THE INTELIGRID PLATFORM FOR VIRTUAL ORGANISATIONS INTEROPERABILITY

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SUMMARY*: The EU project InteliGrid (2004-2007) combined and extended the state-of-the-art research and technologies in the areas of semantic interoperability, virtual organisations and grid technology to provide diverse engineering industries with a platform prototype with flexible, secure, robust, interoperable, pay-per-demand access to information, communication and processing infrastructure. This paper presents some of the key findings and developments related to the semantic grid architecture for virtual organisations and primarily distributed engineering in construction. After a general introduction to the overall vision of the InteliGrid project, the paper presents key identified user roles in the system as well as top end user requirements. This is followed by a description of the system architecture including conceptual, service frameworks and key developed components that the system offers. The paper concludes with a description of an integrated demonstration from the architecture, engineering and construction sector that has been the basis for requirements and validation of the results.*

KEYWORDS*: virtual organisation, interoperability, engineering collaboration, service oriented architecture, ontologies, semantic grid, InteliGrid.*

1. INTRODUCTION

1.1 Problem statement

The integration and interoperability of engineering software applications supporting the design and construction of the built environment constructed by virtual organisations comprised of numerous enterprises have been providing one of the most challenging problems for the application of information and communication technologies. The "islands of automation" problem has been identified by the AEC community in the late 1980s, and several national and EU projects have been tackling the problem since. Conceptually, the integration solutions have been traditionally based on commonly accepted and standardized data structures, such as ISO-STEP or IAI-IFC standards. Projects such as COMBINE (Augenbroe, 1995), COMBI (Scherer, 1995), ATLAS (Greening and Edwards, 1995), ToCEE (Scherer et al., 1997), ISTforCE (Katranuschkov et al., 2001), OSMOS (Wilson, 2001), GLOBEMEN (Kazi et al., 2001) and others proved both theoretically and with prototypes they developed that interoperability based on product data technology is achievable and the industry can benefit from it. But despite all R&D efforts such solutions are still rare in the industry. Since the focus of the above mentioned projects was primarily on the data structures describing the problem domain, the actual research communication platform prototypes used whatever the ICT state-of-the-art was at the time. This included CORBA, COM/DCOM, Web Services, etc. (Dolenc et al., 2005).

Foster et al. (2002) capture the essential requirements of collaboration inside the engineering sector: *"the problem is coordinated resource sharing and problem solving in dynamic, multi-institutional virtual organizations [...] not primarily file exchange but rather direct access to computers, software, data, and other resources, as is required by a range of collaborative problem-solving in industry. This sharing is highly controlled, with resource providers and consumers defining clearly and carefully just what is shared, who is allowed to share, and the conditions under which sharing occurs"*. This statement became one of the definitions of grid computing, particularly for the evolution of grid technology towards *semantic grid*. It gave ground to the InteliGrid hypothesis (InteliGrid, 2004) that grid technology could provide the solution to the interoperability, security, and information access problem.

1.2 The InteliGrid approach

The main goal of the InteliGrid project was to achieve a challenging integration solution providing a flexible, secure, robust, interoperable, and pay-per-demand access to: information, communication, and processing infrastructure. The project addressed this challenge by combining and extending state-of-the-art research and technologies in three key areas, namely: semantic interoperability, virtual organisations and grid technology – an approach similar to Semantic Office Task Automation (SOTA) described by Tsai el al. (2003). Thereby it provided: (1) a standards-based set of ontology enabled services and grid middleware in support of dynamic virtual organisations, and (2) a representative collection of grid enabled engineering applications.

It was recognized that if the grid technology had to ensure the underlying interoperability and collaboration infrastructure for a complex engineering virtual organisation, it had to support *shared semantics*. This is the area where major innovations and extensions of the current grid middleware technologies are required.

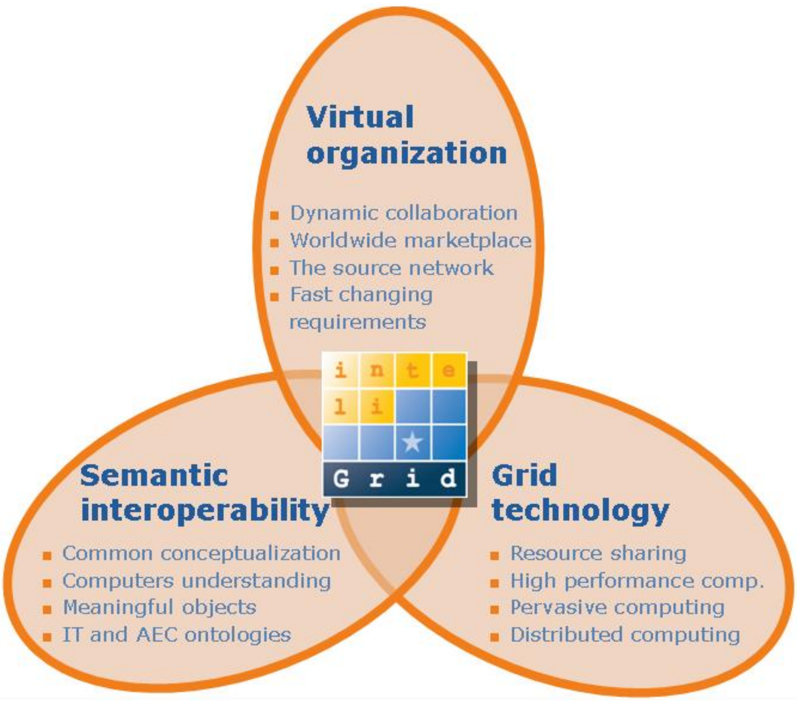


FIG. 1: The InteliGrid project addressed three key technology areas.

2. INTELIGRID PLATFORM

2.1 Requirements

Key requirements for the InteliGrid platform were gathered through an extensive requirements elicitation and analysis process and were used as a baseline in the design of the high-level InteliGrid architecture (Katranuschkov et al., 2006). The requirements analysis performed in parallel with the InteliGrid architecture development resulted in the definition of top 10 requirement lists related to end user needs and technology issues (see Table 1 and Table 2 below). Based on the work done by the OSMOS project (OSMOS, 2001) and the requirements analysis seven key user roles were identified as relevant for the InteliGrid platform:

- **Engineering end user (EEU).** This role summarizes all engineering roles acting as consumers of the infrastructure and middleware services as well as of services provided by dedicated, independent or virtual organisation related service providers.
- **Virtual organisation manager (VOM).** The virtual organisation manager is responsible for the completion of the construction project in time. Currently this goal evolves from creating and managing documents and drawings to creating a data model in a data base.
- **Grid software developers (SD).** Software developers are challenged by the InteliGrid platform if their software is supposed to be used in the InteliGrid virtual organisation environment. They develop InteliGrid compliant applications and services.
- **Grid Administrator (GA).** This role defines actors responsible for the overall functioning and quality of service of the grid. The Grid Administrator is responsible for establishing and maintaining the grid environment of virtual organisations, managing security policies, etc.
- **Service Providers (ASP).** Within InteliGrid service providers are defined as virtual organisation participants or third party actors that utilise the grid environment to offer specialised services dedicated to the specific domain of the VO.
- **Real Organisation CIO (RO CIO).** The end user in this role is responsible for both the internal IT infrastructure and the external links of his company with regard to interoperability, security and response times in relation to the costs of the infrastructure.
- **Virtual Organisation CIO (VO CIO).** The counterpart of the real organisation CIO is the virtual organization CIO who formally represents the IT infrastructure of the grid on high (project) level. His responsibility is the coordination of the setup of the grid infrastructure with respect to standards, ontology, access for the participating companies, tools, services, etc.

