The Future of Enterprise Systems in a Fully Networked Society

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Abstract. The industrialised countries are living in an crucial phase for their economies and social systems. Computers and digital technologies have traditionally played a central role for the development of the socio-economic systems, and of enterprises in particular. But if the socio-economic scenario undergoes profound changes, also the enterprises need to change and, consequently, enterprise computing. In the next decade, enterprise software systems cannot continue to evolve along the beaten paths, there is an urgent need for new directions in the ways enterprise software is conceived, built, deployed and evolved. In this paper we illustrate the main outcome of the Future Internet Enterprise Systems (*FInES*) Research Roadmap 2025[1], a study on the future research lines of enterprise systems, promoted by the *FInES* Cluster of the European Commission (DG Information Society and Media.)

Keywords: Future information systems, enterprise systems, new enterprise values, enabling technologies, knowledge technologies.

1 Introduction

This paper has the objective of tracing a synthetic picture of a possible future for the enterprise systems and, connected to them, some research objectives. The presented material is drawn upon the outcome of the *FInES* Research Roadmap Task Force. The work has started by analysing a large number of documents issued by the European Commission, such as the Digital Agenda for Europe[2] and the Innovation Union Europe 2020[3], and, at a more specific level, sectorial studies on technology trends, business trends, etc. Furthermore, there have been several meetings of the *FInES* Cluster and specifically appointed groups and committees that have supported the elaboration of the report.

The work has been characterised by a knowledge management approach that produced an organization articulated in four main knowledge spaces: socio-economic,

[1] http://cordis.europa.eu/fp7/ict/enet/documents/fines-research-ro admap-v20_en.pdf
[2] http://ec.europa.eu/information_society/digital-agenda/index_en.htm
[3] http://ec.europa.eu/research/innovation-union/index_en.cfm

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enterprise, enterprise systems, and technology. This first section provides a brief recap of such a knowledge. Note that in some cases the terminology has been drawn upon the FInES Research Roadmap, for a greater fidelity to the original document, although sometimes it may appear to be 'unconventional'.

1.1 The Reference Framework

As anticipated, the research roadmapping activity has been organised as a knowledge base creation activity. Then, we initially identified four knowledge spaces that form the *FInES* Universe; they are briefly introduced below, bearing in mind that our main focus is on the third space, where the *FInES* research challenges have been identified. However, the first two spaces are important to understand the context, while the fourth is the space that provide the technological support.

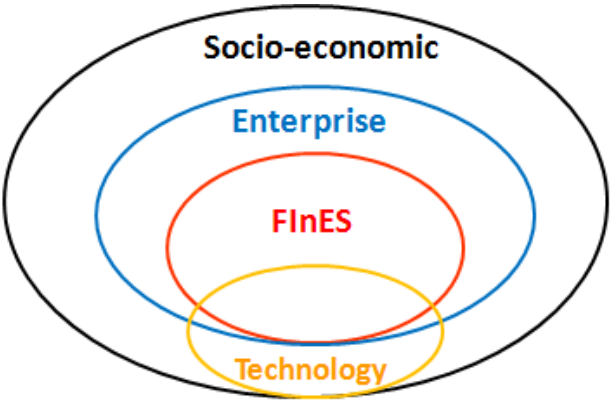

Fig. 1. The four knowledge spaces of *FInES* Research Roadmap

1. **Socio-economic Space** – It represents the larger context in which enterprises operate. It includes topics such as the social responsibility of enterprises, the impact on the environment and their carbon footprint, including the system of values that, in our view, goes beyond the pure financial dimension.
2. **Enterprise Space** – Here we address the key characteristics of future enterprises, the emerging business and production paradigms, new governance and organization models, new forms of cooperation: all geared towards a continuous innovation quest. This space includes the investigation on new styles in the relationships with customers, yielding new market forms and logics.
3. **Enterprise Systems, Platforms, and Applications Space** – this space is specifically concerned with *FInES* Cluster themes, i.e., with the ICT solutions and socio-technical systems aimed at supporting the emerging future enterprises, largely operating over the Future Internet. Continuous Business/IT Alignment is another key issue in this space.

4. **Enabling Technology Space** – this is the knowledge space that concerns the ICT support to *FInES*, including: Future Internet solutions, knowledge technologies, cooperation and interoperability, advanced trust and security services, etc., that will be necessary for the development of a *FInES*. We know that ICT solutions will be evolving according to their own strategies and trajectories, so it is important to understand what ICT solutions will be available 'by default' and what solutions will need to be 'solicited' for the purpose of *FInES*.

The four knowledge spaces will be elaborated in more details in the following sections.

