Delivering Semantic Enrichment of 3D urban models for financial and sustainability decision support

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Abstract
Management of large urban projects requires complex decision-making, which involves a large number of actors. Decision-makers, urban planners, designers, contractors usually have different backgrounds and qualifications. Such a diversity of may lead to conflicting goals,opinions and wrong expectations, which can make the decision-making process inefficient. In many cases, the actors might experience problems understanding each-others position, reasoning or even used terminology. Therefore, tools that support consultation and interaction in the best way is vital for the success of urban projects. This paper describes an 3D ontology based software system that has been used for several years now in more than 50 urban development projects. The paper tries to evaluate it objectively. In addition the paper tries to explain why a small enterprise like StrateGis sees Semantic Technology as very important for their future business but also struggles to adopt it.

Keywords: *Decision Support, Ontologies for urban development, 3D semantic enrichment*

1. Introduction

In a decision-making process various actors are involved, which use large amounts of heterogeneous data (Tegtemeier et al 2009).). In order to realize technically and functionally sound projects that are acceptable to the actors involved and also comply with the principles of sustainable development, it is necessary that policy-makers, designers and sustainable development-experts work together. The success of this process could be seen as a system which allows getting the right resources to the right actor in the most appropriate form (Zlatanova et al 2010). Especially in early project phases we can see that the available project information (at hand for the actors involved) is very limited while the decisions that are made are crucial for success. Figure 1 illustrates the impact of early design decisions on the success of the project. It also shows the availability of information during the project.

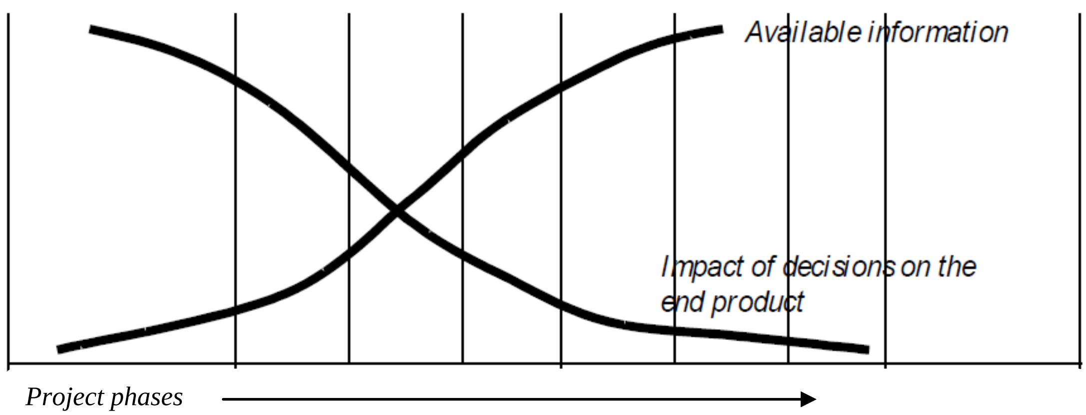


Figure 1: the lack of information in early project phases while key decisions are made there.

Paradoxical is the wealth of available data and prediction models outside the project. Apparently it is difficult to discover and make use of all the information in time supporting a more informed decision making process. From an ICT perspective it can be reasoned that this information is maintained by different application-oriented systems, which have specific representations contributing to the complexity of using this information/ knowledge.

Furthermore, various interoperability problems arise while attempting to integrate these individual data sources. The term ‘interoperability’ means that systems should be able to provide services to and accept services from other systems in an effective manner. Usually three types of interoperability are identified namely system interoperability, syntax/structure interoperability and semantic interoperability (Sheth, 1999). System interoperability refers to the ability to deal with hardware, operating systems, and communications heterogeneity. Syntax and structure (schematic) interoperability is relevant to aspects such as data representation, data models, data schemas. Semantic interoperability refers to as the meaning of the data. Semantics refers to the aspects of meanings that are expressed in a language, code, message or any other form of representation. Semantic interoperability means that the information system understands the semantics of the users’ information request and those of information sources, and uses mediation or information brokering. While much has been done for system and syntax interoperability, the systems which ensure semantics interoperability to support decision-making process are very limited.