TABLE 1: Top 10 user related requirements

	Relevance (user role)						
Description	**EEU**	**VOM**	**SD**	**GA**	**ASP**	**RO CIO**	**VO CIO**
Extend the semantic grid paradigm to support dynamic virtual organisations			✓	✓	✓	✓	✓
Provide support for shared semantics (semantic interoperability)	✓	✓	✓	✓	✓	✓	✓
Demonstrate how typical server side applications can be grid-enabled	✓	✓	✓	✓	✓	✓	✓
Demonstrate how client side CAD applications can interface with the grid	✓	✓	✓	✓	✓	✓	✓
Include the notion of virtual organisations as an integral part of the IT env.	✓	✓	✓	✓	✓	✓	✓
Provide security, authentication, authorisation and access rights support	✓	✓	✓	✓	✓	✓	✓
Address firewall configuration issues of secure grid environments				✓		✓	✓
Provide transparent grid-based document management operations	✓	✓					✓
Provide efficient access to shared heterogeneous data resources	✓	✓					✓
Address issues of the virtual organisation dissolution process	✓					✓	✓

TABLE 2: Top 10 derived technology requirements

	Relevance (technology)			
Description	**Ontology framework**	**Grid middleware**	**Semantic services**	**Other services**
Provision of confidentiality		✓		
Provision of infrastructure integrity and infrastructure availability	✓	✓	✓	
Support of virtual organisation logic: security and trust	✓	✓	✓	
Automated configuration and reaction to changes in virtual org. structure			✓	
Provision of elaborate directory services	✓	✓		
Construction and use of generic and domain specific ontologies	✓	✓	✓	✓
Modelling of business processes in a clear yet flexible way	✓			
Support for description of heterogeneous resources in varying granularity	✓	✓	✓	
Ontology specifications open to future extensions	✓		✓	
Platform independence and compatibility with industry standards	✓	✓	✓	✓

Based on requirements analysis and feedback from various public demonstrations of the InteliGrid platform as well as various formal and informal discussions with different members of the engineering community, the top requirements can be summarised with the term **"5S Grid"**:

- **Security.** Industry is eager to move to a ground-up secure environment (Deloitte, 2005). InteliGrid addressed this requirement by adopting standard Grid Security Infrastructure (GSI) and integrating the Role Based Access Control model RBAC (Ferraiolo et al., 2003) into the platform authorisation processes (Adamski et al., 2006).
- **Simplicity.** The platform must work seamlessly with current client applications and operating systems. The general design principle when developing the platform was to hide the underlying technology implementation from end user and thus not require end user to redefine his usual workflow.
- **Stability & standards.** The need for stable long-term specifications and (open) standards is well known. Sutor (2006) in his essay on open standards and service oriented architecture concludes that "*… we need truly open standards and not vendor controlled or dictated specifications in order for SOA to reach its full potential as a solution for customers …*" The developed platform complies with such open standards (WSRF, WS+I, RBAC, IFC etc.).
- **Scalable service oriented architecture (SOA).** The service-oriented architecture (Erl, 2005) is well-accepted and known system architecture. The InteliGrid project adopted the Open Grid Service Architecture OGSA (Foster et al., 2005) as a baseline, and developed the platform using an OGSA compliant grid middleware.
- **Semantics.** The platform must support rich, domain specific semantics - not about disks and CPUs but about buildings, fuselages, proteins, etc. (Turk, 2005). The InteliGrid project addressed this issue by developing a set of domain specific ontologies: organisational and resource ontology in support of engineering virtual organisations, business process ontology for process centred engineering work and ifcOWL (based on the IFC product model) as specific product ontology for the construction domain.

2.2 Generic engineering user scenario

A number of different use cases were considered while designing the InteliGrid platform, ranging from basic ones, such as joining a virtual organisation, to more advanced cases involving the use of semantic information (Katranuschkov et al., 2006; Turk et al., 2004). The developed use cases are here abstracted into the following *generic virtual organisation end user scenario* (see also Fig. 2):

1. **Entering a grid-enabled virtual organisation.** The end user has a prescribed role within the virtual organisation that enables him or her to perform certain tasks. This step needs to be as simple as possible while still maintaining a high level of security.
2. **Finding objects to work on.** The end user role within the grid-enabled virtual organisation, together with a fine grained role-based access policy for all virtual organisation resources, enables the end user to learn about the object(s) he needs to perform his task(s) on, where objects identify any form of grid virtual organisation resource (document, grid service, task description, storage resource, etc.). In the ideal situation the end user would automatically be presented with only those objects on which he needs to perform his current task depending on a given state of the project/work. Implementation of this step heavily relies on the use of semantic (grid) technologies.
3. **Matching objects to tools.** Tools for performing certain tasks are usually known in advance. In most cases of engineering virtual organisations there exist explicit or implicit rules that define a set of tools/services that can be used.
4. **Using the tools.** As previously described, offline end user applications are often used to perform engineering tasks. That means that objects required to perform the task must be made available to offline end user application in a traditional not grid-related way.
5. **Sharing the resulting object(s).** After completing the task and producing local results/information or generally objects (documents, drawings, etc.) the newly created information must be shared with other actors within the virtual organisation to enable them to perform succeeding tasks. To allow other actors within the grid virtual organisation to find the appropriate object(s) to work on, shared objects are semantically annotated according to the developed grid virtual organisation ontology.
6. **Triggering actions.** Sharing the obtained results can trigger the activation of new/additional tasks and thus enables other actors within the grid virtual organisation to perform their job. Ideally, this would happen automatically and would be triggered by the platform process engine.
7. **Leaving the grid VO.** The end user leaves the grid virtual organisation and removes his or her non-shared resources.

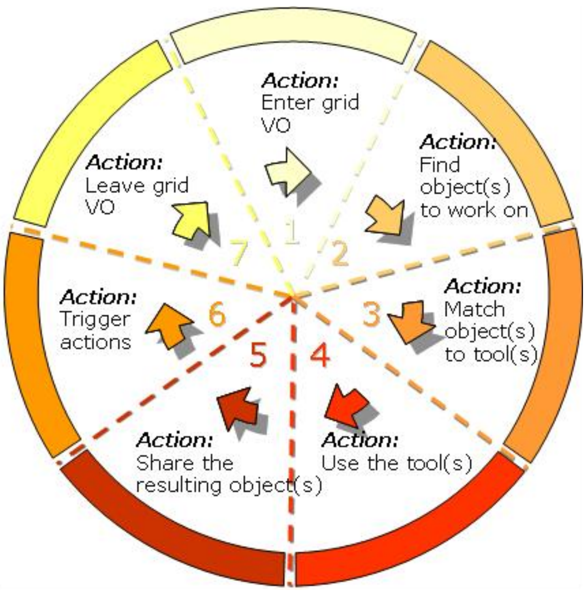


FIG. 2: Generic virtual organisation end user scenario actions.

2.3 Architecture

The InteliGrid architecture is based on the SOA concept as well as on lessons learned in related earlier projects (Scherer et al., 1997; Katranuschkov et al., 2001). It is a high-level architecture, conforming to the key requirement of a generic approach which can be proven by trying to fit the existing architectures of systems developed over the last decade into it.