2 A Vision on the Socio-economic Space

The Socio-economic space represents the larger context in which enterprises operate, interacting with the other players and the environment, aiming at increasing the value production and well-being, while satisfying customers' needs. In this frame, it is important to analyse the trends that characterize the various drivers of societal aspects, in order to forecast what our society will be like in ten years from now (avoiding a systematic forecast that is outside the scope of the this work.) In elaborating our vision of the future, we will focus on the impact that the socio-economic space will have on the way enterprises will operate to achieve their objectives. In this analysis, we intend to consider a societal context where there are values that go beyond the pure economic dimension, such as ethical values and social responsibility, transparency, impact on the environment and carbon footprint.

2.1 The Need for a Socio-economic Discontinuity

Since more than a decade, the Western economies are facing a troubled phase where economic crises follow one another. Today there is large agreement that the existing socio-economic models cannot continue to exist as they used to be: we reached a point of discontinuity (a point of 'bifurcation', according to Complexity Theory.) There are a number of significant phenomena that anticipated such a change: from the serious economic crises of the last decade to the enormous sovereign debts accumulated by the Western countries, and to the limited expansion of their economies, opposed to the marked growth of the emerging economies (well represented by the so-called BRIC: Brazil, Russia, India, China). The marked growth of the latter have an impact on a global scale, pushing upwards the costs of raw material and natural resources while competing against Western economies with low cost goods and services (Emerging economies represent also new expanding markets that, unfortunately, are addressed with the 'usual' consumerism approach.) The mentioned signs have been anticipated and analysed by a number of experts, such as David C. Korten when talking about the advent of 'The Perfect Economic Storm' [1], and the related consequences: from the failure of the financial systems, to the

deterioration of the environment and the increase of social inequality. In essence, there are clear signs that Western countries, and Europe in particular, cannot proceed along the beaten paths, just practicing 'business as usual'. The Western development models require a change of paradigm to guarantee that people will maintain (not to mention improve) the current standard of life.

2.2 Different Growth Rates for Wealth and Well-Being

The key problem of Europe for the next decade will be to find a socio-economic model capable of achieving a growing social well-being in absence of an equivalent growth of the wealth produced by the economic system. To achieve such a double speed socio-economic model, it is necessary to proceed along different lines. Primarily addressing the economic development model, where the established mechanisms, based on consumerism, with a parallel expansion of production and consumption, needs to be revisited. With this respect, it is noticeable that there is a growing awareness in some sectors of the Society and a cultural trend that promotes a set of new socio-economic values. A number of essays and publications provide good clues towards the interpretation of the riches of a country by means of a number of indicators that go beyond pure monetary values to measure the wealth of a country (see for instance the well-known Stiglitz-Sen-Fitoussi Report [2]). Other directions propose an approach that considers the possibility of satisfying the needs of people in different ways with respect to the society of consumption (e.g., see the 'Economics of Enough', by Diane Coyle). Furthermore, there are studies indicating how to approach a future characterised by a limited growth (see Serge Latouche and his 'graceful de-growth [3]) and how to cope at best with such a perspective. The idea is that, having lived a long period of (relative) abundance, we have large margins for improving the life quality by means of optimization, reuse, refurbishing, etc., in essence, using better and longer what we already have.

2.3 Towards a Totally Connected Society

The above sketched scenario needs new forms of social cohesion to be achieved. Internet is changing the way people know each other, get in touch, exchange information, opinion, knowledge; we are rapidly evolving towards a totally connected society, where cultural interoperability will be at the basis of new forms of social innovation [4]. But also solidarity and new types of subsidiary economies (e.g., advanced forms of private-public partnerships and the Third Sector) need to be developed, aiming at exploring new ways of production and consumption for goods and services (i.e., producing to live better with less.) Accordingly, the current notion of 'job market' will progressively evolve, leaving the scene to new forms of enterprise and productive occupation (e.g., with the advent of '*workeprenuer*' as a figure that syntheses a self-employed worker, consultant, flexible employee), jointly

with new solutions for social protection (e.g., evolving along the line of '*flexicurity*'.) Finally, the role of Future Internet is central, to support also new forms of social and political participation. (e.g., deliberative democracy.)

2.4 Innovation in a Knowledge-Based Society

Since more than a decade (see the Lisbon Strategy) it is widely shared that Europe needs to evolve towards a knowledge-based economy[4]. But this objective resulted harder to be achieved than expected (due also to the recurring economic crises.) It appeared that the adoption of knowledge technologies is not enough, the heart of the knowledge-based Society is the people. In the next 'Decade of Discontinuity', it is necessary to foresee a socio-economic model where technological development will take place having the people (citizens, workers, entrepreneurs, etc.) at the centre. Only people are able to deploy the creativity that, supported by the necessary knowledge, is able to promote innovation and social growth.

