An ontology-based multicriteria spatial decision support system: a case study of house selection

Jacek MÄLCZEWSKI* and Mohammadreza JELOKHANI-NIARAKI

Department of Geography, Western University, London, Ontario N6A 5C2, Canada

(Received 1 March 2012; final version received 28 April 2012)

The paper proposes an ontology-based multicriteria spatial decision support system (MC-SDSS) for the house selection problem. The house selection ontology serves as a foundation for spatial multicriteria decision analysis (MCDA) in the house selection domain. It is built using the Web Ontology Language (OWL). The ontology represents the spatial MCDA knowledge associated with house selection using semantic machine-interpretable concepts and relationships in such a way that they can be used by machines not just for display purposes, but also for processing, automation, integration, and reuse across applications. It contains concepts (or classes) including quantitative and qualitative criteria (objectives and attributes), decision alternatives (houses for sale), criterion weights, and location attributes of the decision alternatives. The concepts are organized into a hierarchical classification structure using the Analytic Hierarchy Process. To evaluate the decision alternatives, a set of rules is implemented within the OWL knowledge base with the Semantic Web Rule Language. The rules are expressed as combinations of the OWL concepts and their properties. The paper illustrates an implementation of the proposed ontology-based MC-SDSS architecture using a case study of house selection in the City of Tehran, Iran.

Keywords: GIS; multicriteria analysis; spatial decision support system; ontology; house selection

1. Introduction

One of the most common tools for solving complex spatial decision problems is a multicriteria spatial decision support system (MC-SDSS). The system integrates the geographic information system (GIS) capabilities (spatial databases and analyses) and multicriteria decision analysis (MCDA) techniques to support users in the decision-making process (1–5). The lack of semantic description for the MC-SDSS elements (criteria, alternatives, criteria relative importance, etc.) has been a substantial obstacle in advancing research on integrating MCDA and GIS (4, 6, 7). Such elements are not machine-understandable and machine-interpretable; they cannot be interpreted, processed, accurately searched, shared, and reused by web-based software agents and applications. Furthermore, the systems do not provide a flexible framework allowing users to perform decision analysis in easy-to-use, interactive, and run time manner. The use of ontology for developing the MC-SDSS can alleviate these problems (4). Ontology is a conceptualization of a domain (e.g. the search for housing) into a human-understandable and machine-readable format consisting of entities, attributes, relationships, and axioms (8, 9). Although the term ontology may have different connotations depending on the discipline (e.g. philosophy vs. artificial intelligence), we use the term to mean the classification structure and instances within the knowledge base. In this paper, the ontology is designed to represent the house selection domain (10, 11). The search for housing can be thought of as a multicriteria decision problem involving a set of entities (housing or decision alternatives) which are evaluated on the basis of multiple criteria (attributes associated with the housing alternatives) according to some decision (evaluation/choice) rules (12). From this perspective, ontology is seen as a knowledge-base which models the house selection domain using the MCDA methods such as the Analytic Hierarchy Process (AHP) (13).

A number of decision support systems have been developed in the field of housing over the last 20 years or so (4). These systems were designed to support users in a variety of decision situations including real estate evaluation and house selection (14–20). The Internet has recently been recognized as a platform for developing decision support systems for the house selection problem (17). This trend has been stimulated and reinforced by the paradigm for designing websites for real estate. Over the last decade or so, the number of those websites has increased so considerably that it is often very difficult for the consumers to find what they are looking for (17). For this purpose, an ontology-based MC-SDSS for the house selection problem can be used to assist in selecting a house according to the user’s preferences. The main characteristic of such
MC-SDSS is that it can personalize its recommendation to each user according to his/her preferences. Also, it provides a flexible, machine-understandable, interactive, interoperable, run time, and reusable framework for decision analysis in the house selection domain.

The rest of this paper is organized as follows. Section 2 describes the process of developing ontology web language (OWL) ontology for the house selection domain. The Semantic Web Rule Language (SWRL) rules are elaborated in Section 3. An implementation of proposed approach is demonstrated in Section 4. Finally, Section 5 offers concluding remarks.