The architecture is also used to identify the components that exist and the components that need to be developed. It includes four basic layers (Fig. 3):

- **The real world –** limited, of course, to the domain that is being addressed. In the context of the InteliGrid platform this is the world of buildings, aeroplanes, organizations, engineers, processes etc. In order that IT can assist in this, the real world needs to be conceptually modelled.
- **Conceptual layer** - containing things that exist in the form of standards, ideas, graphs, schemas, ontologies, notions etc. It does not contain services or any other kind of executable code, but just a formal encoding of the concepts from all of the layers. It is quite common that a piece of software has its associated data structures. What is new since the research in interoperability architectures started in the late 1980s is that a common conceptualization that can be shared by several different software applications has been developed. This approach got some additional support from the concept of networked and cross-linked conceptualizations that refer to each other using URIs regardless of the richness of the encoding – an idea that exists both for XML Schema and for ontologies. Finally, with the increased complexity of the interfaces and the environment in which the software would interact with, the modelling of this environment started and is culminating with Web Service and Semantic Web Service architectures. The motivation for the modelling of the IT environment is the same as with the modelling of the real world. It is complex and IT support is needed for managing it.
- **Software layer** - comprised of software that can be compiled, installed, executed, and runs and communicates with other software. In this software the schemas derived from the conceptual layer are used, and the software commits to the ontologies or conforms to standards defined in the conceptual layer.
- **Basic resource layer** – needed to run the software. IT resources are needed to run the applications and services defined in the layer above, e.g. hardware, firmware, software, etc.

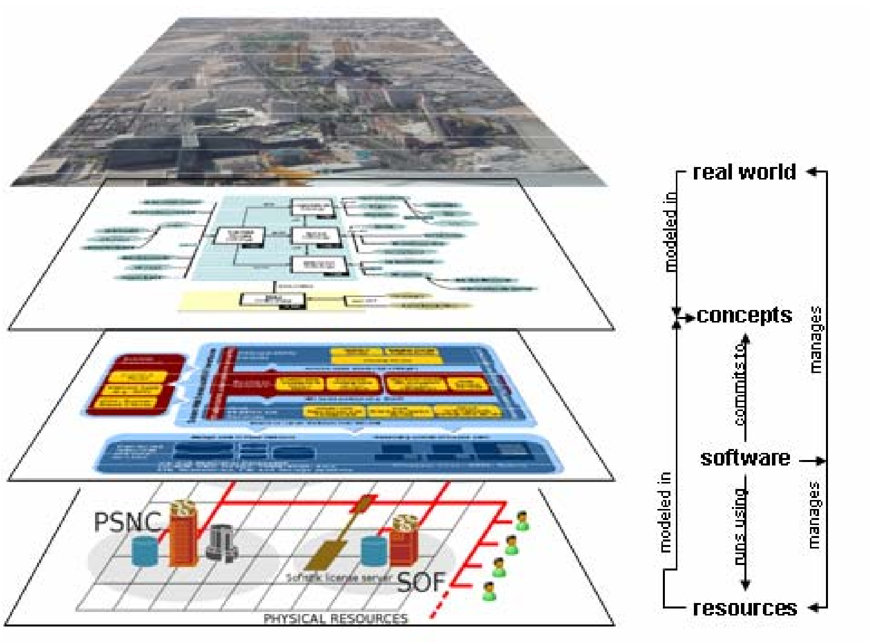


FIG. 3: The four main layers of the architecture and their relationships.

2.3.1 Conceptual framework

In the architecture, this layer must provide information on what concepts exist in the system, and how they are encoded. The concepts are organized into two axes. On the vertical axis is what we call the *conceptual stack*. This stack has three layers of interest: (1) the engineering layer, including concepts that the engineers using the system will deal with, such as walls, bridges, windows, reinforcement bars etc., (2) the services and grid layers, providing IT concepts that describe the IT elements of which the system is built, and finally (3) the resource layer, including concepts describing low level resources, such as CPU, memory, networking, security etc (Fig. 4).

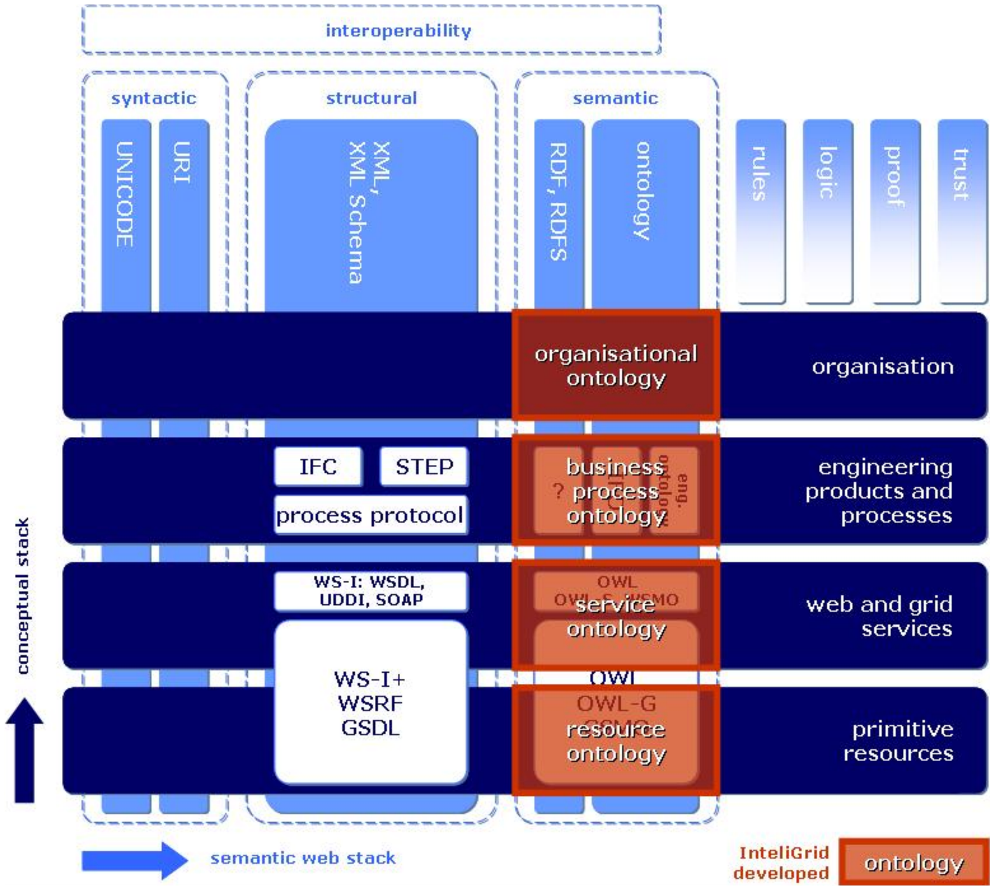


FIG. 4: Conceptual framework with core InteliGrid ontologies. Organisational, business process, service, and resource ontology provide semantic interoperability layer in the InteliGrid architecture. The ontologies are based on or extend technologies from the conceptual stack, for example as service ontology OWL-S was applied.

On the horizontal axis is the so-called Semantic Web Stack (Berners-Lee et al., 2001). Layers related to rules, logic and inference, proof and trust are lively debated and researched. Few mature technologies and solutions for these layers exist; therefore they are drawn in a dashed line.

