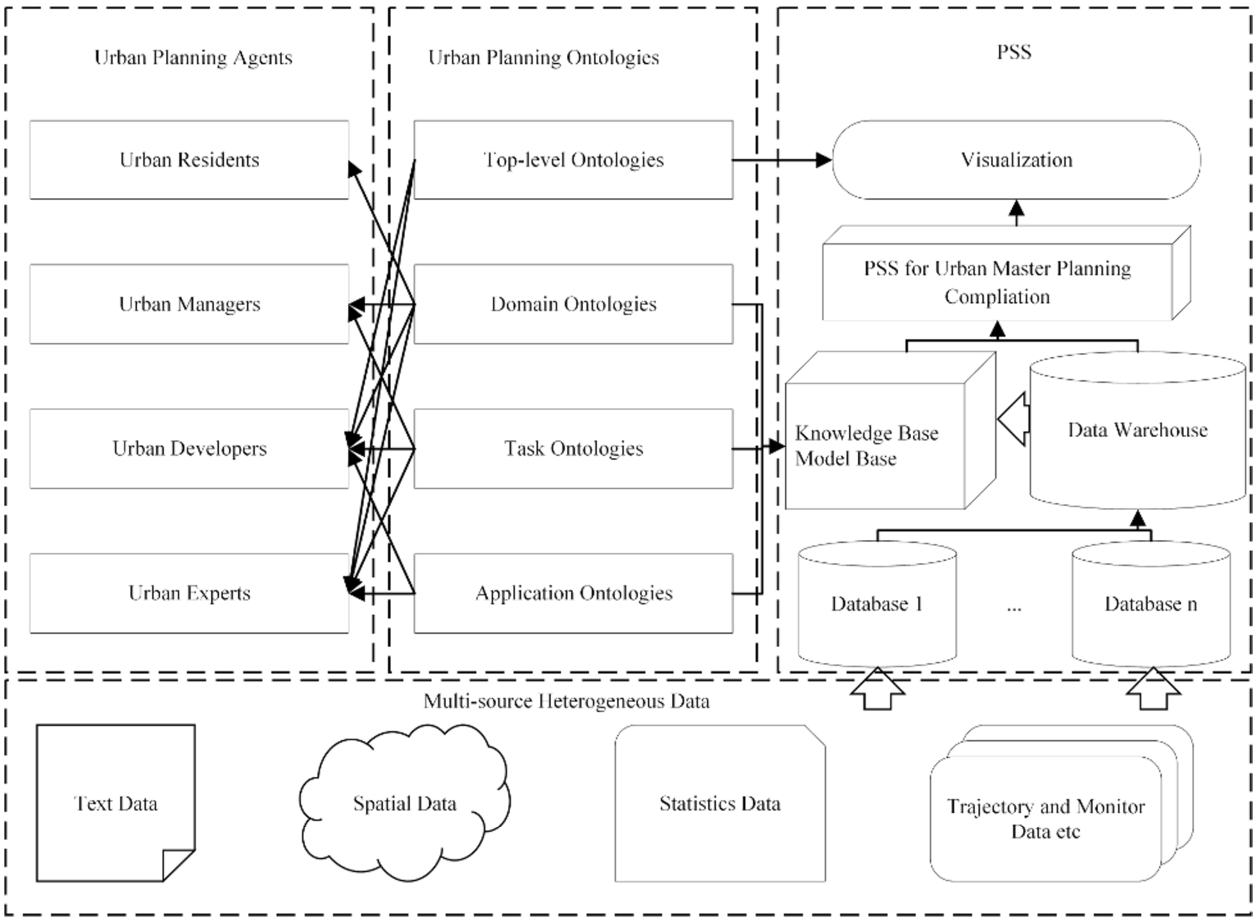

Figure 4 Summary of the relationships between urban planning agents, urban planning ontologies, and planning support system (PSS).

used in this study (the blue line in Figure 5) encompass acquisition, representation, and application. The first of these, knowledge acquisition, encapsulates conceptual terms in the urban planning domain and their inter-relationships in terms of information about urban system characteristics based on the theory of complex adaptive systems, planning standards, and experts in the field. The foundation of knowledge representation, encompassing urban planning ontologies as well as the information and model base, provides support for the construction of a relevant approach and enables the development of a county-level system that can be used to feed into city master planning. At the same time, ontology-driven approaches also support the construction of planning support systems (the red line in Figure 5); in this context, software engineering methods mainly encompass the themes of data and development architecture. The first of these deals with the organization, storage, and management of data; a subject-oriented urban planning data warehouse was therefore established while a model-based knowledge system facilitates the relationship between information from different subjects to augment the discovery process. The development architecture used in this study was based mainly on the Microsoft system integration development platform Microsoft Visual Studio 2012 implemented alongside the object-oriented programming language C# and the GIS secondary development component ArcGIS Engine 10.2.2 (ESRI). These approaches were used to generate an ontology-driven county-level urban master plan and to support the development of an appropriate prototype system.

