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An eco asset ontology towards effective eco asset management

Jehan Zeb
Transportation and Infrastructure Planning, Engineering Department, Regional Municipality of Wood Buffalo, Fort McMurray, Canada

Abstract

Purpose – The purpose of this paper is to develop an ontology of eco or natural assets to represent eco asset knowledge at two levels: eco asset metal model and eco asset ontology (EA_Onto). The three objectives of this paper are to: define eco assets explicitly to reach a common understanding of the terms; evaluate the ontology; and discuss a potential area of application.
Design/methodology/approach – A seven-step methodology was used to develop the proposed ontology: define the scope; develop the eco asset meta model (EA_MM), define taxonomy, code ontology, capture ontology, evaluate ontology and document ontology.
Findings – The EA_MM was developed to represent eco asset domain knowledge, which was further extended to develop the EA_Onto, explicitly defining the eco asset knowledge in asset management. As a part of evaluation, it was found that the knowledge representation is consistent, concise, clear, complete and correct.
Practical implications – Theoretically, the proposed ontology is a significant contribution to the body of knowledge in asset management. Practically, the knowledge representation provides a common understanding of eco assets for asset management experts. In addition, it will be used in applications for effective eco asset management.
Originality/value – The current literature lacks explicit declaration of eco assets, how they are related to built environment for effective integration and how asset management functions are to be applied to accomplish effective eco asset management. Presently, eco assets are managed on an ad hoc basis, which need to be explicitly defined through developing an EA_Onto for implementation in applications for effective eco asset management.

Keywords Asset management, Eco asset, Eco asset knowledge management, Eco asset management, Eco asset ontology, Natural asset

Paper type Research paper

Introduction

Aging infrastructure, high level of service requirements, economic downturn, declining rate of re-investment on infrastructure and high renewal and replacement costs require the civil infrastructure to be managed effectively and efficiently (CIRC, 2016) using innovative asset management approaches, practices, procedures and frameworks. One of such approaches is to integrate the nature and the services it provides (natural environment) with the civil infrastructure (built environment) to develop long-term sustainable infrastructure systems. In this approach, the assets of the natural environment – eco assets or natural assets (e.g. aquifer, creeks, wetlands, etc.) (Cairns and Wilson, 2010) are to be integrated with the assets of the built environment (e.g. engineered asset: reservoir, pump, sewer, road, etc.) to develop more sustainable infrastructure systems through lessening reliance on engineered assets, reducing asset life cycle costs and reducing carbon footprints to maintain a healthy ecosystem. As such, the eco asset management should be viewed as a core piece in the overall corporate asset management. Presently, the eco asset management is in the infancy stage and eco assets are managed on an ad hoc basis (Machado *et al.*, 2012), which needs to be formalised through the development of an eco asset management strategy.

As a first step in exploring the possibilities of developing an effective eco asset management strategy is to formalise and explicitly define eco assets for implementation and management through applications. The core research question is:

RQ1. How to formalise and classify eco assets?

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An ontological approach is proposed to formalise the eco asset knowledge through the development of an eco asset ontology (EA_Onto). An ontology is "an explicit formal specification of the terms in the domain and the relations among them" (Gruber, 1995). According to Gómez-Pérez *et al.* (2005), ontologies are built using a layered architecture at various levels of abstraction: upper ontologies – define the most generic, universal concepts that provide the starting points for the more specific concepts in the lower-level ontologies; domain ontology – define the terms and concepts that are common throughout the area of application and may be shared by different software applications; application ontologies – define information that is specific to a particular application; and user ontologies – that further refine the concepts as they relate to a specific user or data set. Following the layered architecture, the EA_Onto was developed at two levels: eco asset meta model (EA_MM) and EA_Onto. The meta model represents the upper ontology and the EA_Onto represents the domain ontology.

This paper is divided into eight sections. The first section describes the research background. The second section reviews the literature. The third section discusses the development approach. The fourth and fifth sections explain the development of EA_MM and EA_Onto, respectively. The sixth and seventh sections elucidate the evaluation and application of ontology respectively, and the eighth section describes the conclusions.

Literature review

The related literature was reviewed from two perspectives: ontologies in infrastructure management and asset management and ontologies in land management.

