ONTOLOGY-BASED SOFTWARE ENGINEERING AND DISTRIBUTED INFORMATION MANAGEMENT IN THE AEC-FM INDUSTRY

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ABSTRACT

Decision-making in the Architecture, Engineering and Construction and Facility Management (AEC-FM) industry is highly distributed across individuals, organizations, national economies, and over a full facility lifecycle measured in decades. Information management in this environment presents problems to all concerned - the practitioners themselves, manufacturers and suppliers, regulators and even clients and users. For the AEC-FM industry, given its size, information management needs to be tackled through an orchestrated set of modest initiatives leading to a distributed set of interactive components– each able to function independently while serving the larger needs of the industry. A companion paper identifies and deals with three major levels at which the problems have to be solved. The top level is ontological and looks at how the industry might develop and maintain an agreed way of identifying and describing the entities about which data are accessed, processed and exchanged by its decision-makers. The second level is concerned with how this controlled vocabulary can be used to identify and make application specific resources (information, products, materials, and ICT tools) available to the project decision maker. The third level is concerned with making the resources from the other two levels available to support distributed decision-making. Ontology-based Software Engineering is a recent phenomenon wherein the development approach varies from creating more general tools to domain specific solution strategies. This paper reports on a prototype software package applicable at the top, industry-wide level, which demonstrates the feasibility and the desirability of ontological solutions specifically for the AEC-FM sector. The outcome could become part of infrastructure for sector-wide application development.
Keywords: Performance-based project data, Product/Process data management, Ontologies, Ontology-based Software Engineering, ICT, BIM

1. INTRODUCTION

Decision-making in the Architecture, Engineering and Construction and Facility Management (AEC-FM) industry is highly distributed across individuals, organizations, national economies, and over full facility lifecycles measured in decades. Furthermore, buildings are getting larger and more complex, and building technology and material science is becoming increasingly complex and subject to error in specification, installation, operation, and maintenance. These, in turn, are leading to larger and more specialised project teams whose members have increasingly narrower views of the project and of their respective responsibilities towards it. Increased specialisation, globalisation, time, cost and quality constraints, and disparate levels of usage of Information and Communications Technology (ICT) across the industry compound the complex problems.

The problems of information management in the industry include uncoordinated information gathering, reporting and management, as well as multiple redrawing and re-keying of information, which lead to unnecessary costs, increased errors, and misunderstanding (CIDA, 1995). There is also a lack of effective collaboration and coordination of effort. Given the size and distributed nature of the industry, a good architecture of solutions to these problems would be to design an orchestrated set of modest initiatives leading to a distributed set of interactive components – each able to function independently while serving the larger needs of the industry. A separate paper at this conference reports in detail on a framework for such a distributed information management strategy.

Essentially, the framework identifies three major levels at which the problems have to be solved. The procurement, operation and disposal of a built facility involve 100s of project decision-makers (PDM) taking 1000s of decisions or actions (D/A). Spread over space and time, most decision-makers never meet but the degree to which they are able to coordinate their D/As is fundamental to assuring product quality and value, and production efficiency and effectiveness.

Clearly, these decision-makers must use an agreed way of identifying and describing the objects about which they access, process and exchange data. This agreement, because teams change (over the course of a project and from project to project) and because these dialogues commonly involve outside stakeholders (building regulators through to manufacturers and suppliers), must be industry wide. Developing and maintaining this vocabulary is mission critical as computing becomes more and more pivotal to the way the industry functions.

The agreed vocabulary defines the top, ontological, level. The second level is concerned with how this controlled vocabulary can be used to identify and make application specific resources (information, products, materials, and ICT tools) available to the project decision maker, at a time and in a form that will facilitate understanding and application within realistic time and cost constraints. The third level is concerned with making the resources from the other two levels available to support distributed decision-making.