In this socio-economic frame enterprises play a central role, since they represent the primary source of wealth production, being at the same time one of the key players of the delineated social and cultural evolution. Just think about the marketing campaigns, where advertising is based on the promotion of certain life models. Also here we can see important signs of change that will presumably continue in the future. For instance, today we see many ads where a given product (a car, a pair of glasses, etc.) is publicised connecting it to a style of life respectful of the environment: an evident sign that the marketing strategies are changing their 'mantra'. The role of enterprises is, and will continue to be, central also in the cultural development of a Society. Then, we expect enterprises to be the protagonists of such transformations in different contexts: internally, e.g., addressing their own organization, human resources, production and logistics models, and, externally, with the marketing strategies and customer relationships; then, in the socio-political arena, with their lobbying capabilities. Enterprises can be one of the central 'engines' for the coming decade of innovation and discontinuity.

3 The Future of Internet-Based Enterprises

The Enterprise space is where we delineate the key characteristics of future enterprises, for which we expected that their success will be based on knowledge assets, skills and competencies, creativity and innovation, trust and security, awareness of innovation opportunities and related risks (with a wise risk taking attitude) and, last but not least, the capacity of adopting ICT solutions constantly aligned with business needs.

As anticipated, the next decade is expected to see deep changes in the way enterprises operate, mainly due to both a changed socio-economic scenario and the

[4] http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/00100-r1.en0.htm

availability of important enabling ICT innovations, driven by the Future Internet. In this frame, the current section addresses two main themes:

- The first theme concerns a number of key characteristics of Future Internet-based enterprises, referred to as **Qualities of Being,** that we believe will be central in a virtuous development of the socio-economic system of European enterprises. Such qualities are sufficiently general to be applied to the majority of enterprises, independently of their size, nationality, or industrial sector.
- The second theme proposes an **operational framework**, essentially a behavioural paradigm for future enterprises in organising their activities. Such an operational framework represents also a bridge towards the next section, where the systems supporting the future enterprises will be addressed, together with the related research challenges.

3.1 The Qualities of Being of the Future Internet-Based Enterprises

This section reports the key Qualities of Being (QB) that are considered strategic for the enterprises of the future, independently of the industrial sector, the size, the organizational model they follow. Such QBs are considered as directions towards which to proceed, requiring specific organization models and activities to be adopted, rather than as targets to be met once forever. Please note that the presented QB are not orthogonal one another, instead they are mutually interlinked and complementary. The identified qualities, that refer to different aspects of the enterprise life, are tagged with specific keywords (useful to find a better elaboration in the original *FInES* Research Roadmap document.)

The first quality emerges from the constant shift of enterprise systems focus from enterprise resource planning (see ERP platforms) to the support of continuous innovation, with the parallel need to develop creativity and skills in an open and cooperative environment (***Inventive Enterprise***) [5]. New models of cooperative work are another characteristic feature of the future enterprise, which will be able to adopt and exploit new production and organizational models, based on social media (***Community-oriented Enterprise***). The new models and organizational structures will be conceived to put the human skills and capabilities, but also the needs and quality of life of the workers, at the center of the enterprise (***Humanistic Enterprise.***) The cooperation will extend beyond the boundaries of the company, which will gradually fade away making it impossible to distinguish the 'inside' and the 'outside' [6]. It will be the advent of the ***Liquid Enterprise***, where the rigidity of today's organizational models and employment forms will be replaced by new models, based on different levels of involvement and work flexibility. As anticipated, value production activities will be carried out by new professionals (such as *'workepreneur'*, synthesising the employer, freelancer, and employee). New professional figures and new working relationships are needed to quickly respond to the unceasing challenges of the market and to stimulate continuous improvement required by the global competition and made possible by the adoption of new technological solutions [7]. And the answers

have to be implemented quickly, through flexible productive and organizational models (***Agile Enterprise***.)

The future enterprise will be able to interpret the needs of different markets, scattered all over the planet, understanding local specificities and constraints while maintaining an overall view of the opportunities (***Glocal Enterprise***.) Finally, a great change will be in the firm's ability to create winning strategies combining different values and strategies, beyond the profits, developing environmental awareness, social responsibility, attention for the private lives (***Sustainable Enterprise***.)