2.2 Application framework

The data–information–knowledge–wisdom pyramid (DIKW) is a central model of information management, information systems and knowledge

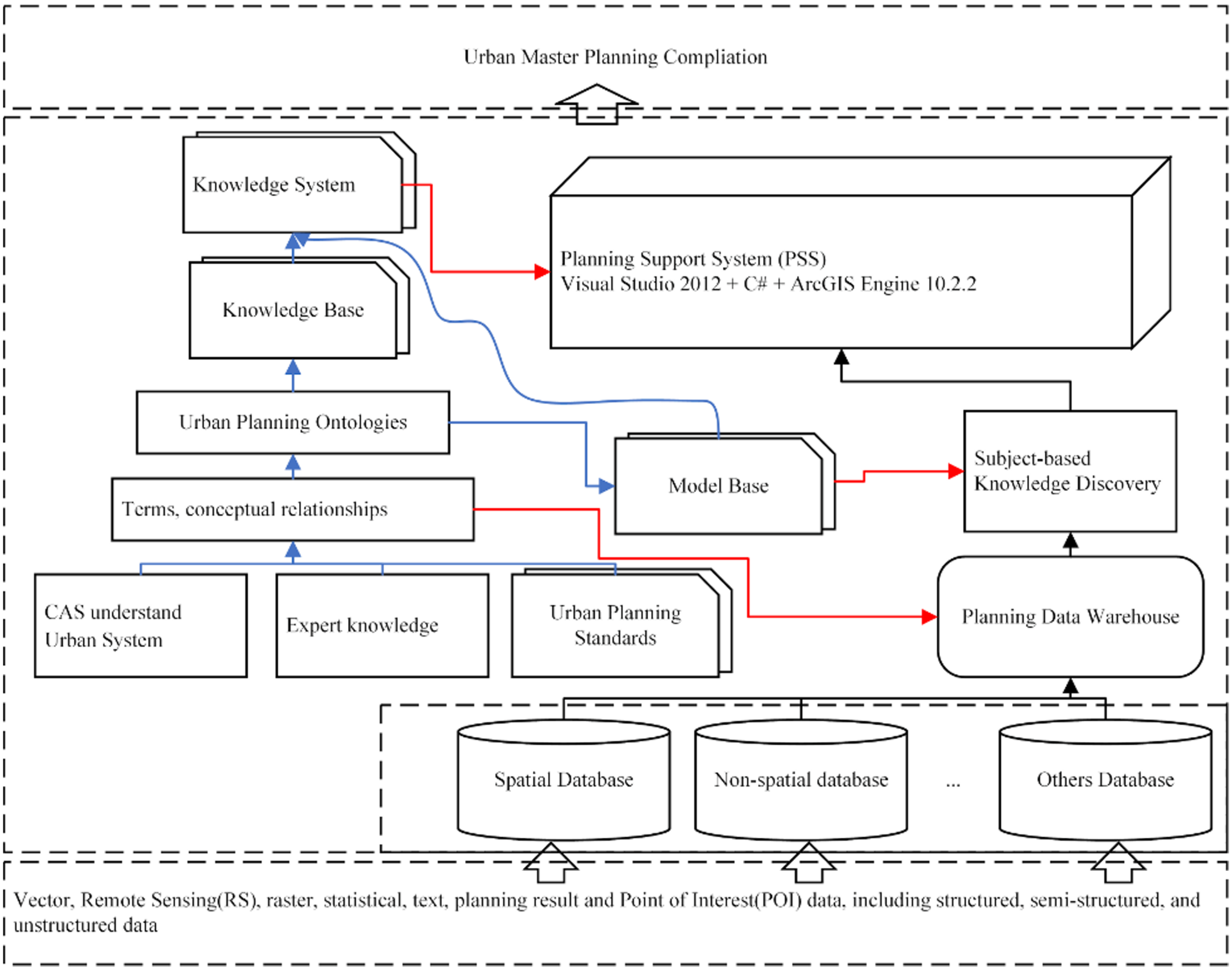

Figure 5 Technology framework of the augmented planning support system framework. The blue line in this figure presents the ontology method, encompass ontology terms acquisition, ontology construction, representation, and application. The red line presents the ontology-driven method supporting the construction of planning support systems. CAS is the abbreviation of complex adaptive system, PSS is the abbreviation of planning support system.

management (Rowley 2007; Kazak and Van Hoof 2018). The concept of DIKW is also a common acquisition and application process that encompasses the two dimensions of context and understanding. Data comprises the lowest level of this system and provides information as it can be used to determine and understand the relationship between contexts, while knowledge is achieved by understanding and discovering embedded patterns. This step also involves the synthesis of new information based on patterns; thus, wisdom is generated via the continuous accumulation of knowledge. Learning the patterns and principles of human and natural behavior means that these data can then be properly applied in context (Ahsan et al. 2006; Hey et al. 2009; Bernstein et al. 2011). It is also important to note that the DIKW transformation process is value-added.