The information and decision support strategy (IDSS) is pragmatic. It is based on the recognition that not all components will be taken up at the same time or evolve at the same rate. There is an explicit acknowledgment that user acceptance of and participation in the strategy will depend upon demonstrable outcomes even as user needs and expectations themselves evolve. Consequently, we have created a prototype software package applicable at the, industry-wide level, to demonstrate the feasibility and the desirability of ontology-based solutions specifically for the AEC-FM sector. The outcome could become part of infrastructure for sector-wide application development. Ontology-based Software Engineering itself is a recent phenomenon, discussed in some detail below.

The rest of the paper is organised as follows. Section 2 identifies the stakeholders across the industry, in contrast with the traditional focus on stakeholders for a project or an enterprise. Section 3 briefly identifies pivotal components of the information strategy – paying particular attention to the ontological focus at the top level. Section 4 briefly reviews the area of ontology-based software engineering, putting the current work in proper context. Section 5 describes and discusses in detail our prototype design for the ontological segment. Section 6 concludes the paper with indications for future work.

The companion paper has already been referred to. The reader is recommended to consult that paper for a detailed analysis of the complexities of information management in the AEC-FM industry. In order to explain our prototype and the ontology-based approach, some of the material below is from that paper.

2. STAKEHOLDERS

The first step in any solution strategy is to identify the stakeholders. Here, stakeholders are the individuals and organisations that have an identified interest in AEC-FM industry and must communicate in a common language. The three sides of the triangle in Figure 1 represent the three key stakeholder groups while the area of the triangle may be interpreted as a 'common language information framework' for the AEC-FM industry.

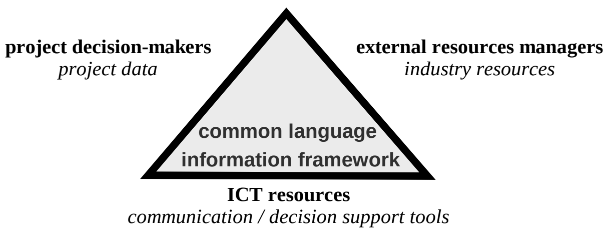

Figure 1 – Stakeholder Groups (source: the companion paper)

External resource managers (ERM) – External resources include information (material ranging from building codes and standards, through to research findings, manufacturers' literature, specification text and construction details, to performance bench marks and office procedure manuals), tools and aids (computers and printers through to jack hammers and site cranes), products and materials (sinks and water heaters through to framing material and concrete), and consumables (power and water through to office supplies). ERMs are individuals or enterprises that generate and/or manage external resources (ERs) accessed and applied by project decision-makers (PDM). In the AEC-FM industry these resources fall into two broad categories: those aimed at assisting a PDM to further define the problem, and those offering potential solutions. Stakeholders developing and managing these resources include:

- *building regulators* – concerned with building codes and standards,
- *industry associations* – concerned with supporting its members and improving the performance of their respective industry sector(s).
- *specialist information providers* – concerned with marketing selected industry knowledge – reference specification text, best practice construction details, unit costs and rates, performance benchmarks,
- *manufacturers and suppliers* – concerned with technical literature associated with marketing products and materials,
- *researchers* – concerned with research and marketing their findings to industry,
- *office managers* – concerned with the functioning of an individual organisation and developing in-house manuals – office procedures, construction details, specification text – for internal use, and
- *people supporting the above*.

Project decision-makers (PDM) – These are individuals or enterprises that access and apply resources toward an objective. In the AEC-FM industry their decisions and actions traditionally result in the procurement, operation and maintenance of a particular facility or a component thereof. These stakeholders include:

- *building owners, asset managers* – primarily concerned with performance against the asset strategy.
- *individual project decision makers* – concerned with particular aspects of the industry and develop a personal reference file,
- *users (corporate and individual), facility managers and maintainers* – primarily concerned with operational use and maintenance.
- *designers, documenters, and builders* – primarily concerned with physical procurement.
- *demolishers, disposers, and recyclers* – primarily concerned with demounting and management of the products and materials out of which a facility is constructed.