With the evolution of the *Internet of Things* information will be generated and consumed in large part by devices, equipments, and technology infrastructures with high levels of autonomy and intelligence (i.e., advanced processing capabilities), but also products and business objects will play an active role, cooperating and forming a sort of 'nervous system', perceptive, active and reactive within the enterprise (***Sensing Enterprise***). Information flows will grow with a geometric progression, at different levels, concerning both the value production operations and strategic decisions for organizational and operational models, supporting the development of strategies in medium to long-term visions. In essence, the company will be able to collect, organize, process and distribute useful knowledge in a targeted way to different agents attending at different activities. But the enterprise systems will be strongly based on the knowledge of the company and of the scenario in which the latter operates (***Cognitive Enterprise***), as described in the next section. In essence, knowledge will be the primary asset in the Knowledge Economy, it will allow the different economic and social players to operate in delivering economic value and social wellbeing, provided that such actors will be able to understand and interpret at best the continuous changing scenarios.

3.2 The Operational Dimension

The above enterprise profiles, the Qualities of Being of Future Internet-based Enterprises, are not easily achieved. They require for an enterprise a marked attitude towards changing and the capacity of continuous improvement and innovation.

This implies the adoption of entirely new operational approaches, with a shift in the priorities from the management of existing assets, where established systems and practices are largely available, to the management of the future, through methods and tool aimed at seizing the innovation opportunities, consistently reshaping the organization, business processes, and activities. A paradigm that encourages continuous change is represented by the fractal model [8]: global, in that it can be repeated in different areas of the company, and iterative, as the pattern is applicable at different operational levels. Having this in mind, we introduce a framework based on 6 operational stages.

Invent. This is the first stage of the innovation cycle that consists in the preliminary identification of new solutions to be adopted, in any possible areas of the enterprise (from production to HR, from logistics to management to marketing).

Plan. Planning is required in order to devise a trajectory capable of transforming a new idea into a concrete solution to be adopted. Here, techniques such as resource analysis, SWOT, and risk assessment play a central role. Simulation and *what-if* analysis can also improve the understanding on the expected cost and performance (including ROI) of the new solution.

Build. This is the stage where the new solutions are actually implemented. Again, this may apply to different enterprise areas and domains, e.g., building new business solutions (including new organizational models, new processes, and new capabilities), or new products, or new competencies for the employees.

Operate. In this stage, the new solutions and capabilities become operational, adopted as integral parts of the enterprise activities and production. The start of this phase is critical since in an Inventive Enterprise, continuous improvements and innovations need to be adopted without affecting the ongoing business (or limiting the impact, in case of radical changes.)

Monitor and Manage. This stage is actually overlapping the previous one, having a specific focus on assessing how the innovation is performing. But in general, the M&M activities need to be constantly operational, also to check how the business operations are performing in 'stable' situations.

Dissolute. In enterprise operations, this phase concerns the termination of a business, a project, a product, requiring stopping activities and moving people, dismissing existing products to introduce new ones. The higher is the dynamicity of business the more this operational stage will be needed.

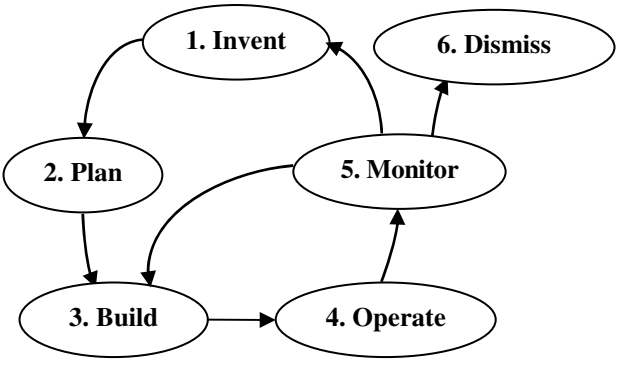

Fig. 2. The Bahavioural cycle

Please note in Fig. 2 the three different circuits, where the internal loop represents the improvement cycle, the outer loop the innovation cycle and the radial arc the end of the lifecycle of a business solution.

3.3 Supporting the Advent of the Future Internet-Based Enterprises

An enterprise is a complex artefact, and its unique anatomy, composed of very different active (human and artificial) and passive (tangible and intangible) elements, has hindered the extensive use of Engineering disciplines. Enterprise Engineering is seen as 'the application of knowledge, principles, and disciplines related to the analysis, design, implementation and operation of all elements associated with an enterprise'[9]. But Enterprise Engineering cannot draw upon traditional engineering discipline that appears inadequate for the purpose. In fact, the latter stems from the Industrial Revolution and the Positivism that has the ultimate objective to keep the reality (in particular, the artificial reality) under the human control. Conversely, with the widening of the horizons and the growing of complexity, we need to accept the idea that for certain artefacts we allow for a limited control, accepting raising levels of autonomy for important business units and actors [10]. For instance, Business Process Modeling and Management will be incomplete, allowing for unplanned business operations to take place, relying on the enterprise capacity of reacting to unexpected events (see Complex Event Processing.) This vision calls for new approaches to Enterprise Engineering based, among others, on uncertainty and Complexity Theory. Furthermore, the Enterprise Engineering approach will be also intersected with social computing, leading to the so called Enterprise 2.0.

