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**Collaborative Environment to Support a Professional  
Community**

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**Dissertação apresentada na Faculdade de Ciências e Tecnologia da  
Universidade Nova de Lisboa para obtenção do grau de Mestre em  
Engenharia Electrotécnica e de Computadores.**

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Lisboa, Setembro 2009



## Acknowledgements

I would like to express my deepest gratitude to all the persons that made this work possible. Whether professionally or personally all the people mentioned below contributed significantly for the accomplishment I make today and there are no words strong enough to express my gratitude to them. My experience in Sweden was very challenging and rewarding at both personal and professional level. Professionally I had the opportunity to work with top level researchers from Stockholm, Finland, England, Germany and Portugal. At personal level, the contact with heterogeneous cultural environment in Stockholm enriched me and made me grow as a human being.

I would like to thank Professor José Barata for all the support during this work and most of all for believe in me and give me the chance to have my first professional experience abroad. I will never forget this year in Sweden and I will be eternally grateful to him for the opportunity and all the support.

I owe big recognition to Professor Mauro Onori, who always supported and encouraged me. Besides being the best coordinator I could hope for, he was always available as a friend making me feel very comfortable and happy at my workplace. Thanks a lot Mauro!!!

Very special thanks to Antonio Maffei. He was my friend and counsellor for all times and contributed a lot for my work and wonderful experience in Stockholm.

I would like also to express my gratitude to Dr. Marcus Bjelkemyr, Dr. Daniel Semere, Dr. Kerstin Dencker, Andreas Hoffman, Niko Siltala, Luis Ribeiro, Pedro Ferreira and Niels Lohse for enriching discussions, valuable help and friendship.

I would like to thank Ann-Sophie Granberg, Margaretha Eneroth and Farazee Asif for assisting me with bureaucratic issues and be always kind and available to help.

Thanks to all my friends in Stockholm. Besides making me enjoy the stay and wish for coming back, the contact with them made me evolve as a person. From all my friends, I have to highlight and give a very special thanks to my dearest friends Clarissa Rojas and Panthea Pars.

Infinite thanks to my parents and twin brother for all the support and unconditional love along the years. I want to thank also to the rest of the family specially my grandparents, my uncle Nelson, my aunt Alice, my beautiful cousins Stephanie and Claudia and my godfather Mannie.

A word of thanks to all my friends in Portugal and specially to Miguel Nave, Gonçalo Martins, André Alpalhão, Murilo Rodrigues, Diogo Gomes, José Venancio and Pedro Arruda.

## Resumo

Recentes roadmaps de manufacutura expõem as limitações dos sistemas de produção actuais, realçando as consequências sociais, económicas e ecológicas da não evolução dos mesmos para os requirements de sustentabilidade. Instituições académicas e empresas estão conscientes desta necessidade e estão emprenhadas para desenvolver soluções que permitam as empresas endereçar sustentabilidade e sobreviver na actual difícil conjectura económica.

O grupo EPS (Evolvable Production Systems) tem vindo a desenvolver profunda investigação na área de produção industrial, de modo a que se consigam obter sistemas de produção industriais que respondam às necessidades tecnológicas, económicas, ecológicas e sociais impostas, caminhando de encontro aos roadmaps actuais. O sucesso deste trabalho de investigação depende largamente do consenso que atinja na comunidade científica e empresarial, e portanto é necessário reunir um forte suporte de massa crítica para ajudar o processo de investigação.

O grande objectivo desta tese é desenvolver uma ferramenta de ambiente colaborativo para assistir o grupo EPS no seu trabalho de investigação e disseminação do recente paradigma de Evolvable Assembly Systems. Este trabalho resultou na ferramenta colaborativa EASET (Evolvable Assembly Systems Environment Tool) que serve de suporte à disseminação do paradigma de Evolvable Assembly Systems através do melhoramento do apoio de massa crítica e da colaboração entre entidades.

## **Abstract**

Recent manufacturing roadmaps stress current production systems limitations, emphasizing social, economic and ecologic consequences for Europe of a non-evolution to sustainable Production Systems. Hence, both academic institutions and enterprises are committed to develop solutions that would endow enterprises to survive in nowadays' extremely competitive business environment.

A research effort is being carried on by the Evolvable Production Systems consortium towards attaining Production Systems that can cope with current technological, economical, ecological and social demands fulfilling recent roadmaps. Nevertheless research success depends on attaining consensus in the scientific community and therefore an accurate critical mass support is required in the whole process.

The main goal of this thesis is the development of a Collaborative Environment Tool to assist Evolvable Production Systems consortium in such research efforts and to enhance Evolvable Assembly Systems paradigm dissemination. This work resulted in EASET (Evolvable Assembly Systems Environment Tool), a collaborative environment tool which promotes EAS dissemination and brings forth improvements through the raise of critical mass and collaboration between entities.

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# 1 Introduction

The world is evolving every day imposing new constraints and new demands in a blink of an eye. This imposes the emergence of two fundamental skills: Adaptability and Agility. Adaptability and Agility are nowadays a core issue and its importance is highly revealed at business and production system level.

Recent manufacturing roadmaps such as EUPASS [5], Manufuture [12], Futman [1] or Manvis [19] stress current Production Systems limitations, emphasizing social, economical and ecologic impacts of such systems and the requirements towards a modern generation of production systems that can cope with the constant evolution of markets and deal with resource scarcity while regarding a social concern.

Hence, research must be oriented towards sustainable manufacturing by focusing on economic, ecologic and social effectiveness of business. There is a need to shift from capital and resource intensive societies to knowledge and service intensive ones [12]. The short term approach where a manufacturing system is built from scratch (or almost) for each new product must be re-placed since it enhances resources and knowledge waste which lead to inefficiency. Manufacturing systems must therefore be designed and developed considering a long term approach enhancing re-usability of components and re-configurability of systems making use of services and modules already available and promoting the use of all the knowledge acquired from the previous systems. This knowledge is valuable for the upper organisational levels of the enterprise since it can help improving the effectiveness of the business in the long run. Hence, enterprises must pursue manufacturing agility from management to shop floor level. The long term success of an enterprise depends on its ability to produce innovative products with good quality, competitive cost and adequate time frame. Hence enterprises seek for more efficient organizational dynamics what led to the emergence of several types of networked interactions: supply chains, extended enterprises, virtual enterprises, collaborative networks, collaborative automation, etc. Such interactions can help enterprises improving agility by forming alliances enabling them to gain competitive advantage over competitors and react quicker to new business opportunities. Current major roadmaps have all clearly underlined that true industrial sustainability must be pursued. According to [52] organisational sustainability is “the ability of an organisation to design its systems so that they address various requirements of all stakeholders to enable organisations sustain competitive advantage and not lead (in future) to diminished quality of life due to depletion of natural resources, loss of future economic opportunities, and adverse impacts on social system due to its operations”. Achieving sustainability is a mean for an enterprise to maintain competitiveness since it regards the adequate use of resources (economical, social and environmental), decreasing social and environmental impact of business while ensuring economic benefits. Organisational sustainability was first targeted through focusing solely in core production processes (e.g. just-in-time manufacturing, lean manufacturing, etc) however this approach proved to be incomplete. Organisational sustainability must be pursued holistically encompassing product lifecycle, enhancing re-engineering processes and avoiding precious knowledge waste. Organisations should increase their agility from shop floor to management level and develop adequate business tools that can bridge gaps between these levels and help analysing processes and effectiveness of the business. The establishment of a close link between shop floor and

management level of an organisation is an example of an improvement that can highly benefit the organisation by helping in decision making and improve agility.

In line with these aspects, the Evolvable Assembly Systems (EAS) paradigm is attempting to develop technological solutions (mechanical and control) and support mechanisms (Ontology, Methodologies, Reference Architecture, etc) that may endow European assembly companies to fulfil these demands.

## 1.1 Problem definition

The Evolvable Assembly Systems paradigm was initially presented in 2002 [4] and has been developed under the EUPASS<sup>1</sup> project (among others). It achieved important accomplishments during this project, which lead their authors to believe that Evolvable Production Systems are a highly feasible approach to the development of future Production Systems. Nevertheless this emerging paradigm needs further developments and tests in order to reach consensus among the scientific community and the product fabricants, or alternatively to be falsified and point a new path. Following the Plan of Use and Dissemination of Knowledge (PUDK) of the EUPASS project, the EUPASS consortium identified two crucial issues:

- Further developments and tests should be carried on both architectural and system component levels
- Critical mass needs to be achieved in order to test and develop the paradigm within a broader community of user & developers.

These two issues are strongly connected in the sense that critical mass supports further developments, since it enhances scientific research by providing the Key Performance Indicators for the developments being done and also helps defining the roadmap for future investigations. Alternatively, the larger community (critical mass) may falsify the approach through practical results, partially or completely. The critical mass community must be represented by specialists of different scientific fields since the paradigm must be falsified by technological viewpoint but also from economic, ecological and social viewpoint. Basically, without a good critical mass support it is very hard to turn an emerging paradigm into a universally accepted paradigm, therefore critical mass can be viewed as one enabler of the research process. The interaction between critical mass and research groups imply collaboration between the entities and in order to enhance effective collaboration mechanisms need to be provided.

This thesis addresses proving that a collaborative environment tool can facilitate this process endowing the actors with tools and mechanisms to collaborate in an effective way, raising critical mass support in the EAS paradigm and enhancing exploitation of knowledge.

Hence, the research question this thesis tries to answer is:

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<sup>1</sup> 6th Framework European Commission co-funded project

### **Research Question**

How can a Collaborative Environment assist in the validation/falsification of the EAS paradigm through a more established Scientific Research?

And the hypothesis established to address the research question is:

### **Research Hypothesis**

EAS paradigm validation/falsification can be enhanced by the use of an accurate collaborative environment tool providing the required mechanisms for EAS dissemination and widespread consensus among the scientific community.

## **1.2 Motivation**

Since the inception of Evolvable Assembly Systems paradigm in 2002 as a methodology for developing next generation of production systems, the concept is being further developed and tested to emerge as a new production system paradigm.

Paradigm evolution is a slow and hard process that according to Thomas Kuhn goes through 3 phases [21]. There is a pre-paradigm phase where the paradigm is emerging and there is no consensus or a very clear theory since the theory is still very incomplete and possesses several incompatibilities. If the actors in the pre-paradigm community are able to make the paradigm more consistent and fault proof and also widespread consensus on the appropriate choice of concepts, methods and experiments to use then a second phase begin. As long as consensus continues and the theory keeps irrefutable while is being falsified then the paradigm keeps the evolution becoming more accurate and consistent. The third phase is the revolutionary phase that usually follows a period of crisis where weakness or incompatibilities of a paradigm are revealed. In this phase is likely that a paradigm shift occur.

According to Thomas Kuhn [21]: “The man who is striving to solve a problem defined by existing knowledge and technique is not, however, just looking around. He knows what he wants to achieve, and he designs his instruments and directs his thoughts accordingly. Unanticipated novelty, the new discovery, can emerge only to the extent that his anticipations about nature and his instruments prove wrong”. This is an interesting comment that supports that critical mass is in fact a very strong ally of science and is fundamental in paradigm evolution process. It stresses the idea that scientists/researchers will try to prove their hypothesis right and sometimes it might be a “false true”.

With a strong critical mass backup a paradigm can be accurately falsified<sup>2</sup> giving rise to more accurate and fault-proof paradigms. Karl Popper emphasizes the importance of falsifying a paradigm as the way towards scientific progress [22]. According to Karl Popper and other Falsificationism supporters [22], the progress of science starts with problems associated with the explanation of the behaviour of aspects of the world or universe, falsifiable hypothesis are proposed by scientists as solutions to a problem and then are criticised and tested. The ones proved to be successful must be subjected to more criticism and testing and this process goes on indefinitely.

The Evolvable Assembly Systems paradigm is currently in a Growing phase. Concepts, methods and experiments are defined and have consensus among the research group. This paradigm needs to be subjected to an accurate falsification process in order to become more consistent and reach the mature phase where it can enable a paradigm shift in Production Systems.

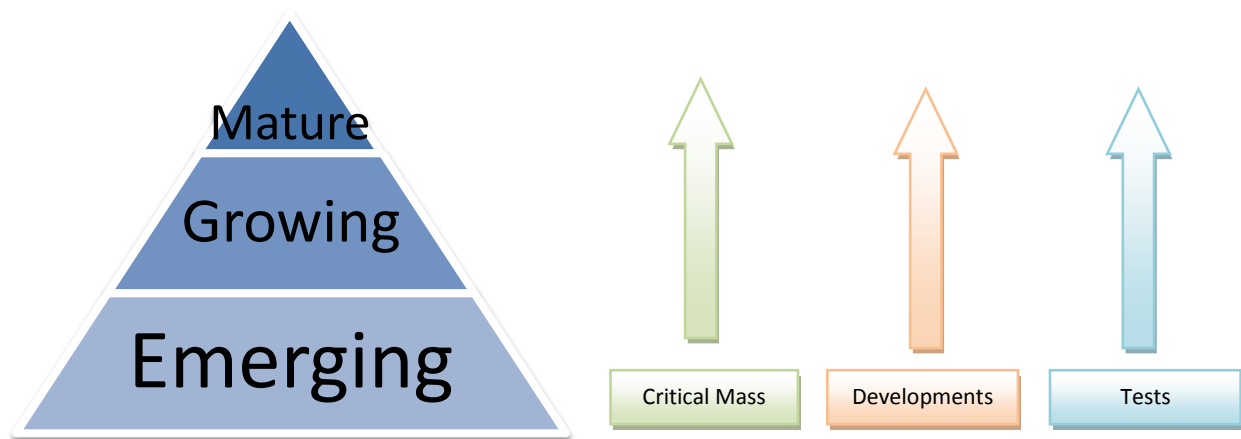


Figure 1 - Paradigm phases and evolution

Critical Mass among the scientific community and more developments and tests are the means with which it is possible to enable falsification and consistency improvement of the Evolvable Assembly Systems paradigm. This work is a first step to enhance this process through the creation of a Collaborative Environment tool aiming at providing the required mechanisms for EAS dissemination and widespread consensus among the scientific community.

The goal of the collaborative environment tool being proposed is to assist in the formation of a more extensive group of developers and users of adaptive assembly systems. It combines commercial solutions, R&D projects, and development topics. This collaborative tool's particular aim is to enhance the development and use of the Evolvable Assembly Systems paradigm in several ways:

<sup>2</sup> "An hypothesis is falsifiable if there exists a logically possible observation statement or set of observation statements that are inconsistent with it, which, if established as true, would falsify the hypothesis." [22]

1. Clarify for both the scientific and commercial enterprises what Evolvable Assembly Systems actually is, and why this paradigm is particularly well suited for highly dynamic production scenarios.
2. Detail for all members the work done to date, the commercially available solutions, future opportunities and the goals for the future.
3. Bring these entities together to work in a collaborative environment in order to accomplish the goals proposed.

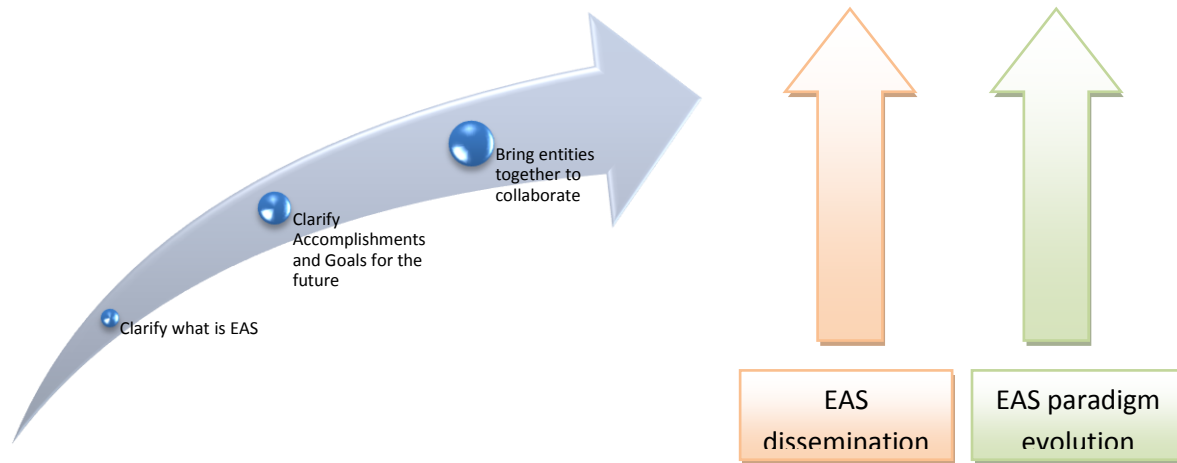


Figure 2 - Goals and expected outcome

### 1.3 Research Methodology

The research methodology used in this thesis will be the KTH-EPS methodology. It is based on hypotheses and Popper's falsification view, i.e. scientific progress is achieved through both falsification and corroboration of hypotheses. Hence, the research question and hypothesis are identified and this thesis will try to prove the hypothesis true while falsifying the same.

### 1.4 Outline of the thesis

Following the previous introduction and problem contextualization, this thesis is organized accordingly to the following structure:

- Section 2: Production Systems – In this chapter will be given a look over the history and evolution of production systems. Actual demands and production approaches will be discussed, with a special focus on Evolvable Production Systems and their characteristics.

- Section 3: Collaborative Networks and Environments – In this chapter an analysis is made to collaboration forms and Collaborative Environments, emphasizing their characteristics and what they can provide. Also will be given an analysis to the applicability of collaborative networks and environments on Evolvable Production Systems and the benefits that can arise from this coalition.
- Section 4: Problem Solution – An analysis will be provided on the solution to the research question.
- Section 5: Implementation – Implementation of the Problem Solution
- Section 6: Solution Validation – Validation of the implemented solution
- Section 7: Conclusions and future work – Conclusions

## 2 Production Systems

Production assumes an important role in the society since it is on the basis of goods and services' creation through the use of resources, and it represents a big share of population's employment. To withstand with political, social, economical and ecological challenges imposed by society production systems need to be able to dynamically adapt and evolve to cope with the increasing society demands. Assembly and manufacturing companies' major problems are related to uncertainty. It's difficult for companies to predict the type and range of products that will have to be developed, volumes of production and lifespan of the products. For these reasons, in order to be competitive and survive, companies need to optimize the cost and the time to market. Customization and the shorter life time of products demand a continuous adaptation of the manufacturing systems and consequently enterprises must change systems development from reaction to short-term events to long term strategic development [12]. Companies also have to struggle with difficult economic conditions, highly competitive environment and scarcity of essential resources (being water and oil in the frontline). Hence, modern production systems must address adaptability and agility to cope with sustainability issues while regarding at instable markets and society demands. Only with very agile and adaptable systems will be possible to enhance material re-usability, reduce energy consumption and give a quick response to unforeseen changed conditions or new business opportunities. These issues had been addressed in several approaches (Flexible Manufacturing Systems (FMS), Re-configurable Manufacturing Systems (RMS), Holonic Manufacturing Systems (HMS), Bionic Manufacturing systems (BMS), etc.) with little success to date [8, 16, 18].

According to [55] for adaptation to occur the systems must possess evolvability, which can be defined as "the genome's ability to produce adaptive variants when acted upon the genetic system" [55] or "the ability of an organism to adapt through evolutionary changes to new or altered environments" [56]. It is also highlighted in [55] that adaptation is possible if improvements can be made in a stepwise approach (through evolution), demanding that improvements in one part of the system should not compromise past achievements. Modularity can enhance evolution of systems and avoid that improvements in one part of the system jeopardize a proper evolution of the system as whole. This is supported by [56] "modularity is simply a consequence of the fitness of an individual such that fitter individuals tend to result in increased modularity". This supports that modern production systems should seek adaptation through the use of a modular approach where the individual modules that compose the system possess evolvability and therefore give evolvability to the system. Hence production systems can evolve, following a "fitness function" in order to accommodate disturbances and meet performance requirements, i.e. to adapt to changed conditions. Evolvable Assembly System paradigm is based on this principle and being evolvability a system concept, is envisaged to address every aspect of an assembly system throughout its life cycle, i.e., design and development, operation and evolution.



## 2.1 Evolution of Manufacturing Systems

Different eras demanded different kinds of assembly systems along time. In the end of the 19<sup>th</sup> century manufacturing was based on customers' needs, and so products were exactly made to suit them according to their individual requests, which mean that the customers' needs were the driver of the production process. The production was based in one product at a time and no standardization was available resulting in expensive prices [2]. To tackle this issue there was an evolution to mass production in the 20<sup>th</sup> century. Mass production phase consisted in producing big quantities of non-diversified products at a reduced price, imposing the product as the driver of the production and not the individual customer. With mass production the customer is forced to adapt to product and not the other way around, which was proved with time not to be the best solution since customers got more exigent with time and few range of products was offered. This means that in the 19<sup>th</sup> century production was very flexible since an enormous range of different products could be offered however production systems didn't possess agility since adjusting quantity and product changes was a long and slow process. In the 20<sup>th</sup> century with mass production the production was fast and with very few products offered so the production lacked in flexibility and agility, since not only few products could be produced but also changing product production was a slow and long process dictated by rigid production systems. Nowadays customers demand high quality products at very low price and little time. This becomes a problem which is boosted by the highly competitive business environment, economical constraints and turbulent markets. Hence to cope with these conditions production systems have to be extremely flexible/adaptable and agile [1,5,12,19], and a question must be raised: In 21<sup>th</sup> century which should be the driver of the production process? The answer for this question will be addressed in the following sections.

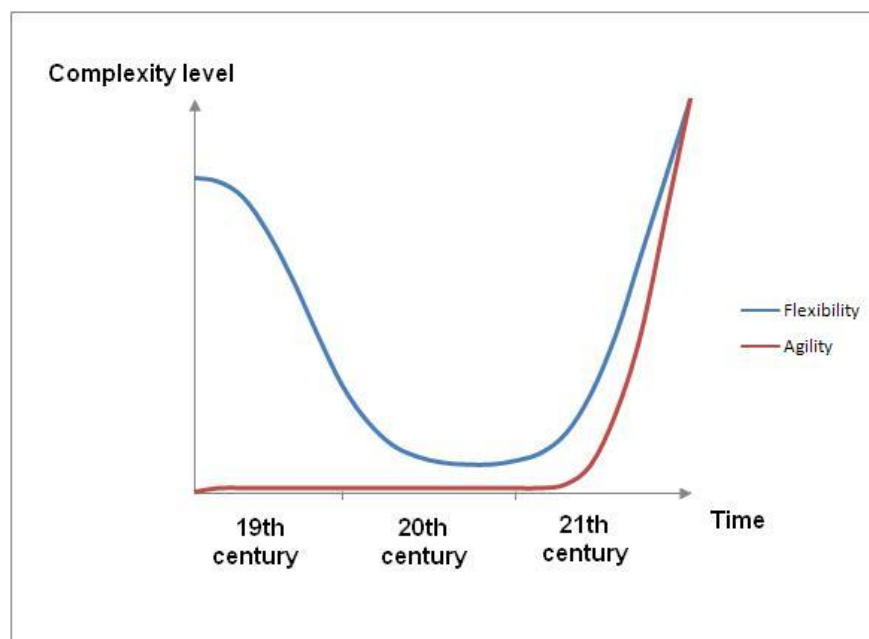


Figure 3 - Flexibility and Agility demands over time

In traditional approach the costs and long time associated with the development of assembly systems was tremendously high. This meant that each time a new product was required the inherent investment and development time was very high leading to a high grade of inefficiency that became unbearable. To cope with this problem, an attempt was made towards developing assembly systems with a high degree of flexibility which could be used in several processes and was easily adapted and thus such assembly systems could be applied in the production of a big range of products. The first attempt was to develop flexible assembly systems (FAS) and flexible automatic assembly (FAA) cells. FAS and FAA systems attempted to create systems that could accomplish several tasks in order to increase the rate of utilization of the equipment. Flexible Manufacturing Systems (FMS) attained efficient results in predefined foreseen situations during the system design, however the control solutions were too rigid and couldn't cope with unpredictable scenarios (new features imposed by market demands) imposing a great programming effort and therefore increasing the installation time and cost [8]. FMS lack of effectiveness guided assembly systems towards Re-configurable Assembly Systems (RAS). With RAS the assembly system design starts from the new product requirements, the product to be assembled is analyzed and then the assembly system is designed, which means the driver of the production process is the product and there is no positive interaction between product and system design. The weak link between product and system design leaves a high degree of freedom to the designers but can harm efficiency which is crucial for company's success. RAS incorporates principles of modularity, integrability, flexibility, scalability, convertibility and diagnosability. Such principles make centralized approaches not suitable, claiming for decentralized approaches to endow systems to cope with dynamic addition and remove of components allowing proper coordination and adaptation with few or none programming effort [18]. RAS considered the need to improve interoperability and lower the costs promoting the use of modular systems. Notwithstanding with such progress the modularization in such systems was based on assembly functions (feeding, handling, etc.) which is not suitable for a dynamic control solution [8]. RAS aimed at achieving general flexibility and the solutions of such systems were fairly adequate to many different product types however they failed to be very performing in any domain.

The Bionic, Fractal and Holonic approaches represent different manufacturing paradigms trying to answer the requirements for agility. They include all the dimensions of a company, from technology to human as well as market and business related aspects. The approaches stay fairly abstract and do not propose concrete solutions.

## **2.2 Manufacturing roadmaps**

Assembly companies' major problems are related to uncertainty. It's difficult for companies to predict the type and range of products that will have to be developed, volumes of production and lifespan of the products. For these reasons, in order to be competitive and survive, companies need to optimize the costs of production and the time to market. Customization and the shorter life time of products demand a continuous adaptation of the manufacturing systems and consequently Enterprises

must change systems development from reaction to short-term events to long term strategic development [12].

Sustainability is given by many roadmaps as one of the most important objectives for future industry, assuming a wide scope that goes beyond production engineering and compiles social, economic and ecological issues. An effort must be carried on in order to reduce energy and resource consumption and enhance quick Time to Market<sup>3</sup> (TTM) enabling enterprises to keep competitive in a world ruled by economic demands. These issues have been addressed by several manufacturing roadmaps and one of the outcomes is to orient Research towards sustainable manufacturing and to stimulate a shift from capital and resource intensive societies to knowledge and service intensive ones [12]. The short term approach where a manufacturing system is built from scratch (or almost) for each new product must be re-placed since it enhances resources and knowledge waste which lead to inefficiency. Manufacturing systems must therefore be designed and developed considering a long term approach enhancing re-usability of components and re-configurability of systems making use of services and modules already available and promoting the use of all the knowledge acquired from the previous systems. This knowledge is valuable for the upper organisational levels of the enterprise since it can help improving the effectiveness of the business in the long run.

European manufacturing companies have disadvantages against developing regions' competitors such as labour costs, working hours, etc., however they have advantages in the skills and qualifications of their workforce and technological innovation. Hence Manufuture roadmap [12] recommendations point towards the creation of innovative products and consequently to develop manufacturing technologies for innovative products. New manufacturing systems must be extremely adaptable and agile to cope with turbulent market demands that involve changing tasks and products. Manufacturing systems must attain modularization with embedded control, aiming at modular systems with scalable, interoperable, co-operative, self-organized and self-optimized behaviour [12].

Several roadmaps such as Manvis report [19] and EUPASS roadmap [5] stresses concern about outsourcing issue, pointing out the consequences of losing more jobs and giving away precious know-how outsourcing services from low wage countries [5,8]. Employment in this sector is crucial to EU's sustainability and economic growth since it represents a big share of Europe's economy. Economic growth is related to the long-term trend in Gross Domestic Product (GDP). Potential GDP can be defined as "what the economy would produce if all resources (land, labour and productive capacity) were fully employed at their normal levels of utilization" [13]. When the economy operates below potential GDP dead-weight losses are generated and these losses will never be recovered. By promoting unemployment and losing business by outsourcing, Europe is enhancing losses to the economy, slowing economic growth and decreasing the living standards of Europeans.

Summarizing there is a need to enhance manufacturing agility from management to shop floor level in order to cope with turbulent markets, socio-economic and ecological constraints, high competitive business environments and constant innovation demands. There is an urgent need to develop technological solutions and support mechanisms that may endow European assembly companies to fulfil such demands remaining competitive economically and in the forefront in ecological matters.

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<sup>3</sup> According to <http://www.businessdictionary.com> Time to market can be defined as "Length of time taken in product development process from product idea to the finished product."