ICT resource providers – In terms of identifying user requirements in the AEC-FM industry, ICT providers may be seen as users in terms of their needs relating to computer networks and hardware environments, i.e. the physical environment. However, their actual work ranges from the development and maintenance of user applications (data management tools, data access tools, decision-support tools, communication tools) through to system applications, all of which are essential for the smooth and efficient running of the AEC-FM industry as a whole, justifying their inclusion as a separate stakeholder group.

3. INFORMATION FLOW AND DATA EXCHANGE

The stakeholders create, manage and exchange information, internally and among themselves, related to projects, products and processes. Each stakeholder will have their own methods and procedures in relation to the information content they are responsible for, giving rise to heterogeneous hardware and software platforms. When it comes to exchanging information, the heterogeneity is a hurdle.
In addition, IDSS identifies the need to ensure that –

The information flows must be directed to Decision/Action points (D/As)

Because each project is unique and the decision-makers change from project to project, the information strategy argues that the D/As are the locus around which to structure information flows.

Traditionally, project management tools identify and relate the decisions and actions necessary for the successful and timely completion of a project (independent of the decision-makers). Building on this, the information strategy focuses on ensuring the decision-maker assigned to a given D/A has proactive access to all relevant input and that the outcome is similarly made available to any subsequent D/A.

The language used to identify and describe the entities about which PDMs access, process, and exchange data need to be separate from that used to exchange this data between computer platforms.

With the range and diversity of the stakeholders, identified above, it becomes necessary to create an industry agreed way of identifying and describing the entities about which project decision makers access, process and exchange data for efficient, error-free communication. This is true also for the standards (protocols) that enable data exchanges between computer platforms. At present, the local industry is responsible for the former and the software developers for the latter and the overlap is a potential source of confusion, error and rework.

These two points hint at the inherent problems in maintaining and communicating information across the industry. While the IFCs enable information in BIM to be shared between computer platforms, the question arises as to whether they can or should be extended to support all aspects of integrated project delivery. Also, the vocabulary found in the local industry's regulatory and reference documents will have to be harmonised. The integration of the two is characterized as BIM+ in the next section.

While supporting IFC and BIM, for our work the starting point is an ontology-based development, which will be taken up in the next section, after a discussion of the types of information flows that must be catered for in any successful system.

DISTRIBUTED INFORMATION NETWORK AND ROLE OF ONTOLOGY

IDSS identified three levels. The first establishes the meta language and templates used by the wider industry. The next level is concerned with having this language taken up and applied by ERMs – including ICT developers. Level 3 looks at project based access and application of these resources.

Figure 2 depicts a distributed information network, with clear demarcation of three tiers. The first will help to establish and maintain an industry agreed way of identifying and describing the entities about which the decision makers will access, process and exchange data. The second will facilitate the activities of individuals and organisations that have a resource (information, products, materials, tools, consumables) and wish to package and make it available to these decision-makers – at a time and in a form that will facilitate access, understanding and application within realistic time and cost constraints. The third tier shows how the decision makers, who may be separated in time and space, might bring it all together to assure the quality (fitness for purpose) and value (cost-benefit) of the resulting facility.