In this paper we presents a system that allows seamless integration of various spatial and non-spatial data. The approach focuses on processing the available data like existing GIS sources, urban master plans, databases with experience figures, financial data en models, sustainability data and models, etc in order to create one consistent 3D semantically enrichment model of the project that can be used for decision support. This model facilitates cooperation between actors making the available project information more transparent and offering more insight in the impacts of decision options. Using the semantic 3D model it becomes easy to explore the solution space resulting in better (more informed) decision making. The systems has focused on 3D financial modelling and uses existing sustainability models to at least put sustainability on the agenda in a systematic way. The models are used for facilitating cooperation by supporting the communication process, quick analysis of what-if scenarios and for capturing all the project data in a consistent 3D model. Figure 2 protrays the effect on decision-making process when a DSS is used, which allows to integrate and analyze heterogeneity information with respect to the goal of the user.

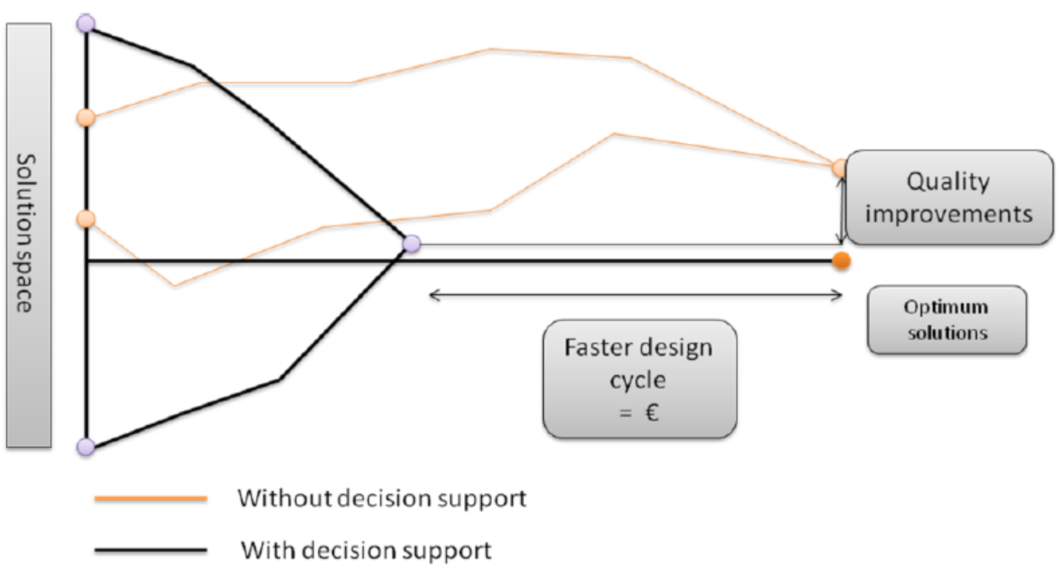
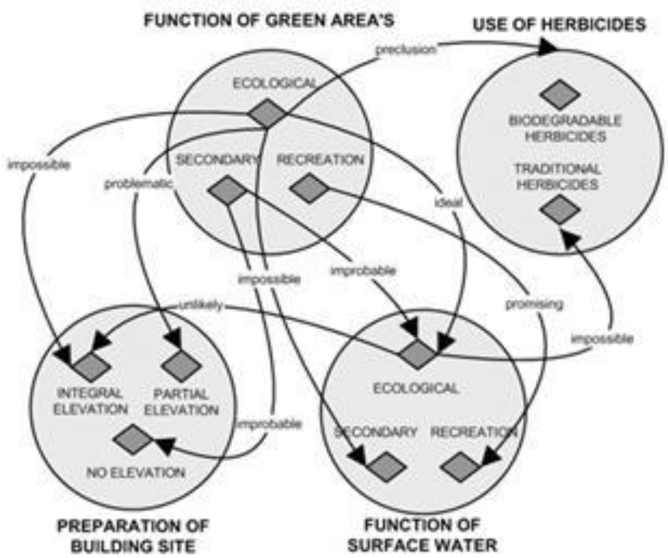