## 2.3 Evolvable Production Systems

In line with the latest roadmaps demands, the Evolvable Assembly Systems (EAS) paradigm is attempting to develop technological solutions (mechanical and control) and support mechanisms (Ontology, Methodologies, Reference Architecture, etc.) that may endow European assembly companies to remain competitive economically and in the forefront in ecological matters. EPS paradigm has a different approach from its predecessors, it comes from a biological inspiration and was created from a more dynamic, mutable and industrially-relevant perspective (trigger issue). EPS paradigm focus on the changes in the production systems and how they can be managed efficiently. It's change that drives the adaptability/evolution of the EPS Systems and not the current known scenarios. EPS tries to cover predicted and unpredicted changes that may occur in a limited product range. Hence it's important to underline that that EPS is not a generic solution but it is rather a specific approach that may be adopted by several products of the same class [16].

To aim at a real flexible system (system that can fully adapt to unforeseen changes in environment conditions) the sub-systems and the control systems must be extremely adaptable. The lower a component is positioned in the hierarchic structure of the system the more flexible it must be in order to empower the system's flexibility [5, 8]. Hence, in line level (greater granularity of the system) the adaptability required is reduced compared with the adaptability required at device level (fine granularity of the system). Figure 4 illustrates precisely this, showing the relation between the complexity level of the system and the needed level of adaptability for it, emphasizing the aspect that the control system requires a high level of adaptability.

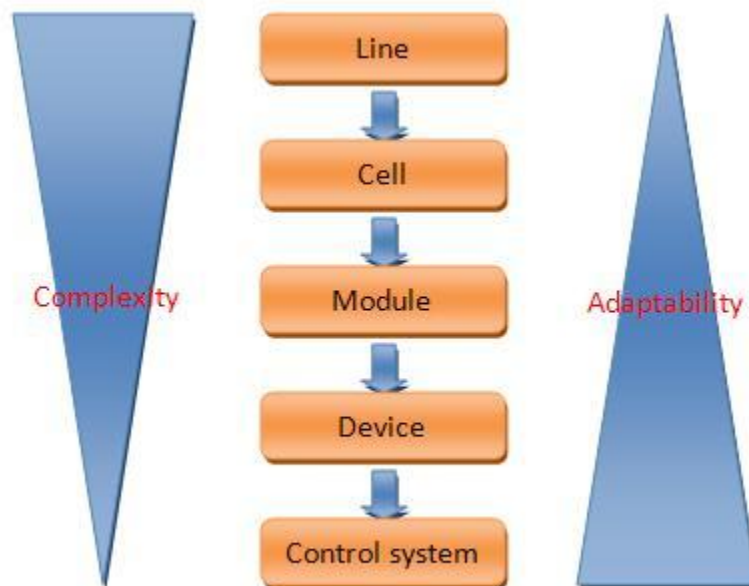


Figure 4 - Adaptability required at different system levels. Image adapted from [8]

The integration between the mechanical and control system is crucial since it's impossible to achieve an Adaptable Mechanical System if it is not available a very Adaptable Control System.

In terms of system characteristics, there has been quite a wide range of discussions on Plug & Produce, interoperability, re-configurability, and other aspects. However, there is a gradual demand being posed on the system components that has to be accommodated, tested, and validated before one may claim to present any given characteristic. For example, as shown in figure 5, the Evolvable Assembly System work may, at this point in time, only truly claim to achieve some level of self-configurability (demands distributed control system and specialized interfaces). As one increases the demands on adaptability, the corresponding technology level must also be attained: self-organising systems demand, at the very least, that all components have embedded control that communicates through the distributed control approach. Likewise, if one claims self-diagnostics, the actual system must at least apply some form of autonomous module parameter feedback & update. Therefore, full adaptability remains extremely linked to control and process issues (which is commonly not underlined).

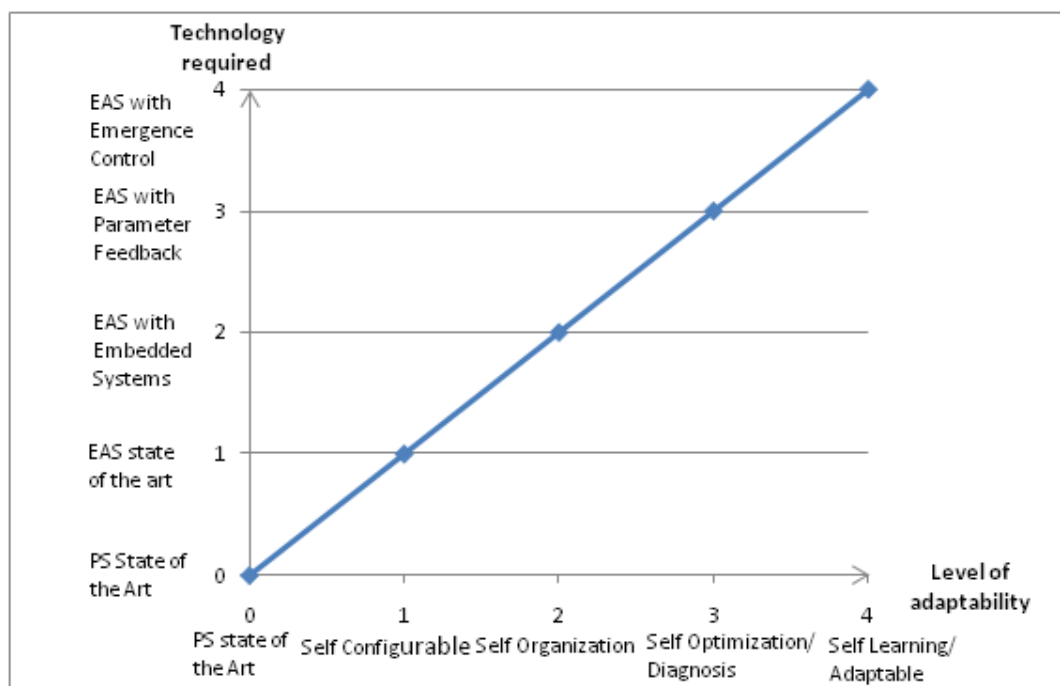


Figure 5 - Control System aimed by EAS [20]

Figure 6 corroborates the previous one at full System level: fault-tolerant Systems with re-configurability must have components with embedded control, operating with distributed control, and with autonomous parameter feedback. Hence, true adaptability/flexibility still requires control R&D.

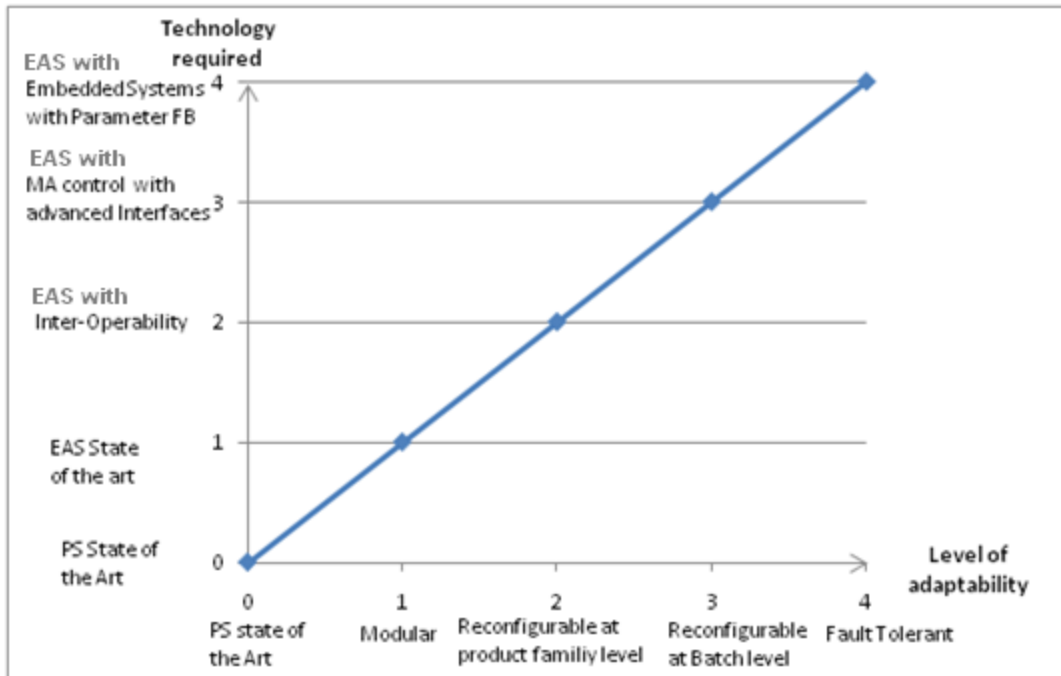


Figure 6 - Mechanical System aimed by EAS [20]

EPS addresses these aspects aiming at systems that enhance continuous evolution and fast re-configurability through the use of re-configurable, task-specific, process-oriented modules. EPS implements an agent based control where individual modules are endowed of several skills and are able to cooperate with other modules creating new skills enhancing interoperability and emergent behaviour. EPS approach sets the system as the driver for the creation of new systems, supporting this by the need of quickly change the product in production and have more economical and ecological production systems. With system is meant the equipment (service oriented modules) that is already available and off course a specific approach will have to be granted.

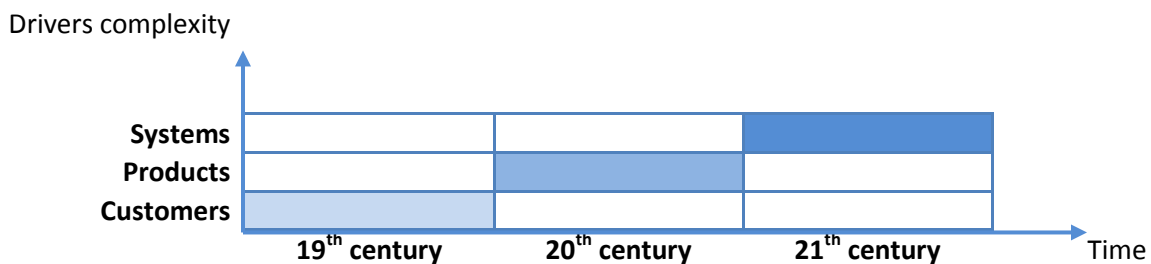


Table 1 - Process drivers along time

Table 1 summarizes the evolution of the production drivers, and its inherent complexity. In the 19<sup>th</sup> century there was low complexity since the products didn't have to meet any standards and production was based on individual requests (customers as driver of production). The production complexity was

increased in the 20<sup>th</sup> century with the introduction of standards and the need for producing exactly the same product each time, forcing the customer to adapt to the range of products offered (product as driver of production). In the 21<sup>th</sup> century the complexity exploded, since optimal technological, economical and ecological results are demanded. Hence in order to accomplish this, the systems must be accounted as drivers and the system design should endow constraints to the product design. In RMS the driver of the whole process is the product, however the EAS paradigm disagrees with this perspective since it compiles economical and ecological disadvantages, as it increases the development efforts in several aspects: building, integrating and programming systems.

Due to EPS process-oriented modular approach it's possible to know à priori the skills available and which module provides the referred skill. The EPS modules are defined by accurate sub-processes (taxonomy is very detailed) that are identified for a product given range and this results in fine granularity<sup>4</sup>. This feature helps setting constraints to the product designer that must account them in order to maximize the efficiency of modules available enhancing re-usability of modules and reducing costs. The efficiency is maximized since a new module will only be developed if it is strictly necessary because similar results of the process cannot be achieved through the use of other modules or the process design of the product cannot be changed [8]. This is illustrated in the model below showing the process flow for system development when a new product idea emerges. The product design phase is enhanced by the use of general ontology (G.O.) and the System Modules (S.M.) that contains all the process oriented modules developed to date, and also by the interaction between the product designer and the system designer.

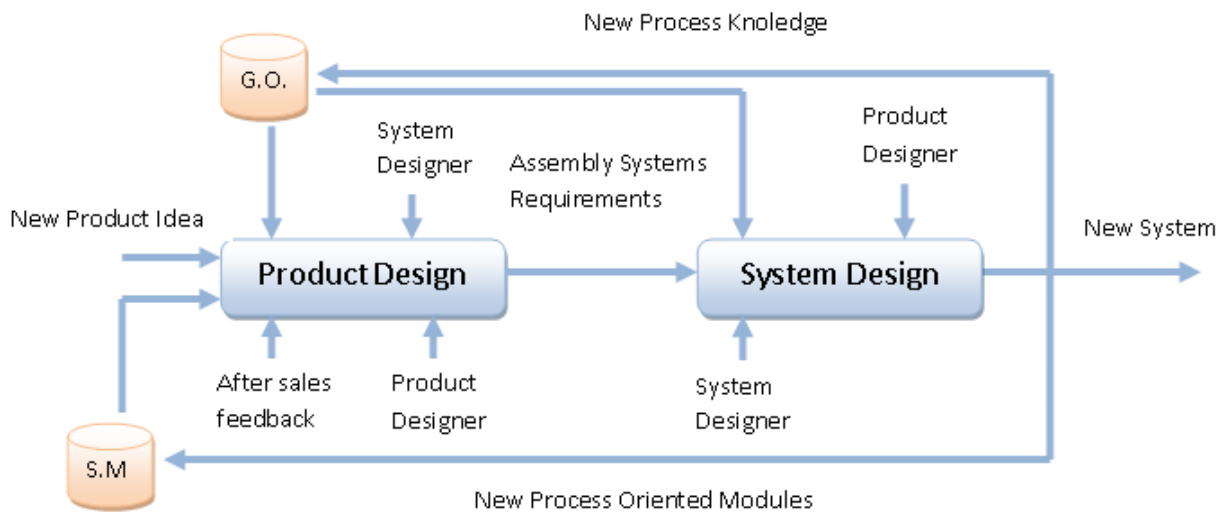


Figure 7 - Development in EPS approach [20]

<sup>4</sup> Granularity concept is used as the level of complexity of the component that composes a manufacturing system. For instance if it is considered an assembly line composed by several cells that are the modules that can be plugged in and out then we have thick granularity. On the other hand, if we have grippers or sensors as modules that can be plugged in and out then we have fine granularity.

With this approach EPS strengthens the link between product and system design phases, establishing the modules as drivers for the product design which leads to several advantages:

1. Lower investment costs and risk factor by new modules development
2. Shorter deployment times and less risk in system installation and integration
3. Improvement of cost effectiveness
4. Ecology improvement
5. Increase of process knowledge since the assembly systems are better structured

### **2.3.1 EAS Characteristics and Properties**

The EPS approach described above suggests that agility/flexibility can only be achieved if the lowest building blocks of a system are those who exhibit highest rate of adaptability/evolvability. As the clustering of components increases in complexity so does the agility/flexibility decrease. According to this approach, each system should be composed by several skill-based and process-oriented units that can accomplish simple actions [23] and so plugability of modules arises as a fundamental characteristic. Each module or manufacturing component is transformed into an agent and each agent will be characterized by its set of skills. The skills are used whenever an agent is requested to perform an action since the agents are asked to perform an action based on the skills they have offered [18]. Each agent knows its capabilities, skills and possible forms of cooperation with other agents. This will result in emergent properties since it will be possible to use module skills to form higher capabilities out of it. For instance, a robot has the basic skill to “move” and a gripper has a basic skill to “grab” so together they form the complex skill of “pick and place”. Due to this approach the control system will become more a collaborating problem rather than developing a specific algorithm for a pre-determined situation, establishing cooperation between the modules as the way to solve the requirements of the system and therefore a very effective orchestration of modules is required. This leads to the need of developing biologically inspired solutions that use principles from biology, complexity theory, swarm intelligence, chaos theory, self organization and emergence [16]. The following citations were adapted from [16]:

#### **Complexity theory**

Complexity Theory looks for simple causes leading to complex behaviours [24]. Complex systems are commonly defined through two key concepts: Evolution and Emergence. These can be used to derive other systems characteristics such as Self-Organization, heterogeneity, etc.

EAS consist of numerous equipment modules which are connected to each other and have multi-lateral interactions and are constraint by other system parts. Together, the modules form a system with the desired global behaviour.

#### **Artificial Life**

Scientists inspire in natural life to create life-like behaviours with the capability of evolution on “artificial” media. Traditional bio-inspired robotics have been applied in navigation or vision systems,



however recent developments have approached concepts of self-organization and embodiment. This is the reciprocal and dynamical coupling among brain (control), body and environment [25]. EAS are very similar to artificial living systems since they have a modifiable structure, exhibit some kind of self-organization, can adapt to their environment, and react to stimuli. EAS systems are capable of evolving according to the circumstances as any living organism, and they will include efforts to keep themselves in a constant well-functioning state through self-surveillance and self-management (at a certain degree).

### **Autonomic computing**

Autonomic Computing is a fundamental concept for EPS because forming large networks and having complex and multiple interactions become difficult to manage. Therefore software should be designed to minimize user interaction and reprogramming effort. EPS approach is based on the ideal of having computer power in each module and as fine granularity is increased it means a CPU almost everywhere. It is very important to emphasise that the more modules of fine granularity include computational power the more is necessary to find new ways of coordination and automatic plugability, which is exactly what EPS want to address.

### **Agent Technology**

Due to its bio-inspired, modular and des-centralised control solutions EPS has to deal with self-organization and emergence issues [5]. Therefore, agent technology become important since it provides a methodology in which the different constituents of the system are considered as modules with intelligence. This means that every manufacturing component at different levels of granularity (from entire workstations to unit or components such as grippers or even sensors) is considered as an intelligent entity (with computational power). Multi-Agent Systems (MAS) and Service-Oriented Architectures (SOA) paradigms arise as strong candidates to such solutions since they assure overall interoperability and integration in heterogeneous environments, and at the same time support self-organizing and emergence concepts.

### **Service Oriented Architectures (SOA)**

SOA paradigm is adequate for applying in EAS [5] since it addresses service abstraction and distributed systems providing:

- Autonomy: there are no direct dependencies between the services.
- Interoperability: is specified at interface level omitting unnecessary details.
- Platform Independence: the services are described using interoperable XML-based formats.
- Encapsulation: services provide self-contained functionalities that are exposed by user defined interfaces
- Availability/Discovery: the services are published in public registries and made available for general use.

Web Services <sup>5</sup>are the preferred mechanism for SOA implementation, which was used in several European projects in the field including industry's heavy weights. These have created a Service

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<sup>5</sup> Web Service can be defined as: "a software system designed to support interoperable machine-to-machine interaction over a network. It has an interface described in a machine-processable format (specifically WSDL).

Infrastructure for Real time Embedded Networked Applications; Devices Profile for Web Services (DPWS), DPWS-based SOA for automation systems, and service oriented diagnosis on distributed manufacturing systems.

### **Multiagent Systems (MAS)**

A Multiagent System (MAS) is a composition of several agents that communicate and cooperate, in a decentralized and asynchronous manner, in order to solve a problem for which none knows all the information to solve it [5]. A multiagent system is very adequate for EPS purposes since it's by nature a decentralized and modular (and thus, easily changeable) environment, able to solve complex problems.

MAS characteristics are:

- Autonomy – agents act individually fulfilling their individual goals.
- Sociability – agents interact among each other establishing an intelligent society.
- Rationality – an agent can reason about the data it receives in order to find the best solution to achieve its goal.
- Reactivity – an agent can react upon changes in the environment.
- Proactivity – a proactive agent has some control on its reactions basing them on its own agenda and objectives.
- Adaptability – an agent is capable of learning and changing its behaviour when a better solution is discovered.

### **Emergence**

Emergent behaviour can be defined as the resulting system behaviour when subjected to disturbances and other unpredicted events [5].

When the conditions change the system must evolve to the changing dynamics and chose the most successful alternative. Exploiting emergent behaviour may lead to the capture and use of new characteristics that may lead to an advantage. Nevertheless from EAS point of view, you cannot predict the properties of a complete system by analysing its single components, since the system will exhibit behaviours that could not be forecasted and this is the consequence of emergence in EAS approach. Positive and negative characteristics may arise so more structured and analytical approaches need to be carried when developing systems that will deal with emergence. Hence EAS needs to develop mechanisms that enable components to acquire, analyse and adapt to changing conditions. EAS methodology takes this into consideration and deals with it by carefully developing a very accurate Reference architecture and Ontology.

### **Self-Organization**

Self-Organization is important to EAS in the sense it can minimize and facilitate user interaction, deal with complexity and increase system autonomy [5]. Deal with a system composed by numerous entities with multi-lateral interactions is a highly complex task. Self-Organization becomes an important issue since it provides system autonomy and the complexity of user interaction decreases as the autonomy of the system increases. Hence in EPS approach, agents need the capacity of organizing their collaboration themselves, in different forms and compositions, according to the needs, without passing

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Other systems interact with the Web Service in a manner prescribed by its description using SOAP messages, typically conveyed using HTTP with an XML serialization in conjunction with other Web-related standards" [26].

through a central coordination point. Self-Organization is robust and adaptive with regard to its environment which means that in presence of perturbations and change, the system is capable of maintaining its organization and functionality. Control systems should therefore be capable of handle problems that may arise and if necessary find alternative behaviours.

EPS may require a kind of leader, a broker or (eventually human) decision maker, which authority may be important in some strategic points.

### **Self-Monitoring, Self-Diagnosis, Self-Healing and Self-Reconfigurability**

Self-Monitoring, Self-Diagnosis, Self-Healing and Self-Reconfigurability are very important concepts for EAS. EPS targets the use of modular and intelligent devices to enable quick re-configuration (avoiding reprogramming) and improve reaction to perturbations and change through the use of diagnosis. Due to EPS distributed and decoupled nature and the demands to cope with self “capabilities” and emergence EPS entities should be able to self-monitor, self-diagnose, self-heal and self-reconfigure themselves. This way faults, perturbations and changes can be detected and optimal system functionality can be pursued. Nevertheless the diagnosis system must also be able to evolve and adapt to changes through time otherwise evolvability and adaptability characteristics of EPS systems will be compromised. So in order to preserve and enhance EPS control system characteristics (evolvability, intelligence, distribution and decoupling of components, robustness, flexibility and agility) the diagnosis system should be proactive, reactive to faults, run predictive analysis, track interaction faults in dynamic environments and preserve system functionalities even if any part of the diagnosis is not working [27]. Despite its importance in the overall optimal behaviour of the modules (and system) Self-Monitoring and Self-Diagnosis can also be crucial to endow companies to have important feedback about modules behaviour and performance.

### **2.3.2 EAS Methodology**

EAS methodological framework is being developed to be able to cope with the current demands imposed by the paradigm characteristics and targets. The EAS methodology provides the reference architecture (RA), modelling formalisms and enablers.

#### **Reference Architecture**

The EAS Reference Architecture specifies the necessary features that a system should have to be an evolvable assembly system. The RA is composed by principles, technical positions and templates.

Two principles describe EAS core ideas about the Evolvable System paradigm:

- Principle 1 - “The most innovative product design can only be achieved if no assembly process constraints are posed. The ensuing, fully independent process selection procedure may then result in an optimal assembly system methodology.”[23]

- Principle 2 – “Systems under a dynamic condition need to be evolvable, i.e. they need to have an inherent capability of evolution to address the new or changing set of requirements.” [23]

The technical positions of EAS are the “design and implementation decisions and objectives set at a technical/technological level that describes the ontology, exploited protocols, standards or specifications for use with each major architectural component.” [23]

The templates and partial models are “reusable diagrams, graphs, objectives and knowledge and rules that address the distribution of system functions and how they relate topologically. Templates use models to show relationships and between components as specified by the technical positions and pertinent knowledge units.” [23]

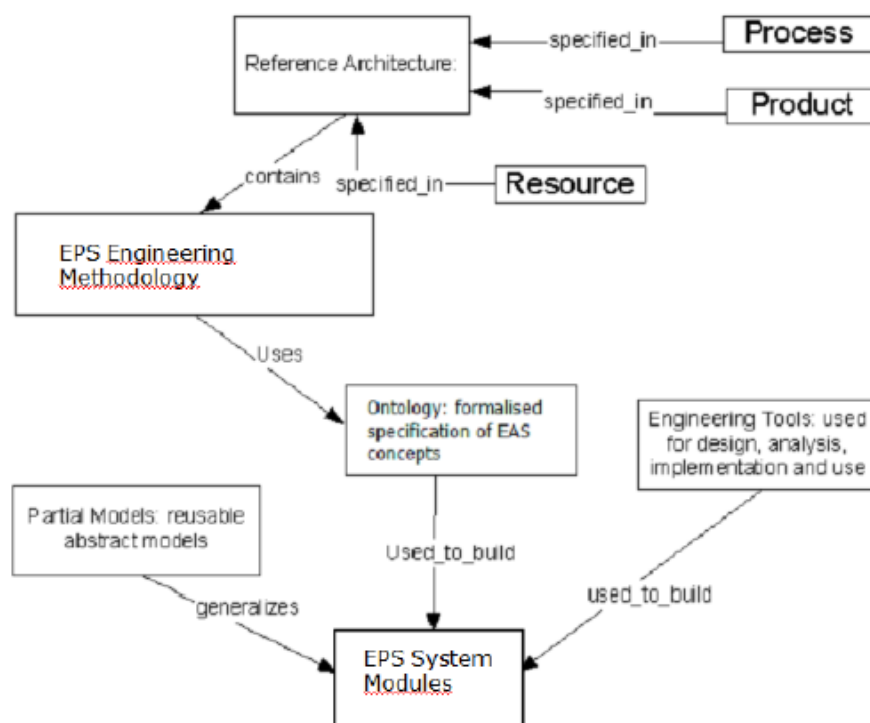


Figure 8 - Basic aspects of the EPS Reference Architecture [23]

## Modelling Formalisms

Modelling formalisms of EAS are the ontology and graphical tools used to build models in the RA and the enablers [23]. EAS Ontology and definitions are represented using a set of descriptive tools such as:

- Definitions of the most important concepts: module, process, product, etc.
- Diagrams (UML, etc) defining the interaction between the concepts and may also show the global system behaviour.
- Formalization of concepts.

## **Enablers**

Enablers provide the necessary models, tools and methods for the development and evolution of an Evolvable System. The enabling models include development process, the business and knowledge models, and they are built using the modelling formalisms and the EAS ontology. The EAS Knowledge Model includes several knowledge domains: Enterprise knowledge, product knowledge, execution knowledge and learning knowledge. The EAS RA can be viewed by several perspectives addressing different concerns and entities (different stakeholders) so it includes several views: functional, communication, control and structure [23]. The knowledge model is the abstract model that provides the solution for the final layout of the system, it is composed by a series of relations and algorithms which use the information of the ontology and it achieves only one solution (instead of traditional approach that achieves a set of adequate solutions) [15].

### 3 Collaborative Networks and Environments

Turbulent markets and an economic crisis impose new demands on enterprises such as high flexibility and agility in business and economic efficiency. In line with these aspects Collaborative Working Environments can help enterprises meet these demands. This is supported by FP7 European Commission Report entitled New Collaborative Working Environments 2020 [29]: “Companies as well as the Society will depend very much on the way they are able to react flexibly and pro-actively on a constantly changing environment. The ability to collaborate over time and space, within and between organisations or communities, is essential to achieve this flexibility by making the best use of the knowledge and competences available. Furthermore collaborative environments (CE) are necessary to increase the productivity as well as the creativity by enabling new forms of work in production and knowledge intensive businesses.” The same report stresses out that CE research should not purely focus on IT technology and research, and that in addition society, organisation, technology, and human factor issues must be considered in CE research.

Before proceeding it is important to distinguish between collaboration and cooperation and clarify some concepts. The following definitions are taken from [38]:

**Networking** – “involves communication and information exchange for mutual benefit. A simple example of networking is the case in which a group of entities share information about their experience with the use of a specific tool. They can all benefit from the information made available / shared, but there is not necessarily any common goal or structure influencing the form and timing of individual contributions, and therefore there is no common generation of value.”

**Coordination** – “in addition to exchanging information, it involves aligning /altering activities so that more efficient results are achieved. Coordination, that is, the act of working together harmoniously, is one of the main components of collaboration. Each entity might have a different goal and use its own resources and methods of impact creation; values are mostly created at individual level.”

**Cooperation** – “involves not only information exchange and adjustments of activities, but also sharing resources for achieving compatible goals. Cooperation is achieved by division of some labour (not extensive) among participants. In this case the aggregated value is the result of the addition of individual “components” of value generated by the various participants in a quasi independent manner. “

**Collaboration** – “a process in which entities share information, resources and responsibilities to jointly plan, implement, and evaluate a program of activities to achieve a common goal. It implies sharing risks, resources, responsibilities, and rewards, which if desired by the group can also give to an outside observer the image of a *joint* identity. Collaboration involves mutual engagement of participants to solve a problem together, which implies mutual trust and thus takes time, effort, and dedication. The individual contributions to the value creation are much more difficult to determine here.”