Data can be used to represent isolated, untreated information in urban planning; in this context, master plan formation mainly refers to data collected during this basis step. Indeed, as the Computer Aided Design (CAD) drawing system has become the default standard in this field, a large component of spatial data tends to be generated using this approach (e.g., status and planning maps). It is worth bearing in mind, however, that CAD format data places more emphasis on cartography and presentation, while urban planning area characteristics are usually represented by a series of symbols and figures that encapsulate little detailed attribute information and have a very weak spatial analysis function. Thus, although data in CAD format cannot be used for urban planning spatial analyses, it is nevertheless an important component for decision-making.

The data conversion process used in this analysis involved cleaning, processing, and standardizing isolated, pre-processed information. This was undertaken by initially converting data in CAD format to GIS format, unifying the coordinate system, and subdividing the contents into different subject information sets (i.e., land use, traffic, building, municipal infrastructure, landscape, social, economic, culture, ecology, and management datasets).

Knowledge in this context refers to the processes of answering and solving problems inherent to the planning process (e.g., the relationship between cities and regions within an urban master plan, the direction of urban development, and the functional layout of land use). In urban planning, knowledge encapsulates a variety of analytical models, including land suitability and evaluation approaches that are applied by combining land use resistance with other potential factors to address issues of construction land layout.

Wisdom in this context refers to the application of a planning analysis model that was developed during the knowledge stage of the urban planning and evaluation process.

We developed a smart application system framework for an urban master plan by following the steps of the DIKW transformation process (Figures 6, 7), first of all, the compilation of urban master plans requires the collection of various types of data, such as statistical data, remote sensing image data, CAD data, spatial data, points of interest (POI) data, and check-in data. These data is isolated and unprocessed. We need to clean, process, standardize and spatialize these data, and manage it in the form of subject information of the data warehouse (land use, transport, building, municipal infrastructure, landscape, social, economic, cultural, ecological, management). The Urban Planning Analysis Model (Knowledge) such as ecological sensitivity analysis, multiple scenario analysis, land suitability assessment uses these information to answer or solve the problems such as urban development direction, urban landuse function layout, equalization of basic public services which existing in the process of urban master planning compliation. And serve the compliation of urban master planning, provide support for the decision of the urban master planning (Wisdom).