Infrastructure management and asset management ontologies

In infrastructure management, five relevant ontologies are of particular importance. The infrastructure product ontology (IPD-Onto) (Osman, 2007; El-Diraby and Osman, 2011) represents knowledge about physical products (engineered assets, e.g. pipe, valve, pump, etc.) in various infrastructure sectors: water, wastewater, electrical, telecommunication and gas. The infrastructure and construction process ontology (IC-Pro-Onto) (El-Gohary, 2008) represents process knowledge including; core design and construction processes, management processes, knowledge integration processes and support processes. The actor-onto represents knowledge related to diversified actors playing a variety of roles in the infrastructure management (Zhang and El-Diraby, 2009). Transaction domain ontology (Zeb *et al.*, 2015) captures communication process while the tangible capital asset ontology (Zeb and Froese, 2014, 2015a, b) represents tangible capital assets (i.e. engineered assets) in four sectors: transportation, water, wastewater and solid waste management to develop an Asset Information Integrator System, AIIS (Zeb *et al.*, 2015) for the exchange of tangible capital asset information between the municipal and provincial governments. Trento and Fioravanti (2013) developed a method to link process and product ontologies (representing engineered assets) to improve interoperability between planning and design software.

The focus of these ontologies is to develop product knowledge, practices, procedures and frameworks to support effective infrastructure management in contrast to asset management. The focus is on engineered assets alone while ignoring the importance of eco assets from long-term sustainability perspective. These ontologies lack to integrate the natural environment (eco asset information) with the built environment (engineered assets information), which is required for effective asset management.

Similarly, some of the related ontologies in the area of asset management are as follows. Frolov *et al.* (2009) developed an asset management ontology to represent a holistic and multi-disciplinary approach that includes the management (reliability and maintainability) of physical assets through well-defined asset management processes. Bhandari *et al.* (2012) developed a knowledge-based system to make optimal decisions related to utilisation of power transformers. Campos (2007) developed an ontology to monitor the condition of industrial assets as part of the maintenance management. Soma *et al.* (2007) developed a semantic framework for integrated asset management to make optimal decisions regarding production forecasting for oilfield operations.

These ontologies and frameworks focus on maintenance management in contrast to asset management. These support improvements and operational efficiencies of engineered assets instead of eco assets. These ontologies lack to represent eco asset knowledge emphasising the need to develop an ontology of eco assets to support the development and management of sustainable infrastructure systems through effective eco asset management.

Land management ontologies

Land is a part of the ecosystem; as such, it is an eco asset that carries or embodies other eco assets like: aquifer, creeks, shorelines, etc. Therefore, the knowledge represented in the EA_Onto was organised in terms of land, defined as the "surface of the earth and all its natural resources" (Merriam, 2016). Some of the land related ontologies are discussed as follows.

Montenegro *et al.* (2012) developed a land use planning ontology, called Land-Based Classification Standard (LBCS) to explicitly define land uses of the urban space in a semantic and computer readable format to make urban development strategies readily available to planners involved in the urban development process. The land use knowledge represented in the ontology was used as a basic structure of the City Information Modelling (CIM) (Montenegro and Duarte, 2009) within the City Induction (Duarte *et al.*, 2011) project to support the development of a tool for urban planning and design. The LBCS classifies urban space based on activity, function, structure, ownership and site. The functional classification is of particular importance, which are regrouped and further extended to include eco assets for effective eco asset management. Roic *et al.* (2016) developed a multipurpose land administration system to administer land through the development of a land register in the form of a cadastre map with sub-cadastres (special maps) developed based on land use, functional use, administrative control and jurisdictional boundaries. The objects associated with each specific land register (i.e. register of state property, forest cadastre, utility cadastre, building cadastre, marine cadastre, cadastre of mining resources, etc.) are semantically defined for seamless integration of special cadastre maps with the land cadastre.

These ontologies do not represent a complete set of the eco asset knowledge to support effective eco asset management. The lack of the eco asset product (aquifer, creek, etc.) and process (asset management functions: asset inventory management, condition assessment, life cycle cost assessment and risk assessment) knowledge identifies the need for the development of an ontology of eco assets. In summary, the existing literature lacks: a formal eco asset classification system from the asset management perspective; a framework for eco asset condition assessment; an approach for eco asset valuation; and eco asset management strategies. These issues emphasis the need to develop an eco asset management strategy (Machado *et al.*, 2012) that includes formal declaration of the eco asset knowledge in a neutral format (ontology) to support the development of information systems for effective eco asset management.