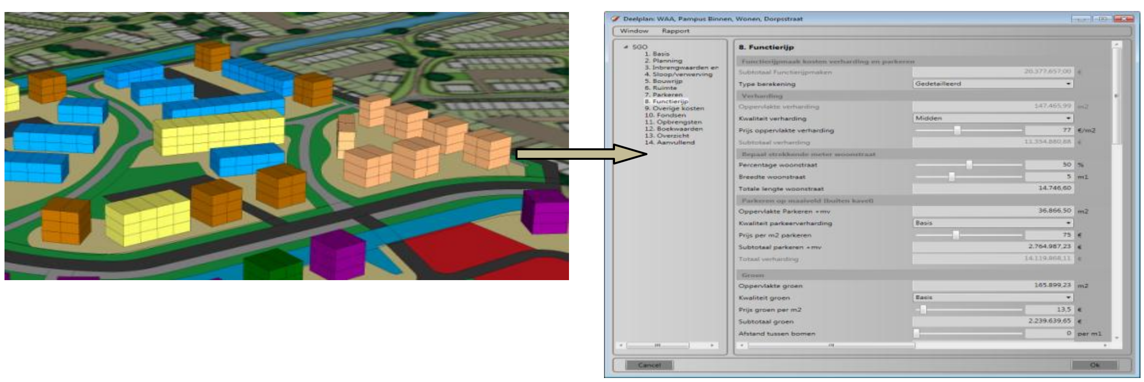
Figure 2: The effect of a decision-support system

2.1 Decision Support Systems for Urban (re) development projects

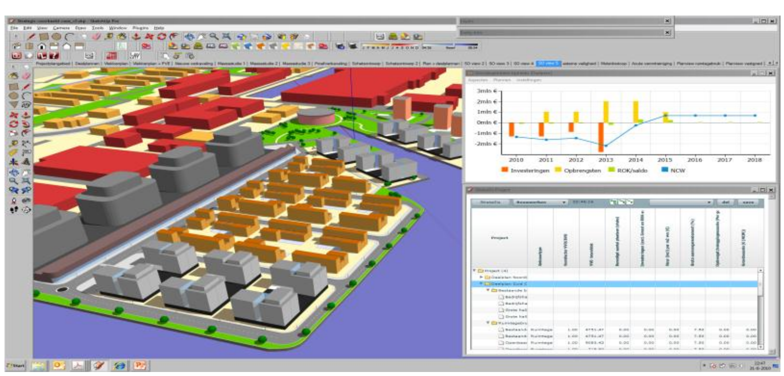
To deal with the large amount of models, the divide and conquer method can deal with the complexity to a certain extend. Models within one domain, on one level of detail, using a fixed characterization are arguably reasonably manageable. Relating these single domain models to each other demands a good understanding of both domains and is difficult but still manageable to a certain extend Hajer, M. (1992) & Roe, E. (1998) .



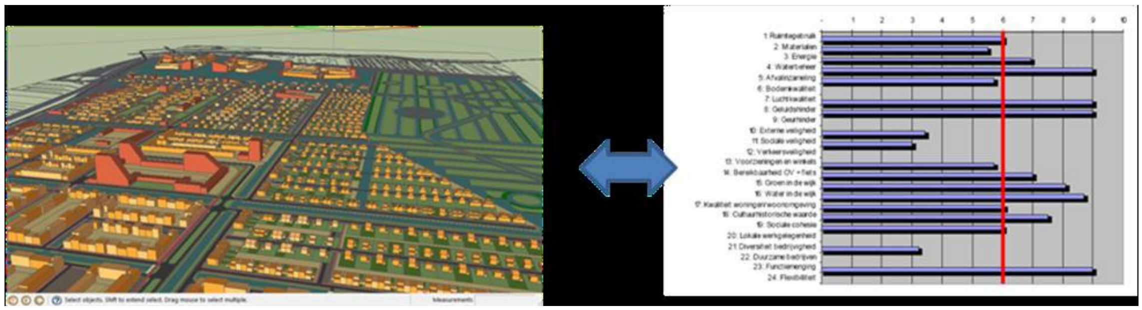
The system presented in this paper the so-called Urban Developer software suite follows this approach. Using Google SketchUp's (*http://sketchup.google.com/*) 3D modelling environment Objects such as projectplan, subareas, existing buildings, water, roads, new buildings, etc can be created. Each object has its own list of properties where some of them are related to the geometry of the object.