2. Developing house selection ontology

Ontology is a set of knowledge terms, including the vocabulary, the semantic interconnections, and some simple rules of inference and logic for a particular domain (21). It is “a formal, explicit specification of a shared conceptualization,” (8) which involves organizing a set of terms into a hierarchical structure (22). Noy and McGuinness (23) describe the process for developing ontology in the following steps: (1) determine the domain and scope of the ontology, (2) consider reusing existing ontologies, (3) enumerate important terms in the ontology, (4) define the classes and the class hierarchy, (5) define the properties of classes – slots, (6) define the facets of the slots, and (7) define instances of the classes. The seven step procedure for developing ontology is shown in Figure 1. One can identify two major phases of this seven step process: (1) the preliminary considerations include the first three steps and (2) the definition of classes, relations, constraints, and instances.

2.1. Preliminary considerations

There are four questions underlying the process of defining the domain and scope (23): (1) What is the domain that the ontology will cover? (2) What the ontology is going to be used for? (3) What types of information the ontology should provide? (4) Who will use and maintain the ontology? The proposed ontology covers the process of searching for a house. It focuses on a particular type of housing: single family houses. The ontology intends to provide information about the housing market at a particular time, the spatial and aspatial properties of the houses, and the hierarchical structures of these properties.

Once the domain and scope of the ontology have been determined, it is important to check if existing sources can be refined and extended for a particular domain. There are libraries of reusable ontologies available on the Web. For example, we searched for relevant ontologies in the DARPA (Defense advanced research projects agency) Agent Markup Language (DAML) library (www.daml.org/ontologies) and the Schema Web Directory (www.schemaweb.info/default.aspx). This search focused on two domains: the house evaluation ontology and spatial (geographical/location) ontology. While we found a few spatial ontologies (e.g. (24–26)), we were unable to identify any relevant house evaluation ontology available in an electronic form. However, there are several websites that can be used in the process of creating ontology for a housing search in Iran including the local real estate agencies (e.g. Iran Estate (iranestate.com) and the Iranian Real Estate (www.irrest.com) and the international agencies such as RE/MAX (global.remax.com). An examination of these websites reveals that they differ considerably in terms of their contents (amount and type of information). Also, a closer look at the websites suggests that all of them are based on the principles of appraisal (e.g. (27–29)).

The preliminary considerations also involve enumerating relevant concepts in order to capture the domain (see Figure 1). The Ontario Real Estate Association can be considered as the domain “expert” and consequently...
the list of considerations, factors, characteristics, and attributes specified in the “Principles of Appraisal” provides the base for enumerating important domain terms. Thus, the procedure involves collecting terms as they appear in the “Principles of Appraisal” (27) and relevant websites. The terms are then organized in taxonomical structures (class hierarchies) (see Subsection 2.2).

### 2.2. Defining classes, relations, constraints, and instances

The main components of the ontology are a set of concepts (classes), properties of concepts (relationships and attributes), and restrictions on properties (constraints). These components together with a set of individual instances of classes constitute a knowledge base. The process of defining classes, their properties and constraints, and creating instances are closely intertwined (see Figure 1). It is hard to do one first and then do the other. Typically, one creates a few definitions for the concepts in the hierarchy and then continues by describing properties of these concepts, and defining constraints and instances, and so on (23). There are several possible approaches for developing a class hierarchy (23, 30).

The proposed house selection ontology is based on a top-down development process, which starts with the definition of the most general concepts in the domain and subsequent specialization of the concepts. This approach can be operationalized in terms of the AHP (13).

The AHP-based ontology for house selection was developed using the Protégé-OWL editor (protege.stanford.edu). The editor supports the OWL, a standard language defined for representing and exchanging ontological data (see (31)).

The use of the Protégé-OWL editor for developing the AHP-based ontology requires a clarification of descriptive conflicts or semantic heterogeneities regarding the terminology used by the two distinctive methods. Table 1 shows the Protégé-OWL terminology and corresponding vocabulary used in the MCDA/AHP modeling as well as GIS-based MCDA/AHP procedures. The Protégé-OWL defines ontology as a set of classes organized in a hierarchy structure to represent a domain’s concepts, a set of slots associated to classes to describe their properties and relationships, and a set of instances (or individuals) of those classes that hold specific values for their properties (protege.stanford.edu/overview).