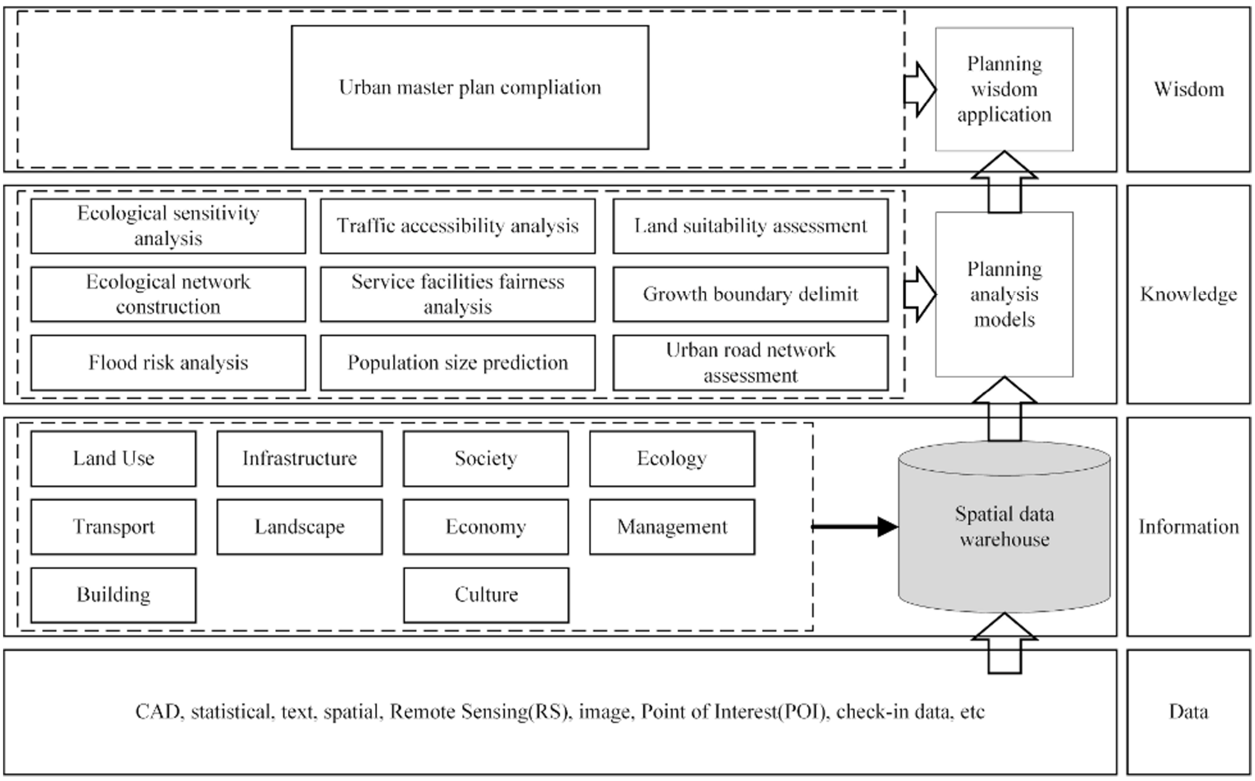

Figure 6 The application framework of the augmented planning support system.

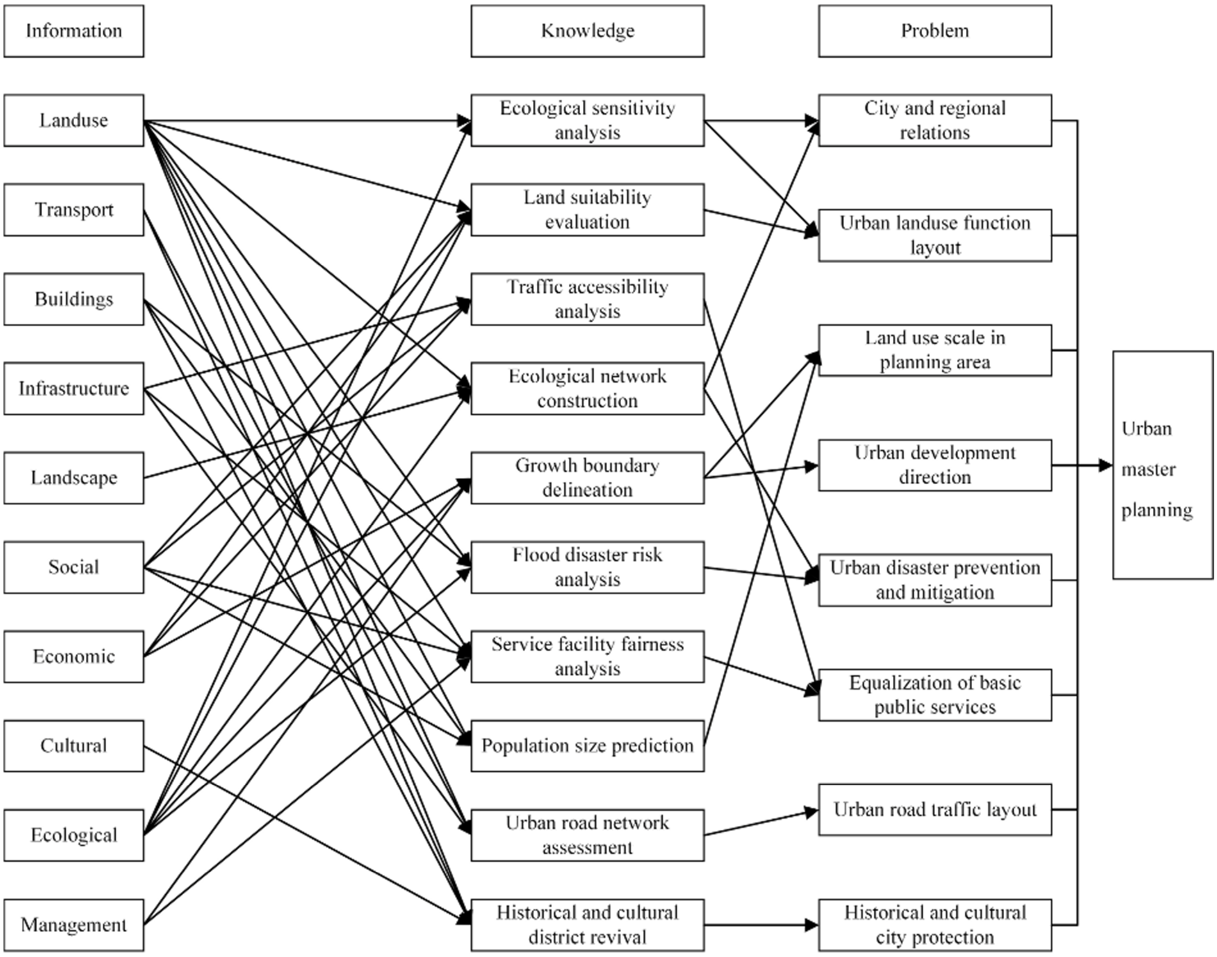

Figure 7 Corresponding Relationship among Information, Knowledge and Urban Problems to be solved in urban master planning.