Approach to develop eco asset ontology

The proposed EA_Onto was developed using a seven-step approach based on various methodologies developed by Fernandez-Lopez *et al.* (1997), Uschold and Gruininger (1996), Noy and McGuinness (2001). Based on these methodologies, a similar hybrid approach was adopted for the development of IPD-Onto (Osman, 2007), IC-Pro-Onto (El-Gohary, 2008) and TCA_Onto (Zeb and Froese, 2015a, b):

- Step 1: define the scope – the purpose, use and users of the EA_Onto were defined. The purpose is to explicitly define eco asset knowledge for implementation into applications and provide unambiguous declarations for industry experts. One of the primary uses is to efficiently and effectively manage eco assets as part of the corporate asset management. The software developers will use the EA_Onto for implementation into applications while asset management experts will use it to manage their assets effectively.

- Step 2: develop the EA_MM – a metal model was developed at the abstract level to organise diversified eco asset knowledge easily and effectively in the domain of asset management using the Unified Modelling Language (UML).
- Step 3: define taxonomy – the abstract knowledge represented in metal model was extended to develop a comprehensive taxonomy of the eco assets.
- Step 4: code ontology – the knowledge represented in the EA_Onto was formally coded in the Ontology Web Language (OWL) using Protégé (2016) Ontology Editor.
- Step 5: capture ontology – soft and hard axioms were developed representing explicit declarations of eco assets using the OWL Description Logic Syntax.
- Step 6: evaluate ontology – the knowledge represented in the EA_Onto was verified using built-in reasoners in the Protégé and validated through industry experts.
- Step 7: document ontology – the eco asset knowledge was finally documented for future use.

Development of eco asset meta model

The metal model representing the eco asset knowledge at the abstract level was developed for two reasons: to capture lean knowledge to understand the domain of interest more clearly and to categorise diversified eco asset knowledge more easily. The proposed UML-based meta model comprises of the following concepts (entities, objects or things) that are related through a set of relationships as shown in Figure 1.

Key concepts

According to Fox and Gruninger (1998), concepts are key entities in the production and services systems and manufacturing systems. A description of the key concepts is presented in Table I.