In the AHP model, a particular problem (e.g. the search for housing) is represented by a hierarchical structure with the top level corresponding to the ultimate goal of the decision at hand (e.g. selecting the “best” house) (see Figure 2). The domain ontology describes the factors, objectives, attributes, attribute values, alternatives, weights, alternative rates, and geographical units associated with decision domain in the form of concepts and define semantic relations among them. The hierarchy descends from the general to the more specific until a level of attributes is reached. This is the level against which the decision alternatives for the lowest level of the hierarchy are evaluated. The attribute value concepts represent different value categories for each attribute. Every individual alternative can be associated with its own attribute value concept. Moreover, the alternatives are associated with different geographical units ranging from the country to street level in order to enable users to search for the house in a particular geographical area. The spatial search for an alternative (house) is based on a hierarchical structure of geographical units (such as provinces, counties, municipalities, neighborhoods, and streets). These are locational attributes of alternatives. A location of a house may be described as either absolute location (the exact location of a house defined in terms of a coordinate system or street address), or relative location (the location of one house relative to another).

Once the classes have been defined, their properties (relations) have to be specified (see Figure 1). A class property is a binary relation between classes. OWL distinguishes two main types of properties according to whether they relate individuals to individuals (object properties) or individuals to data types (datatype properties). The “is-a” and “consist-of” relations are the most often used. For example, the “is-located-in” property is the basic spatial relation used in the house selection ontology. In addition, one can use the property characteristics such as “transitive,” “symmetric,” and “inverse-of” through which the OWL reasoner is able to derive more specific semantic specifications. For example, one can characterize the property “is-located-in” as “Transitive” to infer that if the alternative \( X \) is located in the city of \( Y \), and also the city of \( Y \) is located in the province of \( Z \),

| Protégé-OWL | MCDA/AHP | GIS-based MCDA/AHP |
|-------------|-----------|---------------------|
| Ontology    | MCD model (decision rule) | Combination rule |
| Classes (concepts, categories) | Goal, criteria (objectives, attributes), alternatives | Criterion/attribute maps, spatial objects (points, lines, polygons, and rasters) |
| Slots (properties of classes) | Properties (attributes) of alternatives | Properties (attributes) of spatial objects |
| Facets (value types) | Attribute types | Attribute types |
| Instances (individuals) | Attribute values | Attribute values |
then the alternative $X$ would be located in the province of $Z$.

The properties of classes (or slots) can have different constraints (or facets) describing the value type, allowed values, and the number of the values (cardinality) \((23, 31)\). For example, the value of a “name” slot (as in “the name of a region”) is one string; that is, “name” is a slot with value type “String”. A slot “exterior condition” (as in “building characteristics”) can have multiple values such as “below-average,” “average” and “above-average.” The actual data associated with a class is generated through instances or objects of that class. For example, a given house is an instance of the “building characteristics” class. Since the class defines all exterior and interior properties of a house, the values of properties specific to that house are entered while creating its instance.

Figure 3 shows a fragment of the OWL ontology for house selection. The OWL language syntaxes use OWL (e.g. owl:Class) and resource description framework
Figure 3. A fragment of the OWL house selection ontology.

The procedure that determines how best to evaluate alternatives or to decide which alternative is preferred to another is known as decision rule. It integrates the data on a set of alternatives and decision-maker’s preferences into an overall assessment of each alternative (12). The process of applying the decision rule is concerned with the appropriate combination of the relevant criteria to determine the overall evaluation scores (ratings and rankings) for the decision alternatives.

The AHP method is a decision rule (13). The use of attribute value concepts in the AHP-based OWL ontology is explicitly based on the idea that they provide the standardized, weighted, and structured subconcepts of attributes to serve as the alternative containers. Each of the alternatives can be classified as individuals into the concepts so that each alternative belongs to only one of the subconcepts of every attribute. This means that there are no two subconcepts of a certain attribute that contains the same alternative. In the proposed approach, the overall score for an alternative is determined by adding up the weights associated with the attribute value concepts containing that alternative.