2.3 Concrete framework implementation

An ontology-driven planning support prototype system was established for the development of an urban master planning for Changting County, Fujian Province, China. A decentralized planning analysis model was integrated into a unified interface for management in order to facilitate centralized analysis and decision-making. The Changting urban master planning support prototype system employs the currently popular integrated software development platform Microsoft Visual Studio 2012 utilized in tandem with the ArcGIS component development software package ArcGIS Engine 10.2.2 (ESRI). The C# object-oriented language was utilized for development and this prototype system interface uses the interface library software DotnetBar for Windows Forms 12.7 for organization, adjustment, and optimization. The main interface of the Changting urban master plan support system is shown in Figure 8.

3 Case Studies in Changting

Changting is located in the southwest of Fujian Province, China, at the southern foot of the Wuyi Mountains. It is a mountainous city and a national historical and cultural city. After more than 40 years of rapid development in reform and opening up, great changes have taken place in the urban and rural spatial form and pattern of Changting. With the opening of the Ganzhou-Longyan double-tracking railways, the planning and rerouting of highways, national highways and railways, the regional traffic conditions in Changting have undergone a fundamental change. In addition, the old urban area is mainly a historical and cultural

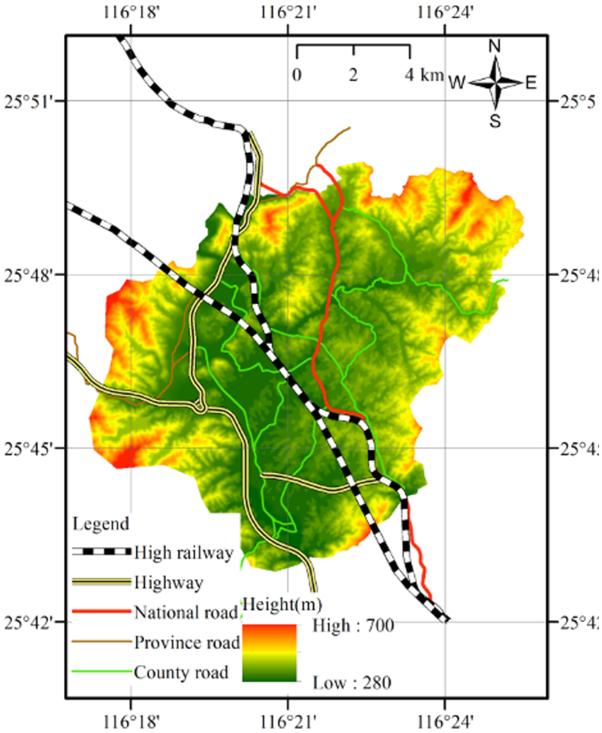

Figure 8 A concrete example of framework implementation: The main interface of the Changting urban master planning support system. This figure is created by the author's secondary development software based on ESRI ArcGIS Engine 10.2.2 + Visual Studio 2012 + DotnetBar for Windows Forms 12.7.

city, and the population and development intensity have reached saturated state. In order to protect the national historical and cultural city, the development direction of the city has shifted to focus on accelerating the construction of the southern new district of Changting. Because urban development faces many uncertainties, these uncertainties affect the pattern of future spatial development. Scenario refers to the future situation and a series of conditions that can make the state of affairs develop from the present to the future. Scenario analysis is a management decision-making tool that studies the uncertain situation of the future. It uses scientific methods to describe and analyze some of the most likely developments in the future track. Multiple scenario analysis is now claimed to support the process of strategic decision making, enclosing aspects as varied as the generation of options and the building of consensus (Bond et al. 1998; Zong et al. 2007). The process of scenario development: Phase one, problem identification and demarcation of its context. Phase two, description current situation and identification relevant factors. Phase three, Classification, valuation and selection of scenario-elements. Phase four, construction of scenarios. Phase five, analysis, interpretation and selection of scenarios. Phase six, supporting strategic decision-making with scenarios (Bond et al. 1998). The case uses a multi-scenario analysis model in the planning support system to analyze the multiple situations of the city's future development, thereby creating conditions for stakeholders to reach consensus under a common understanding. The evolution of urban and rural spatial forms and patterns is a long-term process that promotes the flow and interaction of various factor flows through the combined effects of macro policies, economics, society, major infrastructure, information and communications technology (ICT), minerals and energy resource development. Based on the analysis of the revised urban master planning texts and land use status in the four periods of Changting (2008, 2010, 2012, 2016), the main factors driving the evolution of the urban-rural spatial pattern are extracted: national and regional strategies, total population, urban population, gross output of the secondary industry, third Gross industrial product, regional Gross Domestic Product (GDP), transportation network (mainly high-speed rail and highways to strengthen external links), real estate, flooded areas, ecological protection red lines, national historical and cultural cities protection policy, municipal and public service facilities, mineral energy Development, etc., to form a multi-scenario analysis application ontology. Multi-scenario analysis application ontology is shown in the Figure 9.