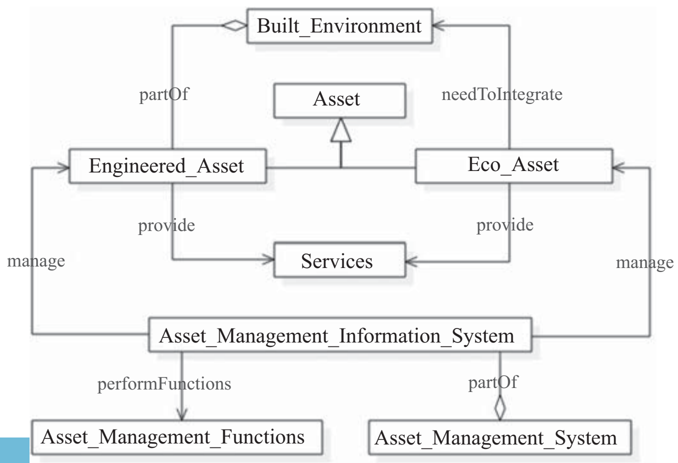

Figure 1.
Eco asset metal model

Key concepts	Description
Asset	Asset is defined "as an item, thing or entity that has potential or actual value to an organisation" (ISO55000, 2014). This value can be tangible or intangible, financial or non-financial, which varies between different organisations and their stakeholders. An asset has two types: eco asset and engineered asset. The focus of the above-mentioned definition is on engineered asset, which is extended in this research work to include eco assets According to Cairns and Wilson (2010), eco asset or natural asset refer to assets of the natural environment; such as, aquifers, creeks and foreshores that provide equivalent civil (engineered) municipal goods and services. On the other hand, the engineered asset refers to the asset of the built environment created through the application of the civil engineering theory and principles that provide goods and services. To create sustainable infrastructure systems, eco assets need to be integrated with the built environment
Built environment	The physical world that has been intentionally created through science and technology for the benefit of mankind (McKechnie, 2008). This definition covers almost everything that is created to provide some service to communities. In this research work, the specific focus of the built environment is on civil infrastructure systems
Services	Services are the set of activities accomplished to provide something beneficial to the public using systems and equipment. The focus of the services in this research work is on the supply of municipal services that includes, but not limited, to the following: water supply service, sewage collection service, waste disposal service, transportation service, transit service, recreational service, etc.
Asset management information systems	Asset management information systems refer to the applications (software) used for asset management. For example, Arc GIS, dTIMS, RoadMatrix, Hansen, SAP, Excel, WebWorks, RIVA, CityWorks, CityWide, AutoCAD, etc. (Zeb *et al.*, 2012)
Asset management functions	Asset Management Functions refer to the core functions that the asset management applications perform to effectively and efficiently manage assets. Vanier *et al.* (2006) identified six core asset management functions: asset inventory management, asset condition assessment, asset service life analysis, asset life cycle cost analysis, asset risk analysis and decision making
Asset management system	Asset management is defined as "coordinated activity of an organisation to realise value from assets" (ISO55000, 2014). Similarly, asset management system is defined as "management system for asset management whose function is to establish the asset management policy and asset management objectives" (ISO55000, 2014). The asset management system includes: processes (abstract and physical), procedures, policies, software established for effective management of assets

Table I.
Key concepts description

Relationships

According to Osman (2007), relationships are the associations between concepts represented in the ontology. The explicit representation of association between concepts provides clarity and helps in modelling the domain of interest. In protégé, relationships are modelled as object properties. Three types of object properties were used to develop the proposed ontology as shown in Figure 2: generalisation-specialisation relationship is a aggregation-composition relationship part-of and associative relationship has-a.

The meta model represents the integration of eco assets with the built environment to achieve long-term sustainability of civil infrastructure systems through effective asset management practices. The engineered assets are part of the built environment, wherein eco assets need to integrate to provide services to users, public, customers, citizens and communities at optimum cost. Both the engineered and eco assets are to be managed simultaneously through a set of asset management information systems (software) to realise value for organisations from a holistic and systemic perspective. The optimum realisation of value is accomplished through a set of asset management functions performed by this software, which are part of the overall asset management system.

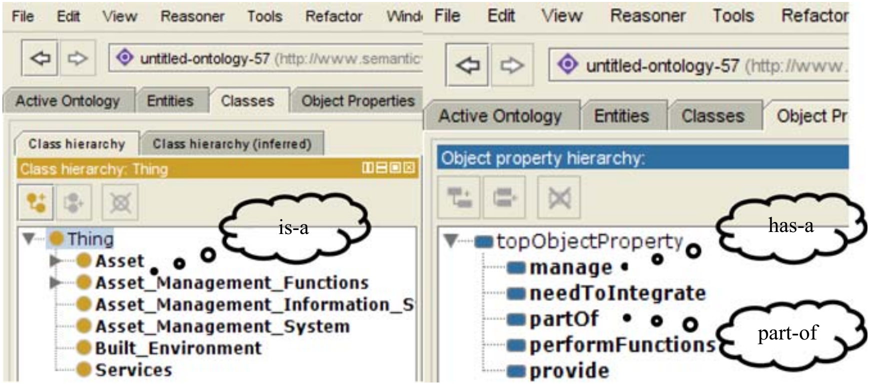

Figure 2.
Relationship or object property modelling in Protégé

Development of eco asset ontology

The EA_Onto was developed through extending the meta model to create a detailed taxonomy of the eco assets in asset management. The eco asset knowledge is organised in terms of land for four reasons: one of core the elements of the natural environment and ecosystem; most of the naturally available assets are either carried by, embodied by or created as part of the land; land is used to provide a variety of communal services; and to ease integration with the LBCS for implementation in the CIM. The taxonomy of eco assets was formally coded in the Ontology Web Language using Protégé (2016) Ontology Editor as shown in the Figure 3. The eco assets in terms of the land are categorised into three types: mineral and energy resource land, use-based land and waterway and waterbody land.