The SWRL was adopted to assign the user’s preferences (weights) to the attribute value concepts and to determine the overall score for the alternatives (32). The SWRL rules can be expressed in terms of the OWL concepts, properties, individuals, and data values to provide reasoning capabilities on the OWL ontology (33). The proposed method requires the definition of as many SWRL reasoning rules as attribute value concepts and a single query rule (Table 2). The SWRL reasoning rules are defined to assign the weights of attribute value concepts. For example, the rule “AVC1(?A) ∧ ConceptName(AVC1) ∧ HasConceptWeight(AVC1, ?W) → HasAlternativeWeight(?A, ?W)” captures the OWL concepts “AVC1” and “ConceptName,” and the “HasConceptWeight” and “HasWeight” properties to indicate that each alternative “A” within concept “AVC1” has associated the “W” weight of the concept “AVC1.”

To add up the weights associated with each alternative and then order alternatives from the most to the least desirable, the Semantic Query-Enhanced Web Rule

| Type of rule | Rule |
|--------------|------|
| **Reasoning** | AVC1(?A) ∧ ConceptName(AVC1) ∧ HasConceptWeight(AVC1, ?W) → HasAlternativeWeight(?A, ?W) |
| | AVC2(?A) ∧ ConceptName(AVC2) ∧ HasConceptWeight(AVC2, ?W) → HasAlternativeWeight(?A, ?W) |
| | AVC3(?A) ∧ ConceptName(AVC3) ∧ HasConceptWeight(AVC3, ?W) → HasAlternativeWeight(?A, ?W) |
| | AVC4(?A) ∧ ConceptName(AVC4) ∧ HasConceptWeight(AVC4, ?W) → HasAlternativeWeight(?A, ?W) |
| | AVC5(?A) ∧ ConceptName(AVC5) ∧ HasConceptWeight(AVC5, ?W) → HasAlternativeWeight(?A, ?W) |
| | AVC6(?A) ∧ ConceptName(AVC6) ∧ HasConceptWeight(AVC6, ?W) → HasAlternativeWeight(?A, ?W) |
| | AVCm(?A) ∧ ConceptName(AVCm) ∧ HasConceptWeight(AVCm, ?W) → HasAlternativeWeight(?A, ?W) |
| **Query** | Alternative(?A) ∧ HasAlternativeWeight(?A, ?W) ∧ Is located in the province of (?A,ProvinceName) ∧ Is located in the city of (?A,CityName) ∧ Has the street address (?A,StreetAddress) → sqwrl:select(?A) ∧ sqwrl:sum(?W) ∧ sqwrl:orderByDescending(?W) |
Language (SQWRL) built-ins “sqwrl:sum” and “sqwrl:orderByDescending” need to be incorporated into the query rule, respectively. Besides the SQWRL built-ins, the query rule contains some properties (e.g. the “is-located-in-the-city-of” property) to indicate the geographical area that the user is interested in. These properties enable the user to limit the search for house to his/her area of interest. A rule engine is required to run the SWRL rules on the OWL knowledge and derives the alternative ratings. When the OWL knowledge and SWRL rules are transferred to the rule engine, the inference is performed using those knowledge and rules, and ultimately the resulting ratings are transferred back to OWL.

4. Prototype implementation

MC-SDSS has typically been developed by integrating MCDA into GIS (2, 4). There are several approaches for integrating the two distinctive technologies. This research is based on the loose-coupling approach (1). In this approach, two systems (GIS and MCDA) exchange files such that a system uses data from the other system as the input data.

The loosely coupled modules provide maximum flexibility and minimize unnecessary interaction among the GIS and the MCDA components. The use of a loose coupling architecture for this web-based application offers a benefit in that the spatial data, MCDA, and GIS elements in the ontology can be reused, shared, and exchanged on the Internet.