Consider the urban-rural spatial development pattern under three scenarios: economic-oriented, ecological-oriented, and coordinated economic-ecological development according to the sustainable development of the city. Economic-oriented is a development mode that maintains rapid economic growth, rapid growth of regional GDP, rapid growth of urbanized population, high utilization of water resources and mineral resources, and continued occupation of ecological and agricultural space by urban land. Ecological-oriented is a development mode that places too much emphasis on ecological environmental protection, low economic growth, slow growth of regional GDP, slow growth of urbanized population,

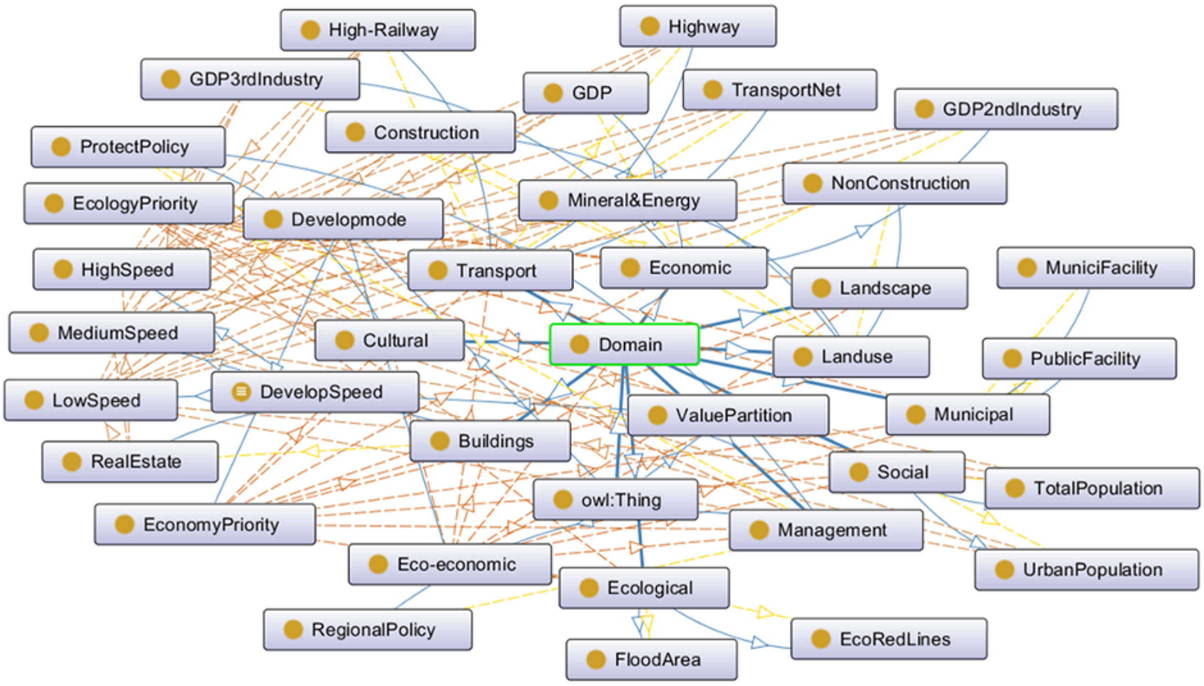

Figure 9 Multi-scenario analysis model application ontology. This figure is created by software Protégé 5.2.0. The blue arrowed line represent "has" relationship between concepts, the yellow arrowed line represent "has Elements" relationship between concepts, the brown arrowed line represent "has Factor" relationship between concepts.

Table 3 Factor settings related to multi-scenario analysis model.

Driving forces	Scenario		
	Economic-oriented	Ecological-oriented	Coordinated economic and ecological development
National and regional strategies	Focus on economic development	Focus on ecological protection	Support coordinated development
Total population growth rate (%)	1.7	1	1.3
Urban population growth rate (%)	1.5	0.7	1
GDP (%)	12	5	8
GDP of secondary industry (%)	14	5	10
GDP of third industry (%)	15	7	12
Historical and cultural city protection policy	Neglect protect	Strict protection	Protection and utilization
Transport Network	Rapid development	Development under the premise of protection	Development and protection
Real estate	Disorder and oversupply	Supply fails to meet the demand	Supply and demand balance
Flooded Inundation area	Neglect protect	Strict protection	Protection and utilization
Ecological protection red line	Damage	Strict protection	Protection
Municipal and public services	Supply fails to meet the demand	Supply fails to meet the demand	Supply and demand balance
Mineral and Energy Resources Development	Pay more attention to development	Pay more attention to protection	Develop and protect simultaneously

low utilization of water resources and mineral resources, and no longer expanding urban land. Coordinated economic-ecological development is a balanced development mode that takes into account economic development and ecological protection. It is mainly manifested in medium-speed economic growth, regional GDP growth, medium-speed urban population growth, and moderate utilization of water and mineral resources, intension existent development of urban and rural construction land. Set the relevant factors of the multi-scenario analysis model according to the social and economic development of Changting, as shown in the following Table 3. Multi-scenario analysis model analysis results about Changting 2025 development are shown in the Figure 10.