Finally the intersections of the horizontal and vertical layering are examined. Existing and proven technologies are drawn with a grey background and future work as hollow, dashed rectangles. The items will be discussed top to bottom, left to right:

- **(Virtual) Organization Layer.** It describes organizations and includes generic concepts such as project, group, actor, role, right, organization etc.
- **Engineering layer.** This layer is quite well developed on the data level with standards such as IFC and STEP, but more work related to the process and communication may be needed there. There is hardly any work in construction IT that would have addressed the RDF (RDF, 2004). Whether it is needed or not is a research question. On the ontology layer there seems to be a need for "Industry Foundation Ontology" (IFO) that could perhaps be derived on the one hand from the IFC models and on the other from the work in the classification systems. This IFO could be further generalized

into an engineering ontology using the Web Ontology Lanugage OWL (OWL 2004). The ifcOWL ontology developed by InteliGrid can be considered as an initial step in this direction.

- **Services layer.** The web services interoperability (WS-I, 2006) provides a well developed set of standards, conventions and frameworks to address the web-services-kind-of functions, but does not sufficiently address the grid technology. The WS-I+ and the WSRF frameworks (Atkinson et al. 2004) extend the concepts not only towards grid services but towards lower level grid resources as well. OWL-S (OWL-S, 2004) is an ontology based on OWL in which web services can be described; similarly there may be a need for extending it so that grid services can be described, too.
- **Resource layer.** Current ideas of grid development go to the direction of anything being viewed at as a service - the low level or virtualized hardware and networked resources as well; therefore, in our graph the boxes from the services layer have been extended into this layer, too.

Based on the above principal concepts, the formal Inteligrid *ontology framework* has been developed. Fig. 5 below provides a high-level overview of that framework; its details are reported in (Gehre et al., 2007).

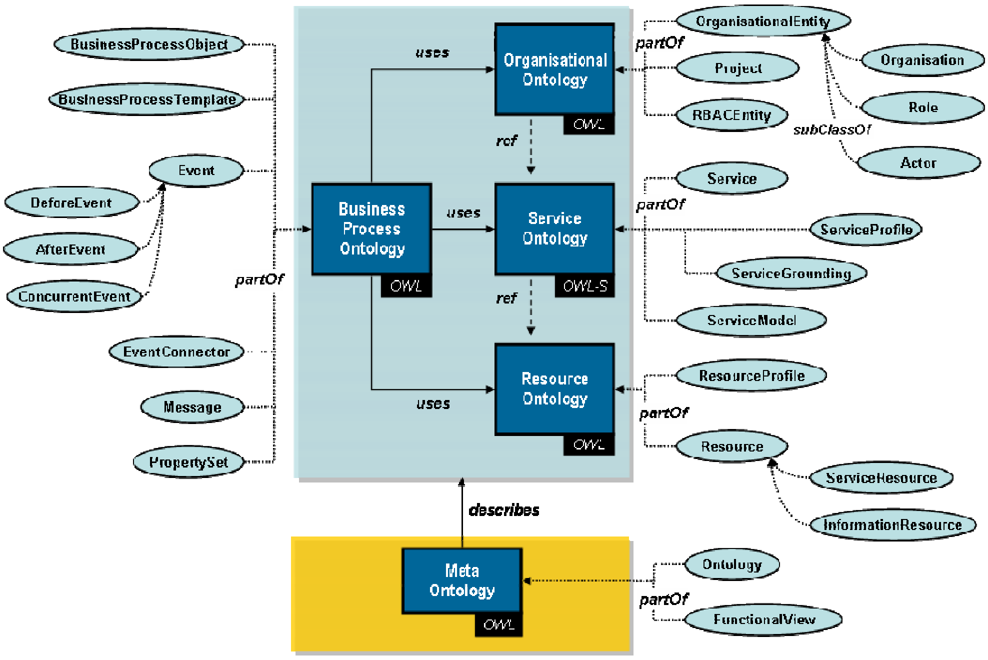


FIG. 5: The ontology framework illustrated with some core concepts.

2.3.2 Service framework

InteliGrid is delivering a generic grid-based integration and semantic-web based interoperability platform for creating and managing networked virtual organisations. The developed service-oriented architecture is presented in Fig. 6 below, together with all its principal components and their interfaces. The following common characteristics can be defined for all InteliGrid services as main platform components:

1. services are modular components that can be semantically described, registered, discovered and finally used by clients,
2. services can participate in specific business workflows, where the order in which they are sent and received affects the outcome of the operations of a service,
3. services may be completely self-contained, or depend on the availability of other services,
4. services are able to advertise details such as their capabilities, interfaces and supported communication protocols according to pre-defined concepts and ontologies,
5. services are loosely coupled, following one of the most important SOA principles; they may be individually useful, or they can be combined to offer a specific higher-level functionality, and

6. all capabilities provided by services as well as communication and data channels among them and clients are protected by security and message level security mechanisms.

From the security perspective, a virtual organisation is a collection of individuals and institutions, represented by various services and service consumers that are defined according to a set of resource and data sharing security policies and rules. Those resource sharing rules must be dynamically controlled and then enforced into the whole virtual organisation environment. Thus, one of the most challenging tasks in the project was to create an appropriate security infrastructure (based on strong GSI authentication mechanisms and advanced RBAC authorization model) covering all aspects of operating within a dynamically established virtual organisation. The InteliGrid platform enables both service consumers and service providers to manage and share their resources securely with any of the individual organizations participating in the virtual organisation.

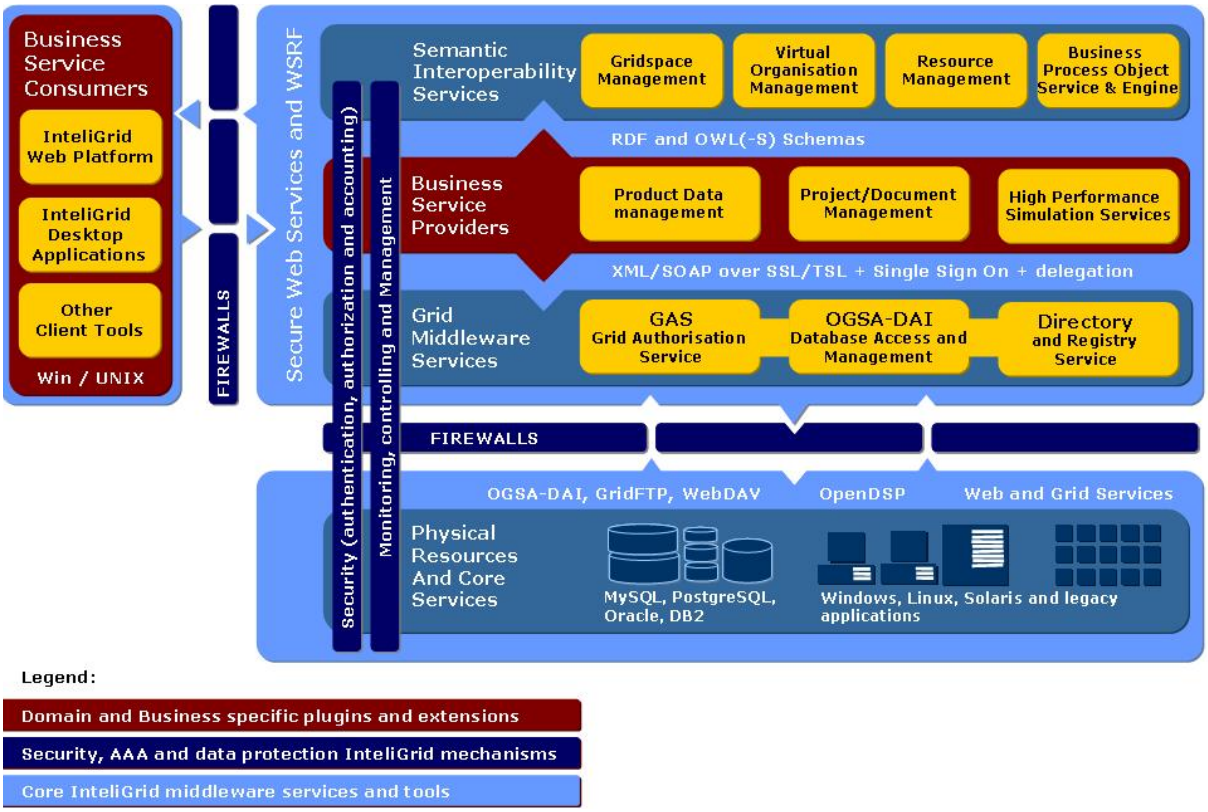


FIG. 6: InteliGrid high-level platform components.