Figure 4 shows the structure and operational flow of the ontology-based MC-SDSS for house selection. The system consists of three core components: the AHP-based OWL ontology, GIS engine, and web application. The GIS engine (ArcGIS) provides tools for displaying, managing, querying, and analyzing the relevant map layers (criteria maps, locations of houses for sale, ratings of the houses, etc.). Using the GIS queries and spatial analyses, the attribute values associated with houses can be obtained and then the houses (decision alternatives) are classified according to the predefined categories. The house categories are stored in the spatial database. Next, they are imported as individuals into corresponding attribute value concepts in the Protegé-OWL ontology (see Section 3). Since the Protegé-OWL editor is an open architecture Java-based tool, it is possible to communicate with other Java-based systems through a plug-in mechanism (34). The editor enables the user to manage the

![Figure 4. The architecture of ontology-based SDSS.](image-url)
OWL ontology, load, edit and visualize OWL classes (concepts), properties, and SWRL rules, execute description logic reasoners, and define logical class characteristics as OWL expressions. The DataMaster plug-in allows the user to import a schema and content of a relational database in a configurable way into OWL or frame ontology. It represents the structure of database in the OWL ontology in the manner that the tables, attributes, and rows are treated as classes, properties, and individuals, respectively. The SWRLTab is an environment in the Protege-OWL editor that allows for creating and editing SWRL rules in the OWL knowledge base. It supports the inference with SWRL rules using the Jess rule engine.

A web application using the OWL ontology (see Section 2) and Google mapping service provides a platform to compute and visualize ratings of houses for sale according to the user’s preferences. The user communicates with the system using a GUI (Figure 5). He/she can input the criterion weights and define the geographical area to be search for houses. Once the user’s preferences (i.e. criterion weights) and search area are defined, they are incorporated into the OWL ontology. The OWL knowledge and SWRL rules are then transferred into the Jess rule engine which reasons over ontology using SWRL rules to determine the overall rating of each house. Finally, the resulting ratings and their corresponding ranks are visualized in Google map.

Figure 5 illustrates the use of the system for evaluating and rating houses for sale in the vicinity of Azadi Street in the City of Tehran, Iran. The locations of 20 houses available for sale in the specified search area are displayed in the right-hand section of the system’s interface. The preferences with respect to the components of the hierarchical structure of the house selection problem are specified in the left-hand section. Specifically, the weights of 40, 24, 25, and 11% are given to the economic, building characteristic, accessibility, and natural and social environment factors, respectively. Each of the factors is described in terms of objectives. For example, the accessibility factor includes a group of six objectives. The sum of weights assigned to these objectives must be equal to the weight associated with the accessibility factor (i.e. 25%). The performance of each objective is measured by a set of attributes. For example, the accessibility to the public transportation services is measured by five attributes: the distance to the nearest bus stop, subway, railway stations, airport, and highway. Accordingly, the sum of the weight associated with the accessibility public transportation services is equal to the value of weight assigned to that objective (i.e. 6%). Finally, the houses available for sale are classified according to the attribute categories. For example, each house falls into one of the categories for the distance to nearest bus stop (i.e. <100, 100–300, 300–600 m, etc.). Each category is assigned a weight of importance (or

![Figure 5. The City of Tehran, Iran: the interface of SDSS for house selection.](image-url)
value/utility). Thus, the value/utility of a particular alternative (house) decreases along with the increasing distance to the nearest bus stop. Once the attribute weights are assigned to each house according to specified preferences, the system computes the overall score by adding the weights. The results are displayed on the Google map in the form of ratings or rankings. Figure 5 shows rankings for the 30 houses available for sale.

The system is flexible and user-friendly, allowing both the expert and lay users to specify their criterion preferences based on which the system ranks the houses. Users are able to refine the preferences and redo the house evaluation in an interactive manner without having to reconfigure the decision rule. It allows nonspecialist users to perform house selection analytical tasks equal to those performed by specialists.

5. Conclusion

The paper presented an ontology-based MC-SDSS for the house selection problem. It has proposed an ontological framework that structures all the necessary MCDA elements for the house selection domain, and acts as a foundation for MCDA analysis. The framework is based on the development of domain knowledge, formal ontology concepts (classes, relations, constraints, and instances) and taxonomic hierarchies using the AHP method.