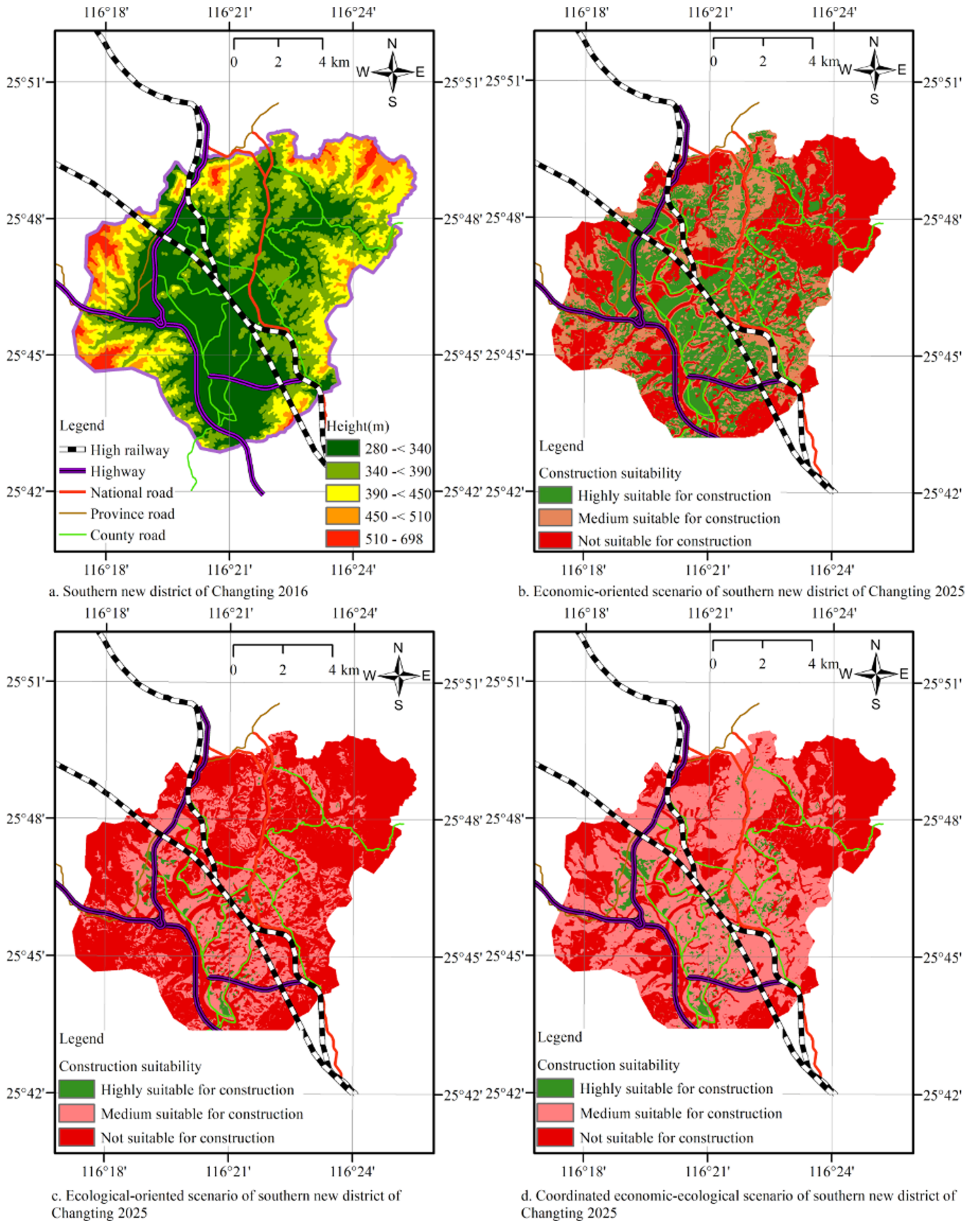

Figure 10 The base year scenario of the master planning in the southern new district of Changting in 2016 (a). Economic-oriented scenario of the master planning in the southern new district of Changting in 2025 (b), ecological-oriented scenario of the master planning in the southern new district of Changting in 2025 (c), coordinated economic-ecological of the master planning in the southern new district of Changting in 2025 (d).