4 The Future Internet-Based Enterprise Systems

This section is specifically concerned with *FInES*, i.e., with the socio-technical methodologies, platforms, applications, systems, and ICT solutions aimed at supporting emerging future enterprises [11]. Here we intend to delineate the key characteristics of a *FInES* and the related research challenges to be faced in the next decade. The key objective of a *FInES* is to support enterprises in achieving the illustrated QB, while producing value for stakeholders and customers [12].

This section is organized along three basic dimensions: the **Knowledge Dimension**, since before doing it is necessary to know, the **Functional Dimension**, to see what will be the main functions of a *FInES*, and the **Engineering Dimension**, to investigate new development techniques, with a specific focus on software applications.

4.1 The Knowledge Dimension

The degree of penetration of the ICT in the production reality will continue to a point where all that we need to know about the enterprise will be coded in digital form, equally accessible and processable by computers and (mediated by the latter) by humans. Such an extensive digital representation will be referred to as *Unified Digital Enterprise* (*UDE*.) Today we are very close to this, if you consider the massive amount of documents and data that are electronically produced, acquired, and

circulated within an enterprise [13]. The knowledge dimension we consider here has basically a methodological nature: the main challenge being to identify methods and paradigms aimed at modelling the enterprise reality, including resources and objectives, to be directly used by business experts (substantially reducing the role of knowledge engineers.) To reach this goal we need to promote high quality research in several directions. Among the key ones, we have the following Research Challenges (Again, the interested reader can use ***RC*** tags as pointers to the more elaborated *FInES* Research Roadmap document.)

In the knowledge representation and reasoning area, research has already produced important results, based on various forms of logic and algebra, aimed at processing and consistently managing enterprise knowledge bases (e.g., inference engines, query systems, truth maintenance systems). However, not as much has been done on the application side, in particular to achieve an actual impact on the business world, for instance focusing on enterprise architectural frameworks. The first ***RC1*** therefore refers to advanced methods to obtain a unified view of enterprise knowledge, and the related methodologies. But different business sectors require different solutions, and rigorous knowledge requires a high level of disciplinary specialization, with diversified content and applications that contrast with the need to reach an open and integrated view of an enterprise knowledge base. *Linked Open Knowledge* (along the line of *Linked Data*) represents a promising direction of research to broaden and interlink expertise and knowledge (***RC2***), overcoming the various enterprise barriers (cultural, organizational, spatial, etc.) existing today. Finally, it is well known the impossibility of building an accurate model of reality, if it exceeds a certain level of complexity[5]. In essence, we need to accept the idea that we will increasingly develop artefacts (such as an enterprise, with its application systems) that we can only partially know, thus working in the absence of overall models able to predict behaviours and evolutionary trajectories. Here the studies on complex systems will help us living in a future of 'limited sovereignty' over the business reality (***RC3***).

4.2 The Functional Dimension of a *FInES*

Traditionally, enterprise software applications (ESA) are primarily conceived to support the day-by-day value production of an enterprise, with an optimal management and planning of the resources (ref. ERP). There are other vital functions and activities that are partially integrated, from the strategic marketing to the R&D, to financial scouting, to organizational innovation. According to the notion of a *UDE* (*Unified Digital Enterprise*), the idea is to proceed towards a totally integrated approach also from a functional point of view, where different aspects and activities are seen in a unique frame. This must be achieved in the context of a highly dynamic scenario that requires constant monitoring of internal and external events and a capacity of quickly aligning to changes, but also the capacity of generating winning discontinuities, i.e., business innovation to achieve a competitive advantage.

[5] See H. Stachowiak: Models. In Scientific thought, Some underlying concepts, methods and procedures, UNESCO 1972
(`http://unesdoc.unesco.org/images/0000/000022/002251eo.pdf`)

In this dimension, the first research challenge (***RC4***) deals with the functional coverage of the 6 operational stages presented in the enterprise section. In particular, we consider a vision where the key challenge consisting in a unified system integrating the enterprise applications developed to support: invention, planning, building, operations, monitoring and management, and dismissing of business solutions. The second challenge of this section (***RC5***), linked to the previously introduced knowledge management issues, concerns platforms for enterprise knowledge, with advanced capabilities for collecting and aggregating knowledge coming from very diverse sources, both internal (from sensors to documents, from databases to intranet forums) and external (primarily from the Web). The (logically) integrated enterprise knowledge will be made available to people and machines in various ways, e.g., in response to queries, but also proactively, e.g., with semantic routing of the information to the info-needy actors, even if they are unconscious of the need, in the right moment, in the right form and level of detail (determined by the task currently performed.)