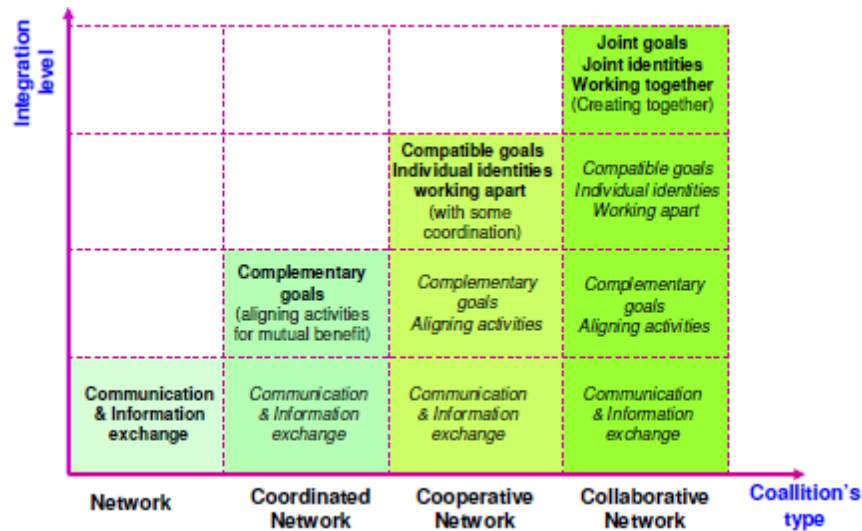


Figure 9 - Coalition type and respective integration level [38]

A collaborative network (CN) is defined by Camarinha-Matos and Afsarmanesh as “a network consisting of a variety of entities (e.g. organizations and people) that are largely autonomous, geographically distributed, and heterogeneous in terms of their operating environment, culture, social capital and goals, but that collaborate to better achieve common or compatible goals, and whose interactions are supported by computer network” [38]. Collaborative networked organizations (CNOs) are collaborative networks that imply some kind of organization over the activities of their constituents, identifying roles for the participants, and some governance rules. A collaborative networked organisation is defined by Camarinha-Matos [53] as: “a group of autonomous entities, which may be organizations, people, or artificial agents that have together formed a cooperative dynamic network to reach individual or group benefits.” Different types of collaborative organizations can be considered such as Virtual Organizations (VO), Professional Virtual Communities (PVCs), E-science, etc.

The first class mostly focuses on the basic interactions to support business collaboration among enterprises and exhibits little focus on the human collaboration. The second class is mostly dedicated to support collaboration among humans, although some of the projects also consider the organizations behind the professional virtual communities. The third class is focused on a special case of human collaboration. It combines both inter-organizational and human collaboration, including the access to remote equipment such as machines or sensors.

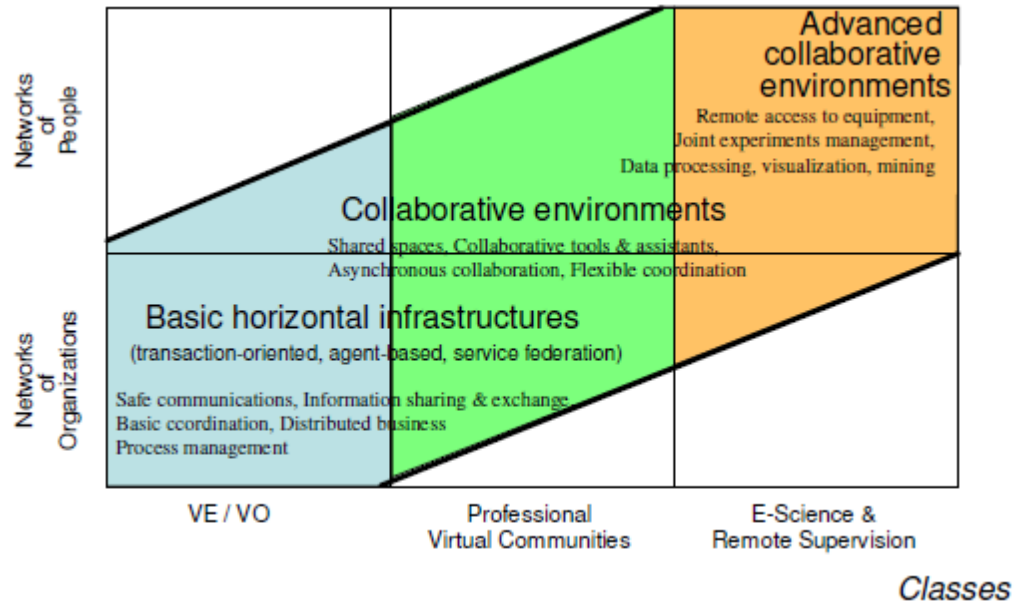


Figure 10 - Main classes of collaborative networks and corresponding infrastructures [30]

Participation in a collaborative network can bring benefits for the involved entities such as increase survivability if organizations in a context of market turbulence and increase the probability of achieving common goals by excelling individual capabilities. When joining collaborative networks, organizations seek: acquisition of a larger dimension through synergies, access to new/wider markets and new knowledge, sharing of risks and resources, joining of complementary skills and capacities, innovation and creation of new value by confrontation of ideas and practices, etc. [38]

Nevertheless the value created by each member in collaborative networks is not easy to identify and therefore it's hard to have clear schemas for distribution of revenues and liabilities. The structure of a value system, and therefore the drivers of the CN behaviour include maximization of some component of its value system (economic profit) or the amount of prestige and social recognition in altruist networks. Other factors that influence the behaviour of a network and therefore its value generation capability are scheme of incentives, thrust relationships, management processes, ethical code, collaboration culture, and contracts and collaboration agreements. Understand CN behaviour is fundamental to achieve sustainability, helping to find ways of combining agility with some sense of stability (life maintenance support, knowing and thrusting partners, having fluid interfaces, etc).

Making CN benefits explicit and being able to measure global and individual performance of a CN is an important step to boost level of trust among partners and confidence in business since it endows it to have perception of value created and compare it to risks and expenses. Camarinha-Matos and Afsarmanesh in [38] identified some indicators of benefits in collaborative networks and synthesized it in the table presented below. The benefits received by a participant include benefits resulting directly from activities performed by this participant and also benefits resulting from other participants' activities (external benefits).



<b>Social Contribution Benefits</b> - sum of benefits contributed by an actor $a_i$ to its partners as a result of its performance in the collaboration process.
<b>External Benefits</b> - sum of benefits received by an actor $a_i$ as a result of the activity of the other actors involved in the collaboration process.
<b>Total Individual Benefits</b> - sum of external benefits plus self-benefits of an actor $a_i$
<b>Individual Generated Benefits</b> - sum of social contributed benefits plus self-benefits of actor $a_i$
<b>Total Received Benefits</b> - sum of external benefits achieved by a set of actors
<b>Total Contributed Benefits</b> - sum of social contributed benefits generated by a set of actors
<b>Total Network Benefits</b> - sum of benefits achieved by a set of actors in a specific collaboration process or over a period of time.
<b>Progress Ratio</b> - a macro indicator that represents the variation of the global benefits over a period of time.
<b>Social Capital</b> - density of the network benefits relation
<b>Cooperative Development Ratio</b> - measures the progress of cooperation benefits for a set of actors over a period of time.
<b>Individual contribution index</b> - Normalized contribution of an actor to the collaborative network
<b>Apparent individual contribution index</b> - based on the number of contribution links (i.e. the <i>out degree</i> of the actor in the graph representing the cooperation benefits), this index gives an apparent and simple to compute measure of the involvement of an actor in the collaboration process.
<b>Individual external benefits index (IBI)</b> - Normalized external benefits received by an actor, expressing the <i>popularity</i> or <i>prestige</i> of the actor.
<b>Apparent individual benefits index</b> - indicator based on the number of received contribution links (i.e. the <i>in degree</i> of the actor in the graph). Like IBI, this index also expresses the <i>popularity</i> or <i>prestige</i> of the actor.
<b>Reciprocity index (RI)</b> - balance between credit (sum of benefits contributed by an actor $a_i$ to all its partners (or one specific partner)) and debit (sum of benefits received by an actor $a_i$ as a result of the performance of all actors (or one specific partner) involved in the cooperation process). $RI < 0$ – selfish behavior, $RI = 0$ – null balance, $RI > 0$ – altruist behavior.

Table 2 - Examples of indicators of benefits in collaborative networks [38]

ECOLEAD project has contributed significantly to consolidate and synthesize the existing knowledge about CN as well as provided some research progress by adopting a holistic approach to collaborative networks. Due to the complexity involved and the inter-dependencies among the involved business entities, social actors and technologic approaches research breakthrough cannot be achieved with increment of innovation in isolated areas and therefore holistic approach becomes fundamental helping to better understand value systems, benefits and success factors of collaboration.

### 3.1 Professional Virtual Communities

Within cooperation environments professional virtual communities emerge constituting a fundamental element of value creation, innovation and sustainability. Virtual Communities and Communities of Practice are not new concepts but they acquire specific characteristics and increased importance when considered in the context of the collaborative networked organizations [30].

Professional communities are a kind of virtual community that bring together professionals to collaborate. Professionals inserted in a professional community share similar values, professional

standards and conduct. According to Camarinha-Matos and Afsarmanesh a PVC is “an alliance of professional individuals, and provide an environment to facilitate the agile and fluid formation of Virtual Teams (VTs).” VT is defined as a temporary group of professionals that work together towards a common goal using computer networks as their main interaction environment.

PVCs are characterized in terms of the socio-economic context, governance principles, social and legal implications, value systems, metrics and business models, as well as support platform for collaboration. According Camarinha-Matos the life-cycle of PVC has 4 stages: Creation, Operation, Evolution and Metamorphosis.

- Creation – Planning, incubation, constitution and start up.
- Operation – PVC established and operating in membership management, knowledge management, business process management and creation, operation/evolution and dissolution of virtual teams.
- Evolution – Learn from experiences, tuning, adaption to customers requirements, small changes in membership, etc.
- Metamorphosis – Major changes in the PVC scope, principles and objectives. It might end with the PVC due to internal conflicts, lack of interest, loss of trust, etc.

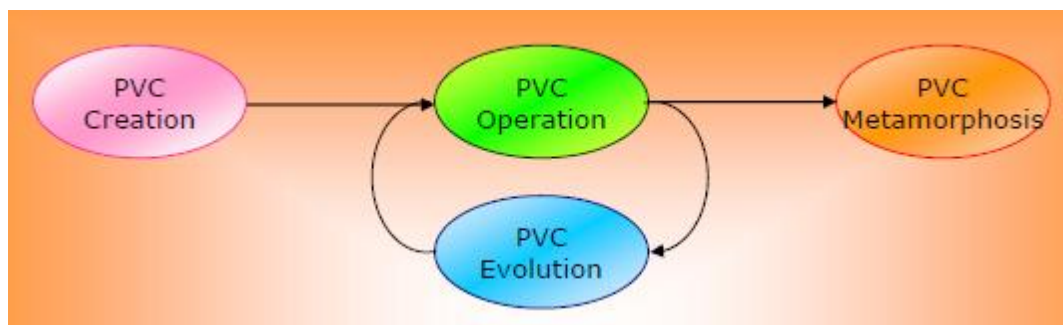


Figure 11 - PVC life-cycle

Professional virtual communities constitute a fundamental element of value creation through the establishment of a platform of collaboration. The use of technology enables professionals to collaborate and share knowledge virtually enhancing value creation for organizations.

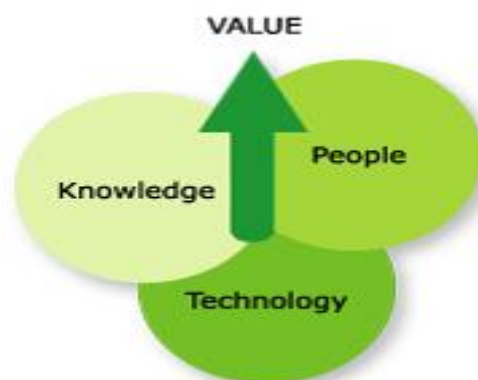


Figure 12 - Value creation in collaborative network organizations

Corporate value creation processes usually include three elements [43] and they can be applied to PVC:

- Hierarchical value creation – include the primary drivers of overall corporate value creation: top management qualities, coherence and credibility of strategy, management remuneration schemes, developing employees' human capital, R&D effectiveness, product innovation, brand power, brand and financial management skills, etc. When applied to PVC hierarchical value creation can include management qualities (robustness and effectiveness of PVC governance, experience of PVC leaders), coherence and credibility of strategy (internal and external support for PVC strategy), performance systems for PVC, intensiveness of knowledge creation within PVC, PVC brand, etc.
- Horizontal value creation – Include value drivers (tangible and intangible) at middle management, employee and operational levels. In the horizontal value creation process companies exploit structural capital such as brands, quality of distribution systems, R&D systems, innovation for new products, technological skills, customer and supplier relations and other intangible values distributed throughout the business. When applied to PVC horizontal value creation can include the way products and services are delivered within PVC (PVC supply chain), the confidence and competency that PVC members show using supply chain tools (knowledge of IT platform and other IT infrastructure).
- Network value creation – Include the sharing of value drivers (tangible and intangible) via alliances, suppliers, and distributors and matching these to weak points in the internal value creation process, especially in the boundary areas. When applied to PVC network value creation can include managing extensive networks of individuals and their relationships with external suppliers, distributors. PVC network value creation can therefore work through the strategy for recognition at the market.

According to [31] firms have to deal with fragmentation of knowledge which results from differentiation in hierarchical layers, functional departments, or different geographical sites. Nowadays adverse business conditions make knowledge management issue a top issue for organizations. All the process involving the creation, storage and use of knowledge can be a leading issue that separates a successful organization from an unsuccessful one.

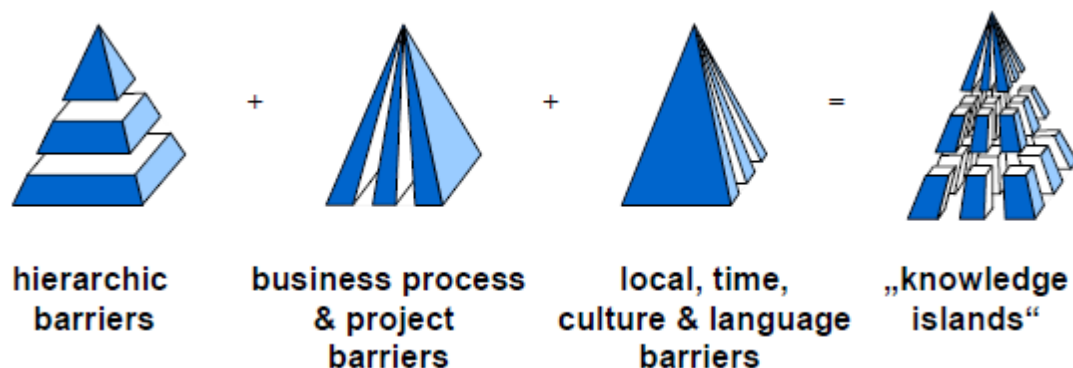


Figure 13 - Fragmentation of knowledge [31]

PVCs can emerge to support organizations in the creation, storage and use of knowledge avoiding the creation of knowledge islands. The insufficient support for human-to-human interactions over a network is a strong limitation for a wide adoption of PVCs. Several reasons origin this weak support for human-

to-human interactions, among them one may find social elements and the adaptation capabilities of humans [44]. In [44] are identified two main characteristics that arise for PVCs:

- PVCs as heterogeneous environments – The heterogeneity of PVCs exists at different levels of granularity. At high level one may identify different sub-communities and each one is different from the other coexisting in the same PVC sub-community with similar goals, intentions, knowledge, processes, members, etc. Some sub-communities may share members allowing knowledge to be transferred from one sub-community to another, while others are isolated. At lower level one may identify that the structure of sub-communities is complex and heterogeneous since the roles played by sub-community members, their skills and competences usually present discrepancies.
- PVCs as dynamic environments – The dynamics of PVC are hardly foreseen at design time since the changes of given PVC are related to business environment and other non-deterministic conditions. The dynamics of PVCs exists at different levels of granularity. At high level one may find evolvability over time in the following aspects: new sub-communities are created to deal with new needs and opportunities, while others are dissolved, new members enter and leave community, etc. At low level one may find evolvability over time in the following aspects: members get job promotions or get new roles assigned, skills of members usually improve, members can find new situations such as new ways of collaboration, etc.

Due to knowledge fragmentation faced by organizations, the weak support for human-to-human interactions over a network and the heterogeneous and dynamic environments of PVCs two concepts arise as fundamental for implementation of PVCs: Knowledge Management and Trust Management.

## 3.2 Knowledge Management

According to Nonaka, Takeuchi and Senge (among other authors) knowledge management is considered as the major competitive advantage of organizations. This has led to research focused in processes and strategies to better facilitate the acquisition and dissemination of knowledge.

Such a management strategy is the learning organisation. Garvin states [41]: “A learning organisation is an organisation skilled at creating, acquiring and transferring knowledge and at modifying its behaviour to reflect new knowledge and insights”. A good observation is stressed out by Blackman and Henderson [41]: “learning organisations can only enable competitive advantage via learning if knowledge exists, can be identified as important to the organisation, can be transferred and if the learning organisation does all this better than other organisations”. Knowledge acquisition and management is a problematic that has been investigated in the last decades and its study and understanding can bring benefits for organisations.

According to SECI's model of Nonaka and Takeuchi the creation of knowledge is a process of interactions between explicit and tacit knowledge. Tacit knowledge is personal and hard to formalize, including daily experience, subjective insights, intuitions and hunches. On the other hand, explicit knowledge can be expressed in words and numbers and therefore this knowledge can more easily be acquired and shared. Knowledge should flow to create new knowledge or to be improved and the flow of knowledge is composed of four steps [35]:

- Socialization – when tacit knowledge is created from tacit knowledge. A clear example of this is communication between employees, i.e. one employee can acquire tacit knowledge by communicating or simply observing and imitating other employee.
- Externalization – requires the expression of tacit knowledge and its translation into comprehensible forms that can be understood by others, e.g. formalizing knowledge in reports, documents, etc.
- Combination – use of explicit knowledge to create more complex explicit knowledge by combining information that resides in formal sources like reports, documents, etc.
- Internalization – generate tacit knowledge from explicit knowledge, e.g. when a person improves the tacit knowledge by consulting formal sources such as reports, documents, etc.

According to [35] the knowledge management performance measurement can be done by analyzing the knowledge circulation process that consists in 5 stages:

- Knowledge creation – Occurs when new information is obtained and understood.
- Knowledge accumulation – Process of storage of information to be used in the future.
- Knowledge sharing – Process of share of information in an organization.
- Knowledge utilization – Degree of knowledge utilization in an organization.
- Knowledge internalization – Capability to internalize task-related knowledge, education opportunity and level of organization learning.

Collaborative tools are an important feature in organizations for knowledge management since they can enhance the knowledge creation, accumulation, sharing, utilization and internalization, giving an important competitive advantage towards organizations with lower level of knowledge management.

### 3.3 Thrust Management

Trust among team members is fundamental in any kind of collaboration or partnership. When different entities are collaborating, the process of building trust and maintaining is hard and even more if the cooperation partner is at the same time a competitor. This is called a situation of coopetition and is characterized by entities joining efforts with competitors to work together in their business to have some business benefits. This is supported by Ishaya and Macauly in [45]: “The success of virtual teams depends largely on building and maintaining trust between the team members. Trust has been identified as the most important component, which makes partnerships, strategic alliances and networks of small firms successful”. Virtual teams transcend distance, time zones and organizational boundaries, and have been facilitated by the developments of computer technology that enable electronic work to be carried on and services to be provided independently of distance and time constraints. Ishaya and Macauly in [45] defend that the analysis of the process of building and maintaining trust should be made through an integrated view over the rational and social perspectives of trust. The rational perspective of trust is based on calculations that weight the cost and benefits of certain courses of action between members. The social perspective of trust is based on individual shared common values. According to Ishaya and Macauly [45], a combined approach of both perspectives enables identification of elements of trust needed to allow for cooperation and possible establishment

of a social relationship. A case-study carried on by the same authors identified three main levels of trust in virtual teams: Technological level, Media level and Social level. The technological and media levels of trust are the mechanism and software used for collaboration. If problems are detected in these levels members will be discouraged to collaborate virtually and this can originate rupture of collaboration. The social level includes the interactions between the individuals, groups and organizations of members of the virtual team. This study revealed that computer-based communications can destroy trust in virtual teams since the people are more critics and impose and demand more than over face-to-face communication. The same study revealed that groups who trusted their members had higher performances than groups who distrusted their members and compiled information about the factor that deepens and retreats trust:

<b>Trust Deepens</b>	<b>Trust Retreats</b>
<ul style="list-style-type: none"> <li>• Communication was frequent, so members were well informed and shared their understandings</li> <li>• Messages were pre-categorised, which provided timely responses from each member</li> <li>• Tasks were clearly identified, so members knew group objectives</li> <li>• Members kept to schedules and deadlines</li> <li>• Constant positive feedback was provide, so members had positive reinforcements</li> <li>• Members were supportive to one another</li> <li>• Individuals' and groups' expectations were identified</li> <li>• Members were seen to be very committed and kept to promise</li> </ul>	<ul style="list-style-type: none"> <li>• There was little communication between members, so ideas were not shared</li> <li>• Members were not responsive, messages that required urgent reply were ignored</li> <li>• Goals were not properly identified</li> <li>• There was little or no positive feedback provide, so members had positive reinforcements</li> <li>• Members were looking for excesses for not participating rather than making contributions</li> <li>• Individuals' and groups' expectations were not identified</li> <li>• Members were not seen to be committed</li> </ul>
<b>High Performance</b>	<b>Low Performance</b>

Table 3 - Factors that deepens and retreats trust [45]

Increase of business with space and time constraints, and consequent language and cultural barriers impose new demands to organizations. Collaborative tools arise as an important feature for competitive advantage in organizations enhancing new forms of collaboration in intra and inter organization business. Nevertheless such collaboration forms can fail if there is lack of trust between partners and therefore trust management arises as an important issue for new collaboration forms such as PVCs.



### 3.4 Collaborative Environments for Evolvable Production Systems

The kinds of Collaborative networks have been identified above in this thesis. Within cooperation environments professional virtual communities emerge, constituting a fundamental element of value creation, innovation and sustainability. Evolvable Production Systems, as an emerging paradigm, can benefit from forming PVC in the sense dissemination and joint collaboration among professionals can be achieved (e.g. members from research institutes, enterprises and academic members can use the PVC as a brokerage environment forming virtual teams), aiming at a network organization that endows Collaborative Engineering. EPS can also benefit from the inclusion of E-science and Remote Supervision concepts. For instance, this is important to have remote access to equipment that can be important to implement remote monitoring and control operations of an assembly cell. This can be useful for shop floor implementation to have quick feedback about an assembly cell performance (and therefore enhancing shop floor, supply chain and enterprise agility) or at dissemination level endowing the demonstration of performance measuring and evolution of an Evolvable Assembly System.

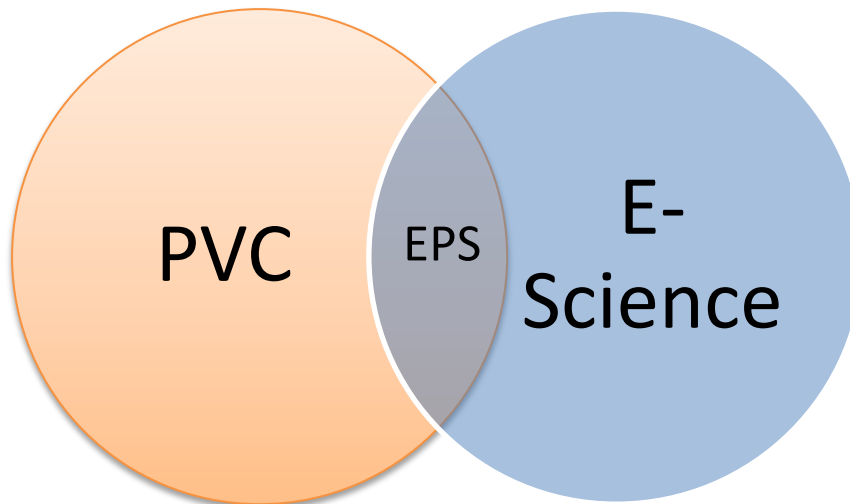


Figure 14 - Collaborative Networks for Evolvable Production Systems

In industrial context three main factors support the use of collaborative environments for EPS:

- Actual Business conditions – Globalization, deregulation and removal of trade barriers have changed the character of doing business demanding agility and dynamics as main drivers. New forms of business (i.e. e-business) and organization (i.e. e-government) are therefore emerging to deal with actual demands. Networks of interacting and collaborating customers, employees, business partners and suppliers, as well as offer of complementary services that extend business boundaries are a signal of modern business context [46].
- Progress on Information Technology (IT) – Progress in the area of IT has created massive amounts of data associated with customer and operational processes. The management of physical assets (characteristic of industrial revolution) shifts towards the management of

intellectual assets. Knowledge must be unified and integrated and not fragmented. The arise of IT-networks of collaborating enterprises and employees associated with collaborating customers and suppliers create collaborating tasks and functions that require shared and integrated information. The creation and sharing of knowledge facilitated by IT technologies create a competitive advantage for organizations. The informatization of enterprises also results in developments in the relationship of enterprises and customers since enterprises will now have enormous amounts of data about the customers. The exploitation of this data can enable the extension of the relationship with customers for more than a single transaction. Zuboff and Maxim support that information intensive enterprises and society enables a shift from transaction economy towards support economy, shifting short term transaction orientation towards a long term relational orientation [46].

- Enterprise Organization evolution – The business domain changes are reflected on enterprise organization. E-business services and collaboration with business partners and suppliers requires extensive processual and informational integration what implies changes for enterprise organization. Organizations need to shift from mechanistic<sup>6</sup> to organismic<sup>7</sup> way of organizing [46]. Cooperative work structures supported by IT infrastructure can help stimulating agility and dynamics of enterprise avoiding rigidity and inertia associated with traditional, formal and hierarchical structures. Hoogervorst states in [46]: “Hierarchies and conventional central management becomes less relevant for networks of teams and individuals connected virtually and directed towards the cooperative execution of an end-to-end process.” New enterprise organizational forms must enhance enterprise flexibility increasing the ability to change and adapt. Information from low levels of an organization (e.g. shop floor, supply chain, etc) can be used at management level to improve decision making. This enables organization’s agility and responsiveness to business opportunities and can be facilitated by collaborative environments.

PVC enables individuals from a specific knowledge scope with a specific business orientation to generate value through members’ interaction, sharing and collaboration. The PVC generated value consists of:

- Advanced knowledge – Knowledge relevant to the community knowledge scope.
- Professional services – Collaborative business activities performed by the members exploiting the community knowledge.
- Social cohesion – the social relationship that enables fast start of collaboration process and knowledge sharing and creation.

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<sup>6</sup> “Mechanistic perspective considers the traditional vision of Organizations, where they are seen as a rigid, deterministic and mechanic system. Organizations are considered to have fixed functionality, time invariant behaviour, stability and predictability.” [47]

<sup>7</sup> “Organismic perspective considers an Organization as a living body, interacting in an evolving system. Therefore uncertainty and learning, play an important role. Assuming too many relationships (known and unknown) to be predictable at top level, it is considered that behaviour must emerge bottom up. In this perspective the members’ involvement is essential, being the igniters of re-design of the Organization – allowing adaptation and change.” [47]



The PVC business activities are performed by virtual teams, i.e. PVC business activities consist in professional knowledge services exploiting knowledge developed by the community [49]. PVC characteristics are very suitable approach for an emerging paradigm such as EAS since it enables members from research institutes, enterprises and universities to use the PVC as a brokerage environment to form virtual teams to address business/research activities and generate value through interaction, sharing and collaboration.