Currently a single object has approximately more than visible 300 properties. A typical urban plan contains more than 1000 objects resulting in a wealth of data. This rich model is used for detailed financial calculations including complete cash flows of the project taking many boundary conditions into account.



Charts and reports can be configured to produce the necessary information.



3 Conceptual software architecture

This section presents the conceptual architecture of the Urban Developer and describes the current limitations. The architecture of the software is roughly presented in the following Figure3. The major components of the system are CAD system with API, the StrateGIS Framework and the Excel-based ontology.

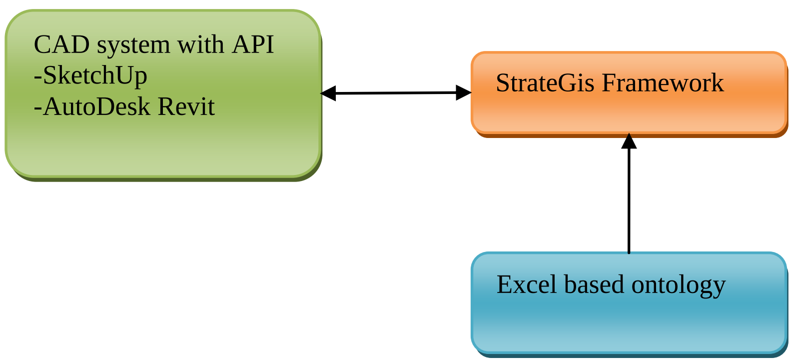
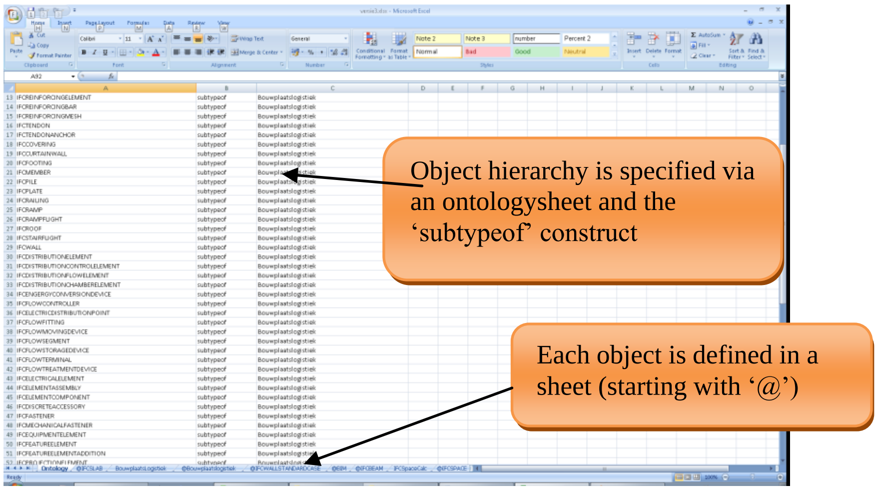