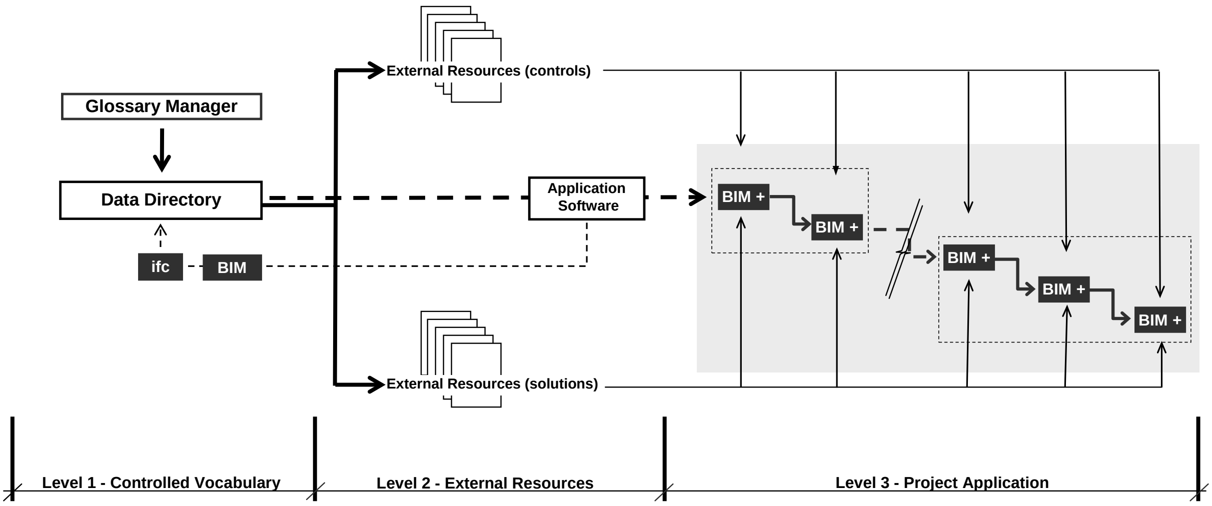

Figure 2 – Distributed information network

In addition to avoiding overburdening local practitioners, the separation of vocabulary and from its supporting technology will –

- provide tools (GM and DD) for ongoing development and maintenance of the vocabulary
- enable software developers greater freedom to develop and up date software, open their markets by providing region specific application tools, and
- enable the building industry to manage international harmonisation when and as they feel it is necessary (the local groups using the DD to develop their vocabulary in response to identified needs, and a separate group looking at these DD to identify opportunities to move them to an internationally agreed one),
- this bottom up approach will, over time, allow international harmonisation to occur independently of the application resources and in response to identified need,
- harmonisation would occur not at the application level entity by entity, within the DD.

Level 1 represents ontological considerations for the AEC-FM industry. Ontology-based development is a broad area with a great deal of activity and research currently being carried out (Alonso, 1998, Bouchlaghem et al, 2004, de Almeida et al, 2003, Wongthongtham et al, 2003, Bachman et al, 2007, Dillon et al, 2008, Guarino, 1998, Ruiz and Hilera, 2006) The next section briefly covers the relevant parts of this work.

4. ONTOLOGIES AND ONTOLOGY-BASED DEVELOPMENT

Section 3 described and briefly discussed the strategic information flows (access and exchange) and points to the necessity of an agreed vocabulary, or ontology, to identify and describe the entities about which the decision makers will access, process and exchange data. In the philosophical sense, an ontology is "a particular system of categories accounting for a certain vision of the world" whereas, in the ICT field, ontology refers to an "*engineering artifact*, constituted by a specific *vocabulary* used to describe a certain reality, plus a set of explicit assumptions regarding the *intended meaning* of the vocabulary words" (Guarino 1998). It is in the latter sense that ontology-based software engineering or application development has proceeded. It is also the view adopted here, leaving aside the debates about the philosophical arguments and treatises on ontologies.

Alonso (2006) cites Ruiz and Hilera (2006) to clarify the variety of roles ontologies play in ontology-based software engineering. They encompass requirements specifications, checking a system's design, reuse of sub-domains, searching (an ontology as a knowledge repository), system maintenance and knowledge acquisition. Ruiz and Hilera (2006) also propose two categories of ontologies. The first is as 'ontologies of domain', i.e. (partial) knowledge of a particular domain. The second category is 'ontologies as software artifacts' to be used during a software process.

In the light of the above analysis, it can be seen that ontology for the AEC-FM domain will need to identify all entities, including any transformations it might undergo over its life cycle as well as attributes of each entity for:

- the whole sector,
- specialized sub-groups within the sector, and
- specific projects.

There may also be a need to import 'control data' – outcomes of earlier D/As and external sources such as code, standards, and industry best practice. Furthermore, the decision makers not only draw upon the existing vocabularies, they also create project specific terms (and attributes) that may be carried over a long term.

An information management system will then have to be capable of:

- passing entity and attribute data from one stage or decision maker to another, and
- checking them for compliance at each stage.