The third challenge of this group (***RC6***) refers to the functions of communication, community building, resource sharing, and cooperative work. Here also the goals are ambitious, reaching up to the development of new forms of collective intelligence.

4.3 The Engineering Dimension of a *FInES*

Having discussed the joint issues related to enterprise knowledge management and enterprise applications, we investigate now the third pillar of *FINES*: the set of methods and tools needed to develop such systems. Software Engineering, that show a long time evolution in parallel with the information systems of today, requires a profound rethinking to meet the challenges of *FInES*. Traditionally, software engineering techniques [14] have difficulties in supporting the software updates, required by the fast pace of the ever changing reality [15]. This will be even harder in a *FInES* scenario, seen its increased complexity and richness with respect to the existing enterprise systems. As anticipated, the structure and behaviour of a *FINES* will be centrally based on the enterprise knowledge collected and managed as an *UDE* repository. Here, the first challenge is to ensure a continuous alignment of the *UDE* with a business reality that continuously evolves, and that the application software is aligned with the latter (and therefore with the enterprise needs.) These objectives require major research results, as described below.

The Fig. 3 depicts the three *FInES* contexts but, being necessarily sketchy, it does not render that fact that both *UDE* and *FInES* are largely interwoven with the enterprise reality. This fact derives from the progressive spread of networks of intelligent objects. Be they physical or intangible objects, there will be a growing number of processing units capable of performing business operations, especially the more repetitive ones, with a good degree of autonomy, keeping therefore the humans out of the loop. This will be achieved pushing forward the research on autonomic systems (***RC8***).

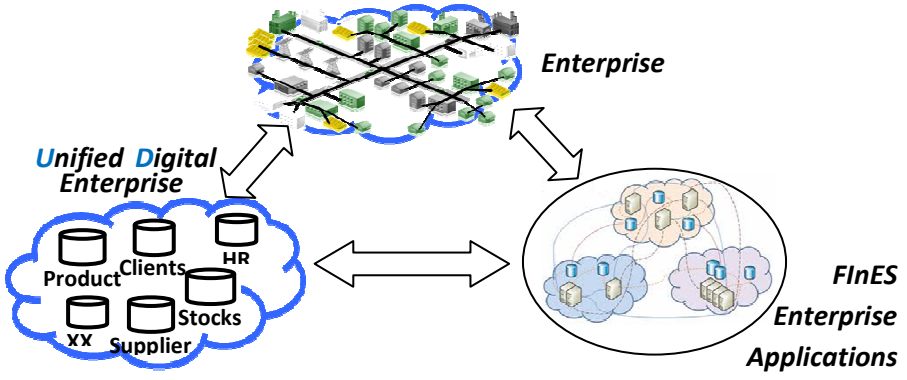

Fig. 3. The Three *FInES* contexts

In essence, when developing a *FInES*, business operations will be progressively delegated to autonomic networks, while humans will focus on high level operations and business strategies. The development of higher level functions will be based on innovative tools, conceived for end-users, supporting the analysis, modelling, and design of business solutions. Such tools will be able to generate computational business models, starting from repositories of highly reusable business objects. Such business objects will be implemented by intelligent software components, directly deployable and executable (called *FINER: Future Internet Enterprise Resource* [16]), capable of connecting and cooperating to achieve increasingly important business solutions [17]. The final architecture of a *FINES* will thus emerge from the interplay of explicit 'human-driven' (often incomplete) specification of the business solutions and the autonomic activity of cooperating smart components (we refer to this approach as *Proactive Mashup* that represents ***RC7***).

A *FInES* that will be developed as indicated above, will make use of a number of advanced technologies (see next section): from intelligent agents to rule-based systems, from web services to business process management systems, from ontologies to 'traditional' legacy software, that need to effectively cooperate in performing business operations. Here also there is the need for intense research activities to devise flexible, versatile runtime platforms (***RC9***). Such platforms will be capable of hosting a rich diversity of active components, while guaranteeing continuous, on-the-fly reconfigurations, and interoperability (both of data and functions) for different applications, developed by using different technologies, without penalising the performances [18].