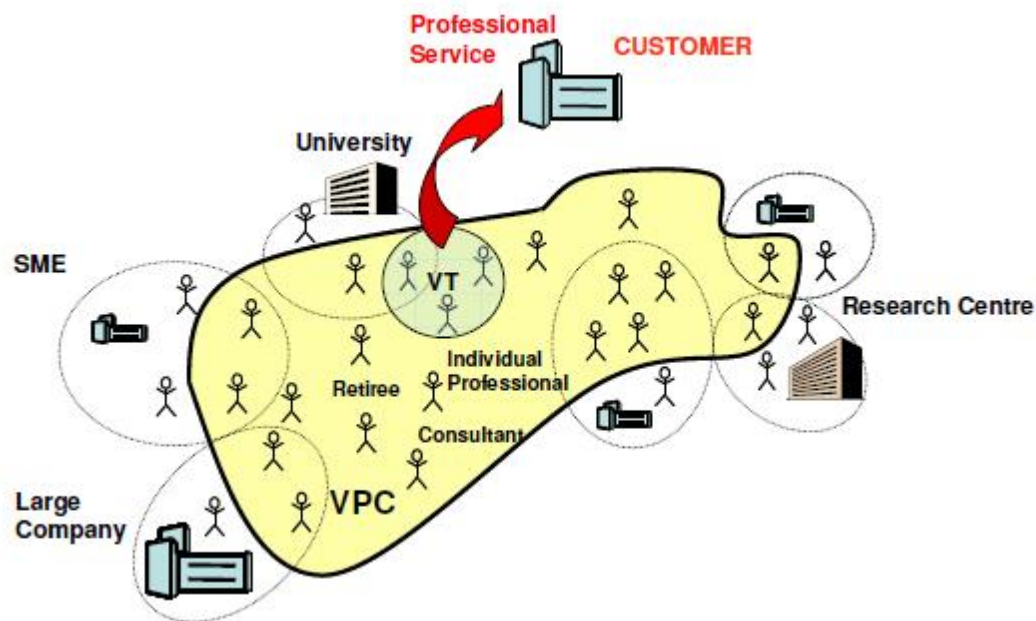


Figure 15 - PVC interaction [49]

PVC is based on three basic principles: alignment of collective objectives to individual ones, address knowledge, business and social dimensions in a comprehensive and balanced way, and enable of collective intelligence by seemingly contradictory interactions among opposite elements (e.g. knowledge diversity of members within the same scope, members can belong to the community and at the same time to an enterprise or university, collaboration among conflicting interests since members within a team compete with each other to gain knowledge rights or positions, distinct teams compete for business activities, etc.) [49]. PVC principles mentioned above fit in EAS consortium's motivation for PVC creation since EAS consortium is composed by several partners distributed across Europe within the manufacturing/assembly scope but with different areas of specialization and therefore different interests. However all share one common objective: the development of EAS paradigm which will benefit all of them in their research/business. Also the PVC creation enhances the possibility of having more members which increase the possibility of value creation in the sense that more knowledge is brought to the community and more diversified virtual teams can be formed. Competition is also stimulated which enhances creation and innovation through the increase of motivation and creativity. This is a crucial factor for actual business demands and R&D that is highly dependent of innovation and creation of new ideas and products. PVC facilitates this since it promotes interaction of diverse

knowledge (team members with different disciplinary knowledge within a focused community environment) increasing the possibility of breakthrough innovation. PVC intends to provide a long-term collaboration environment which is also adequate for EAS consortium since it enables a long-term approach for learning and collaboration among members to address the so mentioned breakthroughs and innovations in science and the accurate use of the knowledge created to address business activities enhancing the value created by the PVC. The collaboration process can be enhanced if concepts of thrust and knowledge management are not overlooked in PVC approach. In a situation where collaboration is the base of interaction between partners there is a need to stimulate knowledge to flow across members (enabling sharing and learning) which depends highly on the level of trust between partners. Therefore the study and application of these two concepts can dictate the difference between successful PVC and an unsuccessful one.

### 3.4.1 Collaboration platforms for PVC

PVC addresses better use and share of knowledge held by its members, facilitates interaction and enhance collaborative work. PVC's members interact face-to-face but also virtually what gives rise to one demand: an accurate ICT platform that can support the PVC in its activities [50].

Such platform should support human interaction in several ways:

- Conversational interaction – Exchange of information between one or many participants with purpose of discovery or relationship building. It involves free communication with no defined constraints neither a central entity (e.g. telephones, chat, e-mail, etc).
- Transactional interaction – Exchange of transaction entities where the transaction entity alters the relationship between participants (e.g. one participant exchanges money for goods and becomes a customer).
- Collaborative interaction – The main function of the participants' relationship is to alter a collaboration entity (e.g. development of ideas, achievements of a shared goal, etc). So collaboration platforms enable participants to “work on” a common deliverable by allowing document or file management, threaded discussions, etc.

Such platform should offer, depending on the level of collaboration, the following tools:

- Electronic communication tools – tools that facilitate information sharing by allowing exchange of messages, files, data or documents between members (e.g. e-mail, faxing, voice-mail, web publishing).
- Electronic conferencing tools – tools that facilitate the sharing of information but in a more interactive way (e.g. forum, chat, audio and video-conference, etc).
- Collaborative management tools – tools that facilitate creation and managing of group activities (e.g. online calendars, project management system, knowledge management system, etc).

In order to cover knowledge, business and social aspects of PVC a collaboration platform should cover:

- Social & networking functionalities – members can build and maintain/strengthen personal and professional relationships enhancing social interaction in the PVC.
- Human Competency Management and Team Building – virtual teams can be formed according to specific needs and objectives comparing competencies of potential members.
- Collaboration rewarding – a PVC member can be rewarded by his performance at individual, team or community level.
- Governance – allow PVC administrators to track the evolution of the PVC, examining general and individual performance.
- Knowledge IPR management – identification and tracking of the knowledge exchanged inside the PVC and related tools to enforce the associated Intellectual Property Rights.

Collaborative problem solving is another important aspect to be considered in PVC's ICT platform:

- Planned collaboration – supports the creation, running and dissolution of collaborative projects where members are collaborating in a structured way to achieve a common goal (e.g. project with fixed structure with responsibilities, tasks and deadlines defined at creation time).
- Mediated collaboration – supports the creation, running and dissolution of collaborative problem solving sessions where the relevant problem requires an unstructured interaction among members mediated by a moderator (e.g. process that needs negotiation between involved parties).
- Ad-hoc collaboration – supports the creation, running and dissolution of ad-hoc virtual teams (e.g. quick formation of a team to address an urgent decision accounting members knowledge and expertise but also immediate availability).

Another important aspect of a collaboration platform it's integration. Aspects that should be considered include authentication (avoid standalone tools that demand several authentications which is bad for user and administrator, may contain different policies and difficult easy administration for tool maintenance and user identification , etc) and information storage and availability (e.g. avoid duplication of information, easy search and archiving of information, etc).

All the aspects referred in this section are encompassed in the Advanced Collaboration Platform (ACP) tool developed under the ECOLEAD project and which details were analyzed for this thesis' purpose and can be found in detail in [50].

### **3.4.2 Aligning corporate governance with PVC governance and shop floor activities**

Enterprises have to deal with external forces such as market instability, customer behaviour, technologic advances, politics, etc. Enterprises deal with uncertainty and changes creating its own dynamics through strategic choices such as reorganization, business cooperation, products/services

development, etc. Uncertainty and constant changes demand enterprises to be flexible and agile and to be able to learn and evolve. According to the congruence theorem enterprises operate more effectively and perform better the higher the degree of unity and integration (consistency of several enterprise aspects). This is supported by Collis and Montgomery as they state “In a great corporate strategy all elements (resources, business, organization) are aligned with one another” [46]. This section will provide an alignment of the more recent corporate governance trends with PVC governance state of art and shop floor approach of EAS. This analysis aims at showing that manufacturing enterprises adopting modern corporate governance strategies and EPS approach can win competitive advantage by not only benefit of the single advantages of each approach but also benefit of the use of the congruence theorem.

From the organizing point of view there is a need to shift from mechanistic approach to the organismic approach to endow enterprises to deal with increasing of complexity and dynamics involved in business [46]. Hence there is a need to shift from top-down control to bottom up empowerment. To deal with uncertainty enterprises tend to decentralize authority and raise responsibility in the lower levels, encouraging employees to take care of problems by working directly with one another and encouraging team work. This is supported by Neves in [47]: “an enterprise must be designed with both holistic and local capacity to adapt to a new strategy, a new environment or new systems constraints. According to the organismic perspective of organizations, this behaviour must be enforced bottom up, since as lower is the complexity as easy is to evolve and change”. Figure 16 shows the relation of organisation levels, the associated complexity and the required level of adaptability. For instance, at team level there is less complexity than at department level and therefore at team level it is required higher level of adaptability than at department level. More, if there is not high level of adaptability at team level it's impossible to achieve adaptability at department level.



Figure 16 - Organization complexity and consequent adaptability required [47]

Zuboff and Maxim support that: "Flexibility and agility have replaced long-term planning", and according to the view of Neves can only be achieved by a bottom up enforcement. However some kind of central governance is still needed to orchestrate all the process: "the ability for local freedom and self-organization depends on some central governance that ensures that conditions for local freedom and self-organization exist" [46]. Hence central governance is needed to establish rules, legislation, provide necessary mechanisms (e.g. ICT structures) and define the strategy of the enterprise for being followed by the low level structures of the enterprise. The main characteristics identified above for modern enterprise governance are: Decentralized approach, bottom up empowerment, self-learning, self-monitoring, self-healing, self-reconfigurability, self-organization and evolution.

PVC governance emerged as an organization form to deal with turbulent markets and very competitive business environments and it follows the same principles identified above promoting agility and flexibility to deal with it. PVC defends all decisions and responsibility must be taken at the lowest hierarchical level which supports a decentralized approach and bottom up empowerment. VT members establish business activities with clients while the PVC just has brokerage function to facilitate the process. This promotes flexibility agility since the lowest complexity level of the structure the more adaptability it possesses. It also promotes self-learning, self-monitoring, self-healing, self-reconfigurability, self-organization and evolution of the entities. PVC is an association of individuals that have a specific knowledge scope with an explicit business orientation. Their members share a common interest and the PVC has a central governance mechanism (identified in corporate governance as essential): the chromo-management system is used to set strategic targets for both individuals and PVC [49]. This system helps steering the direction of the PVC. The PVC has rules that result in internal (e.g. members benefits and dues in the community, deontological code, etc) and external agreements (e.g. rules of members' participation and behaviour in PVC activities, etc). Once again the concept of a learning organisation and evolvability are present what strength the organisation's capability of success.

As extensively detailed in section 2, an EAS system is designed to be extremely flexible and capable of evolving through self-learning, self-monitoring, self-healing, self-reconfigurability and self-organization properties. To aim at a real flexible system (system that can fully adapt to unforeseen changes in environment conditions) the sub-systems and the control systems must be extremely adaptable and the lower a component is positioned in the hierarchic structure of the system the more flexible it must be in order to empower the system's flexibility. Hence in EPS approach it is also taken a bottom up empowerment. The EPS paradigm focuses on the changes in the production systems and how they can be managed efficiently. Change drives the adaptability/evolution of the EPS Systems and EPS tries to cover predicted and unpredicted changes that may occur in a limited product range. EPS is not a generic solution but it is rather a specific approach that may be adopted by several products of the same class. This means that despite its decentralized approach EAS also needs a central governance mechanism to orchestrate the processes. Each system developed with EAS methodology cannot be applied to all products, what brings forth the concepts of needed governance that will endow each system to cope with products of the same range. It's also being developed autonomous parameter feedback for EAS that can help in production's strategy alignment. This means important data from the shop floor is exported to higher organizational levels to support decision making and promote supply

chain and enterprise agility. Hence with high level of adaptability at shop floor level and accurate business tools to support shop floor, supply chain and enterprise management it can be targeted to quickly address new business opportunities or accommodate the required actions due to changes in the business/production environment.

This section tried to encompass main characteristics of modern enterprise governance, PVC governance and EPS approach at shop floor level and their similarities, that suggest (following the congruence theorem) that the utilization of EPS approach in manufacturing systems of enterprises using modern governance, as well as the use of PVC for EPS or enterprises joining PVC, can bring competitive advantages for organizations willing to follow this strategy.

## 4 Problem Solution

Like stated before, the work objective of this thesis is to prove that EAS paradigm validation/falsification can be enhanced by the use of an accurate collaborative environment tool providing the required mechanisms for EAS dissemination. The knowledge usage resultant from a big project such as EUPASS needs to be maximized and not just result in individual use of knowledge by the partners of the consortium. This thesis aims at bringing forth a solution that endows maximization of knowledge utilization and progress of R&D through collaboration of parties related to manufacturing and assembly.

### 4.1 Exploitation of knowledge in EUPASS

EUPASS exploitation of knowledge consists in the utilization of any foreground information (adequately supported by background information) developed within the EUPASS project in order to achieve a commercial, industrial and/or any economic advantage.

Due to EUPASS complex nature of the partnership, wide scope of the technologies and technological development approaches, as well as the different industrial areas and manufacturing typologies being encompassed into the category of precision assembly processes being addressed, it's obvious that the nature and variety of potential exploitation actions will be large and differentiated:

- Direct exploitation (DE) - Actions arising from one partner directly using its own results on its own, eventually with a minority support of other partners' foreground or background information, for either internal utilization or marketing of the result.
- External exploitation (EE) - A partner and/or an external organization, agreeing to use EUPASS know-how from one of the partners in order to exploit a single result
- End User exploitation (EU) - Exploitation on the part of end users, that is to say the utilization of project's foreground and background information on the part of partners internal to the project with no foreground information pertinent to that product)
- Joint exploitation (JE) - Partners joining together and conferring their know-how to each other and/or to a purpose-built third organization in order to exploit the whole or a large part of EUPASS project results.
- Dissemination (DI) - Exploitation on the part of academic partners through the circulation of public available project knowledge.

The above forms of exploitation have been subdivided, in EUPASS, into three main categories: Single-Partner Exploitation (DE, EE, EU), Joint Exploitation (EE, JE, DI) and Dissemination (DI).

The focus of this thesis is to build a collaborative environment tool that, given these demands, can facilitate the Joint Exploitation and Dissemination of EUPASS knowledge endowing collaboration among entities for mutual benefit and booming R&D efforts.

This Collaborative Environment tool intends to create a true resource brokerage environment by applying the EUPASS methodology and a modified reengineering architecture (CoBaSa [2]). This is what is commonly known as a Knowledge Brokerage Environment (KBE). The goal is to structure, integrate and coordinate the required topics such that knowledge and services can be made available, in an effective manner, to the users and developers. This entails the formation of expert groups that are created by the KBE, with the related agreements, limitations, and performance monitors. As shown in figure below, the KBE will search through its resources to find the best possible alternatives for any given information request.

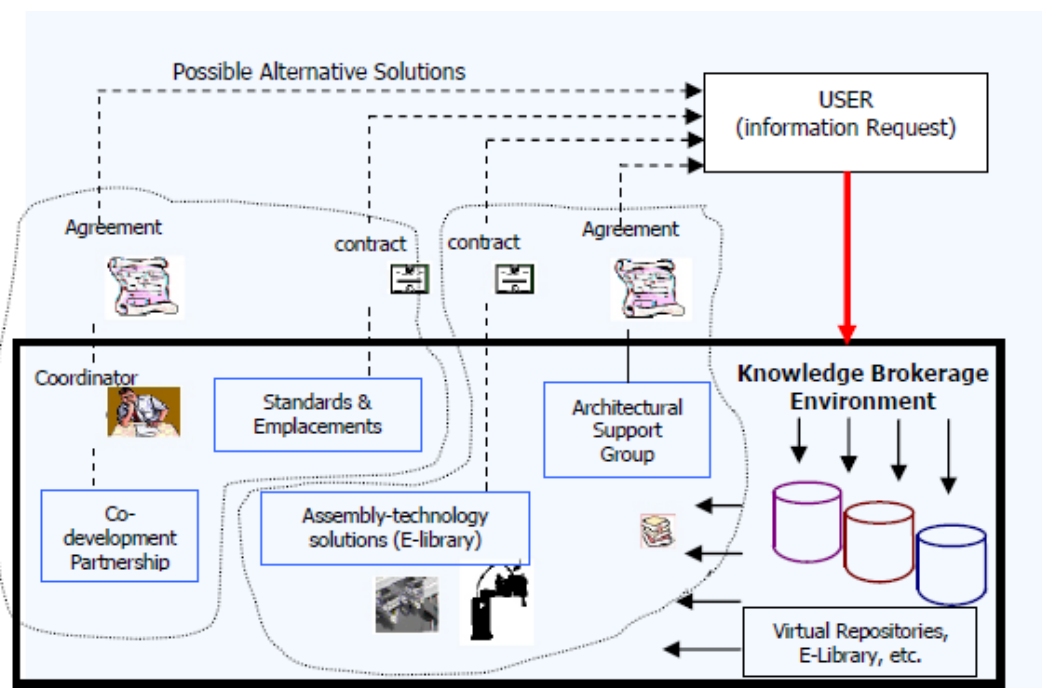


Figure 17 - Some KBE possibilities

The control architecture, with data validation techniques, will evaluate which alternatives can be suggested and which contracts need to be signed for each alternative. Obviously, there will be simple, non-binding alternatives for conventional information retrieval as well. However, for more advanced support measures such as consultancies or other consortium agreements (such as co-developments) the KBE will keep track of the contractual implications. Hence, KBE will help forming and managing virtual consultancies and expertise brokerage groups.

The requirements for developing interoperable Evolvable Assembly Systems include the development of web-based services that can assist the deployment of systems by providing standards, interfaces



(emplacements), architectural guidelines, etc. Research teams in Europe and around the world are working in developing such models, standards and services, along with the practical implementation of their work. The problem is the poor information sharing between working groups, which usually get the information through scientific publications. Once the reader processes the information, a practical implementation of the model is necessary. This implementation, many times in form of a software module, is re-created since the first time was carried out by the primary researcher. If one considers the integration of assembly systems, the concept becomes even more serious as any duplication of the engineering work is production down-time and longer TTM. In order to avoid such duplication of effort, EUPASS proposes to create an Evolvable Assembly Systems Environment activity that will enable different users and developers to collaborate by creating a virtual repository of applications. These would then be available for use, along with the related information (blueprint files, guidelines, source code, publications, etc.) for them to develop their own applications based on the original methodologies using the original implementations. In return, they would assist in the further development and consolidation of the technology, giving a competitive advantage to the European assembly sector through a virtual collaboration group.

## 4.2 Identification of actors and roles for EAS

To form a successful collaborative environment that endows entities to collaborate it's essential to promote a thorough analysis of the scope of the actors and their relations and intentions. Defining the domain, features and targets of a collaborative environment tool sets the right demands for building an accurate collaborative environment tool. This collaborative environment tool will be designed to aim at users on the manufacturing/assembly domain.

The actors identified for EAS collaborative environment tool are:

- Guest User – Actor that consults information in the collaborative network environment tool without being a collaborator.
- User – Actor that consults information and can communicate with other user or enter group discussions, without collaborating at higher levels.
- Collaborator – Actor that can be an industrial or academic collaborator. These actors actively collaborate to implement projects and enhance R&D. The collaborators can be Proposers, Developers, Module Suppliers or System Integrators.

The use-cases identified for EAS domain are:

- Consult information – Consult information related to EAS including information concepts, definitions, achievements, etc. and also opinion articles from EAS experts about Assembly and manufacturing.
- Share Information – Share own information with others.

- Propose Standards, Modules, Reference Architecture, etc – Propose Standards, Modules, Reference Architecture, etc to EAS community. This will lead to an appreciation and discussion of the same among the community.
- Access Standards, Modules, Reference Architecture, etc. – Access Standards, Modules, Reference Architecture, etc already developed by previous collaboration (i.e. previous projects whether they involved the use of a collaborative environment tool or no)
- Group discussion – Discussion in group of topics regarding EAS and assembly and manufacturing in general.
- Communicate with other actors privately – Communicate with other actors privately without exposing it to other members.
- Form virtual collaboration teams – Form teams to collaborate i.e. virtual consultancies and expertise brokerage groups. This is made through discovery of partners and communication through EAS environment.

The use-case model is represented below:

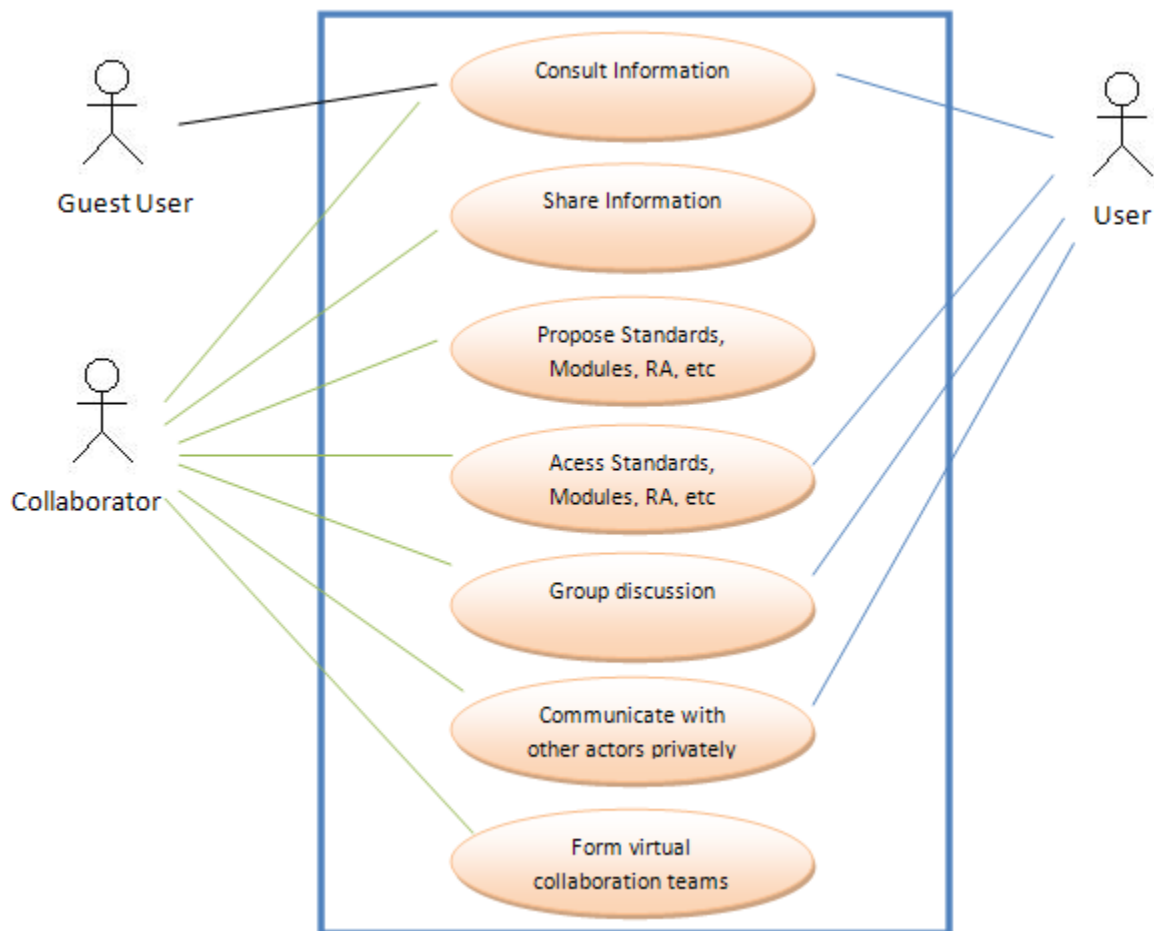


Figure 18 - Use cases for EAS

The needs for this collaborative environment tool can be summarized:

- Present what is EAS
- Present achievements of EAS
- Clarify EAS definitions
- Present opinion of EAS' experts about production systems
- Propose new standards, modules, Reference Architecture, etc.
- Endow users to communicate privately
- Endow group discussions among members
- Endow the formation of virtual collaboration teams

Identified the fundamental features that will need to be developed there is the need to discuss how this can be accomplished through the creation of an Evolvable Assembly Systems Environment Tool.

### 4.3 Evolvable Assembly Systems Environment Tool (EASET)

The success of a collaborative environment tool depends in great part of an accurate analysis and identification of actors and relations that transmit the real needs for the tool to be developed. Nevertheless without a thoughtful technological design it's impossible to best fulfil the needs identified and to overcome spatial distance between members and achieve social cohesion and collaboration among the same. The first step towards achieving a successful solution is to define the governance principles of EASET:

#### **General Management and Support**

- Administration and technical support – EAS PVC consortium decided to leave this matters to the administrator of the tool.
- Contents and business support – This will be in charge of some collaborators that will be assigned to manage and support these matters.

#### **Membership Management**

- Member type – The consortium decided to create 4 types of membership: guest user, user, collaborator and administrator.
- Membership – Any guest user can become a user as long as he goes through a registration process. The registration intention is to endow the EAS community to track member's identity (e.g. name, nationality, etc), actual status (e.g. belong to an enterprise or university) and background (e.g. research or working field). The administrator is in charge to manage the roles of the community's members.

## Knowledge Management

- Access to contents – The contents will be divided in closed and open part. The open part contents are visible independently of the membership type. The closed part is not visible to guest users and to access these contents the guest user needs to proceed to the registration process. EASET is blocked to Asian IP's because its intention is to support European development and use the know-how acquired in Europe.
- Contents update and verification – The administrator and pre-defined collaborators will be in charge of this task.

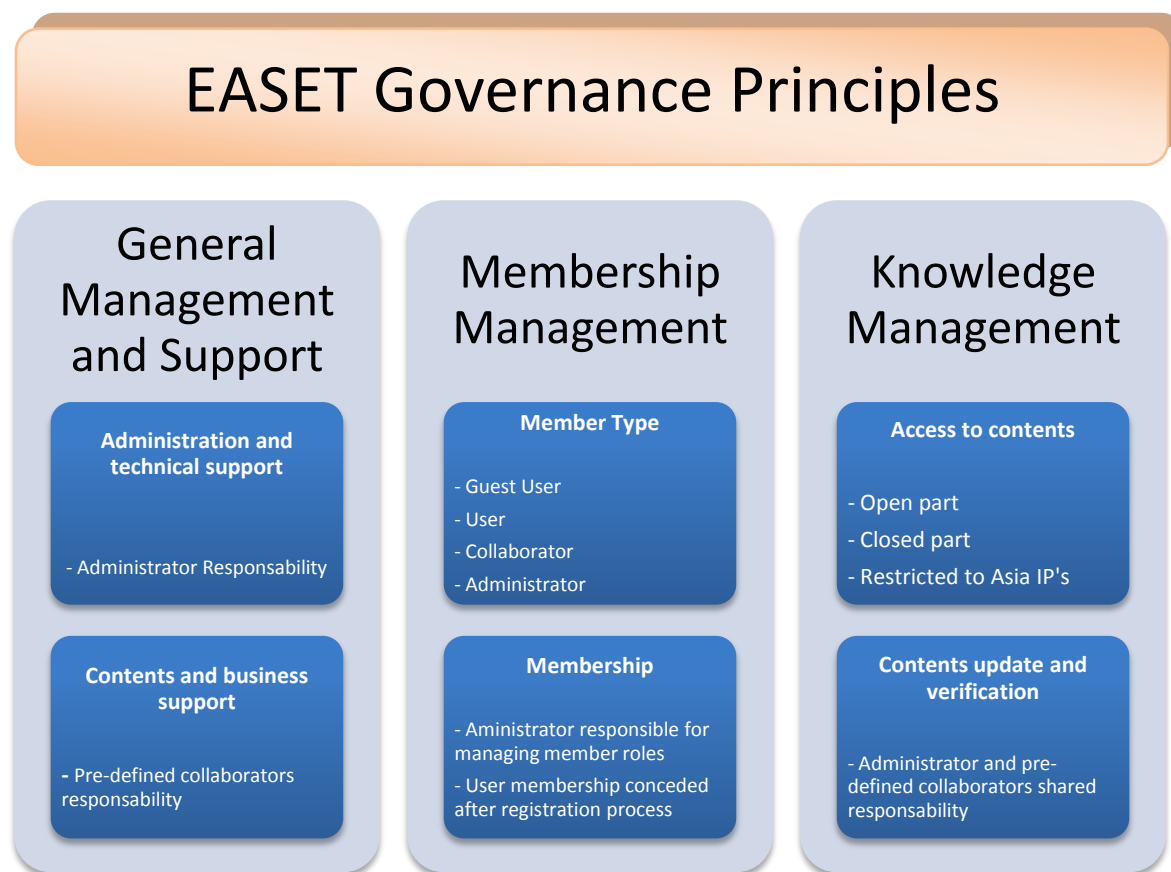


Figure 19 - EASET Governance Principles

EASET needs and governance principles were identified above and technological solutions that best fit the collaborative environment tool's purpose and demands can now be discussed. EASET tool should be evaluated and designed according to fulfil the needs previously identified. EASET should be able to support the EAS PVC in knowledge management, dissemination activities and collaboration actions.