These general requirements lead to domain specific constructs in the following categories:

- A **controlled vocabulary,** i.e. a list of terms that have been enumerated explicitly.
- A **taxonomy,** i.e. a collection of controlled vocabulary terms organized into a hierarchical structure.
- A **thesaurus,** i.e. a networked collection of controlled vocabulary terms.

Section 5 describes in some detail the Glossary Manager which is a prototype for controlled vocabulary as well as a tool for ontology management.

5. BUILDING AEC-FM ONTOLOGY

There are three main strands to building ontologies in the AEC-FM industry: a glossary manager, a data directory derived from the glossary manager and tools to facilitate the process.

5.1 Glossary Manager

The state of information management in the AEC-FM sector is such that tackling the ontological problem at higher, institutional level is likely to delay the full-scale solution as well as its successful adoption. Familiar examples of controlled vocabularies are ebXML, UBL, bcXML and similar efforts with varying success and take-up rates. An example of the inherent difficulties is the first author's experience, while editing the 5th edition of the NCRB Glossary of Building Terms (2004). This edition brought together terms and definitions used in a range of industry reference documents. It was not uncommon to find terms with two or more definitions, or, less commonly, different terms with the same definition. While some of these differences were simply grammatical, others were in direct conflict with one another. For example –

Maintenance — regular routine activity aimed at preserving the operational standard and cleanliness of equipment, <u>which includes inspection, repair, preventive service and cleaning.</u> (ASNZS 3666.2:2002)

Maintenance — all regular and routine actions necessary for retaining an item or asset in, or restoring it to, a specified condition. <u>It includes inspection, servicing, and repair activities, but excludes building cleaning and/or rehabilitation.</u> Maintenance sustains the service potential of an item or asset but does not improve it. (GFMT 2001).

While adopting ISO Standards will go some way toward addressing this problem, it cannot resolve it.

The solutions needed, therefore, include creating flexible software tools and packages that will allow the stakeholders to directly manage all the informational aspects related to a project, rather than depend upon the software experts to create bespoke solutions with all the attendant problems of having to explain the requirements in the first place and then asking for changes as they come to light throughout the project and product life cycles.

The tasks over both the short and long term involve:

- Creating the project and product-specific vocabularies - These may or may not be pre-specified, standard or controlled tags. Building industry glossary, for example, is a pre-specified, standard and controlled vocabulary constantly in use. UBL and ebXML are pre-specified and standard but not heavily used as yet. Given the nature of AEC projects, it should be possible for decisions makers to create such vocabularies/tags and apply them in practice. Over time, a taxonomy of languages will evolve to help standardization.

- Developing and maintaining the vocabularies - How to maintain appropriate control of the way these vocabularies develop while encouraging use input will need careful consideration. While yet to be determined, the most promising approach seems to be to build the vocabulary 'rules'into its software so user groups can add terms with conflicts being reported to a central group for resolution.

The prototype Glossary Manager is a starting point in constructing these ontologies. Starting with the terms and definitions found in the industry's current documentation, the objective of the GM is to help the industry to establish, over time, an internally harmonized, agreed set of terms and definitions leading to improved communication and information exchange. In its current form, the GM highlights these multiple definitions. The strategy is to point out errors and conflicts, to make it easy for the industry to examine the options and to move to a preferred term. Where two or more industry sectors find they must use the same term (with different definitions) the terms will be differentiated in the GM – in a way that will appear as a simple term and definition when downloaded for inclusion in a publication. Over time, as the glossaries are revised, republished, or replaced the required industry agreed terminology will emerge.