We have demonstrated the applicability of the framework for the house selection problem in the City of Tehran, Iran. The paper has also shown an approach for evaluating the decision alternatives using SWRL rules over the OWL knowledge base.

The proposed approach demonstrates the ability of ontology to formally, semantically, hierarchically, and explicitly formulate the underlying knowledge required for house selection in a machine-understandable structure. The idea behind such an approach is to promote the flexibility of MC-SDSS by providing an easy-to-use, interactive, interoperable, modular, run time, and reusable framework for MC-SDSS. Furthermore, the proposed MC-SDSS potentially equips the users with tools available online for expressing their preferences and evaluating the houses according to the preferences. The system is flexible and easy-to-use. It allows individuals explore the decision problem in an interactive way, change and refine the weights, and perform alternative evaluation easily at a real time manner.

The proposed approach deals with the traditional AHP that handles the preference judgments by means of the crisp values. In many cases, users may not be able, or may be unwilling, to specify a precise numerical judgment with respect to the evaluation criteria because of the uncertainties involved in the spatial decision-making. Users may feel more convenient and confident to provide fuzzy judgments instead of specifying numerical values. Therefore, it is suggested to employ the fuzzy method using a set of linguistic terms such as “low,” “medium,” and “high” to elicit user’s preferences. Additionally, a collaborative setting is needed to build a house selection decision ontology that supports a consensus process for the criteria and the subsequent hierarchical structure by a group of domain experts. In such settings, the experts can make contributions to enhance the current ontology. For example, some may apply the partial knowledge about adding or varying a number of criteria and subcriteria associated with the house selection domain.

Notes on contributor

Jacek Malczewski is a professor of Geography at Western University, London, Ontario, Canada. His research interests include: multicriteria decision analysis, GIS, and land-use planning.

References

(1) Jankowski, P. Integrating Geographical Information Systems and Multiple Criteria Decision Making Methods. Int. J. Geogr. Inform. Syst. 1995, 9, 251–273.
(2) Jun, C. Design of an Intelligent Geographic Information System for Multi-Criteria Site Analysis. URISA J. 2000, 12, 5–17.
(3) Joerin, F.; Theriault, M.; Musy, A. Using GIS and Outsourcing Multicriteria Analysis for Land-Use Suitability Assessment. Int. J. Geogr. Inform. Sci. 2001, 15, 153–174.
(4) Malczewski, J. GIS-Based Multicriteria Decision Analysis: A Review of the Literature. Int. J. Geogr. Inform. Sci. 2006, 20, 703–726.
(5) Chakhar, S.; Mousseau, V. GIS-Based Multicriteria Spatial Modeling Generic Framework. Int. J. Geogr. Inform. Sci. 2008, 22, 1159–1196.
(6) Sadeghi-Niaraki, A. Ontology-Based and User-Centric Spatial Modeling in GIS: Basics, Concepts, Methods, Applications; VDM Verlag: Berlin, 2009.
(7) Sadeghi-Niaraki, A.; Kim, K. Ontology Based Personalized Route Planning System Using a Multi-Criteria Decision Making Approach. Expert Syst. Appl. 2009, 36, 2250–2259.
(8) Gruber, T.R. A Translation Approach to Portable Ontology Specifications. Knowl. Acquis. 1993, 5, 199–220.
(9) Guarino, N. Formal Ontology, Conceptual Analysis and Knowledge Representation. Int. J. Human Comp. Studies 1995, 43, 625–640.
(10) Bourne, L.S. The Geography of Housing; V.H. Winston & Sons: London, 1981.
(11) Bond, M.T.; Seiler, M.J.; Seiler, V.L.; Blake, B. Uses of Websites for Effective Real Estate Marketing. J. Real Estate Portfol. Manage. 2000, 6, 203–211.
(12) Malczewski, J. GIS and Multicriteria Decision Analysis; Wiley: New York, NY, 1999.
(13) Saaty, T.L. The Analytic Hierarchy Process; McGraw-Hill: New York, NY, 1980.
(14) Wyatt, P.J. The Development of a GIS-Based Property Information System for Real Estate Valuation. Int. J. Geogr. Inform. Sci. 1997, 11, 435–450.
(15) Peterson, K. Development of Spatial Decision Support Systems for Residential Real Estate. J. Housing Res. 1998, 9, 135–156.
(16) Zeng, T.Q.; Zhou, Q. Optimal Spatial Decision Making Using a GIS: A Prototype of a Real Estate Geographical Information System (REGIS). Int. J. Geogr. Inform. Sci. 2001, 15, 307–321.
(17) Rinner, C.; Heppleston, A. The Spatial Dimensions Of Multicriteria Evaluation – Case Study of a Home Buyer’s Spatial Decision Support System. *Lec. Notes Comp. Sci.* 2006, 4197, 338–352.