EASET should compile the best techniques and technologies for an effective knowledge creation, accumulation, sharing, utilization and internalization. In matters of knowledge management the essential questions taken into account when designing EASET were:

#### **Knowledge creation**

- Does the tool help finding information? Is it user-friendly?
- Are the contents understandable?

#### **Knowledge Accumulation**

- Does the tool have a database to store information? Is the database of enough quality?
- Does the tool help to document daily activities or information?

#### **Knowledge Sharing**

- Does the tool endow people involved to communicate?
- Does the tool helps knowing what work is being developed by other people?
- Does the tool help trace who works on similar tasks to help forming virtual teams?

#### **Knowledge utilization**

- Does the tool have techniques for information search?
- Does the tool help avoiding noise in the information?

#### **Knowledge Internalization**

- Does the tool help to learn how to perform tasks or best practices?
- Does the tool help improving member's abilities and capacities?
- Does the tool transmit the organizational philosophy, standards and "client profiles"?

EAS PVC's needs were identified above and questions related to the effectiveness of knowledge flow were raised. Hence the solution proposed for EASET is formed by a website, Forum, Blog, Wiki, Remote Monitoring and Control tool and Emplacement Web service. Below is given a detailed description about the purpose of each feature and its importance in the 4 stages of knowledge identified by Nonaka (SECI's model): socialization, externalization, combination and internalization.



Figure 20 - EASET essential features to accomplish EAS PVC needs

#### 4.3.1 Website

The creation of a website is fundamental to accomplish EASET goals. The website gives a powerful mean for EAS dissemination, since it enables any user to have immediate access to EAS concepts and achievements. This improves the user's knowledge about EAS which can lead the person to become a member of EAS community to increase his knowledge and join collaboration activities.

The website enhances the flow of knowledge mainly in two ways:

- Knowledge internalization – tacit knowledge is generated from explicit knowledge in the sense that EAS explicit knowledge is generating knowledge in the users of the website whenever they access the contents of the same.
- Knowledge externalization – explicit knowledge is generated from tacit knowledge in the sense the website makes possible to document tacit knowledge acquired by EAS through developed work along time in a format that is easily accessed by EAS community.

#### 4.3.2 Wiki

The wiki is a very important feature that complements the website because it contains definitions used in the website. EAS major definitions should be included in the wiki as well as best work practices. Wikis are very powerful in the sense they are collaborative web sites that allow user to add and edit content as well enables information sharing. In order to achieve knowledge as accurate as possible the wiki should restrict users that can edit contents than others that can only read them. The wiki should be linked with the website enabling users to most benefit from it.

The wiki enhances the flow of knowledge mainly in two ways:

- Knowledge internalization – tacit knowledge is generated from explicit knowledge in the sense that EAS explicit knowledge is generating tacit knowledge in the users of the wiki whenever they access the contents of the same.
- Knowledge externalization – explicit knowledge is generated from tacit knowledge in the sense the wiki makes possible to document tacit knowledge acquired by EAS through developed work along time in a format that is easily accessed by EAS community.

#### **4.3.3 Blog**

The aim of the blog is to endow EAS experts to stress out their opinion about certain topics of EAS or manufacturing and assembly in general. The blog is an article opinion possessing more personal opinions of EAS expert and not explicit EAS knowledge.

The blog enhances the flow of knowledge mainly in one way:

- Knowledge externalization – The blog aims to give personal opinion of EAS experts to the rest of EAS community, this way it facilitates the translation of tacit knowledge into comprehensible form that can be understood by others.

#### **4.3.4 Forum**

The forum feature complements all the features described before since it enables the discussion about contents in the website, wiki and forum. Also it enables group discussions started by EAS registered users about other topics considered important.

The forum enhances the flow of knowledge mainly in three ways:

- Knowledge socialization – Tacit knowledge generates tacit knowledge since users of the forum discuss and share knowledge enhancing the creation of tacit knowledge.
- Knowledge combination – Explicit knowledge creates more complex explicit knowledge since the forum enables users to discuss about explicit knowledge present in the wiki and website, creating more complex explicit knowledge.
- Knowledge externalization – The forum endows users to discuss and state their convictions and opinions and this way helps translating the tacit knowledge of the users into explicit knowledge.

#### 4.3.5 Emplacement Web Service

A very important feature in the current state of the EAS paradigm is the Emplacement Web Service. Today's production systems have presently continuous changes like load variations, new products, faults, change of process modules, etc. which require new methods to react to them quicker, sustainable and more automatically. In order to answer these requirements a concept called Emplacement has been developed under the EUPASS project to describe, manage and use the information of process equipment in modular and reconfigurable production systems like Evolvable Assembly Systems. EAS process oriented and modular approach demands exchangeability of modules, which is realized by a clear definition of the attributes of the modules and putting them into a classification scheme which allows the identification of compatible modules with the desired functionality. It is necessary to define and link these attributes to the module description. The Emplacement Concept proposed in the EUPASS project represents the link between all aspects. It bridges the gap between the functionality of a module and its mechanical representation as part of a running system. All aspects (from a product idea to a running production system) are covered by this concept. All these data is approved and collected by the Emplacement Web Service and all new modules have to be registered there also. More detailed information can be found in [42].

The Emplacement web service offers:

- Access to Emplacement files and their documentation
- Access to a set of Blue Print files and their documentation
- User can generate specific template out of selected Emplacement and Profile for his/her process module.
- Generate HTML documentation of Blue Print or Emplacement
- Access the associated XML Schemas
- Review the summarized content of the Emplacements and Blue Prints available in the service.

Integration of the Emplacement Web service in EASET becomes crucial to make this important tool available for the collaborative network users.

The Emplacement Web Service enhances the flow of knowledge mainly in three ways:

- Knowledge externalization – The emplacement web service endows explicit knowledge to be generated by formalizing all the information mentioned above.
- Knowledge combination – Explicit knowledge will generate more complex explicit knowledge through the use of the Emplacement Web Service, since users can access all information and combine it and develop it more.
- Knowledge internalization – EASET Users will increase their tacit knowledge by consulting the explicit knowledge and exploring functionalities available in the Emplacement Web service.



#### 4.3.6 Remote monitoring and control tool

A very useful feature that can be developed to support EAS dissemination is an online tool to enable the monitoring and control of an assembly cell remotely. It should endow parameter feedback to be accessed externally and also endow some control operations of the cell. The purpose of this feature is to enable a user to accurately track what is actually happening in the assembly cell and have a performance measurement. In a world of innovation where we have the technical tools to monitor production remotely it doesn't make sense to restrict it to the factory level, since it impossibilities rapid feedback delaying important information to reach management level of the enterprise where it can be useful for decision-making. The inclusion of this tool in EASET strengthens the link between management level and shop floor level promoting enterprise agility at both levels since it enhances quick feedback and control for management level which enables faster decision-making that is crucial on today's very competitive business environment. This tool can support EAS dissemination in the sense it enables live demonstrations of an EAS assembly cell to collaborators (or possible collaborators), showing performance measurements and fast evolution of an assembly cell to another working condition.

Adaptability/sustainability cannot become an autonomous ability overnight, and remote monitoring is a gateway to supervise the efficient adaptability of systems to small disturbances (a kind of remote human "broker"). This service can therefore be an important step forward into achieving efficient adaptability of systems by enhancing quick detection and correction of failures that could compromise the implementation of an evolvable assembly system. More, this service is developed to cover the lifecycle of an equipment/system developed and enable that managers, system designers, module suppliers, system integrators, etc. have valuable information that can be used to improve actual systems/products and/or next developments.

The Remote Monitoring and Control tool enhances the flow of knowledge mainly in three ways:

- Knowledge externalization – Tacit knowledge that was only possessed by employees at factory level can now be translated into explicit knowledge that other actors will access by enabling parameter feedback and database storage of this information.
- Knowledge internalization – The explicit knowledge generated by the process enables other actors to generate tacit knowledge by analyzing the parameter feedback and the outcome of control operations.

#### 4.3.7 Collaboration in EASET

It is important to underline how does EASET enhances collaboration and why is it a collaborative environment tool. Let's remember the definition of collaboration [38]: "a process in which entities share information, resources and responsibilities to jointly plan, implement, and evaluate a program of activities to achieve a common goal. It implies sharing risks, resources, responsibilities, and rewards, which if desired by the group can also give to an outside observer the image of a *joint* identity.

Collaboration involves mutual engagement of participants to solve a problem together, which implies mutual trust and thus takes time, effort, and dedication. The individual contributions to the value creation are much more difficult to determine here". According to <http://www.thefreedictionary.com> a tool is "Something used in the performance of an operation". Hence, a collaborative tool can be defined as work platform used by a group to collaborate with the intention of achieving a common goal. The common goal identified by EAS PVC is EAS paradigm dissemination and validation/falsification through the raise of critical mass and collaboration between entities.

EASET enhances collaboration between entities and facilitates the achievement of EAS PVC common goal by giving a common work platform that endows individual and group communication, knowledge creation, accumulation and sharing (in form of text, figures, models, pictures, audio, video, etc), use of EAS emplacement concept and monitoring and control operations of an assembly cell. Performance and value creation measuring is hard to perform, as stated before, however an analysis to essential ingredients of collaboration identified by Soliman, Braun and Simoff [48] will be provided. These ingredients don't guarantee that a group's goal will be accomplished but are indispensable for establishing collaboration at any level. The study performed identifies eight essential ingredients of collaboration:

- People – Collaboration is a people-to-people process and the differences between people play an important role in establishing the people-to-people process. Differences can be identified in perception, education, culture, family, knowledge, personality, experiences, etc. People are the fundamental element in collaboration however people alone are insufficient for its existence.
- Shared space – A Shared space provides common sensory inputs to the participants of a collaboration session and is a widely accepted necessity. Shared spaces have two components to accomplish this objective: communication environment and point of interaction. The communication environment is a tool which sets boundaries for the way people communicate. For instance a text-based chat communication environment will enable people to communicate through written words but will not allow verbal communication. The point of interaction is a more abstract view and represents the space where inward thoughts and feelings are outwardly expressed. The point of interaction is where each participant can perceive other people's thoughts and add his own. For instance when writing a paper collaboratively the document is where the authors derive their sensory experience (interaction point) and simultaneously where the objective is being out-worked. The selection of an inappropriate shared space will limit potential success of collaboration.
- Time – A group have to invest time for a collaboration result. The success of collaboration is affected by the amount of the time available versus difficulty of work to do. People are motivated by deadlines and so deadlines also influence collaboration performance: little time can cause stress and result in low results while too much time can also influence negatively the performance since there is a tendency to be less efficient. So choosing reasonable timings and deadlines is a crucial factor in collaboration. In time matters it's also important to underline that collaboration can take place synchronously or asynchronously and the selection of the most appropriate shared space that allow the selected kind of communication to occur effectively is crucial also.

- A common objective – Another fundamental ingredient for a successful collaboration is that a common objective is shared by all participants involved. Each participant can have different reasons to join collaboration activities however they must be united by a common objective.
- Focus on the objective – Participants must be focused on accomplishing their objective. Sometimes people have time and resources available to accomplish one objective but they get distracted from it. Focus on the tasks is therefore crucial in successful collaboration. Focus is not only limited to the work activities but also to coordination, planning and monitoring activities.
- Common language – User interaction is facilitated by the use of common language. This is not reduced to the spoken or written language but also includes select the same language for modelling, present results, etc. For instance includes question like should results be presented in tables or graphs? Should the models be in UML?
- Knowledge in the area of the objective – Participants need to have individual knowledge in the area of the objective. In most cases all participants will learn something new with other participants but they must have relevant knowledge about the area in the beginning of the collaboration. If learning is required due to lack of relevant knowledge by participants it may reduce collaboration effectiveness as resources are invested into learning rather accomplishing the collaboration objective.
- Interaction – Interaction describes the activity of using the other ingredients to accomplish the common objective. Ideally the interactions in a session should not be too high (each person participates few) neither too low (dynamic nature of collaboration is lost) and even more important none participant should dominate the interaction enabling true collaboration.

EASET intention is the support of EAS PVC in collaboration activities and the eight ingredients for successful collaboration identified by Soliman, Braun and Simoff were taken into account in the design process. In section 3.4.1 an analysis is given to collaboration platforms for PVC and aspects that should be considered are: Human interaction mode (conversational, transactional and collaborative interaction), collaboration tools (electronic communication, electronic conference and collaborative management tools), collaborative problem solving (planned, mediated and ad-hoc collaboration), integration and cover knowledge, business and social aspects of the PVC.

EASET allows human interaction in the following forms:

- Conversational interaction – this is facilitated by the Skype feature integrated in the website as well as the forum that allows private messaging and group discussions.
- Collaborative interaction – this can be achieved in a simple way through the use of the forum. Members can discuss projects and publish files. For that the forum just needs to be re-configured. Also the website endows file management if a new section with that purpose is created. EAS consortium didn't find the need at this point to include tools that endow project management and similar activities, keeping the level of collaboration at lower level at the beginning phase.

EASET enables the use of the following tools:

- Electronic communication tools – this is achieved using mainly the website, wiki and blog for information sharing.
- Electronic conference tools – this is achieved mainly by using Skype feature integrated in the website and the forum that allow interactive communication (private messages or group discussions).

EASET covers knowledge, business and social aspects of PVC in the following ways:

- Social & networking functionalities – members can socialize using the Forum or Skype functionalities.
- Human Competency Management and Team Building – members can discover other members through the Forum or Skype module integrated in the website.
- Governance – there's no mechanism to track individual performance of members, it's only possible to follow threaded discussions in the forum and tangible results.

EASET allow collaborative problem solving:

- Planned collaboration – It's possible to support collaboration in the forum. EASET don't implement e-contracts and project management tools to accommodate this.
- Mediated collaboration – It's possible to support mediated collaboration by the forum, acting one member as the moderator.
- Ad-hoc collaboration – For quick formation of teams to address a business opportunity or a problem that aroused EASET has the Skype (e.g. fast communication 1-1) and forum (e.g. broadcast information for a group) functionalities that enable communication between members.

EASET should have all the tools fully integrated to endow members' management and simple activity tracking (e.g. track forum participation) and also to allow the user to make a single sign in. EASET should have a central database for use of all functionalities avoiding duplication of information.

## 5 Implementation

The implementation of the problem solution is analyzed in this section. The six tools proposed in the problem solution have to be integrated in one unique collaboration platform: EASET. EASET uses a unique web server (titanic.uninova.pt) located in Portugal that is supported by Uninova research institute. Also a unique database is allocated in the same web server.

### 5.1 Website

After analyzing several possibilities it was decided to use JOOMLA software [51] to implement the website. JOOMLA possesses a vast community and therefore a good background support that can be exploited in the implementation phase and also in the future. JOOMLA possesses also several extensions developed by its community that can be used what can represent an advantage in the present and future. The domain chosen was [www.eas-env.org](http://www.eas-env.org) (EAS Environment). It was registered for a long period and associated with the server's IP.

JOOMLA software was installed on the server and the website started being built. The structure and contents of the website were carefully selected to best fit the website's purpose. At the same time in parallel a logo was developed by professional logo experts because it was agreed among the consortium that it was fundamental for identity and credibility of EASET.

The website is divided mainly in five sections:

- EAS – It includes concepts of EAS, conferences, publications and courses about EAS, manufacturing roadmaps and related projects to EAS.
- Commercial achievements – It includes pictures and videos to endow the user to see some demonstrations of achievements. It also includes a list of the partners (and respective link to the information about them) and also the commercial modules available. This can be very useful so interested parties realize what modules are available already and which partners have developed them, what can lead to the intention of forming collaboration partnerships.
- Theoretical framework – In this section a more strong background is given on EAS theoretical framework. It encompasses EAS reference architecture, ontology and emplacements and blueprints.
- Resources – It includes EAS standards, control and tools that can be used. It also includes pre-formed lectures that EASET collaborators can use.
- Work in progress – It encompasses EAS work in progress such as standards, reference architecture, processes and skills and new modules.

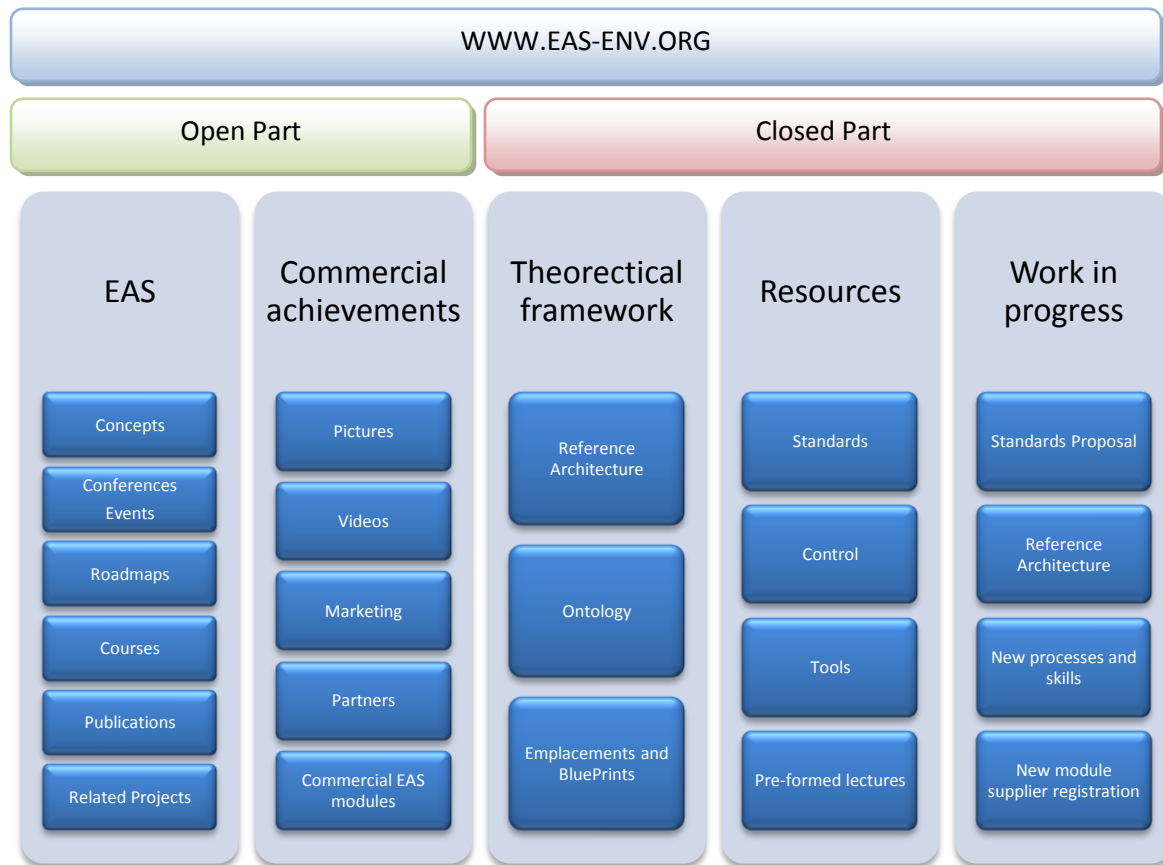


Figure 21 – EASET Website structure

In EASET's website was included a news feed section that provides latest news provided by European commission. There are also links to the forum, wiki, blog and emplacement web service.

JOOMLA extensions implemented in the website were:

- Skype manager – This module provides an interaction of users by voice or chat. This module endows a user of EASET that is connected to Skype to be shown available to other users that have Skype. For instance, if a user knows that the user X is specialist in a topic and he realize he can be reached by call then a quick collaboration is provided.
- File manager – A file manager extension was installed to provide attachments (e.g. roadmaps. Pre-formed lectures, etc) in the website. The attachments are only available to EASET collaborators i.e. that can access the closed part of the website because they have been through a registration process.
- IP ban – This extension has the objective of block Asian IP's because it was considered important by EASE consortium.
- Backup manager – This extension enables backups of the website so it's possible to recover from errors.

- Pictures manager – This extension provides an easy way to organize pictures in galleries.
- Integration tool for forum – This extension provides an easy integration of the website with the forum.
- RSS feed – This extension enables the use of RSS feeds.

The final result of the implementation of the website is presented on the next figures.

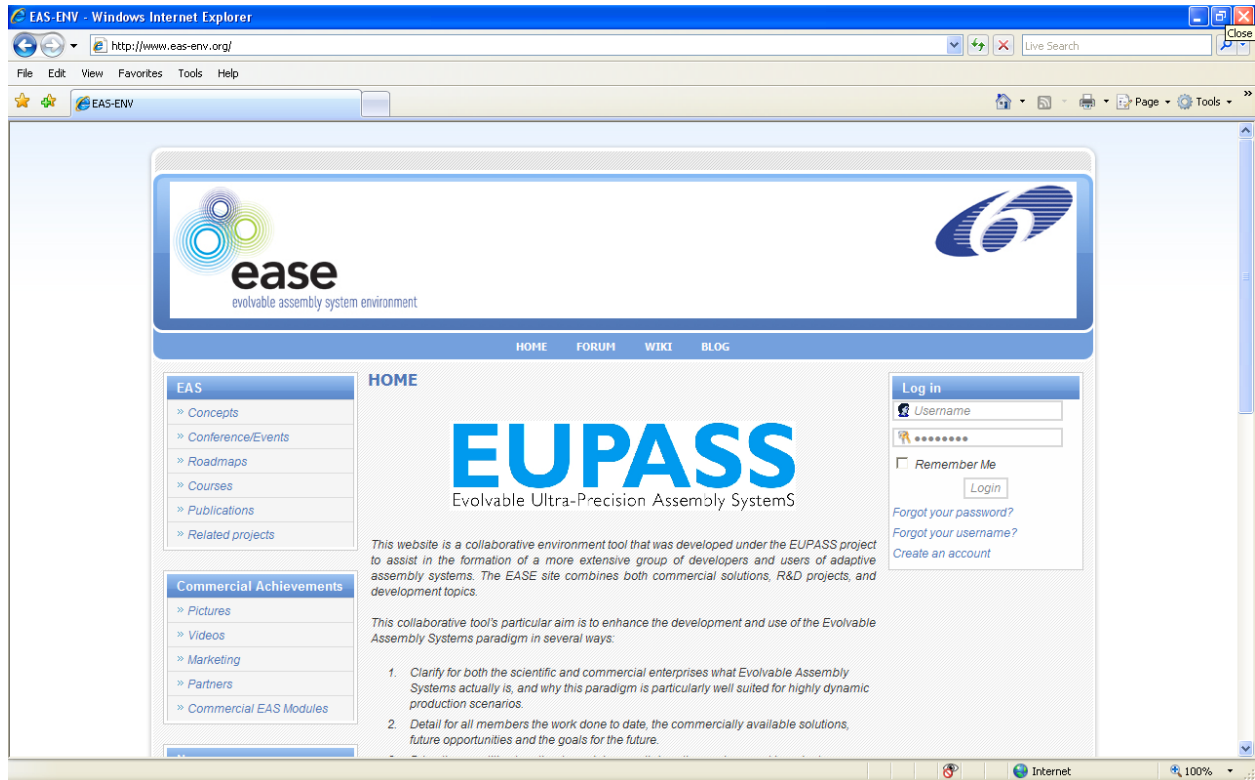


Figure 22 - EASET website homepage

It's possible to see EASET logo and the open part of the website composed by EAS, Commercial achievements and RSS feed sections. It can be noticed the links to the forum, wiki and blog, remaining the website as the only mechanism used to register new users in EASET.

The partners of EASE are identified and there is a link for all as presented on figure 23. An user can therefore identify active collaboration entities of EASE.

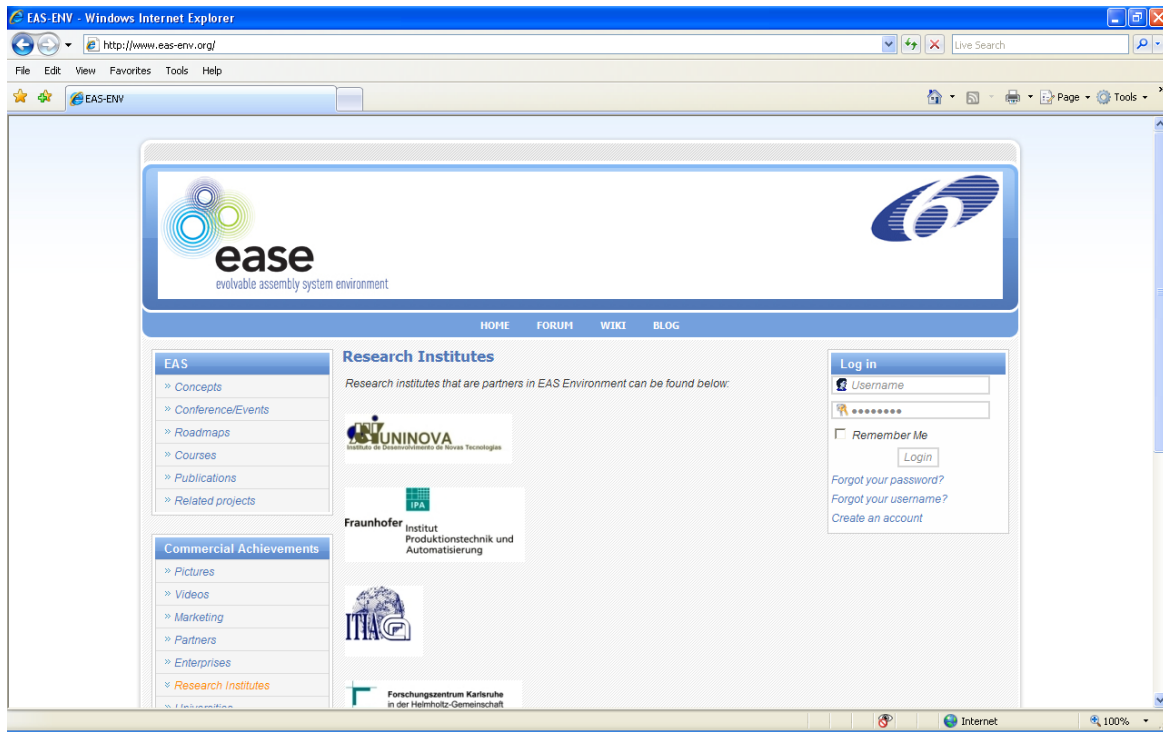


Figure 23 - EASET website EAS partners

The website widespread the commercial modules developed according to EAS paradigm as visible on figure 24. This is very important at dissemination level endow external entities to realize the progresses of EAS and the developments made to date.

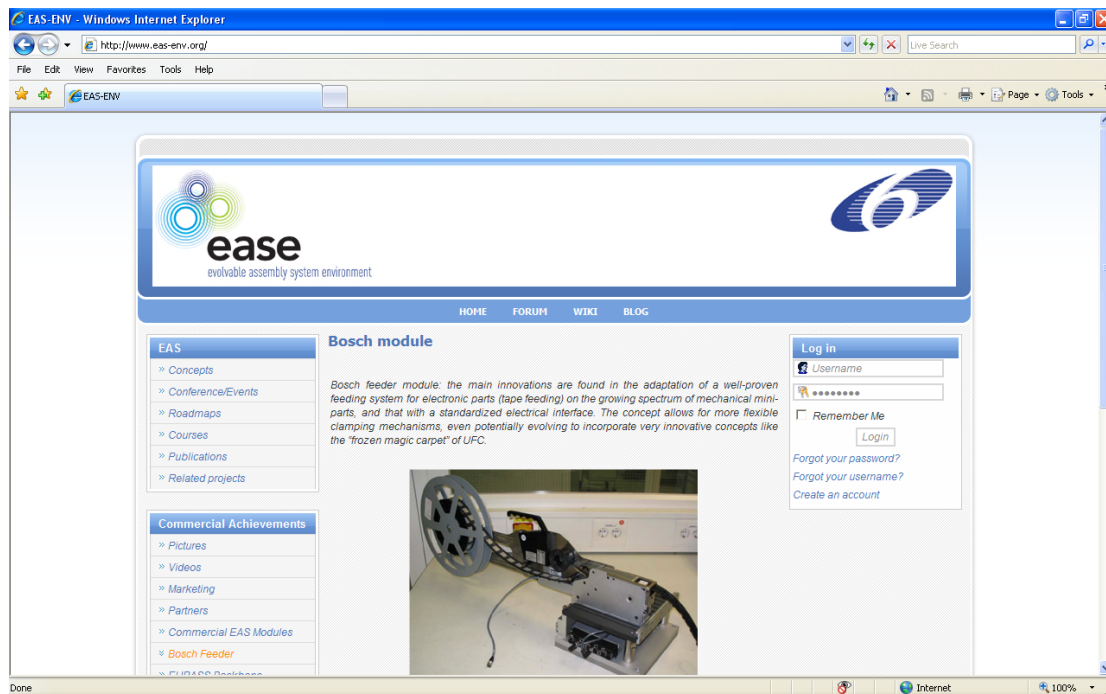


Figure 24 - EASET website commercial modules



To access the closed part of the website the user has to go through a registration process as presented on figure 25.