Figure 3: The system architecture of Urban Developer

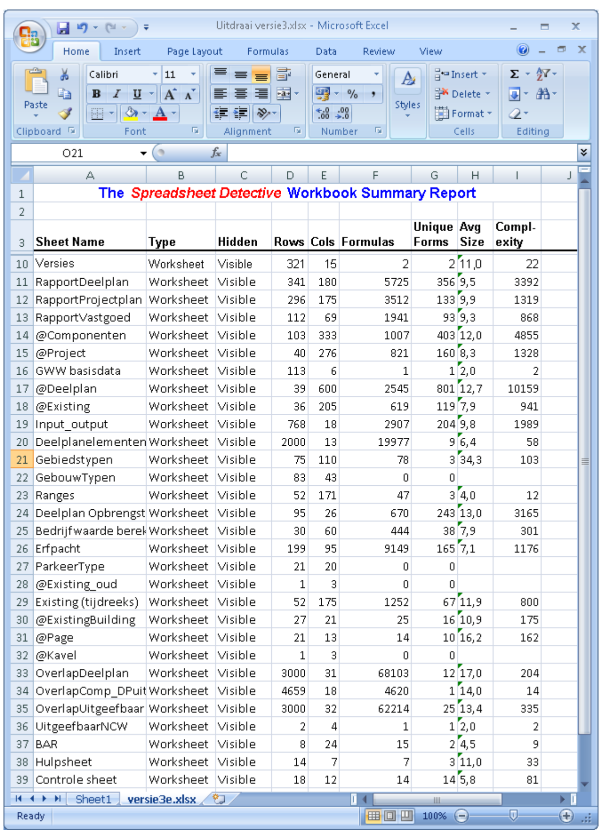
Existing CAD systems are extended with a Framework that supports a spreadsheet based ontology. The framework and the ontology enrich the spatial objects in the CAD packages with Object definitions, properties, relationships and spreadsheet calculations. Spreadsheet sheets are used to define objects, each column is use to specify a property. Rows are used to specify the property itself such as the name, type (string, float, etc), GUI type (textbox, combobox), minimum value, maximum value, etc. Excel functionality is used to put in the necessary calculations. Similarly charts can be defined within the spreadsheet environment by a set of agreements taking again the advantage of the spreadsheet environment for calculation purposes. Even several OO principles like sub typing are supported.



Subtype relationships can be specified declaratively. The framework will construct the whole Object hierarchy.

3.1 Evaluation of the current implementation

The current implementation enabled StrateGis to evolve the software (both the framework as well as the spreadsheet based ontology). A couple of years ago we had a simple spreadsheet as the ontology while now it contains many calculations and sheets. The following picture shows for example the complexity of the spreadsheet based ontology: Objects with more than 200 properties up 600. More than 100.000 calculation formulas although matrices of copied formulas exist in the workbook. Roughly StrateGis thinks to have created more than 10.000 unique calculation rules.



The Spreadsheet Detective Workbook Summary Report

Sheet Name	Type	Hidden	Rows	Cols	Formulas	Unique Forms	Avg Size	Compl-exity
Versies	Worksheet	Visible	321	15	2	2	11,0	22
RapportDeelplan	Worksheet	Visible	341	180	5725	356	9,5	3392
RapportProjectplan	Worksheet	Visible	296	175	3512	133	9,9	1319
RapportVastgoed	Worksheet	Visible	112	69	1941	93	9,3	868
@Componenten	Worksheet	Visible	103	333	1007	403	12,0	4855
@Project	Worksheet	Visible	40	276	821	160	8,3	1328
GWW basisdata	Worksheet	Visible	113	6	1	1	2,0	2
@Deelplan	Worksheet	Visible	39	600	2545	801	12,7	10159
@Existing	Worksheet	Visible	36	205	619	119	7,9	941
Input_output	Worksheet	Visible	768	18	2907	204	9,8	1989
Deelplanelementen	Worksheet	Visible	2000	13	19977	9	6,4	58
Gebiedstypen	Worksheet	Visible	75	110	78	3	34,3	103
GebouwTypen	Worksheet	Visible	83	43	0	0		
Ranges	Worksheet	Visible	52	171	47	3	4,0	12
Deelplan Opbrengst	Worksheet	Visible	95	26	670	243	13,0	3165
Bedrijfwaarde berek	Worksheet	Visible	30	60	444	38	7,9	301
Erfpacht	Worksheet	Visible	199	95	9149	165	7,1	1176
ParkeerType	Worksheet	Visible	21	20	0	0		
@Existing_oud	Worksheet	Visible	1	3	0	0		
Existing (tijdreeks)	Worksheet	Visible	52	175	1252	67	11,9	800
@ExistingBuilding	Worksheet	Visible	27	21	25	16	10,9	175
@Page	Worksheet	Visible	21	13	14	10	16,2	162
@Kavel	Worksheet	Visible	1	3	0	0		
OverlapDeelplan	Worksheet	Visible	3000	31	68103	12	17,0	204
OverlapComp_DPuit	Worksheet	Visible	4659	18	4620	1	14,0	14
OverlapUitgeefbaar	Worksheet	Visible	3000	32	62214	25	13,4	335
UitgeefbaarNCW	Worksheet	Visible	2	4	1	1	2,0	2
BAR	Worksheet	Visible	8	24	15	2	4,5	9
Hulpsheet	Worksheet	Visible	14	7	7	3	11,0	33
Controle sheet	Worksheet	Visible	18	12	14	14	5,8	81