Glossary Manager is an application intended to capture terms and definitions currently found in industry publications (referred to here as ‘sub-glossaries’), to display them in a manner that will highlight the similarities and dissimilarities between the identical terms used by the different glossaries, and provide tools to assist each organisation to identify and if appropriate, to adopt the industry preferred term. The Glossary Manager simply facilitates the identification of conflicted terms and provides tools to effect change – it in no way interferes with the ‘sub-glossary owner’s control of or responsibility for ‘their’ terms. Figure 1 shows the first screen of Glossary Manager, with all the terms, currently accessed, on display. The screen shows two entries for ‘basin’ in the list of Domain Terms, one from NCRB-Glossary 2000 and the other from Standards Australia, indicating that ‘basin’ has multiple definitions. Expanding nodes with multiple definitions and then clicking on any one of the terms displays a screen, superimposed on the main Glossary Manager screen in Figure 3, with the full definitions according to the different glossaries that define them.
In its current version, the demo incorporates glossaries from NATSPEC, NCRB, Standards Australia, ISO and FMA. The data have been imported from Excel spreadsheets. There is provision to import more data from similarly constructed spreadsheets.

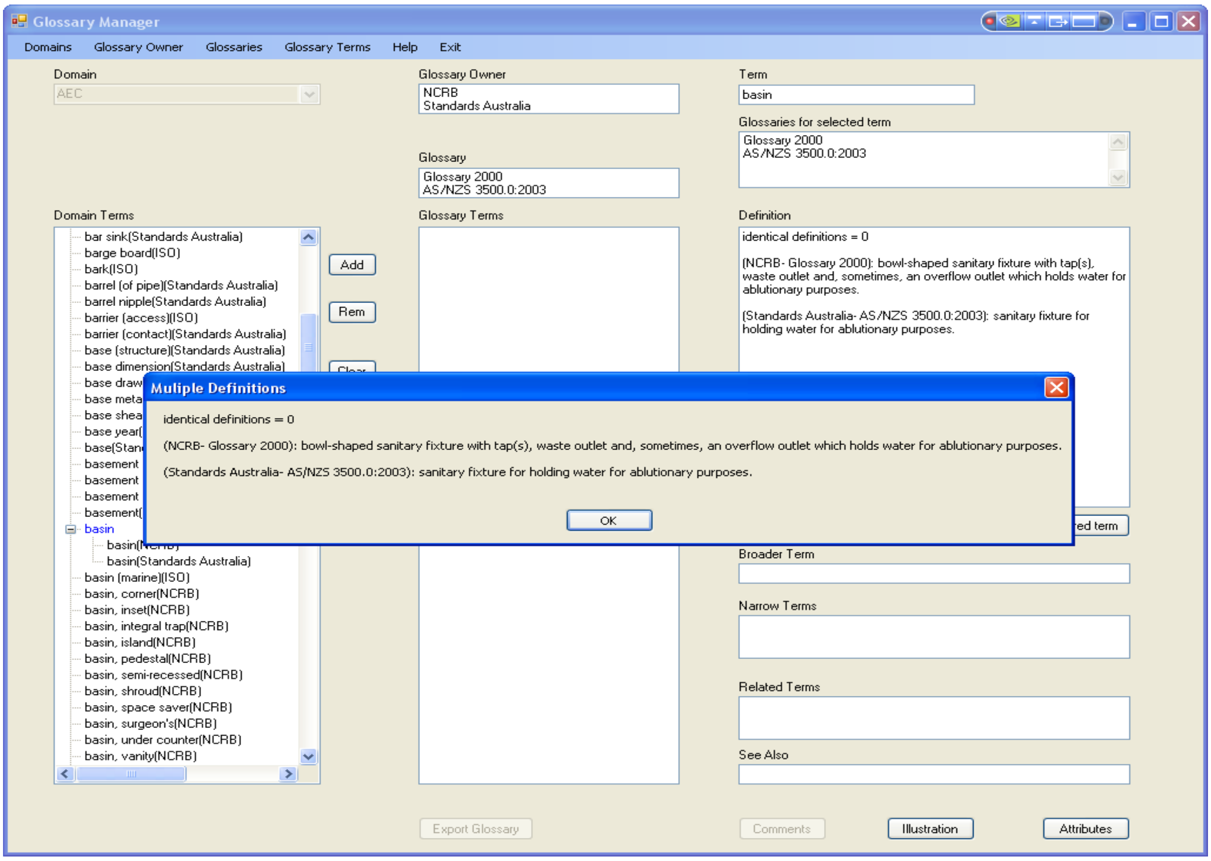

Figure 3 – Main Screen of Glossary Manager, superimposed by the Screen of Multiple Definitions of Basin