Technically speaking, components are deployed either at some workstation or at a remote node on the grid. If on the grid, it is not important where they are deployed physically; the resource where they run will be very likely allocated dynamically. The grouping of the various services in Fig. 6 is presented according to the logic of the service and does not necessarily imply who uses which service. There are four main types of components in the InteliGrid platform:

- **Business specific applications.** These applications are the consumers of the business service providers and are usually accessed through a web based portal interface, although desktop applications can also make use of different available services.
- **Secure Web Services and WSRF compliant services.** They can be further divided into: (1) interoperability services (top tier) that simplify the interoperability among all services, and (2) domain and business specific services that perform some value added work. There are two kinds of business services: (a) collaboration services that provide file and structured data sharing and collaboration infrastructure, and (b) vertical business services that create new design or plan information.
- **Middleware services.** These services offer traditional grid middleware functionality extended with particular needs of the InteliGrid platform, e.g. GAS (Adamski et al., 2005), OGSA-DAI (Antonioletti et al., 2005), GRMS (Allen et al., 2003), etc. The services are based on mature grid

technologies and their open source reference implementations – the underlying service framework is based on the Globus Toolkit (Foster, 2006), Gridge (Pukacki et al., 2006) and FedStage (FedStage, 2007).

- **Other resources.** The bottom layer consists of various physical infrastructure resources that suppliers offered to the platform. All these resources are available and can be accessed remotely through well-defined interfaces and secure communication protocols. Among others services include: (1) remote data access via GridFTP (Allcock, 2003) and WebDAV (Whitehead and Wiggins, 1998), and (2) remote application submission and control – Open DRMAA Service Provider OpenDSP (OpenDSP, 2007).

Business services as a part of the InteliGrid Platform are available on demand for end users when they need them. In general, business services provide secure SOAP-based interfaces using Web Services and WSRF technologies. Thus, various remote clients are able to discover their location, policies, interfaces and protocols. Note that business services based on Web Services and WSRF technologies are in fact distributed software components that provide information to applications rather than to humans through application-oriented interfaces. The information is well structured using XML that can be parsed and processed easily by end user applications but there is little or no semantic and metadata included which might be essential at the business level. Furthermore, it is assumed that in dynamic and complex virtual organisation environments a number of business services and capabilities they offer may be difficult to discover. Thus, end users are able to take advantage of the provided interoperability services to speed up the process of connecting to appropriate business services. Finally, the connection process between business service provider and consumer is established over a secure mutually acceptable protocol, e.g. SSL/TLS with delegation extensions or grid security infrastructure.

2.4 End user perspective

The InteliGrid platform appears to the user just as any other collaboration environment. It is the functionality and features of the shared environment that make the difference. Fig. 7shows what an average user would make of the platform - "something" that allows him or her to collaborate inside the virtual organisation, share computing, application, data storage and other networked resources in general. The feeling that there is in fact such a thing as the "InteliGrid Platform" is apparent only with specific activities, for example: getting or storing data, finding and running services and applications, etc. With actions like that the user will feel that the application that he or she is using is communicating with the platform - some services which are somewhere on the network, on the grid. An end user will have hands-on experience with domain and business specific components in the architecture (FIG. 6). Only identified user types (e.g. grid administrator, virtual organisation CIO) will need to care about what is on the lower layers of the architecture.

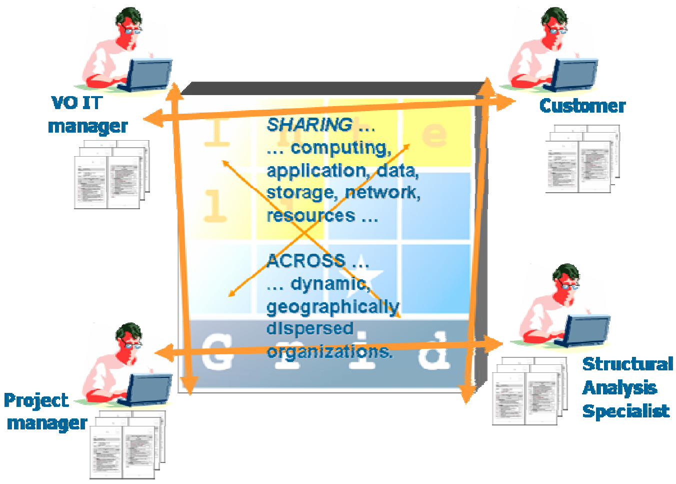


FIG. 7: End user perspective - functional view.

2.5 Tools and services

The developed InteliGrid platform includes different client side applications and tools as well as many server side components enabling potential end users to securely execute high-performance calculations, access heterogeneous data resources, and generally work in established virtual organisations. The description of all available applications and services is available on-line at http://www.InteliGrid.com/products. The following sections provide an overview of three main InteliGrid products:

- **Collaboration platform** that provides a working testbed environment, including online access to available resources;
- **Ontology services** that, together with the developed ontologies, establish the conceptual and architectural backbone of a semantic grid infrastructure;
- **Semantic document management service and tools** that provide a major testing application for the ontology services.

2.5.1 Collaboration platform for Virtual Organisations

The InteliGrid collaboration platform for virtual organisations has been designed to allow members to dynamically create and manage virtual organizations or collaborative networked enterprises in various engineering industry sectors. It has been designed independently of any particular computing, data storage mechanism or access protocol enabling people and resources from different organizations to be formed to address and solve a given problem.

From the ICT perspective, the platform enables secure sharing and control of resources (computing, applications, databases, storage, files, etc.) across dynamic and geographically dispersed organizations and SMEs that are much stronger at local business and more flexible than big companies and silos information technology systems. It uses semantic and ontology based search and reasoning mechanisms helping virtual organisation members to find and control the right resource. Furthermore, it provides transparent remote access and control mechanisms for data and computing intensive experiments and business processes. The platform features a secure, semantic-based and robust grid middleware together with easy-to-use web based interfaces for information integration, communication and interoperability.