The screenshot shows the EASE website's registration page. The browser window is titled "EAS-ENV - Windows Internet Explorer" and the address bar shows "http://www.eas-env.org/". The website header includes the EASE logo and the tagline "evolvable assembly system environment". A navigation bar contains links for HOME, FORUM, WIKI, and BLOG. On the left, there is a sidebar with categories: EAS (Concepts, Conference/Events, Roadmaps, Courses, Publications, Related projects), Commercial Achievements (Pictures, Videos, Marketing, Partners, Commercial EAS Modules), and News (a snippet about Delcam's CAD/CAM software). The main content area is titled "Registration" and contains a form with the following fields: Name (required), Type of institution (dropdown menu with "University" selected), Name of institution (required), Role (dropdown menu with "CEO" selected), Field (dropdown menu with "Assembly Systems" selected), Contact (text field), Username (required), E-mail (required), Password (required), and Verify Password (required). A note states "Fields marked with an asterisk (\*) are required." and a "Register" button is at the bottom of the form.

Figure 25 - EASET website registration process

The user is logged in and the closed contents, as well as the Skype module are now available as presented on figure 26.

The screenshot shows the EASE website's home page after a user is logged in. The browser window is titled "EAS-ENV - Windows Internet Explorer" and the address bar shows "http://www.eas-env.org/". The website header includes the EASE logo and the tagline "evolvable assembly system environment". A navigation bar contains links for HOME, FORUM, WIKI, and BLOG. The main content area is titled "HOME" and features a large "EUPASS" logo with the tagline "Evolvable Ultra-Precision Assembly Systems". Below the logo, there is a paragraph of text: "This website is a collaborative environment tool that was developed under the EUPASS project to assist in the formation of a more extensive group of developers and users of adaptive assembly systems. The EASE site combines both commercial solutions, R&D projects, and development topics." and another paragraph: "This collaborative tool's particular aim is to enhance the development and use of the Evolvable Assembly Systems paradigm in several ways:". Below this, there is a list of two points: "1. Clarify for both the scientific and commercial enterprises what Evolvable Assembly Systems actually is, and why this paradigm is particularly well suited for highly dynamic production scenarios." and "2. Detail for all members the work done to date, the commercially available solutions, future opportunities and the goals for the future." On the right side, there is a "Log in" button, a "Logout" button, and a "Skype Live Users Module" section showing the names "Pedro Neves" and "Andreas Hoffmann". Below this, there is a "Work in Progress" section with links to "Standards Proposal", "Reference Architecture", "New Processes and Skills", and "New module supplier registration".

Figure 26 - EASET website closed contents visible

On figure 27 is presented the EUPASS control available on the closed part of the website (just available to registered users).

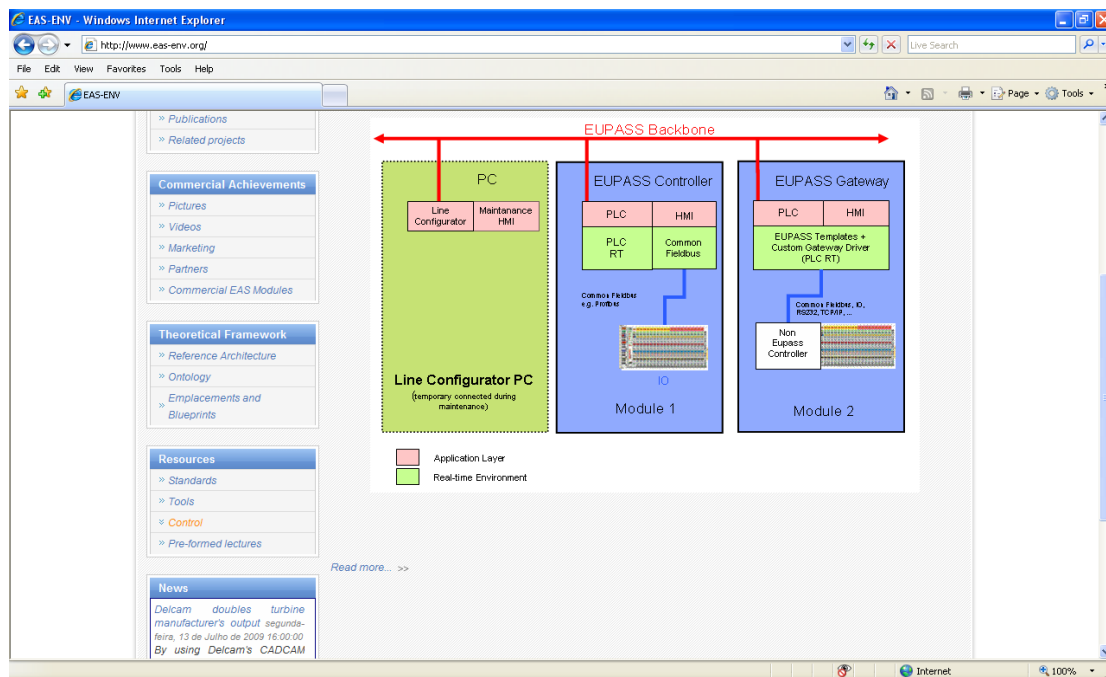


Figure 27 - EASET website control resources

There are some pre-formed lectures about EAS paradigm that can be downloaded as visible on figure 28.

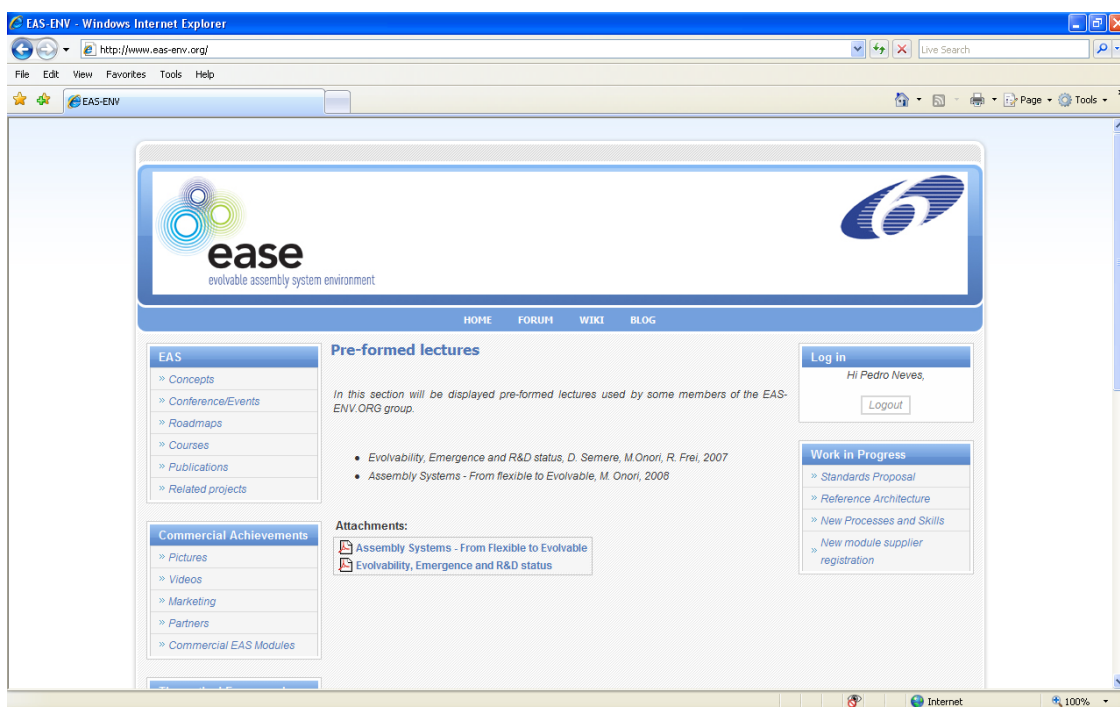


Figure 28 - EASET website pre-formed lectures

## 5.2 Wiki

Choosing among several possibilities for wikis was carefully analysed. For this purpose was used the following source <http://www.wikimatrix.org> . This provides a comparison between several wikis and facilitates the choice of the most adequate. After a comparison of several wikis it was decided to use TikiWiki because of convenient features such as the programming language, data storage, license fee, system requirements, etc. Another feature that was considered positive was the fact it could include also blog, forum, etc. However the forum would be discarded and decided to use PHPBB since it was more familiar and of easiest implementation and integration.

TikiWiki software was downloaded and copied to the host (titanic.uninova.pt). After it was installed and properly configured. The Wiki homepage is presented on figure 29.

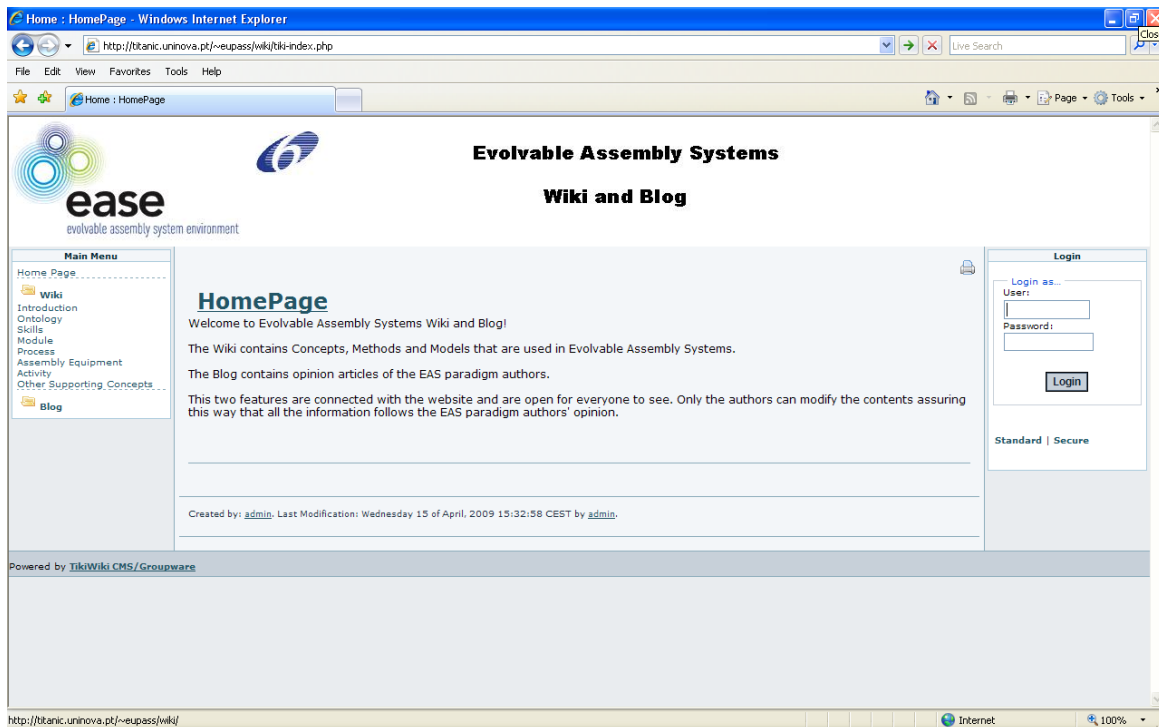


Figure 29 - EASET Wiki homepage

It was decided in consortium that the wiki could be visited by any user but only altered by specific credited users to avoid that the information accuracy was compromised. An example of the contents is presented in figure 30.

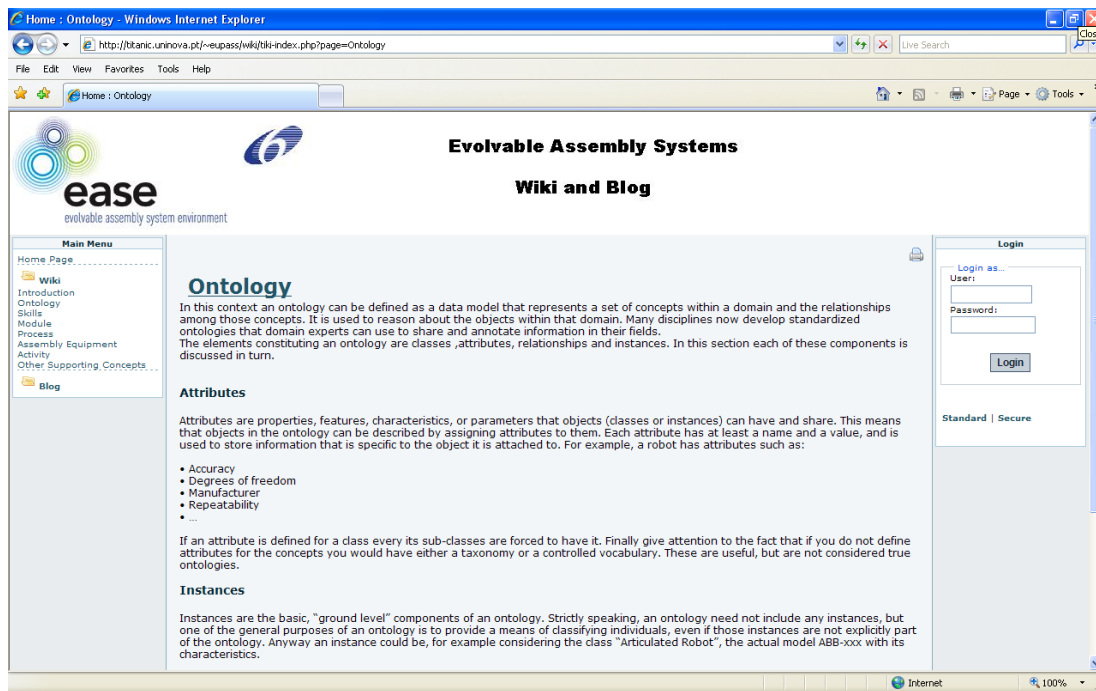


Figure 30 - EASE Wiki 2

## 5.3 Forum

It was used PHPBB software to implement the forum. The files were downloaded from the website and copied to the server (titanic.uninova.pt). After the installation, the forum was integrated with the website. This task was eased with the help of JOOMLA extension Jfusion. A new member of EASET can only register through the website what guarantees no duplication of users and enables an easy identification and tracking of users. If a user is already logged on the website then when he clicks the link to the forum the authentication is immediately done, otherwise the user can use his website's user and password to log in the forum. After this integration, the structure (e.g. sections, logo, etc) of the forum was defined as well as users' permissions and roles. The forum gives an important mechanism for collaboration through group discussion and also private messaging. It's possible to discuss important matters related to EAS and also to propose new standards, changes to the reference architecture, etc.

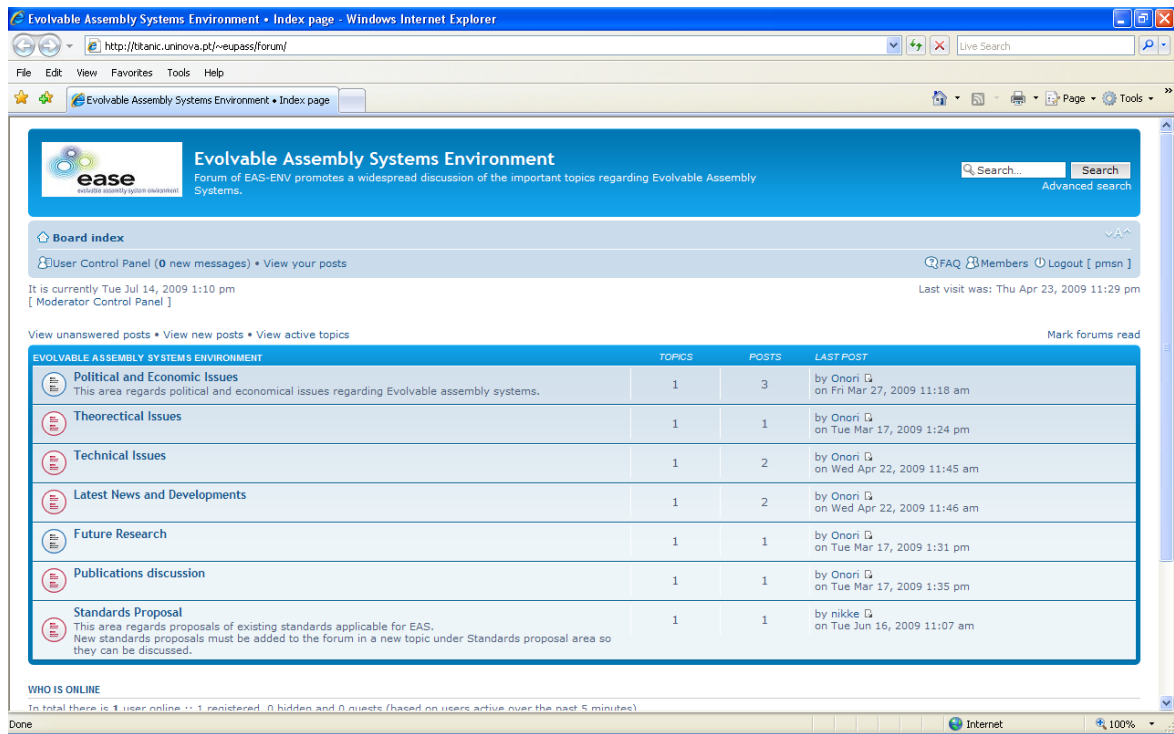


Figure 31 - EASET Forum homepage

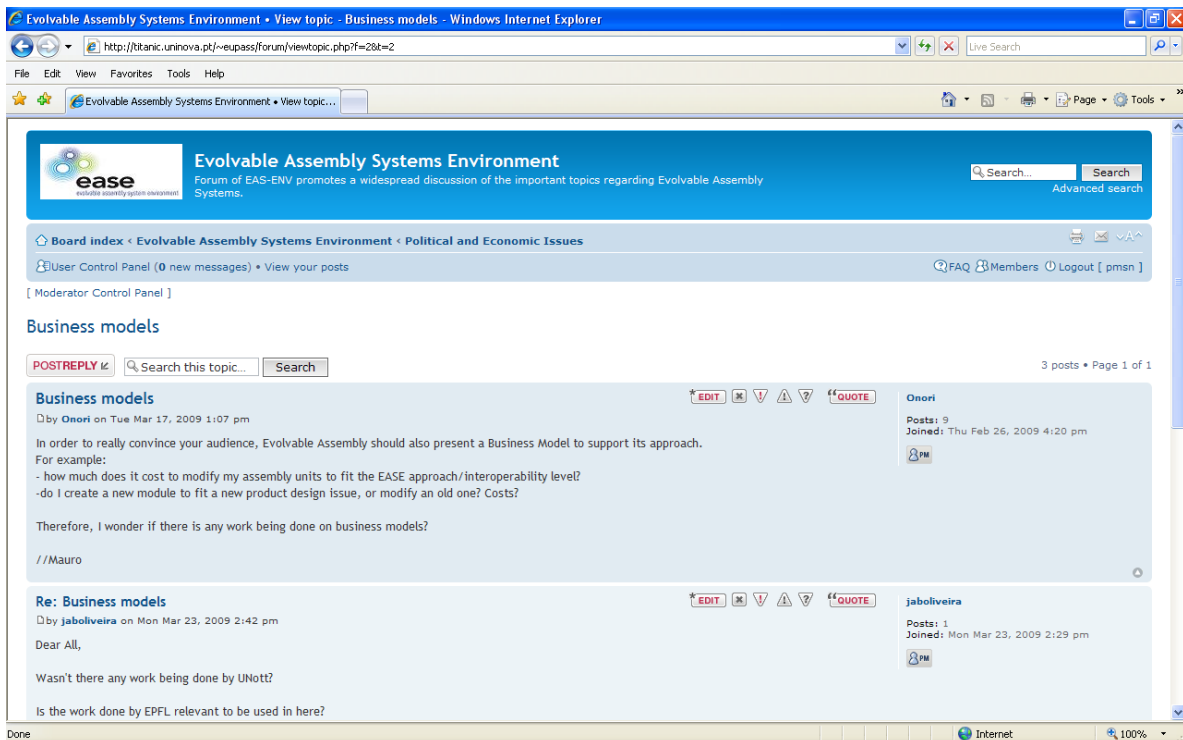


Figure 32 - EASET Forum example of collaboration through group discussion

## 5.4 Blog

For the blog implementation was decided to use TikiWiki software. The fact that the blog could be linked with the wiki contributed to this decision since it facilitates integration between services provided to the user. The installation was done with the Wiki (detailed in section 5.2) so the blog only had to be configured and was ready to use. Figure 33 shows the final aspect of the blog.



Figure 33 - EAS blog

## 5.5 Emplacement Web service

Like referred before the Emplacement Web service was developed during the EUPASS project so the integration of this powerful tool in EASET became vital for EAS community. The website has a link for the Emplacement WS and it was decided to ask the user for re-login again for security reasons.

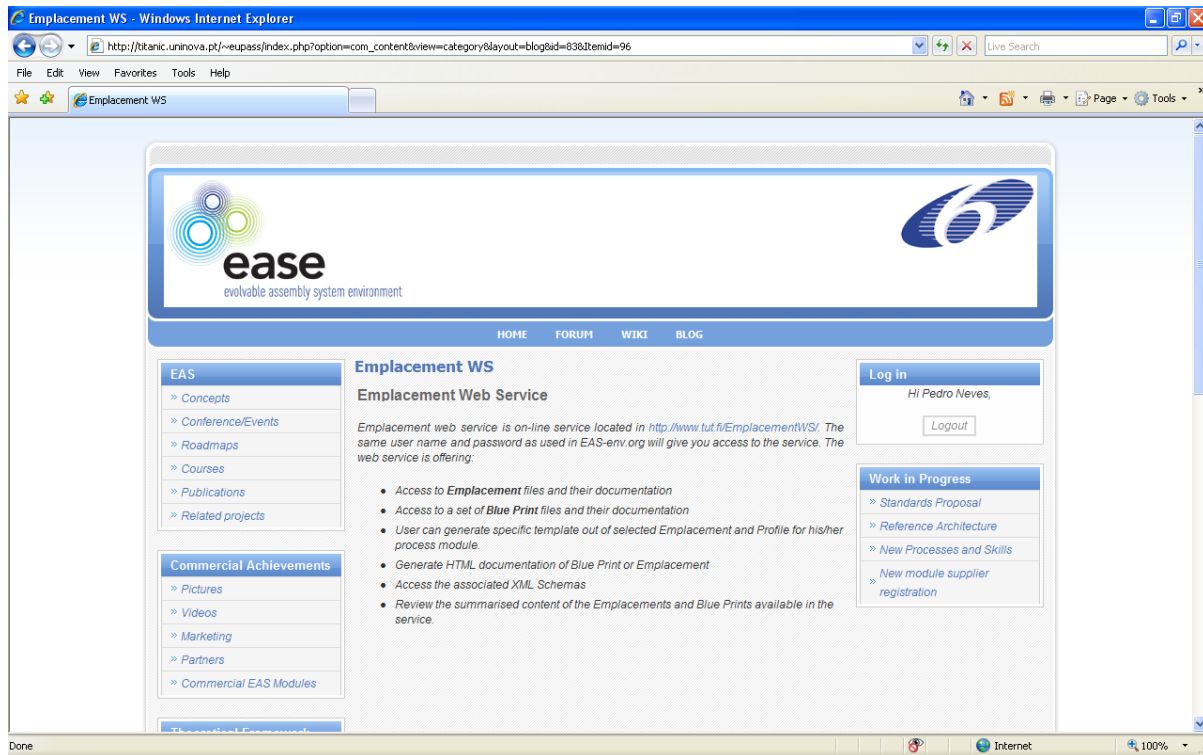


Figure 34 - Emplacement WS link in the website

The user uses the same user and password of the website (once again it's possible to verify EASET integration of all tools at user level). Integration between the website and the Emplacement web service was developed to assure this purpose.

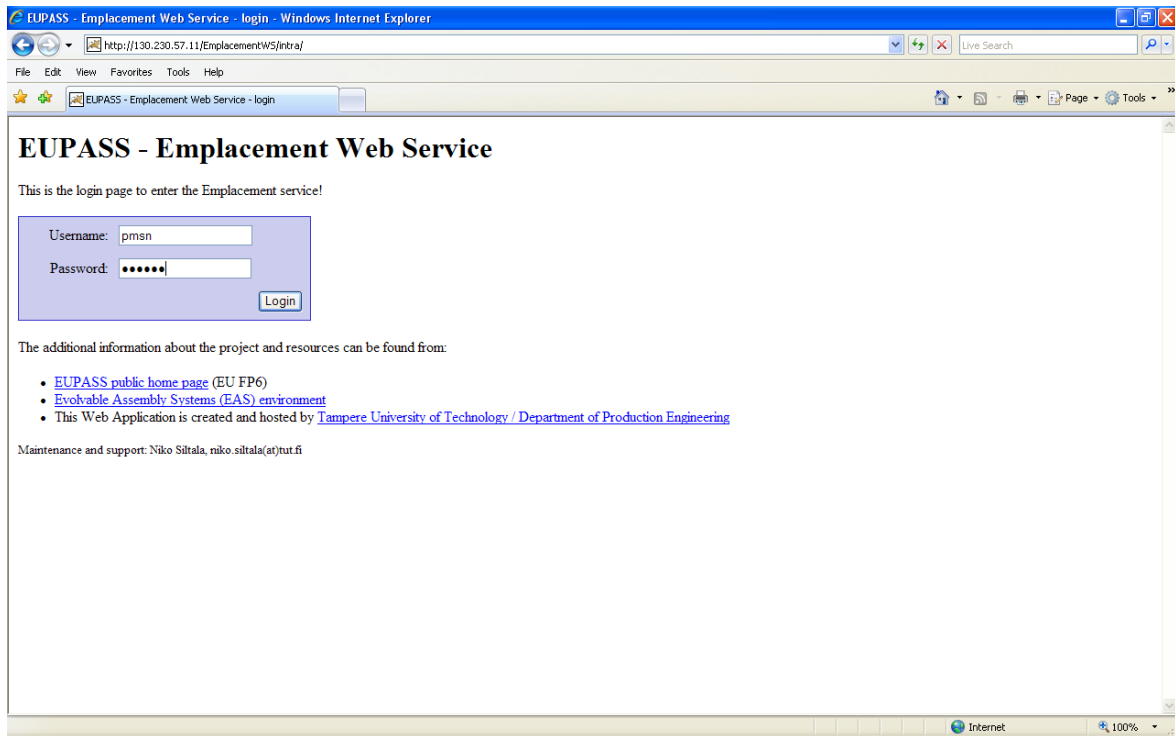


Figure 35 - Emplacement WS authentication page

The solution implemented is illustrated through a sequence diagram shown in figure 36 and consisted in user of EASET access the emplacement web service through a link in the website. The user gets redirected to the emplacement WS and has to re-authenticate for security reasons. After the log in submission the database is checked on the Emplacement web service side (1) and in case of success the emplacement web service is open and the user can use it. In case of user not found in the emplacement web service side then a request for log in is ran on the website side (2). If the user is found in the website database then the Emplacement web service is open otherwise the access is denied.

In the authentication process it's used http connection through Get statement to establish the communication between the website and the emplacement web service. The databases in the website and emplacement web service differ in the encryption of data. The website uses md5+salt and the emplacement web service uses md5. For this reason it was decided to transfer the user and password information in plain format and each side would proceed to its own encryption of data when checking its own database.