The economic-oriented development mode has proven to be an unsustainable development mode. In Figure 10b, the construction land area reached 34.96 km² in 2025. Based on the per capita construction land area of 100 m², the population reached about 350,000 people, far exceeding the population development scale of 39,500 people. Land urbanization is faster than human urbanization. Municipal and public service facilities cannot meet the needs of a rapidly urbanizing population. Rapidly and disorderly developed cities occupy ecological and agricultural space, causing serious consequences such as soil erosion, floods, and other disasters, and causing serious waste of resources and energy.

The ecological-oriented development mode places too much emphasis on ecology and environmental protection, restricting the increase in construction land (Figure 10c), the construction land area reached 1.79 km² in 2025. Based on the per capita construction land area of 100 m², it can only carry about 18,000 people, which is far smaller than the population development scale of 39,500 people, low-speed growth of urban population and regional GDP, causing demand for real estate, municipalities and public service facilities to outstrip supply. Changting is currently in the middle stage of industrial development, with ecological-oriented development mode is incompatible with the current development stage of Changting.

The coordinated economic-ecological development mode emphasizes sustainable economic, ecological, and social development (Figure 10d), the construction land area reached 4 km² in 2025. Based on the per capita construction land area of 100 m², it can carry about 40,000 people, which is basically equal to the population development scale of 39,500 people. This is compatible with the stage of Changting's industrialization and urbanization, and also compatible with the current background of China's development. In the development process, we pay attention to both development and protection, and continuously improve the well-being of the people under the premise of protecting the ecology, and create a mountainous city where people and nature live in harmony.

4 Discussion and Conclusions

Urban planning is one of the most complex activities in the public arena as it involves the interrelationships and interactions of various components of urban complex systems. Good urban planning can reduce and adapt to environmental impacts on nature. As an important tool to assist urban research, urban planning decision-making and implementation effectiveness, the planning support system needs a comprehensive and systematic "understanding of complex urban systems - extraction of knowledge elements in the field of urban planning - construction of knowledge in the field of urban planning - construction of urban planning support systems" framework. At the same time, the current planning support system is generally a "user (stakeholder) -system" construction mode. There is no effective communication between users and the system, which limits the user's understanding of the planning support system. The complex adaptive system theory, as the latest achievement of the development of systems science theory, provides a new theoretical perspective for understanding urban complex systems. Ontology, as a technical method for sharing knowledge in the field to promote consensus among stakeholders, provides a methodological perspective for the construction of urban planning ontology. This study attempts to build a systematic and complete planning support system framework, that is, complex adaptive system theory to understand urban complex systems-to extract knowledge elements in the field of urban planning-to build the urban planning ontology-to build a planning support system for urban master planning, and apply this framework to the practice of mountainous city master planning.

The research attempts to understand urban complex systems through the theory of complex adaptive systems, and analyze the material (landuse, transport, buildings, municipal infrastructure and landscape) and non-physical (social, economic, cultural, ecological and management) subsystems that make up urban complex systems. On this basis, the basic characteristics and knowledge of urban complex adaptation systems are extracted to provide support for the construction of urban planning ontology. The urban planning ontology (domain ontology, task ontology, application ontology) provides support for the construction of the urban master planning knowledge system and the urban planning analysis model. The urban master planning knowledge system and urban planning analysis model based on the urban planning ontology facilitate stakeholders' reach consensus based on a common understanding of planning domain knowledge. The urban planning ontologies supports the construction of the planning support system in temporal (development including requirement analysis and conceptual modeling as well as operation including communication facilitation) and structural (ontologies impact on information system components including databases, application programs, and user interfaces dimensions). Promote the transformation of the planning support system construction mode from "user (stakeholder)-system" to "user (stakeholder)-urban planning ontology-system". On this basis, the Data-Information-Knowledge-Wisdom mode is used to build a planning support system for the master planning of Changting, a mountainous city. The multi-scenario analysis of the future urban development of Changting has proved the practicability of this systematic planning support system construction method.

At present, the systematic planning support system framework proposed in this study still needs to be improved. The understanding of urban complex systems through the theory of complex adaptive systems results in only some preliminary results, and the in-depth study of urban complex systems will be the focus of future research. The reasoning ability of urban planning ontology is not enough. In the future, the knowledge graph for mountainous city planning will be built on this basis. The urban master planning compiled ontology by the research facilitates the user's understanding of the knowledge of urban planning, and plays a role in the interactive understanding of users and systems, but it needs to be continuously improved in future research.

Acknowledgements

This paper was funded by the National Natural Science Foundation of China (Grants No.51278239, 51778278 and 41771133). We appreciate the contributions of two anonymous reviewers.

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