This approach has worked for StrateGis arguably for the following reasons:

- Domain experts where able to work in their favourite environment (Excel) and by relatively simple agreements they are able to define objects with properties, calculations, user interfaces and charts without any (real) coding.
- A minimal communication between software engineers and the domain experts. Both parties could work relatively independently once the agreements were made.
- Reasonable scalable approach to build intelligent software systems.
- Incredibly flexible system enabling StrateGis to add new calculation models requesting addition information (object properties) within days and consequently enables StrateGis quickly include the necessary calculations.

3.2 Limitations

The authors of this paper feel that the current framework is at its limit regarding the desired functionality.

The sheer complexity. The fact that it is so easy for domain experts to insert properties with calculations and reports has resulted in an almost unmanageable ontology. Currently certain object definitions have more than 500 properties! One reason for this is simply the sheer complexity of financial modelling. StrateGis is aiming for one configurable model for all their projects. Another reason for the current complexity is that several calculation models are integrated into one system. These financial models differ from each other because of the level of detail, different input information or even different calculation methods. A very simple example: land use prices can be calculated based upon the profits of the real-estate but also based upon simple land use experience figures. Different levels of detail and different input information is supported resulting in even more properties and calculation methods.
To (partly) solve this StrateGis has embarked on a ‘divide and conquer’ method by creating a network of ontologies (related spreadsheet based ontologies). The idea is to put each calculation model into one workbook and use it whenever it is necessary: basically a plug and play approach for the spreadsheet ontologies. Hopefully it will result into a set of more manageable ontologies. However we are not too sure how to deal with the interrelations between these ontologies. Arguably we need to work with an upper ontology facilitating the interoperability.

Semantic technology for domain experts: Another topic of discussion and perhaps related to the discussion above is the introduction of OO techniques into the ontology functionality. For the software engineers this functionality is pretty logical. The current implementation already supports a limited form of object specialisation. However taking advantage of this requires a good understanding of OO principles. Since the ontology is made by domain experts it is 1) necessary to educate the domain experts to take advantage of this or 2) alternatively introduce a knowledge engineer to work on the ontology as well. We’re not sure if the enthusiasm of the domain experts will stay when the ontology becomes too difficult. And we are also not sure how effective a knowledge engineer is that tries to elicitate the knowledge for the domain experts in order to develop the necessary ontologies. New technologies for enhancing the ontology such as Description Logic and Set theory might fuel this discussion even further.

Implementation limitations: The complexer the ontology becomes the more complicated the execution sequence becomes. The financial model contains interrelations between objects demanding a cyclic execution iterating to a stable situation. Objects like subarea have relationships with new real-estate buildings. Calculations related to the building need information from the subarea and vice versa. Although this is solvable relatively easily, it becomes apparent that the framework needs to identify these interrelations between the objects in order to calculate the right execution order. Directed graphs of all the interrelated calculations need to be constructed. Luckily good open-source software is available to do just that. Currently we do not have this implemented and are very much wondering when StrateGis decides to go for an alternative platform based upon Semantic Web technology how to deal with the execution sequence. Is it built in or do we have to manage it ourselves. This also raises questions regarding non-monotonic processes.

4 Towards Semantic Web

StrateGis is inspired by Semantic Web technology and partners already have had a lot of experience by applying it various cases (Schevers et all, 2006) & (Schevers et all, 2007). Having said that the current approach using spreadsheet based ontologies has been very successful for StrateGis. Dividing the spreadsheet based ontologies (and interrelate them), introducing more OO functionality and perhaps even Description Logic techniques makes the software of StrateGis more and more conceptually comparable with Semantic Web ideas. Such a strategy assures an evolutionary approach: StrateGis can still use the current framework and spreadsheet based ontology system. Another idea is to convert the spreadsheet based ontology into OWL taking advantage of the already available OWL software. The third strategy is to completely start over.