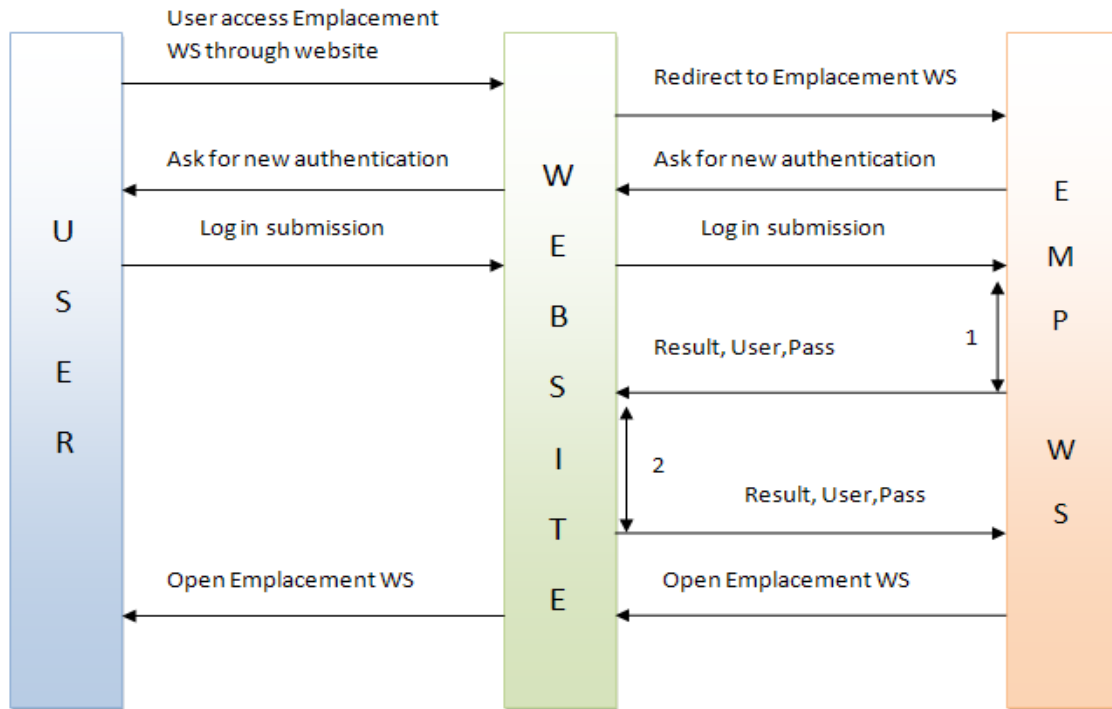


Figure 36 - Sequence diagram of Emplacement web service integration with the website

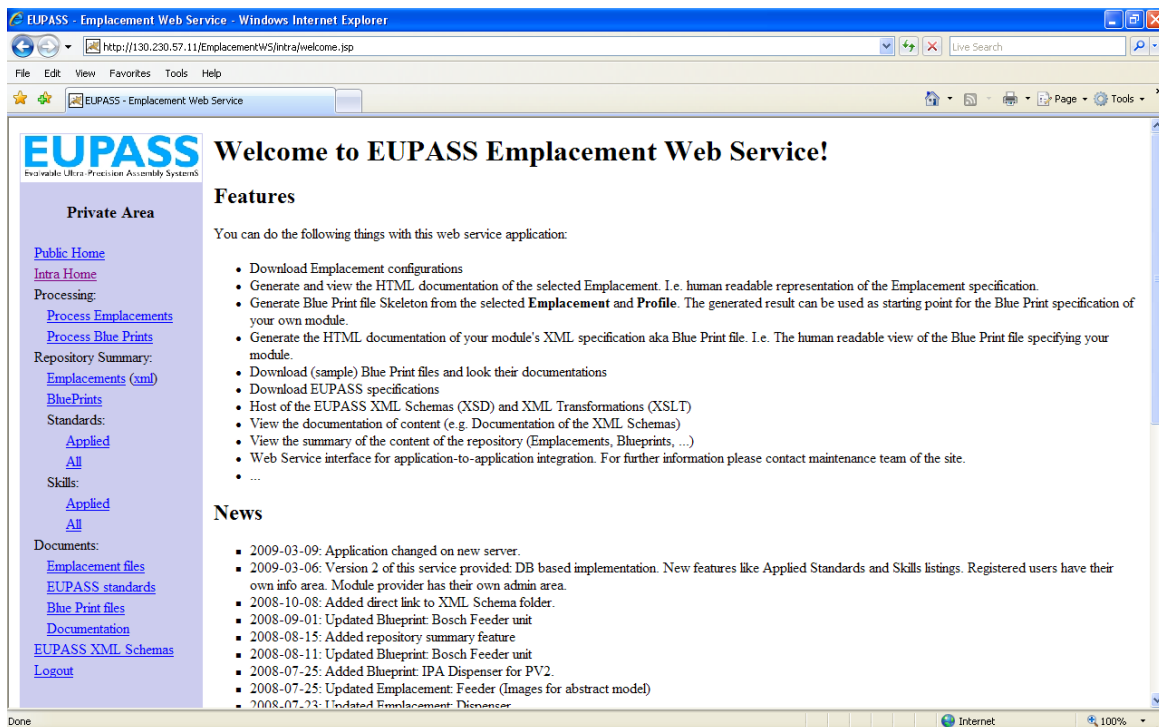


Figure 37 - Emplacement WS homepage

The emplacement processor enables the user to select an emplacement and generate emplacement documentation and blue prints. The emplacement WS was developed under the EUPASS project and was improved under the EUPASS Extension project. The EASE consortium decided to maintain the Emplacement web service hosted and managed by Tampere University.



Figure 38 - Emplacement WS emplacement usage

## 5.6 Remote monitoring and control tool

The architecture of EASET remote monitoring and control tool is presented on figure 39. R1, F1, R2, and G1 represent examples of individual entities (robots, feeders, grippers, etc) that are agentified and work autonomously according to EAS architecture. These autonomous agents possess all EAS characteristics including self-monitoring and self-diagnosis property. The goal of this tool is to send agents' monitoring information to a central agent responsible for overall monitoring of the system performance and gathering individual monitoring information from the individual entities that form the system. Web-services technologies are used for publishing information and make it accessible through the website of EASET. The collected information will be stored on a database on EASET side. The manufacturing responsible or a manager of the company can now easily monitor the system performance and decide accordingly if new instructions should reach the shop floor level. EASET is then responsible for enhancing all manufacturing process by enabling real time parameter feedback and control instructions that will best suite current business demands.

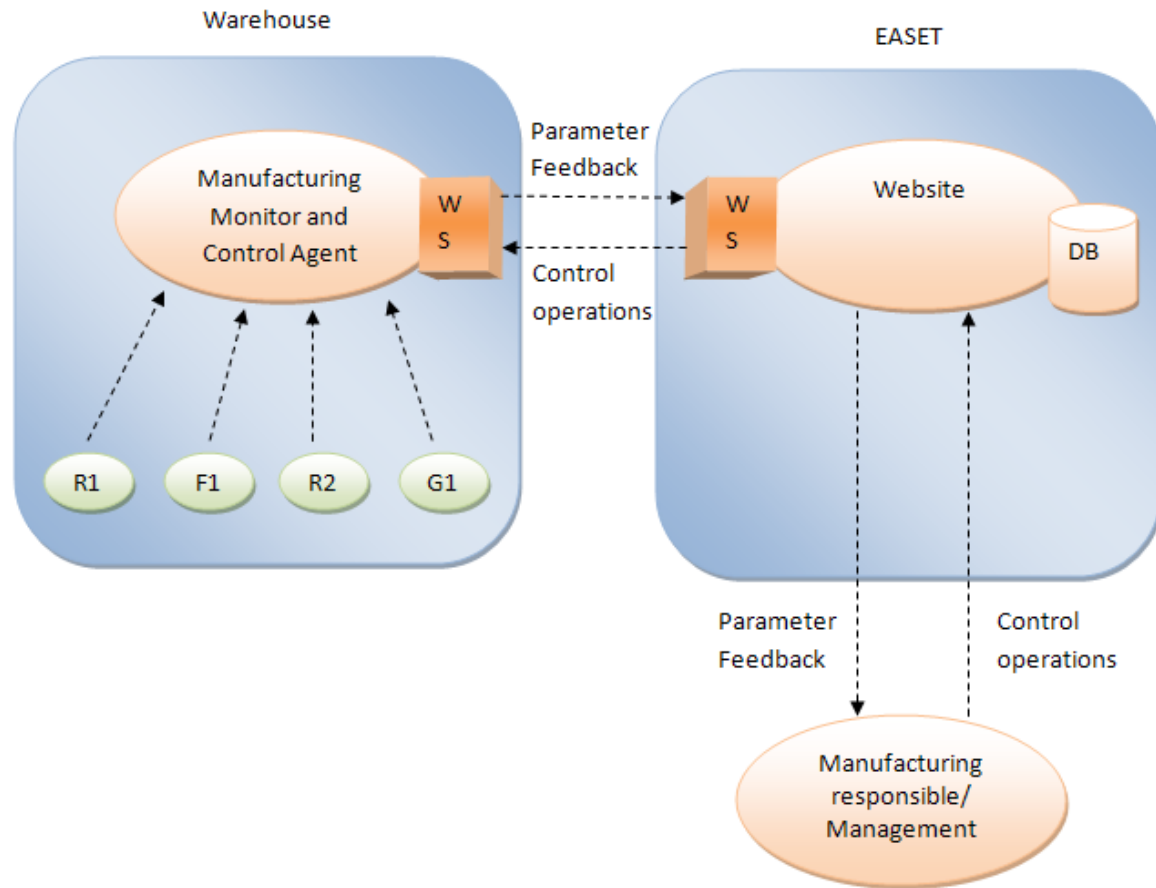


Figure 39 - Flow of information in remote monitoring and control tool of EASET

The implementation of this thesis' remote monitoring and control tool was done using several agents running on a computer interacting and publishing information resultant from interaction in a database. After a web service was created to endow clients to access the database in remote locations. For this thesis' purpose the important issue is showing that monitor parameters from agentified components present in shop floor can be exported and used remotely through the use of web service technology. For proving the concept it was created a multiagent environment using JADE (Java Agent Development framework) and JAVA to simulate the behaviour of an evolvable assembly cell. Information gathered from monitoring is stored in a database (implemented in Mysql) that is afterwards accessed by an external user (implemented using C# and ASP). This intends to simulate the use of shop floor information at management level.

The database created using Mysql has the following DER:

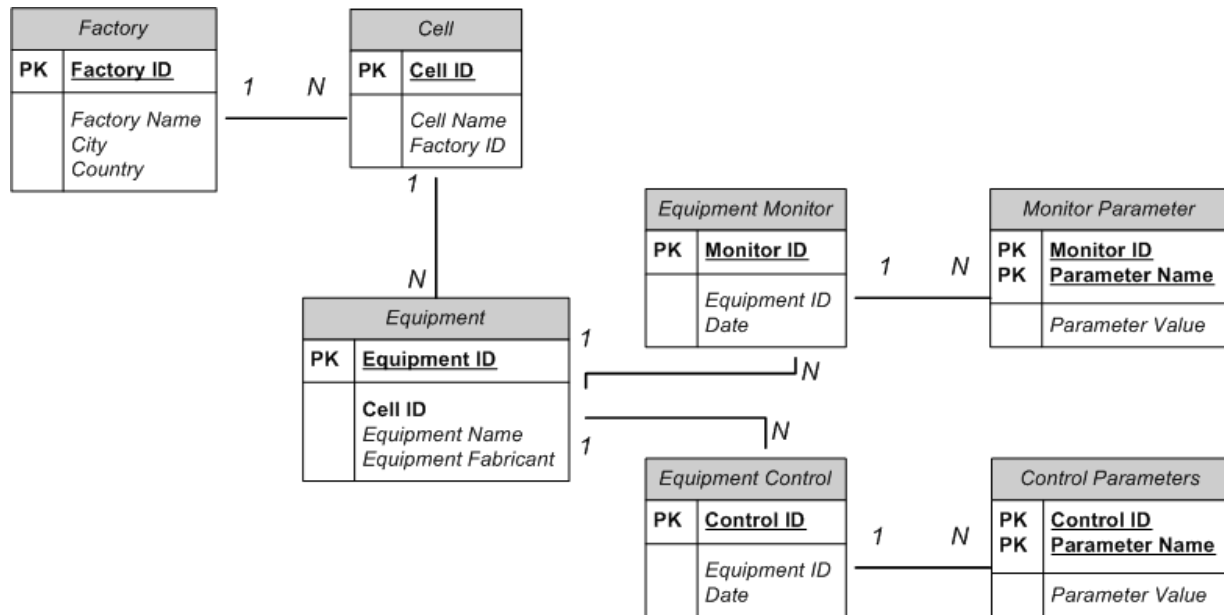


Figure 40 - RMCT database DER

This intends to simulate an industrial case where an enterprise can have several factories and each factory can have different cells operating inside. Each cell has diverse equipments that have different monitoring parameters.

Two kinds of agents were created and used in the multiagent environment: equipment agent (agents representing robots, conveyors, grippers, etc.) and main agent (agent responsible for orchestrating the equipment agents). The equipment agents exchange information with the main agent through FIPA Request Protocol [10] shown on figure 41.

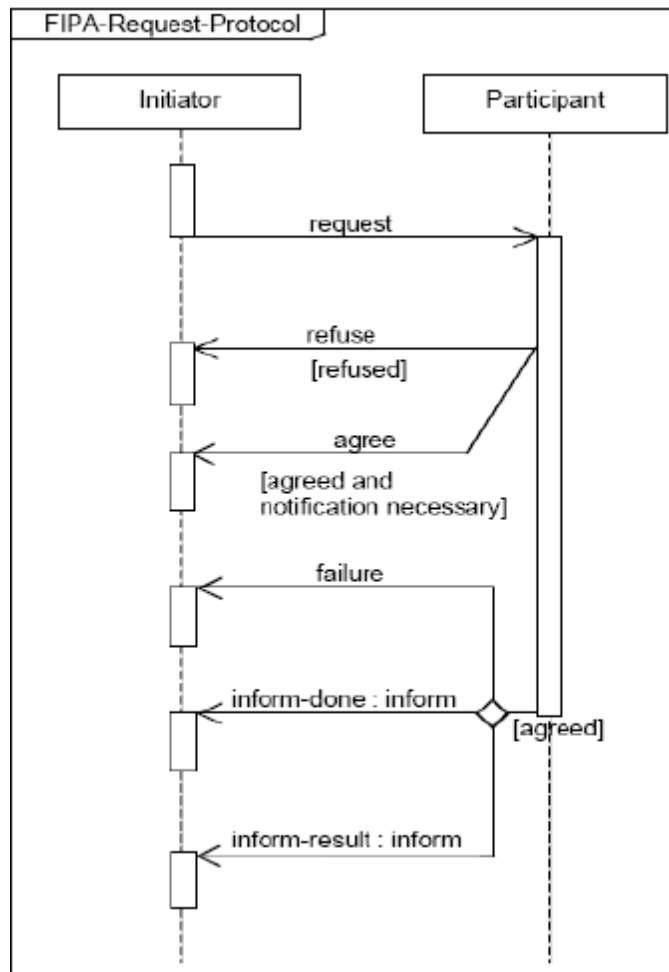


Figure 41 - FIPA Request Protocol

A graphical user interface was developed in Java for both equipment agent and main agent. The main agent shows the requests that it has received from the equipment agents under its orchestration. In figure 42 is presented an example where equipment agent feeder1 and robot1 sent monitor parameters (with the use of their GUI) to the main agent through the FIPA request protocol. After receiving a message from an agent under its orchestration the main agent will access the database to store the parameters resultant from the equipment self-monitoring action.

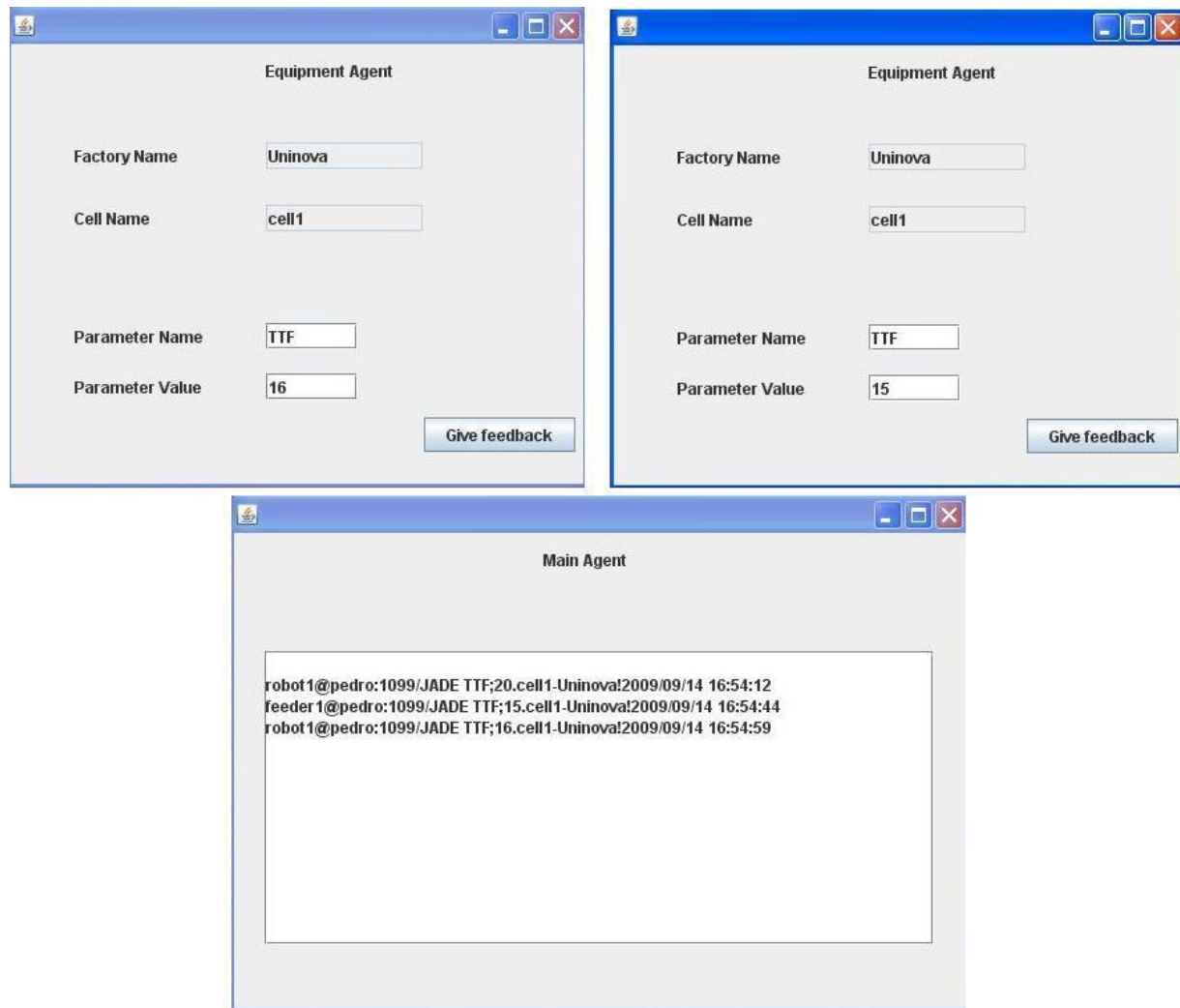


Figure 42 – Example of use of GUI of equipment and main agents

After the implementation and test of the simulation of shop floor's flow of parameters to a database a web-service was created to endow clients to access the database in remote locations. This implementation was done using C# and ASP.

Five functions were created in the server side:

```

[WebMethod]
public string HelloWorld() ...

//functions that allows login for a user
[WebMethod]
public bool Login(string username, string pass) ...

//function that gets all the factories registered in the database
[WebMethod]
public string getfactories(string username, string pass) ...

//function that gets cells from a given factory in a specific city
[WebMethod]
public string getcells(string username, string pass, string factory, string city) ...

//function that gets parameters from a given equipment
[WebMethod]
public string getparameters(string username, string pass, string eqID) ...

```

The functions were tested and published online as demonstrated in figure 43:

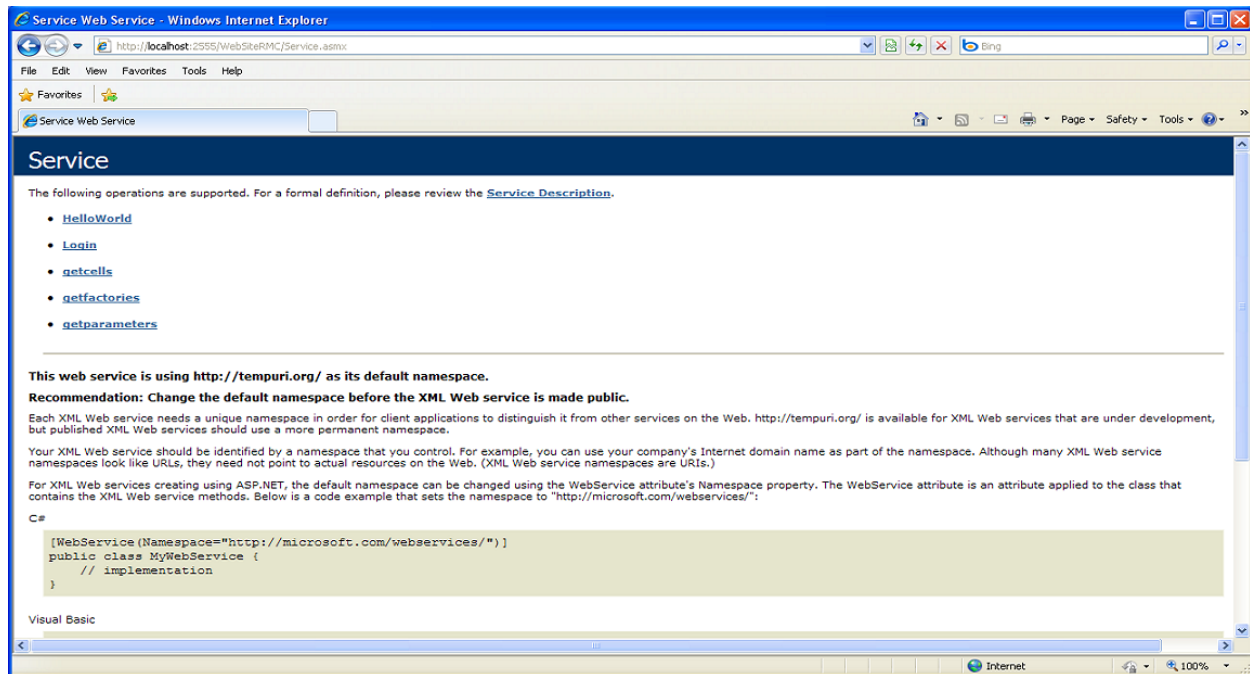


Figure 43 - RMCT Service published online

After this step an ASP client was created to access the service. As shown in figure 44, after the log in the user inserts the equipment ID and click get parameters to receive the monitoring parameters of the given equipment.

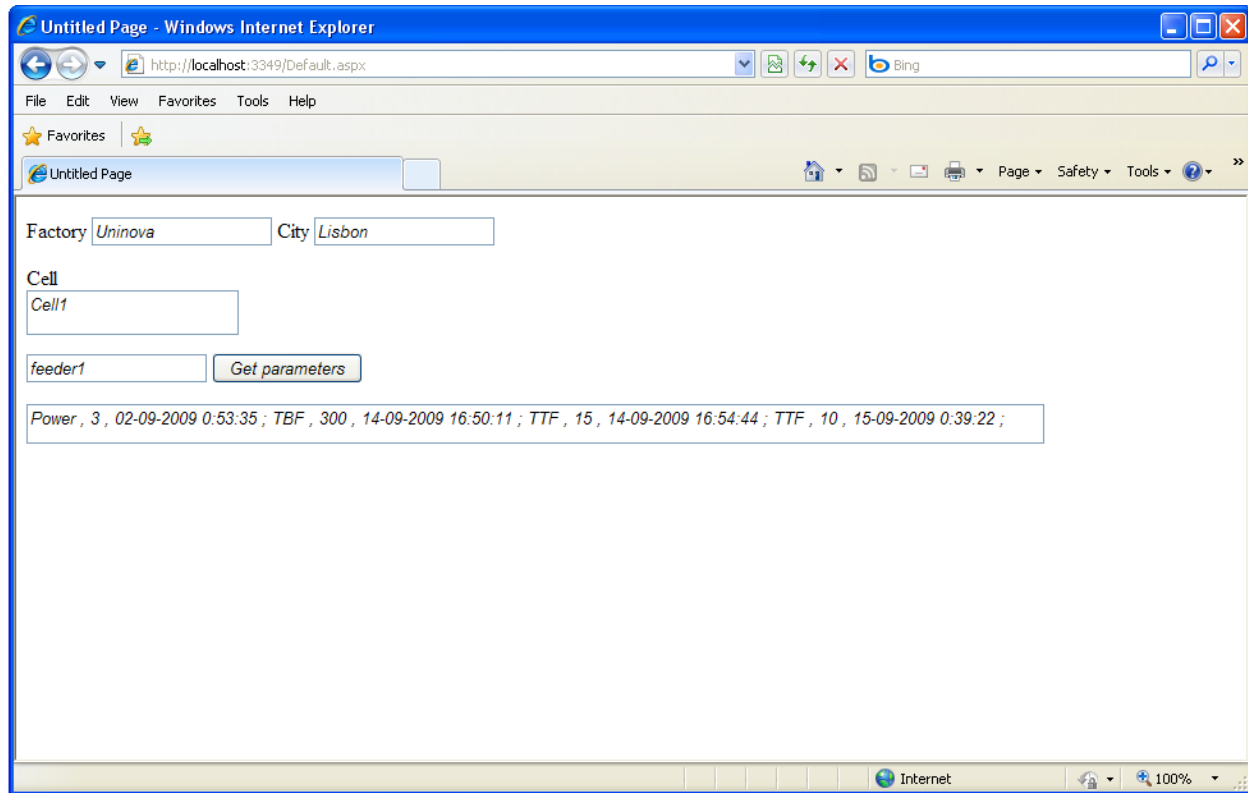


Figure 44 - ASP client to access the RMCT database remotely

It is hereby demonstrated that monitoring parameters from the shop floor with agentified environment can be accessed remotely. This will enable information to flow from shop floor to management level for improving decision making and enhance agility at shop floor, supply chain and enterprise level.



## 6 Solution Validation

Value created by each member in collaborative networks is not easy to identify and therefore performance and value creation measuring are hard to realize. Hence the solution validation present in this thesis will be limited by these factors.

EASET should be able to support the EAS PVC in knowledge management, dissemination activities and collaboration actions to target validation/falsification of the EAS paradigm through a more established scientific research. As detailed in section 4.3, EASET should compile the best techniques and technologies for an effective knowledge creation, accumulation, sharing, utilization and internalization. Questions were formulated, in the same section, which will now be answered by members of the Evolvable Assembly Systems Professional Virtual Community. This will endow arguing about the utility of the work developed on this thesis for EAS paradigm evolution, collaboration and dissemination purpose. Hence, this thesis' validation method will be the analysis of answers from EAS PVC members of the following questionnaire:

### **Knowledge creation**

- Does the tool help finding information? Is it user-friendly?
- Are the contents understandable?

### **Knowledge Accumulation**

- Does the tool have a database to store information? Is the database of enough quality?
- Does the tool help to document daily activities or information?

### **Knowledge Sharing**

- Does the tool endow people involved to communicate?
- Does the tool helps knowing what work is being developed by other people?
- Does the tool help trace who works on similar tasks to help forming virtual teams?

### **Knowledge utilization**

- Does the tool have techniques for information search?
- Does the tool help avoiding noise in the information?

### **Knowledge Internalization**

- Does the tool help to learn how to perform tasks or best practices?
  - Does the tool help improving member's abilities and capacities?
  - Does the tool transmit the organizational philosophy, standards and "client profiles"?
- 
- Did the collaborative environment contributed in your work as EAS PVC member?

The EAS PVC members that collaborated in this survey were Tiziano Maraldo (Electrolux, Italy), Niko Siltala (Tampere University of Technology, Finland), Antonio Maffei (Royal Institute of Technology, Sweden), Marcus Bjelkemyr (Royal Institute of Technology, Sweden) and Pedro Ferreira (University of Nottingham, UK).

The survey's results are presented below as well as an interpretation of the same.

## Knowledge creation

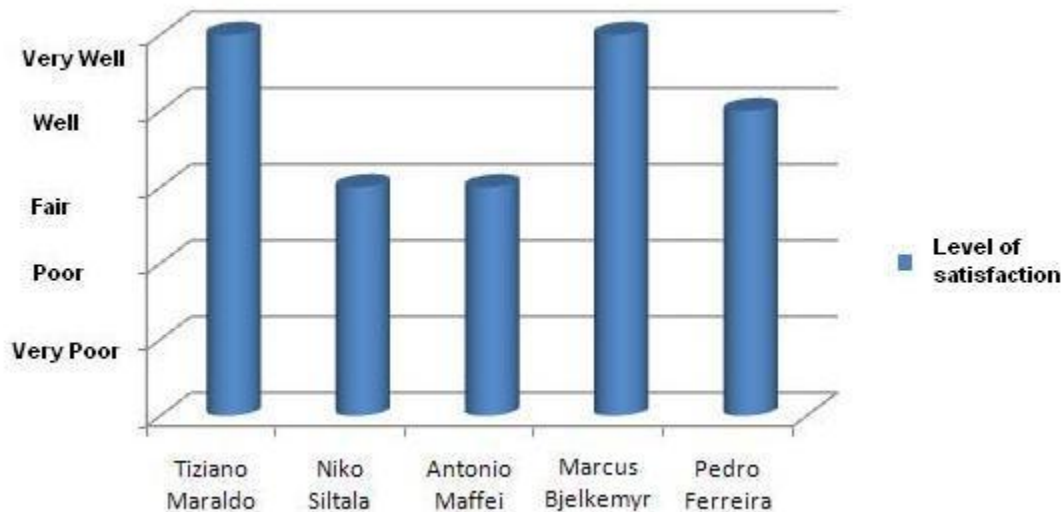


Figure 45 - EASET survey: How well does the web-based tool help you access/finding knowledge? Is it user-friendly?