5 Future Technologies for *FInES*

Digital Technologies, from its inception, have been characterised by an impressive innovation rate, particularly relevant in the last 20+ years, after the VLSI and the telecommunication revolutions. Then, in the last decade, the diffusion of the Internet

started to exhibit a significant impact on the socio-economic sphere. ICT development will continue with a marked innovation rate, but with increasing difficulties for what concerns the socio-economic impact that will hardly maintain the same pace. One of the main problems is due to the fact that the ICT engineering methods of today will hardly scale up to tackle the enormous future challenges, in particular the size and complexity of the Future Internet and, specifically, of the *FInES* applications. Innovation and developments of the Future Internet applications will heavily challenge computer science and engineering methods and tools we use today. The massive amount of data [19] (the well-known *data deluge* issue [20]), the management and coordination of trillions of intelligent objects, with convergent and pervasive networks connecting everyone and everything: all this needs new methods and tools to developing, maintaining, and managing future large, complex, interconnected socio-technical systems [21].

An encompassing study of technology trends is outside of the scope of this document. Here we intend to focus on a subset of ICT research areas connected to the *FInES*. Furthermore, we will abstract from the basic computational and networking technologies, assuming that in the next decade they will substantially develop (according to the Moore's law that appears still valid.) The objective of this section is to provide a *FInES-oriented* point of view on a possible (and/or desirable) evolution of ICT solutions. In particular, the technological areas included in this section concern: networking, knowledge, applications, computing and storage, user interactions.

5.1 Future Networking Technologies

Networking (Future Internet) will be one of the key areas that will exhibit the most impressive progression, sweeping away any barrier of range (LAN, WAN, sensors networks, Zig-Bee, ...), technology (TCP/IP, Enthernet, WiFi, WiLD, ...), carrier infrastructure and mobility solutions (cable, radio signals, ...), etc. Future Internet is expected to fully and seamlessly connect nodes of a different nature, belonging to 4 categories: (1) Real entities, (2) Virtual entities, (3) Natural entities (firstly people), (4) Artificial entities, allowing them to effectively exchange data and cooperate in a secure and trusted way.

The Future Internet will be characterised by a progressive functional enrichment, fostering the commoditization of a growing number of services and facilities that will stretch the current notion of networking, supporting, e.g., advanced forms of collaboration, interoperability (ref. *ISU: Interoperability Service Utility*), trust and security, social computing [22], etc. Particular attention will be also dedicated to the correct handling of digital (multiple) identities.

5.2 Future Knowledge Technologies

This is another key area that will enable the development of high-performance knowledge networks aimed at managing content from any possible source or actor (natural or artificial), represented in different forms (from text to video, to structured

information) [22]. The knowledge will travel freely (safeguarding IPR) through the network to reach (on request or spontaneously, proactively) any entity that needs it (e.g., with semantic routing): don't search, the right information will find you! When you need it, where you need it. In particular, among the most interesting areas of technology, it is appropriate to mention the spreading of Fuzzy Knowledge Bases, based on the evolution of the current Linked Open Data. Another key technology is that of the Knowledge Mining, that is, methods and tools for creating 'noble' knowledge, at a conceptual level, from the analysis of large amounts of factual data, both structured and unstructured, numerical and textual. Finally, in enterprises, there will be a substantial increase of the importance of the knowledge bases for business innovation, with the contribution of open repositories of scientific findings, results of simulations, information technology and market trends, with advanced services of similarity reasoning to support 'lateral thinking.'

5.3 Future Application Technologies and Complex Systems Engineering

This is the key enabling technology for *FInES* in the next decade. According to MITRE, "As [enterprise] systems become increasingly large and must seamlessly interoperate with other systems in ways that were never envisioned, system engineers are bumping into the limits of the tenets, principles, and practices traditionally used in systems engineering." [23]

When trillions of intelligent entities (natural or artificial, real or virtual) will be able to connect and interoperate, the problem of developing, deploying, and maintaining software applications will be another challenge hard to be addressed with today's methods and tools. Application software engineering and enabling technologies need new developing paradigms. Specifically, it is important to base the development of future enterprise systems on the future knowledge management assets (starting with *UDE*), keeping the two areas constantly aligned (and the *UDE* aligned with the business reality).

One of the future architectural models, based on computational business entities (style *FINER* [16]), will emerge from the evolution of some existing technologies, such as: multi-agent systems and Swarm Intelligence [24]. Along this line, there are numerous challenges that the research will have to face, such as:

- How to create smart objects with marked cooperation capabilities;
- How to interconnect them in an efficient and flexible way, providing them with the ability of dynamic networking and reconfiguration (horizontal aggregation);
- How to safely grant an increasing degree of freedom and autonomy (for objects and people), self-organizing to form more complex entities, without a central authority which drives the processes (vertical aggregation).