Figure 3 shows the main screen of the Glossary Manager with another screen superimposed on it to highlight that NCRB and Standards Australia have somewhat different definitions of a ‘basin’. The main screen lists all the domain terms in the Glossary There is an option to select specific terms from these glossaries so that users can create customised sub-glossaries, e.g. for a new publication or perhaps to establish a project glossary. When an entity is selected, the programme displays data about the entity, such as the standard(s) it is defined in, its definition(s), broader, narrow and related terms with further options to view its illustration and attributes.

With reference to Figure 4, the various menu items of Glossary Manager that allow additions, deletions and updates to domains (currently AEC), glossary owners, glossaries and individual terms within glossaries can be seen. As noted, each organisation retains full control of the terms and definitions in their sub-glossaries, and they can download them for inclusion in their publications as and when they wish.

Glossary Manager is the first step in managing and exchanging data in platform independent manner. As appropriate, entities identified and defined in the sub-glossaries will be listed in the Data Directory where they will be fully attributed and thereby enable project decision-makers to access, process, and exchange data about an entity – from their respective areas of concern. Glossary Manager provides options to enter attribute specifications which saved for future use. Decision makers will be able to create usable templates for a range of projects.

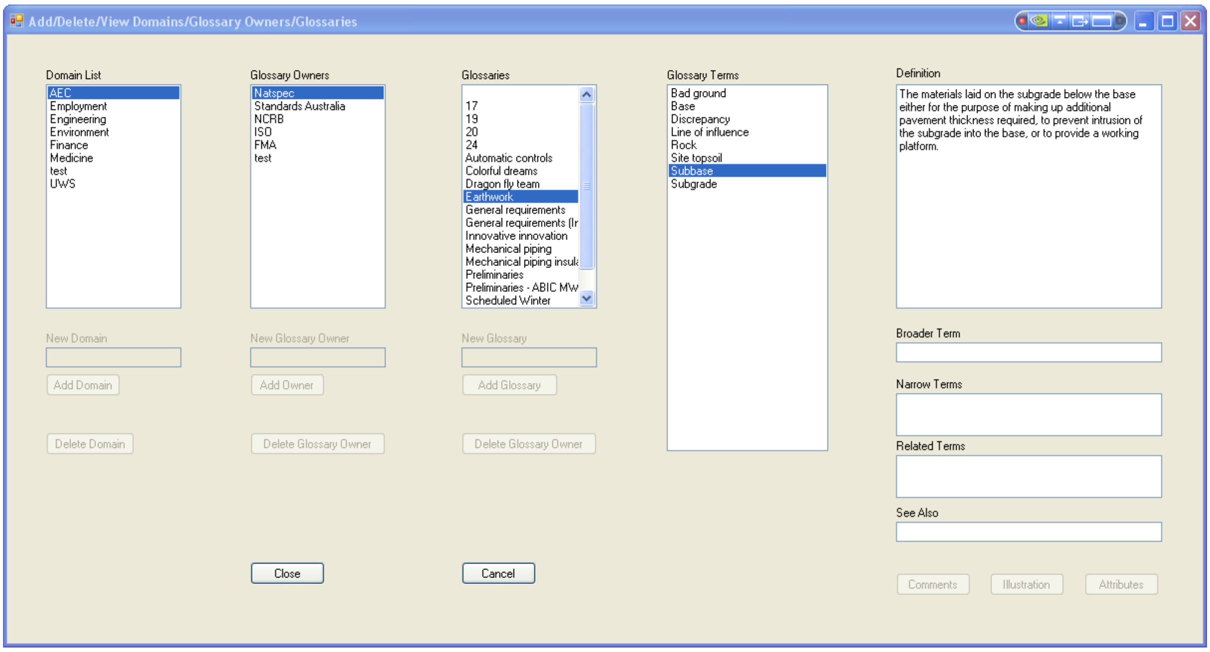

Figure 4 – Screen for Domains, Glossary Owners, Glossaries, Glossary Terms and their Definitions

5.2 Data Directory –

GM is the first step in identifying and defining the entities. The next one is to define their attributes in a way that will enable project decision makers to access, process and exchange information about them. This is the role of the DD.