The web interface is built on the GridSphere portal framework (Novotny et al., 2003) which provides an open source portlet-based web portal. The portlet framework enables developers to quickly produce and package third-party portlet web applications that can be run and administered within the portlet framework container. By using GridSphere, InteliGrid provides a user-friendly web interface as a gateway to access distributed InteliGrid platform services. Built-in single sign on, authentication, authorization and control mechanisms allow end users such as engineers, designers, architects, etc. to create their own space within a virtual organization to securely share relevant information and resources with other business partners and groups. The platform enables local administrators and IT staff to monitor the status and conditions of all provided services. It also allows virtual organisation managers to orchestrate and control access to different business service providers. Other actors such as virtual organisation project managers and grid administrators are able to establish and dynamically modify virtual organisations and their resources including users, services, databases and computation resources. From the end user and business perspective, the platform provides the following features:

- possibility to discover new consumers, partners and collaborative users,
- enabling a business relationship between different entities in a distributed environment over the Internet,
- improving tremendously day-to-day communication processes along with cross-organization computing and storage operations,
- reducing infrastructure costs by sharing computing and data services across an enterprise-wide set of customers, partners, users and projects, and
- increasing efficiency and ROI through centralized and on-demand management of distributed computing services and improved access to storage, data and information services.

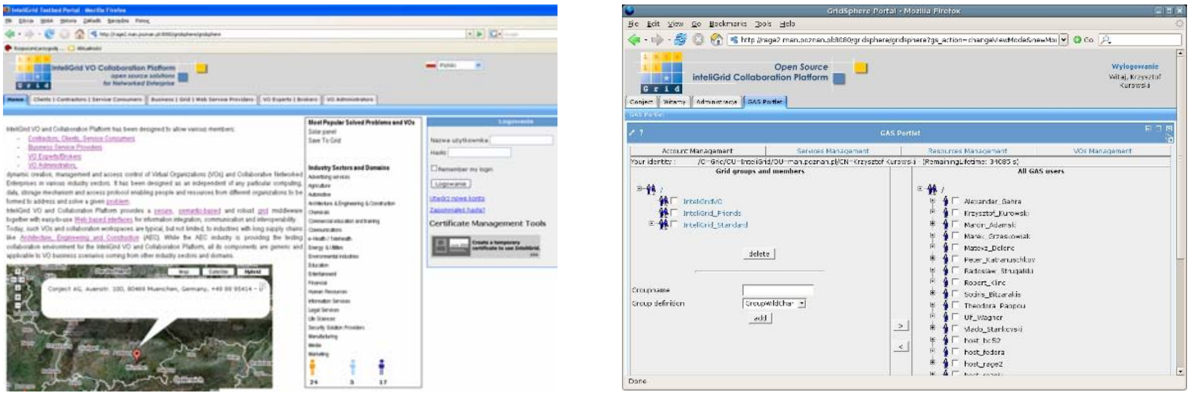


FIG. 8: InteliGrid testbed portal – GridSphere based portal implementation providing entry point to the available online services (left) and the portlet for managing virtual organisation security settings (right).

2.5.2 Ontology services

Developing ontologies for semantic virtual organisation interoperability is only the initial step in supporting real business cases as targeted by the InteliGrid platform (Gehre et al., 2007). However, to fully utilise the advantages of the ontology-based approach, ontology services – providing convenient methods for management of ontology instances, i.e. semantic metadata about entities in the IT environment – need to be developed and made available through the platform service framework (Fig. 6). These services constitute the interoperability layer and make use of the grid middleware services that provide basic authorisation management and generic access to all grid resources. The ontology services provide generic and specific convenience methods to create, manipulate and manage the ontology instances of classes defined in the ontology framework. Interfaces make use of the XML-based OWL notation for data exchange (cf. OWL 2004). The SPARQL query language (Prud'hommeaux & Seaborne, 2007) is used for ontology querying. Convenience methods provide access to instances of dedicated ontology classes and facilitate their management.

The developed ontologies and ontology services establish the conceptual and architectural backbone of the semantic grid infrastructure. They facilitate information management, improve the consistency of the distributed environment and make it less prone to errors. However, end user applications can also strongly benefit from the added semantic value. The technology is well suited to support human-computer interactions because semantic models are more related to end user perceptions than the usually applied IT based schemas. All developed business services and end user client applications use ontology services actively to enhance end user experience. The client applications include virtual organisation and gridspace (platform) management clients (see Fig. 9), a document management system, etc. Full description of the ontology services and clients is out of scope of this paper but can be found in (Gehre and Katranuschkov, 2007).

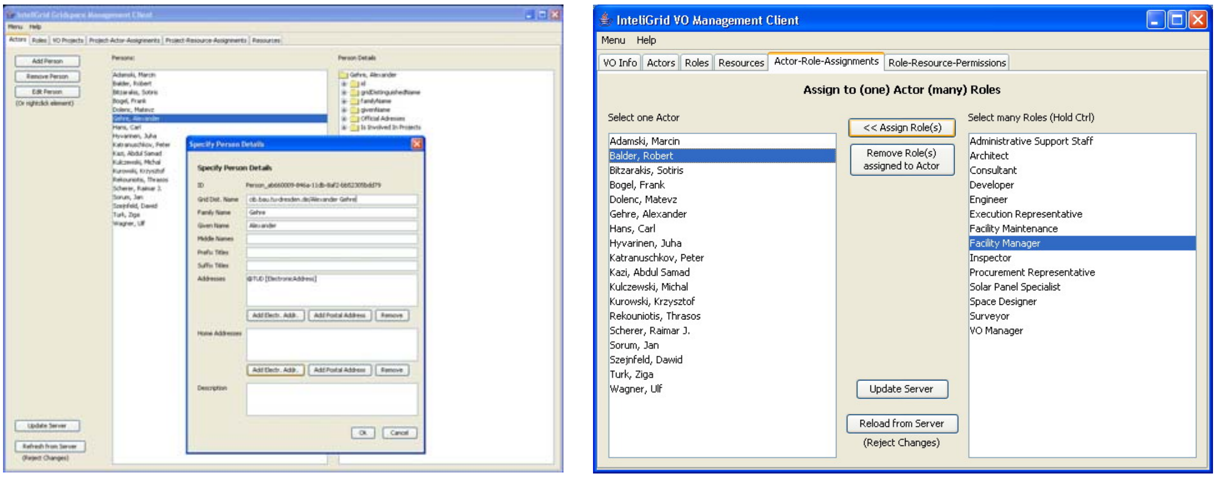


FIG. 9: Ontology service clients – screenshots of the gridspace (platform) management client (left) and the virtual organisation management client (right).

2.5.3 Document management service

In engineering in general, the ability to securely access diverse data sources in a collaborative environment is becoming an essential requirement for optimising the design, development and maintenance phase of the engineering product life-cycle. While a product model based exchange of information is slowly replacing the traditional RDMS and file based information exchange (Fischer and Kam, 2002), it is true that the majority of communication in a typical engineering project is still document based. It is therefore essential for collaboration environments to provide tools and services that enable end users as well as other services to access document based information in a secure, location independent, personalised and on-demand way.

To address the above issues as well as the problem of information overload (Miller, 2004), a semantic document management system has been developed based on the InteliGrid semantic grid architecture. Thus, the right document can be delivered to the right place at the right time to support the decision-making process at any level of a (virtual) organization. The document management system offers a generic, grid based, ontology enabled document management solution that provides client as well as server side components with a well-defined web services interface that enables a remote access to the underlying document management services. The system architecture allows realisation of several relevant use cases. Most importantly, the main actor performing document management operations (annotation, searching, storing, retrieval, etc.) can be also other grid or web service as a part of an automatic workflow. Some of the main features of the developed system are as follows:

- The system is generic and can support any domain specific ontology or taxonomy used in document annotation. Domain specific resources are treated as properties of a specific VO.
- Actors (organisations, individuals, services) can specify different preferred settings, e.g. storage resource, remote directories, etc.
- Security, based on the RBAC model, is strictly enforced and all document transfers are encrypted.
- Several end user client applications are provided for document annotations, document storing, retrieval, etc. Thin clients (FIG. 10) are based on the GridSphere portal framework and are developed as JSR 168 compliant portlets while fat clients are Java based applications with specific operating system components for better integration with other native applications.
- The system supports several different schemes for storing/uploading documents. Currently, it fully supports only manual and semi-automatic uploading of documents (based on a predefined local directory structure). However, the agent-based uploading (updating) is also being investigated.