Mineral and energy resource land – refers to the land that provides minerals and energy resources. It is sub-categorised into three types: gas, mineral extraction and oil sands. These categories can be extended further to include a variety of other related assets. In the Canadian context, these assets are usually administered at the provincial or federal levels, thus beyond the administrative control of the municipal or local government. Whatever the administrative control is, these assets need to be effectively managed at each government level to improve social, economic and environmental sustainability.

Use-based land – classifies land-based on a variety of land uses. There are three types of use-based land: farm land, municipal servicing land and wild land. Farm land – is used for farming (to grow agriculture products) and ranching (raising grazing livestock). Municipal servicing land – used to serve a variety of services at the municipal level. There are different administrative controls over different types of lands. Whatever the control is, these lands are defined based on the services these provide in a municipal jurisdiction. Examples of these lands are: commercial (used to develop business centres), industrial (used for the development of industries), institutional (used to establish educational, health facilities, etc.), recreational (used for the development of parks), residential (used for the construction of houses) and transportation (used for the construction of roads to provide commuting services) lands. Wild land – is used to grow forests, vegetation and wood for a variety of public uses.

Waterway and waterbody land – refers to the water related land used to flow, keep or embody water to provide a variety of services. For instance, an aquifer can be integrated with a water supply system to provide water supply services. Similarly, ponds and ditches can be used in the storm system to provide storm management services. It has the following eight subclasses: aquifer, creek, ditch, pond, river, shore, spring and wetland.

Explicit declarations of the eco assets were accomplished through the development of soft and hard axioms as part of ontology capture, which means the specification and

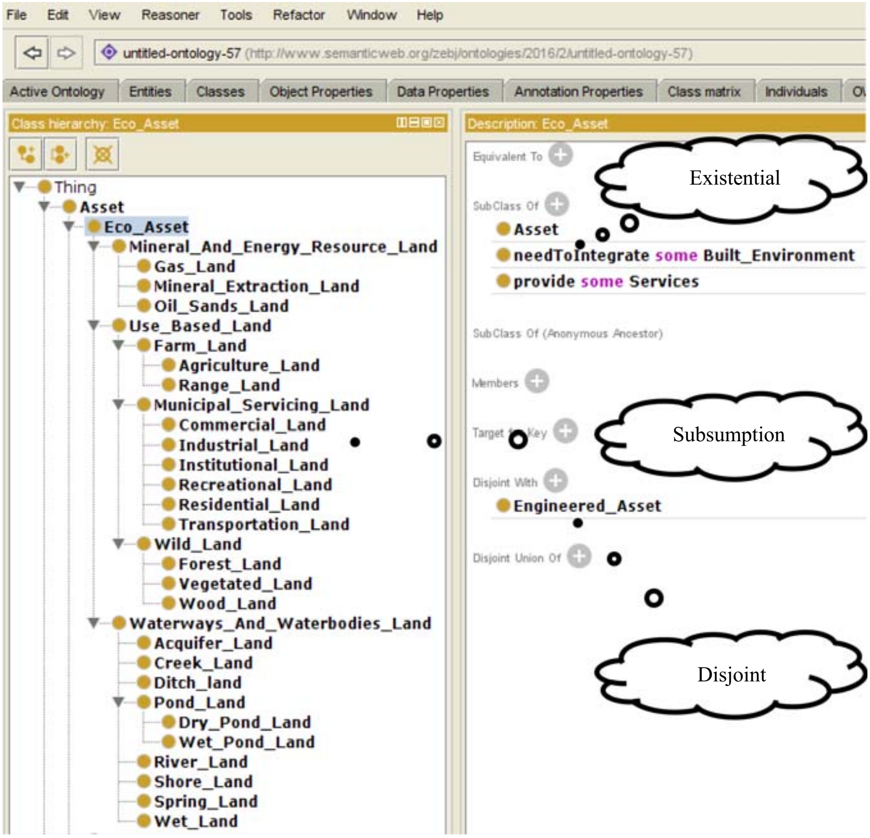

Figure 3.
A taxonomy of eco assets in the area of asset management

formulation of axioms in the ontology. According to Gruninger and Fox (1995), axioms unambiguously define the concepts in the ontology and constraints on their interpretation. Axioms in the EA_Onto are classified as soft axioms (describing concepts in plain English) and hard axioms (describing concepts in OWL Description Logic Syntax). As shown in Figure 3, three types of axioms were defined in the EA_Onto: sub-sumption/is-a axiom; property restriction axioms: existential, universal and cardinality restrictions; and disjoint axiom. After capturing the ontology, the proposed ontology was evaluated as discussed in the evaluation section. The ontology was documented for any future uses.