The purpose of the DD is to establish a comprehensive, industry agreed, way of identifying and describing these entities over their respective life-cycles, and to do so in a manner that is fully compatible with the IFCs and capable of incorporation into BIM+.

Approach –

Notionally, to ensure clear concise communication in regards a give process the decision makers simply have to agree the identifiers and descriptors to be used. On a practical level this agreement must be industry wide –

- because the outcome of one process is commonly input to another,
- because these 'new' processes might involve a different constellation of decision makers, and
- because external resources managers must prepare their ERs in advance of and without reference to specific processes.

Each PDM and ERM brings a unique perspective to the work at hand. The entities and entity attributes used to build a view is, in essence, an ontology. None has priority over another. The correctness of each is determined on the basis of its ability to support the successful conduct of one or more production or production management processes. In this context the role of the DD is simply to establish a comprehensive list of fully harmonised entities and to make them available to industry stakeholders.

Implementation –

Like the GM, developing a DD will be a long and involved process so there is a need for an overarching framework that will enable it to be managed over time. With new products, materials and processes constantly being introduced and old ones withdrawn, the system will need to be easily modifiable, and it should be immediately useable. Furthermore, so long as the system is incomplete, practitioners will find gaps. Routines must be available to the PDM that will enable them to instantiate the entity/entity attributes they require and to apply them to the work (*process*) at hand.

Unlike the GM, there is no need for industry agreement as to what entities or entity attributes are included in the registry. If a group of decision-makers need to access, process or exchange data about an entity it needs to be in the system. It remains to the DD to provide the tools to make sure it is appropriately identified and is consistently described in the appropriate manner.

Demonstration DD software has been developed. In populating it, a number of *processes (production or production management)* will be nominated and the decision makers involved will be asked to identify the entities and their respective attributes that they require. The same routine will be used by practitioners to identify attributes that may be missing in the fully operational directory.

5.3 Tools for Processes

These are third party resources and therefore beyond direct input by IDSS developers. Suffice it to say here that the demonstration software discussed in the previous section will be used to show ERM the potential of the strategic frameworks and the opportunities available to those who do.

From an IDSS perspective the intention would be to assist ERMs –

- to draw from the DD the entities and entity attributes that are relevant to their particular their resource(s).
- to use these descriptors to key those resources so a PDM 'call' can be received, understood and proactively used to search for relevant input.

Where the DD does not contain the required entities or entity attributes, they would be asked to use one of the DD routines to enter them – thus enabling them to get on with the development of their resource and contribute to the development of the directory.

6. FURTHER WORK AND CONCLUSION

The paper has presented a prototype product created to support ontology-based software development for distributed information management strategy in the AEC-FM industry, which is presented in a separate paper. The outcome, a Glossary Manager, can be used as a partial knowledge repository as well as a software artifact which leads on to the next stage.

Overall, a four-stage approach is proposed for Glossary Manager project, as follows.

I. Proof of concept – This is the current stage of the project, presented in this paper.

II. Bench test – A trial of the demonstration software under normal operating conditions will be conducted. This will involve a number of key industry associations and regulatory authorities who would trial the system using their respective terms and definitions and following normal operational procedures. The outcomes will help to identify the strengths and weaknesses of the software, and to determine how to make the software may scalable in order to manage all industry terms and definitions within realistic time and cost constraints.

III. Field trials – The third stage envisages establishing a 'terminology central' i.e. an industry resource that, in addition to supporting the Glossary Manager, establishes a point of reference and contact in regards to terms and definitions. Wider industry participation will be sought to involve organisations active in some aspect of the BIM so that Glossary Manager is properly linked to current industry practices. The software will be modified as required and made available on the WWW.

IV. Roll out – The final will be developed in association with 'bench test' partners.

A similar process is planned for the Data Dictionary.

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