The following considerations are present:

- StrateGis needs in the near future new ways to deal with the sheer complexity in order to generate trust and to be able to incorporate more aspects in their decision support system
- Domain experts in our context need to be able to create the ontology/rules/calculations

4.1 Perceived advantages of using Semantic Web technology

The following advantages are perceived as true when adopting Semantic Web technology

Improved ability to deal with the complexity: According to Motta (1999), a new approach that explicitly distinguishes a universe of discourse and Knowledge Representation Language (KRL) with a Problem Solving Method (PSM) improves the scalability and re-use of Knowledge-Based Systems. Semantic Web separates the universe of discourse (ontology) from PSMs. This results in many PSMs operating on the same ontology. In addition the Description Logic classification mechanisms enable the creation of different ontologies for decision support while certain inference techniques help the ontology creators for enabling interoperability.
In addition Semantic Web technology is inherently distributed and consequently can help StrateGis with a 'divide and conquer' strategy to decompose the ontologies into more manageable submodels.

Data-Interoperability and software interoperability: Although currently hardly available within our domain, StrateGis expects that in the near future the import of data can be done via OWL or at least via translaters that produce OWL from the desired datasource. OWL tools can help to process the data in order to make it useful for our Decision Support System.
Another perception is that more and more intelligent tasks within our domain will be able to deal with OWL data in the near future. Linking and or integrating these tasks will be easier this way. Also the GIS community is looking more and more towards OWL functionality and geo(temperal) Owl models are already present and supported (*http://www.franz.com/*).

Advantages of existing software functionality: Currently a reasonable amount of software is available related to Semantic Web technology and StrateGis hopes and expects that this amount will rapidly grow in the near future. For editing and constructing ontologies, systems such as Topbraid composer (*http://www.topquadrant.com*) and Protege(*http://protege.stanford.edu/*) might be very useful. For the implementation of framework Jena(*http://incubator.apache.org/jena/*), Sesame(*http://www.openrdf.org/*), Pellet(*http://clarkparsia.com*), JESS(*http://www.jessrules.com/*) and Protégé might be very interesting for processing capabilities. Functionality such as scalable databases, SPARQL queries, SPIN, etc. are becoming available for 'free'. For a small company these tools offer a wealth of functionality that is very interesting for our framework.

4.2 Roadmap towards Semantic Web technology

The strategy for adopting Semantic Web technology is still a bit unclear. However many advantages of adopting semantic web technology are perceived as very useful. An evolutionary strategy seems to fit a small company as StrateGis because funding a completely new setup for the system is too much to carry. Re-using the spreadsheet based ontology seems logical. Based upon that the following strategy in put in place:

- Translate the spreadsheet based ontology into an OWL ontology (perhaps based upon an upper ontology) including the necessary OWL constructs to link the domain ontology to a spreadsheet
- Implement a Spreadsheet based K.R. working with OWL so that the core execution is based upon semantic web technology
- Implement the execution engine (sequence finder and actual execution)
  - Deal with Description Logic inference
  - Open the execution engine to enable other KRs as well

Ideally it would be great to infer all the calculations within a spreadsheet that are related to an ontology object in such a way that extracting a subset of calculations can be done automatically. Since large parts of spreadsheet calculations are traceable this might not be too farfetched.

5 Conclusions

StrateGis Urban Develop suite supports urban (re) development projects by using a 3D financial model for exploring design alternatives. The current 3D financial model is based upon a software architecture separating domain knowledge from software implementation via a spreadsheet based ontology system. This has resulted in a very flexible system that has grown almost out of this original intention. To deal with this growth StrateGis is looking for solutions within the Semantic Web domain. Besides taking advantage of the already available software components it is hoped that Semantic Web technology will help StrateGis to deal with the sheer complexity of 3D financial modelling. StrateGis is looking to for a system that works on semantic technology but uses the spreadsheet based ontology system for developing ontologies and calculation rules.

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