Eco asset ontology evaluation

A criteria-based approach was used to evaluate the proposed ontology. The proposed criteria include: consistency, conciseness (Gómez-Pérez, 1996) clarity, completeness (Yu *et al.*, 2007) and correctness (Guarino, 1998). Consistency measures how consistent the knowledge representation is, which means how much contradictory conclusions can be drawn from the definitions of the concepts. Conciseness measures redundancy in the knowledge representation. Clarity measures how clear and understandable a knowledge representation is. Completeness measures how complete knowledge representation is. According to Yu *et al.* (2007), there are no measures developed yet to prove completeness of an ontology, rather it can be demonstrated in terms of incompleteness. Correctness measures the level to which a knowledge representation is accurately modelled from the real-world perspective (Guarino, 1998).

According to Gómez-Pérez (1996), ontologies are verified and validated as part of evaluation. In verification, the test is to assess that the knowledge model is built right from a modelling perspective; however, in validation, the content is checked to assess that a right model of the domain of interest is captured.

The EA_Onto was verified based on two criteria: consistency and conciseness using automated description logic reasoners, a verification tool built in Protégé (2016) Ontology Editor; such as FaCT++, HermiT 1.3.8, Pallet, RacerPro and Snorocket as shown in Figure 4. These reasoners were run to automatically check the content of the ontology for consistency and conciseness. The reasoning analysis result shown in Figure 4 reflects the term "Nothing", under the inferred class hierarchy (an automatically generated class hierarchy), describes a superclass of things having subclasses of concepts with any one of the errors mentioned above. No class has been identified in the inferred class hierarchy that is inconsistent as there are no subclasses found under the superclass "Nothing", which shows that the EA_Onto is consistent and concise. The consistent and concise eco asset knowledge is visualised using OntoGraf (a built-in application in Protégé) as shown in Figure 4.

The EA_Onto was validated through three domain experts who were selected based on three criteria: familiarity with the land administration; familiarity with data or information modelling; and familiarity with the area of asset management. The familiarity of experts with these three areas was recorded on a continuum scale of 0-5: -0 (unable to rate), 1 (not at all familiar), 2 (slightly familiar), 3 (somewhat familiar), 4 (moderately familiar) and 5 (extremely familiar). They were extremely familiar with the area of asset management; however, moderately familiar with the land administration and data modelling. Each of them had more than ten years of experience in land administration, data modelling and asset management. A structured questionnaire was used for the EA_Onto validation.

To assess clarity, completeness and correctness of the EA_Onto, the concepts (i.e. eco assets or natural assets) were represented in the questionnaire. For each criterion, a multi-sheet table was developed to reflect concepts in rows and respondent's responses in the columns. The respondents were asked to rate the concepts on a scale of 1 (strongly disagree) to 5 (strongly agree). Each respondent rated each concept represented in the questionnaire and an average score was calculated, which ranged from 4 (agree) to