The ontology-based implementation of the system enables the realisation of various new end user scenarios, from advanced fine-grained access rights management to enabling semantic based document retrieval. Ontology services developed within the InteliGrid project provide underlying semantic technologies for ontology based VO management, service and resource annotation, semantic search, etc.

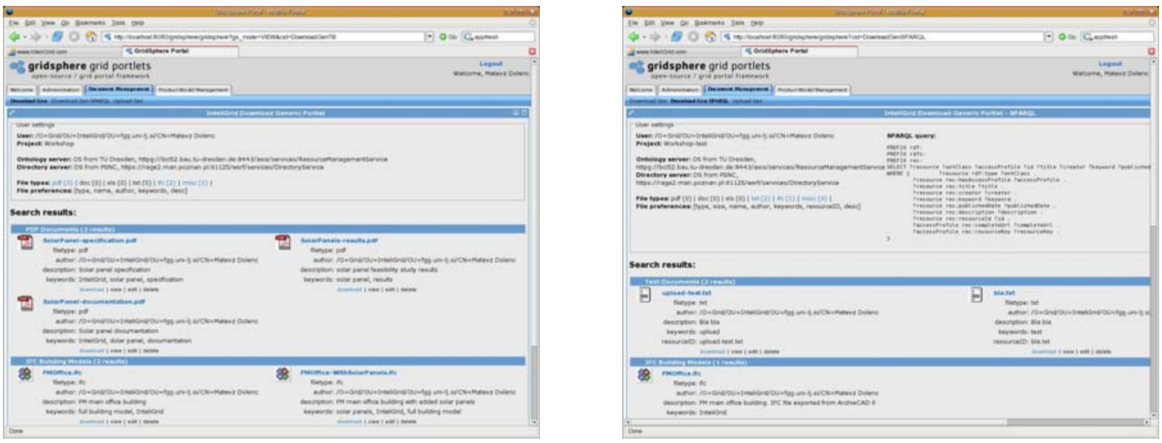


FIG. 10: InteliGrid testbed portal - browsing for documents using semantic based document management system (left) and an example of a semantic search for documents using the SPARQL query language (right).

3. INTEGRATED DEMONSTRATION EXAMPLE

An integrated demonstration from the architecture, engineering and construction (AEC) sector has been the basis both for developing requirements and for evaluation of the achieved results. Although the developed engineering collaboration platform is designed for use in different engineering domains, the AEC sector has been identified as the most challenging environment for application of the developed platform. The primary target audience for the performed public demonstration of the platform were (1) system integrators specialised in the engineering domain, (2) developers of engineering software, and (3) providers of engineering services on the Internet. The end users of such integration, software and services were also targeted, but these two target groups have completely different perspectives on project and business results. Benefits for the user which were identified by the demonstration are related both to the general introduction of virtual organisation principles as well as to the use of the InteliGrid platform:

- **Business Services Providers –** Organisations or individuals getting new business opportunities by presenting their products/services in an InteliGrid *"market place"* and exploiting a deployed grid infrastructure (networks, high-performance and high-throughput facilities, business services, etc), service-oriented architecture enables new business models, etc.
- **Business Service Consumers (Users) –** Organizations' business development is based on organisations basing their business expansion on project development by organising projects in dynamic virtual organisations or more long term organised virtual enterprises. The identified benefits for users are: (1) on demand computing (access to computing centres, databases, services, etc.), (2) flexible membership in various virtual organisations, (3) new licensing models, etc.

The performed integrated demonstration includes several cycles of a generic end user scenario (see Fig. 11), each showing a different aspect of the InteliGrid solution. An extensive description of this demonstration is beyond the scope of this paper, but details are provided in (Dolenc et al., 2007). The screenshots (Fig. 12) show a selection of the developed applications and services for representative steps of the demonstration scenario.

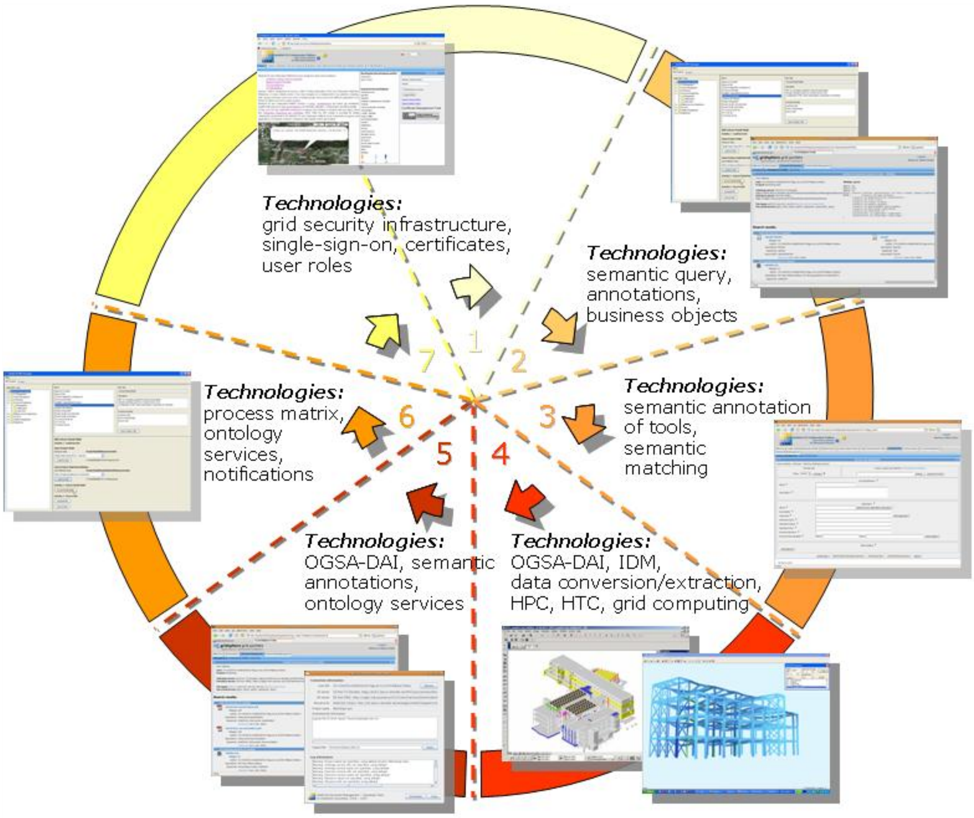
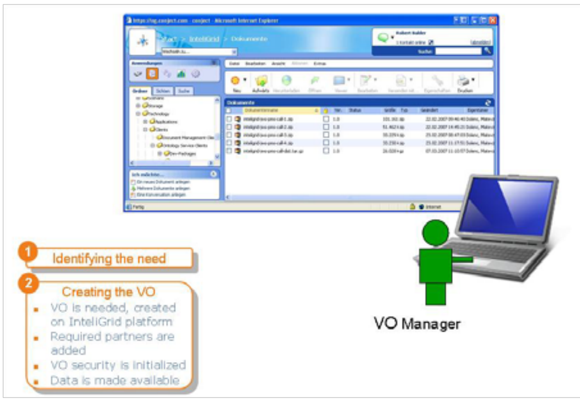
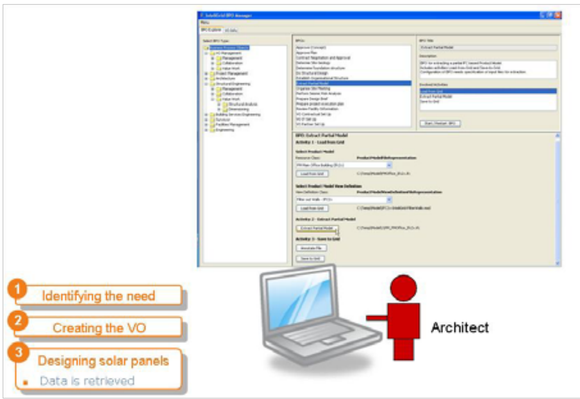


FIG. 11: Generic InteliGrid end user scenario presented with different application screenshots and relevant technologies.