In dealing with the construction of large interconnected systems, it is important to note that, in general, consistency will be locally ensured (in the small), but it will be hardly possible to achieve it at a global level (in the large). Furthermore, these systems will be based on heterogeneous technologies, which, as anticipated, will require new development methods and, when operational, new interoperability and governance solutions.

5.4 Future Computation and Storage Technologies

As anticipated, computation and storage will progressively shift away from the traditional computer centres, moving towards two different (but connected) spaces: on the clouds and on the earth. The former represents a well established and expanding technology (see market figures[6]), and it is plausible that the existing problems, from cloud interoperability to trust and security, to reliability [25], will be satisfactorily solved in the next years. The latter (referred to as *Swarm Computing*) will emerge from the interconnection of the trillions of smart proactive objects that will be able to locally store and process significant amounts of data, and cooperate to provide information and services at higher levels of aggregation [21]. The computation will possibly adopt a *'glocal'* paradigm, going from a local dimension, with detailed and analytical computation on locally confined data, to a global dimension, with general and synthesis computation, yielding and consuming knowledge assets.

In this approach, the current vision of services and service-oriented architecture (SOA) paradigm will be absorbed and superseded by the key notion of smart objects and entities: *Smart Object-Oriented Architecture (SOOA)* that will be able to (autonomously) aggregate to provide complex services (i.e., placing in the centre the service provider rather than the specific service, with an increased semantic approach[7].)

5.5 Future Natural Interaction

In the foreseeable future we will have two main interacting players: people and objects, with computers that will progressively disappear, behind, e.g., a car dashboard, a household appliance, a complex document representing a marketing strategy, images representing people, enterprises, etc., while we will practice less and less with interfaces to computer terminals, laptops, PCs, etc. In essence, we will be interacting with computational entities (common objects, active documents, people, etc.) mainly to perform our everyday activities, getting information and providing our feedbacks in fashions that are different from the keyboard-screen paradigms of today. We will rather have natural interactions [26] (an evolution of today Natural User Interface, for which Kinect is a good example) with the objects and the people we meet during our daily activities. Natural interactions will involve all the entities of the 4 categories indicated in the section 5.1 (object-object, human-human, object-human). Particularly relevant will be the remote, both synchronous and asynchronous, human interactions, characterized by an ever growing sophistication (avatars, acting in personalized and metaphorical ambient, holograms, and the like), yielding to new forms of participation in all the phases of the production cycle (Invent, Plan, Build, Operate, Manage, Dismiss.)

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[6] `http://blogs.computerworld.com/16863/cloud_computing_by_the_numbers_what_do_all_the_statistics_mean`

[7] Beyond the functional and non functional capabilities of a service, the service provider is scrutinised for the sake of trust and security, reliability, costs, etc, but also for administrative issues, like quoting, contracting, billing, etc.

Natural interaction will extensively involve knowledge technologies and augmented reality. For instance, augmented reality will allow us to know details of a beans' can in a food store[8] by simply pointing a mobile device to it. Then, gesture and voice may represent other natural ways of interacting with smart objects around us.

6 Conclusions

The study reported in this article aimed at drawing a framework for research and innovation in the field of enterprise systems, focused on business management and innovation, which plausibly will appear in the next decade. The European task force was aware from the beginning of the difficulties inherent in an assignment of this importance, both for the breadth and complexity of the addressed subject, and for the long-term time horizon. For this reason, the base material has been carefully collected from numerous high-profile sources, while the strategic vision has been largely based on documents produced by the European Commission itself. The original contribution of this paper mainly consists in having outlined a methodological framework, based on a knowledge management approach, that guided the work of selecting and organizing the extensive material available.

A prospective study like this has a high risk that the time, and the continuous innovations that roll one after another, will quickly make obsolete important parts of the document. For this reason, we planned to complement the production of the 'paper' document with a Knowledge Wiki. Initially created from the material of this study (including the additional material collected but not presented for space reasons), it will be conceived to be periodically updated, so as to have a resource constantly aligned with the state of the art. This portal will be realized within the European project Ensemble; we aim at its success and survival, after the end of the Ensemble (August 2012), that will strongly depend on the commitment of the *FInES* Cluster and an active constituency, Wikipedia-style, that can guarantee in the future updates with high quality content.

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[8] See also: 6th Sense , from MIT:
http://www.ted.com/talks/pattie_maes_demos_the_sixth_sense.html

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