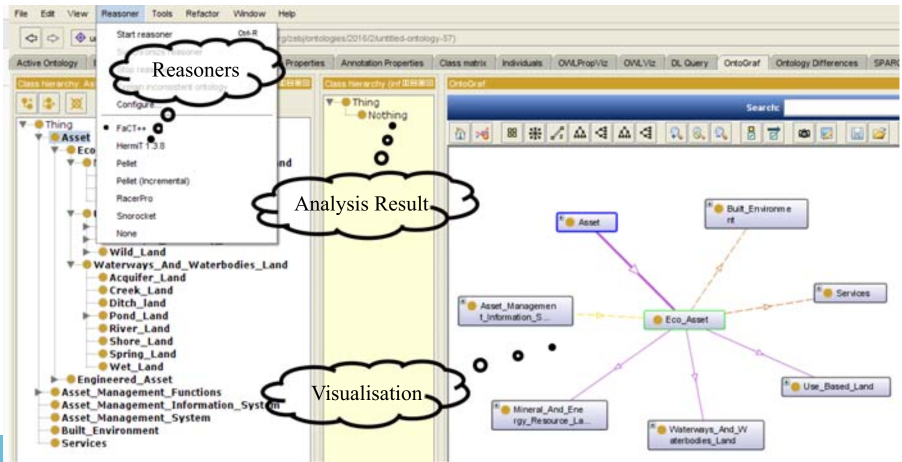

Figure 4.
Eco asset ontology verification and visualisation using OntoGraf

5 (strongly agree). The evaluation results indicate that respondents were in universal agreement on the clarity, completeness and correctness of the knowledge represented in the EA_Onto. An overall ontology validation assessment was also conducted. The overall average rating of the EA_Onto was 4.53 on a scale of 5 indicating the results are satisfactory and respondents are in full agreement on the clarity, completeness and correctness of the knowledge represented in the EA_Onto.

Eco asset ontology application

For the long-term sustainability of the engineered assets, eco assets need to be integrated with the built environment. The eco assets are equally important as the engineered assets because both of them provide beneficial services; as such, these assets need to be managed effectively using asset management applications. Presently, a variety of applications is used to manage engineered assets; however, eco assets are not yet formally managed due to: lack of explicit description of the Eco asset knowledge – ontology; undefined and unclear asset management functions; and lack of regulatory requirements to enforce eco asset management. The knowledge represented in the EA_Onto is to be used to manage eco asset knowledge using CityWide (software) and geographic information system (GIS) currently in use in the municipal environment for the tangible capital asset reporting (PSAB, 2009), asset inventory management and condition assessment (SORP, 2008), respectively.

To manage eco assets effectively and efficiently, the knowledge represented in the EA_Onto will be implemented in the existing asset management applications for asset inventory management. Later, other functionalities, like; asset condition assessment, asset service life analysis, asset life cycle cost analysis, asset risk analysis and decision making will be implemented. The area of eco asset management is in the infancy stage as the condition assessment rating criteria, valuation methods, procedures for life cycle costing, frameworks for risk management and decision making are not yet extensively developed. As the field will be evolved, more and more asset management functions will be implemented toward effective eco asset management.

Conclusions

The eco assets and engineered asset co-exist in the natural and built environment, respectively to provide some services to the mankind. The eco assets are equally important as the engineered assets, their integration with the built environment would result in developing more sustainable infrastructure systems. To accomplish this, eco assets need to be managed effectively from asset management standpoint through asset management information systems (software). For software-based management, eco asset information needs to be explicitly defined to address issues related to data heterogeneity and non-uniform eco asset categorisation. The solution to these challenges is to build EA_Onto.

The proposed ontology was developed using a seven-step procedure at two levels of abstraction: EA_MM and EA-Onto. First, the meta model was developed to represent abstract concepts in asset management to show how eco assets can be integrated within the built environment to accomplish a holistic and integrated eco asset management. Second, a detailed EA_Onto was built to explicitly define eco assets in the area of asset management. A taxonomy of eco assets was developed in terms of land representing three types: mineral and energy resource land, use-based land and waterway and waterbody land.

The proposed knowledge was verified and validated using a set of criteria: consistency, conciseness, clarity, completeness and correctness. Based on the verification results, it was found that the knowledge representation is consistent and concise. Similarly, the validation results indicate that the eco asset knowledge is clear, complete and correct.

The proposed EA_Onto is to be implemented in two asset management applications: Arc GIS and CityWide system to test and validate the approach further.

From a theoretical perspective, the EA_Onto is a significant contribution to the body of knowledge in the domain of asset management. From a practical perspective, the proposed eco asset knowledge: provides a common understanding of the eco assets for industry experts; eases consistent implementation in applications; and eases knowledge base extension in case more eco asset knowledge is added in future.

Some of the limitations of this research work include: the lack of a full fledge implementation in applications to test and validate the approach. The knowledge represented in the EA_Onto will be used for asset inventory management now due to lack of defined criteria and frameworks for condition assessment, valuation assessment and risk assessment that are necessary ingredients for effective eco asset management. In future research work, the knowledge represented in the EA_Onto will be implemented in asset management applications. Moreover, criteria and frameworks will be developed for condition assessment, life cycle cost assessment and risk assessment for implementation in applications to accomplish true benefits of eco asset management.

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Corresponding author
Jehan Zeb can be contacted at: jzmir1@hotmail.com