(18) Natividade-Jesus, E.; Coutinho-Rodrigues, J.; Antunes, C. H. A Multicriteria Decision Support System for Housing Evaluation. *Decis. Support Syst.* 2007, 43, 779–790.

(19) Fang, Y.; Lin, L.; Huang, C.; Chou, T. An Integrated Information System for Real Estate Agency-Based on Service-Oriented Architecture. *Expert Syst. Appl.* 2009, 36, 11039–11044.

(20) Sun, L.; Zhu, H. GIS-Based Spatial Decision Support System for Real Estate Appraisal. ICCIT 2009 – 4th International Conference on Computer Sciences and Convergence Information Technology, 2009, 5368471, 1339–1344.

(21) Hendler, J. Agents and the Semantic Web. *IEEE Intell. Syst.* 2001, 16, 30–37.

(22) Swartout, B.; Patil, R.; Knight, K.; Russ, T. In: *Toward Distributed Use of Large-Scale Ontologies*, Proceedings of the Tenth Knowledge Acquisition for Knowledge-Based Systems Workshop, KAW ’96, Banff, Alberta, Canada, November 9–14, 138–148, 1996.

(23) Noy, N.; McGuinness, D. Ontology Development 101: A Guide to Creating Your First Ontology. Stanford Medical Informatics, Department of Medicine, Stanford University School of Medicine: Stanford, 2001.

(24) Rager, D. Geofile, 2001. http://www.daml.org/2001/02/geofile/index.html (accessed Feb 20, 2012).

(25) Haglich, P. Horus Ontology of Locations, 2002. http://horus.isx.com/onts/2001/12/draft/horuslocusont.daml (accessed Feb 20, 2011).

(26) Reitsma, F. GeoFeatures, 2004. www.mindswap.org/2004/geo/geoontologies.shtml (accessed Feb 20, 2012).

(27) Ontario Real Estate Association (OREA). *Principles of Appraisal;* Ontario Real Estate Association: Don Mills, ON, 1983.

(28) Rees, W.H.; Hayward, R.E.H. *Valuation: Principles into Practice*, 5th ed.; Estates Gazette: London, 2000.

(29) Isaac, D. *Property Valuation Principles;* Palgrave: London, 2002.

(30) Uschold, M.; Gruninger, M. Ontologies: Principles, Methods, and Applications. *Knowl. Eng. Rev.* 1996, 11, 93–155.

(31) Horridge, M.; Knublauch, H.; Rector, A.; Stevens, R.; Wroe, C. *A Practical Guide to Building OWL Ontologies Using the Protégé-OWL Plugin and CO-ODE Tools;* The University of Manchester: Manchester, 2004.

(32) Horrocks, I.; Patel-Schneider P.F.; Boley, H.; Tabet, S.; Grosof, B.; Dean, M. SWRL: A Semantic Web Rule Language Combining OWL and RuleML, W3C (World Wide Web Consortium) Member Submission. 21 May 2004. http://www.w3.org/Submission/SWRL/ (accessed Feb 20, 2012).

(33) Chang, X.; Terpenny, J. Ontology-Based Data Integration and Decision Support for Product E-Design. *Robot. Comput.-Integrated Manuf.* 2009, 25, 863–870.

(34) Corsar, D.; Sleeman, D. Reusing JessTab Rules in Protégé. *Knowl.-Based Syst.* 2006, 19, 291–297.