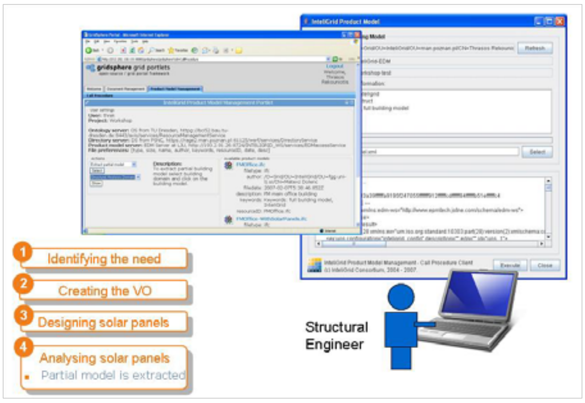
Step 1 (Order a feasibility study of solar panels) – The InteliGrid platform is used to semantically search for relevant main contractor who takes the role of virtual organisation manager.



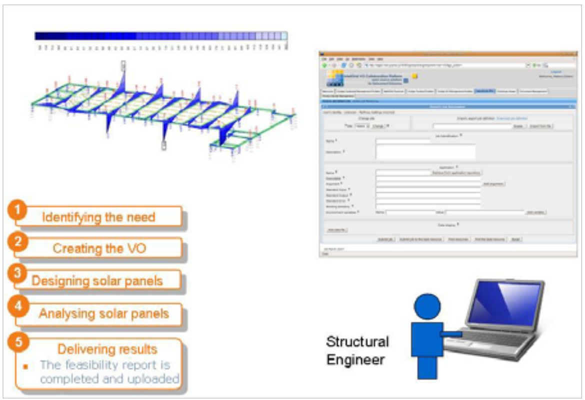
Step 2 (Make data/documents available) – Initial data (document, specifications, design plans, etc.) is annotated and made available to the established virtual organisation.



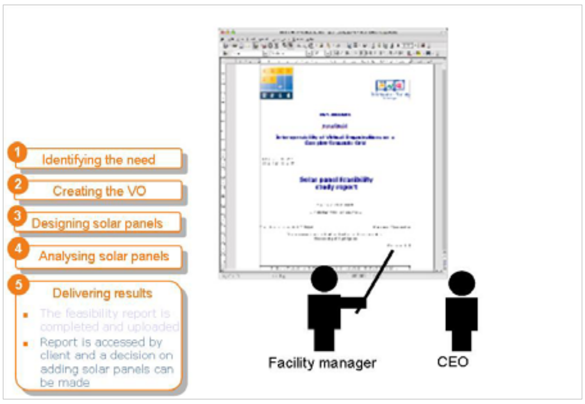
Step 3 (Documents found and used) – An end user responsible for designs finds the relevant documentation and delivers the modified architectural designs.



Step 4 (Initial data available for structural analyses) – A structural engineer accesses partial model of the modified design.



Step 5 (Feasibility study completed) – A structural engineer utilises high-performance components to perform structural analysis.



Step 6 (Feasibility study results) – The final report of the study is delivered to the client who makes a final decision about further investments

FIG. 12: Representative steps in the integrated demonstration showing the use of the platform as well as some of the developed applications and services.

4. CONCLUSIONS

In this paper, we presented an overview of a collaboration platform developed within the InteliGrid project that combines and extends the state-of-the-art in technology areas of semantic interoperability, virtual organisations, and grid technology. The defined overall framework is largely independent of technology and fits to several specific IT architectures that the engineering interoperability research has created to date. The presented high-level architecture also allows for different implementation approaches (toolkits, middleware, programming languages). From lessons learned during the implementation phase as well as from public demonstrations it became clear that:

- The presented architecture can support different engineering domains. Although the main integrated demonstrator was from the AEC sector it has been shown in a number of partial demonstrations that the developed platform can be adapted for other engineering sectors as well. The InteliGrid project established an industry advisory board (http://www.InteliGrid.com/iab.htm) comprising of companies from different sectors. They provided an important input to making the platform architecture more generic and thus applicable to different engineering domains.
- The use of semantic description for resources in general (from IT type resources to domain specific resources) enables the development of a truly plug-and-play environment.
- Building a platform where different resources can (must) be registered to be included in dynamic virtual organisations has some clear benefits, e.g. relatively straight forward business model. We should try to go a little bit further and ask ourselves whether this is the only possible way or we can build an environment where this is not necessary. It needs to be investigated whether a pure peer-to-peer system architecture is more appropriate for supporting dynamic virtual organisations.

Target groups for the InteliGrid solutions are industries that work with complex projects where the organisation changes over time and where there is a need for advanced software, high performance computing and data management support in different phases of the projects. The presented semantic collaboration platform provides many potential benefits for two distinct groups: service providers and service consumers (traditionally end users). The potential of InteliGrid is closely related to the uniqueness of the platform. This does not mean that InteliGrid may be sold because of its *unique user functions* only - other reasons for choosing InteliGrid as a virtual organisation platform are related to the following:

- InteliGrid is the only gateway to grid resources using semantic business awareness to directly access these resources – saving on search and analysis to find and use the right resource.
- It is the only known business ontology based toolkit for designing and managing VOs in a grid environment. Once the roles are defined, InteliGrid will automatically assign the context.
- The grid is offering a unique flexibility in the assignment of computational power and storage capacity/functionality. InteliGrid offers a unique opportunity to use such cost saving resources without requiring specific grid competence.

The technology used in implementing the platform evolved rapidly in the last three years since the start of the InteliGrid project. If there were some concerns over the maturity of the used technologies, standards, principles, etc. during the initial design stages of the project, the design and prototype implementation convincingly provided the proof of the concept. The InteliGrid developed services and tools are maintained and further developed by their owners (Dolenc, 2007) who also make them available as open source products. Research and development efforts are still needed regarding a better support of domain-specific ontology extensions, availability and interoperability of different engineering services, etc.

What remains to be seen is how engineering industries will adopt different solutions and technologies proposed by the InteliGrid project and other similar projects as well. According to Gartner Research (Gartner, 2006), the grid computing as well as the Semantic Web have 2 to 5 years until reaching the plateau of productivity and general industrial use. Another important issue regarding the selected technologies used by the project is whether or not the explicit semantic descriptions using ontologies for describing different resources are appropriate or some other methods of describing could be used instead (e.g. folksonomies (Mathes, 2004), tagging, etc.).

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