In general EAS PVC members find that the EASET is user friendly and enables them to find knowledge easily. The negative issue pointed by a member was the not optimal server performance that derives in slow response sometimes.

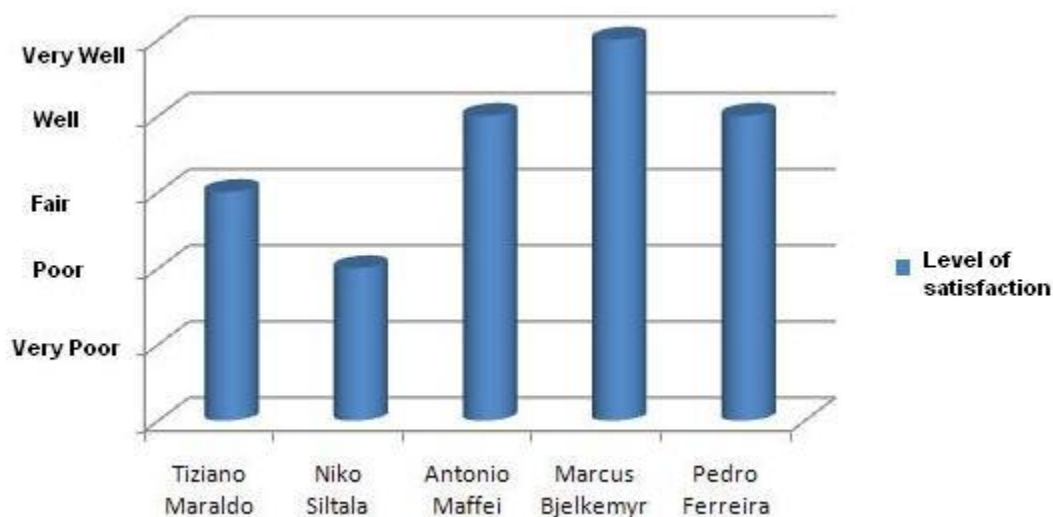


Figure 46 - EASET survey: Are the contents understandable?

In general there is a good level of satisfaction with understandability of contents however there was a small complaint from some members regarding illogical structure of JOOMLA.

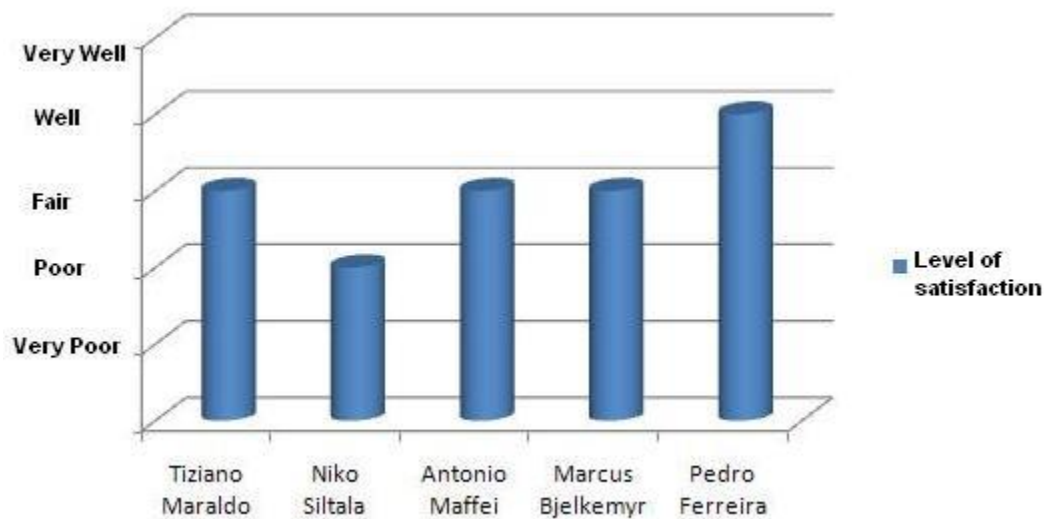


Figure 47 - EASET survey: Are you able to upload your organisation's work/information easily and efficiently?

In this question there was a lower level of general satisfaction, being pointed out that small adjustments should be made in the website menus to facilitate information upload.

## Knowledge Accumulation

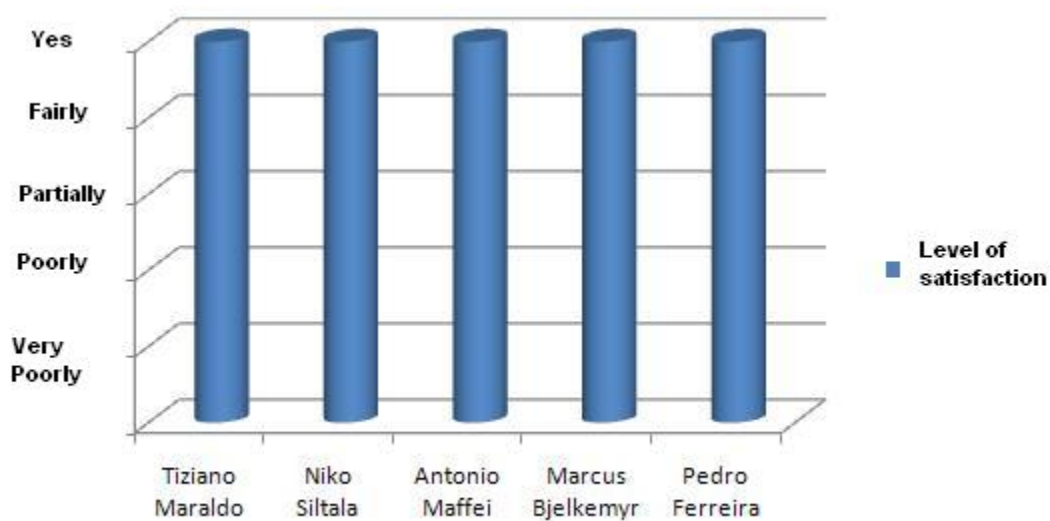


Figure 48 - EASET survey: Does the tool have an adequate database to store information? Is the database of enough quality?

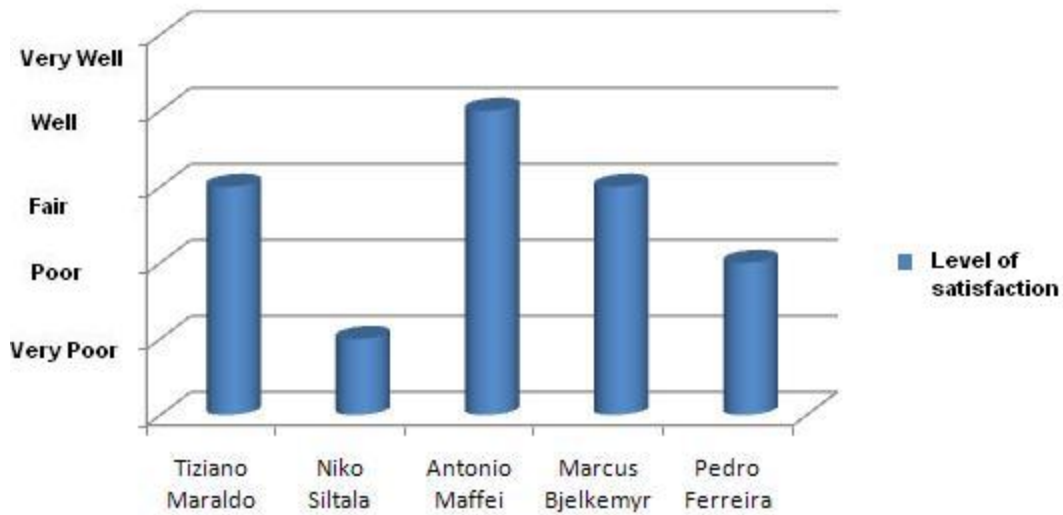


Figure 49 - EASET survey: Does the tool help to document daily activities or information?

General opinion about this subject was that the forum can be used to document daily activities when required. Was also underlined by the members that this feature is not considered essential, being the main focus sharing relevant acquired knowledge and not the documentation of daily activities.

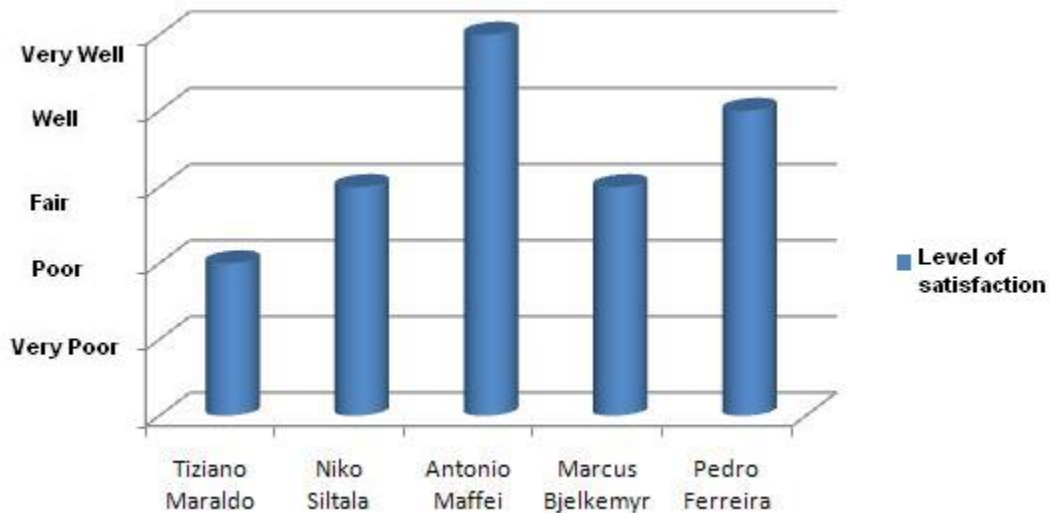


Figure 50 - EASET survey: Is one able to trace back information in terms of development steps?

Members are generally satisfied by the available mechanisms for tracing back information in terms of development steps. Members that are not completely satisfied with the available mechanisms also underline that they consider this issue very important for them.

## Knowledge Sharing

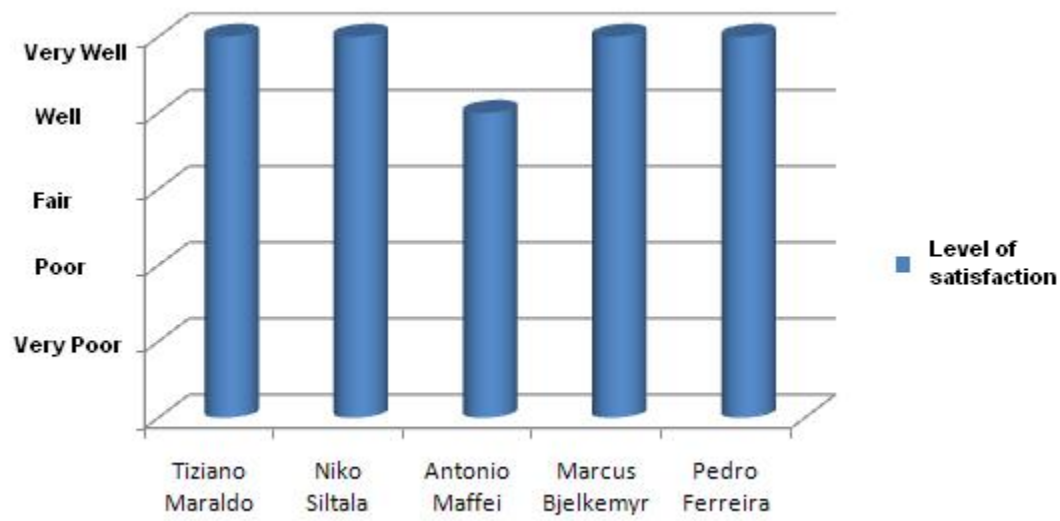


Figure 51 - EASET survey: Does the tool endow people involved to communicate?

EAS PVC members are very satisfied with the available mechanisms to communicate, underlining that there is no need for improvements in this aspect.

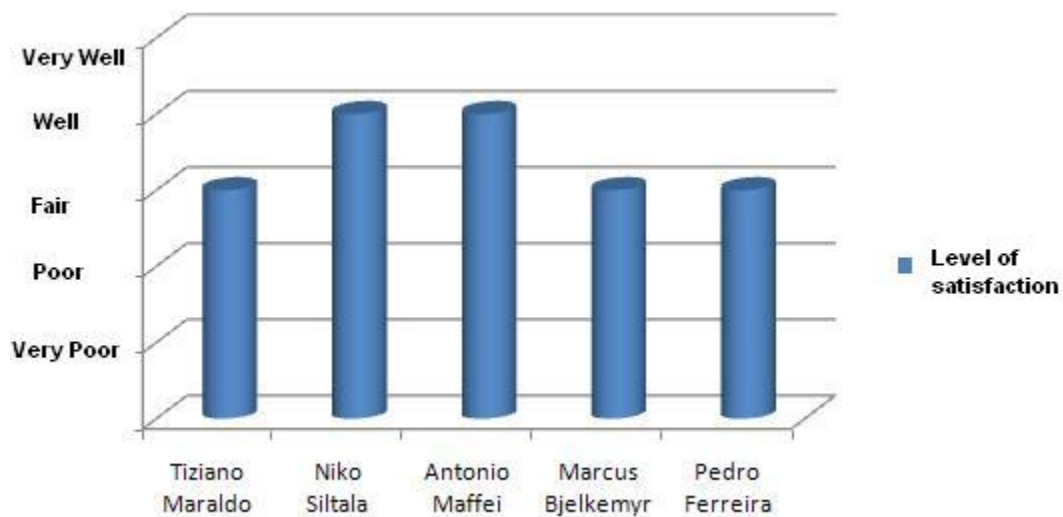


Figure 52 - EASET survey: Does the tool helps knowing what work is being developed by other people?

Members are satisfied with mechanisms available to track other users work under development.

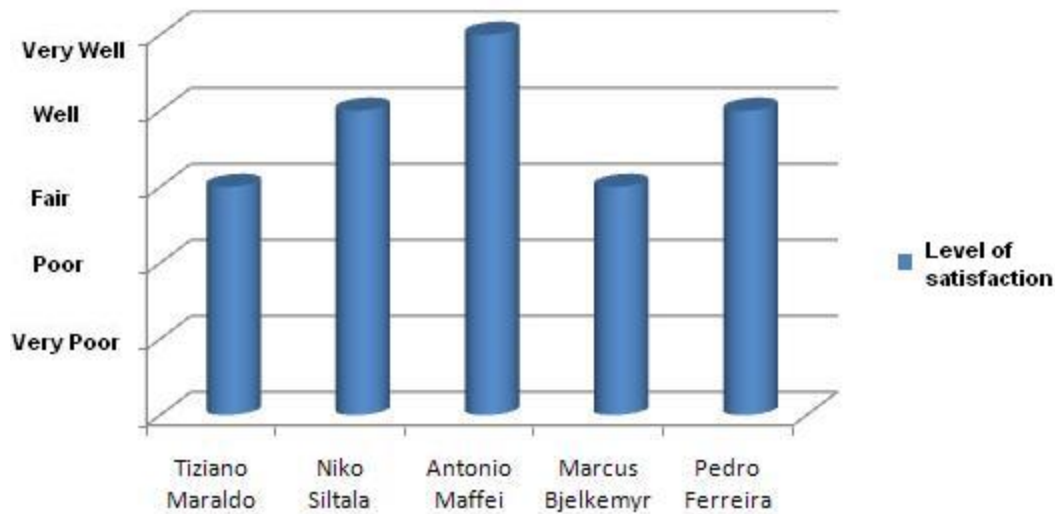


Figure 53 - EASET survey: Does the tool help trace who works on similar tasks to help forming virtual teams?

Members are satisfied with EASET regarding forming virtual teams. It is possible to track developments and the responsible persons, and at the same time establishing communication between members is facilitated by the communication tools. A mechanism of e-contract was suggested to facilitate forming virtual teams and tracking actual virtual teams.

### Knowledge utilization

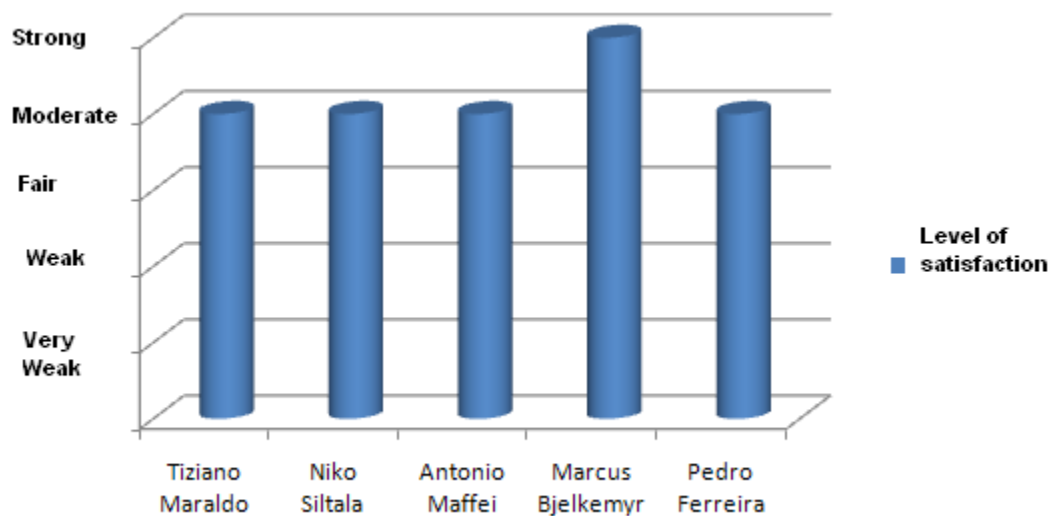


Figure 54 - EASET survey: Does the tool have techniques for information search?

There is a general satisfaction in the techniques for information search however was pointed out that a search mechanism should be placed in EASET's website and wiki to facilitate knowledge search.

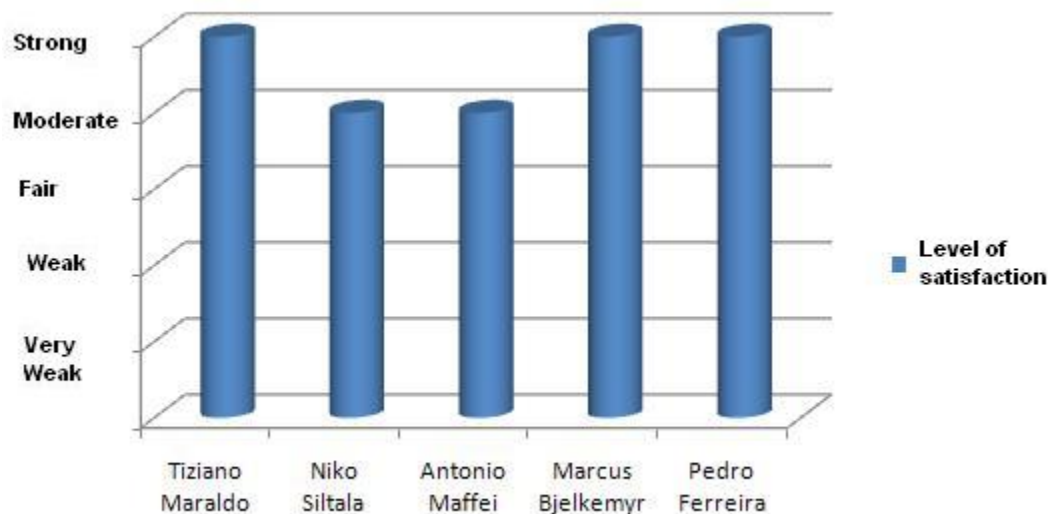


Figure 55 - Does the tool help avoiding noise in the information?

It is commonly agreed that EASET help filtering noise in the information and possess the knowledge present possesses a very good level of accuracy.

### Knowledge Internalization

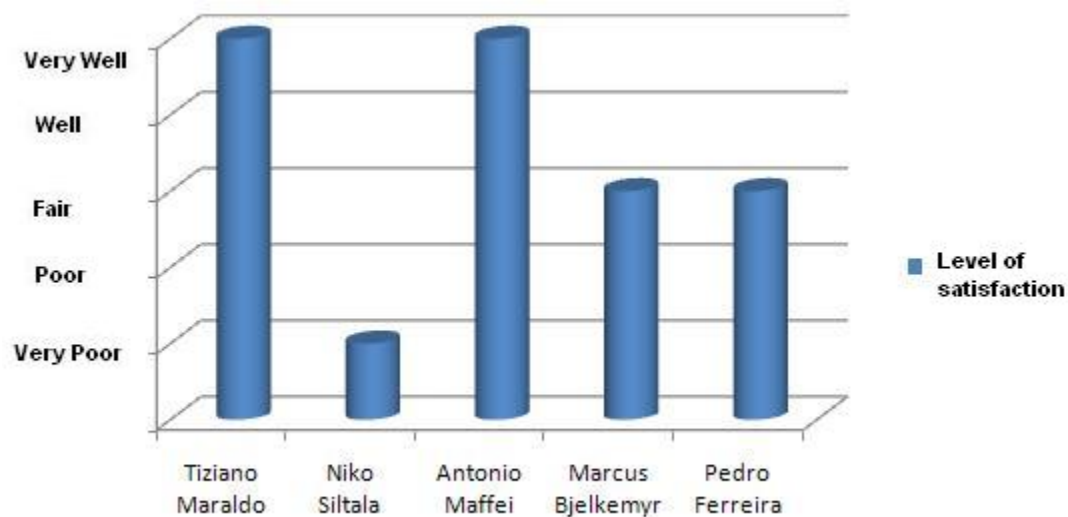


Figure 56 - EASET survey: Does the tool help to learn how to perform tasks or best practices?

Some members are not very satisfied with this characteristic pointing out that it should be improved. It is mentioned that there is lack of information regarding this aspect and that a separate section should be created.

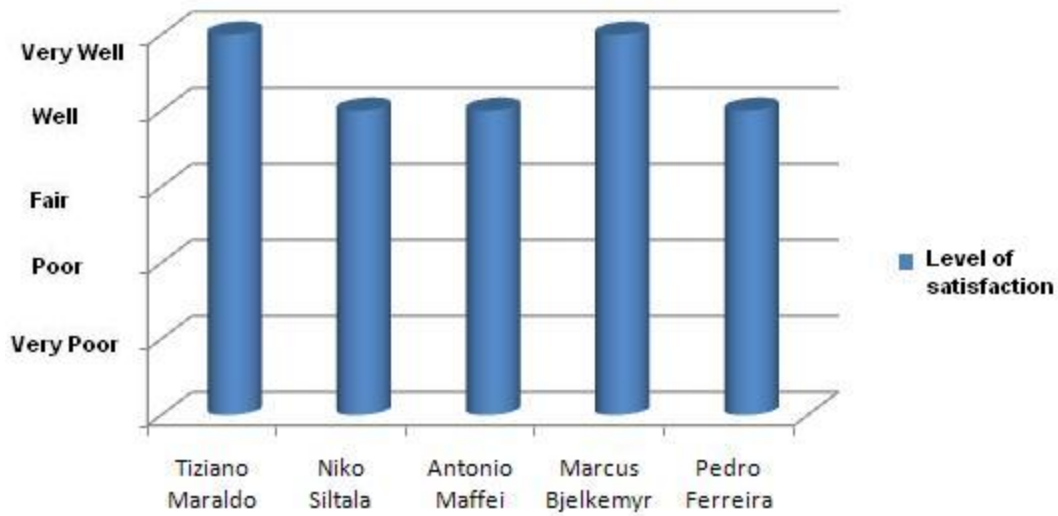


Figure 57 - EASET survey: Does the tool help improving members' abilities and capacities?

Members agree that they improved their abilities and capacities mainly by accessing knowledge available on EASET's website and wiki and by discussions in the forum.

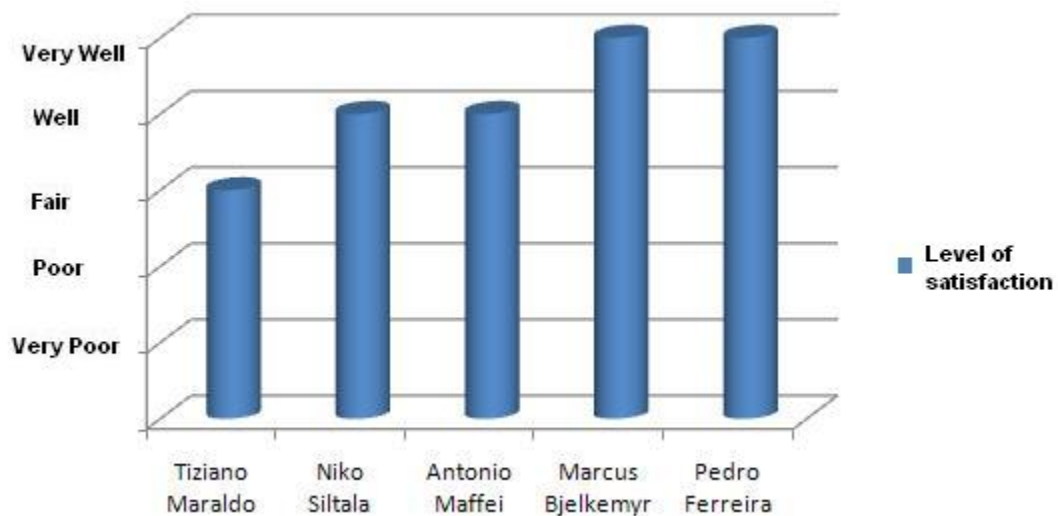


Figure 58 - Does the tool transmit the organizational philosophy, standards and client profiles?

Members are generally satisfied with EASET regarding this issue.



## Work progress

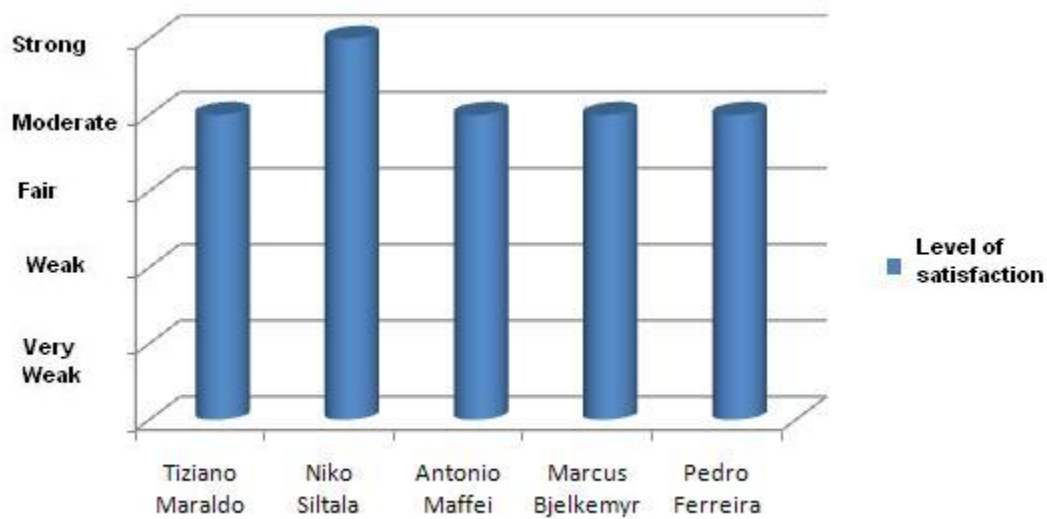


Figure 59 - EASET survey: Did the collaborative environment contributed in your work as EAS PVC member?

All members agree that EASET has contributed in their work as EAS PVC member. It is also underlined that EASET enhanced wide spreading of EAS concepts and helped in the acquisition of new members to the group.

## Overall result and comments

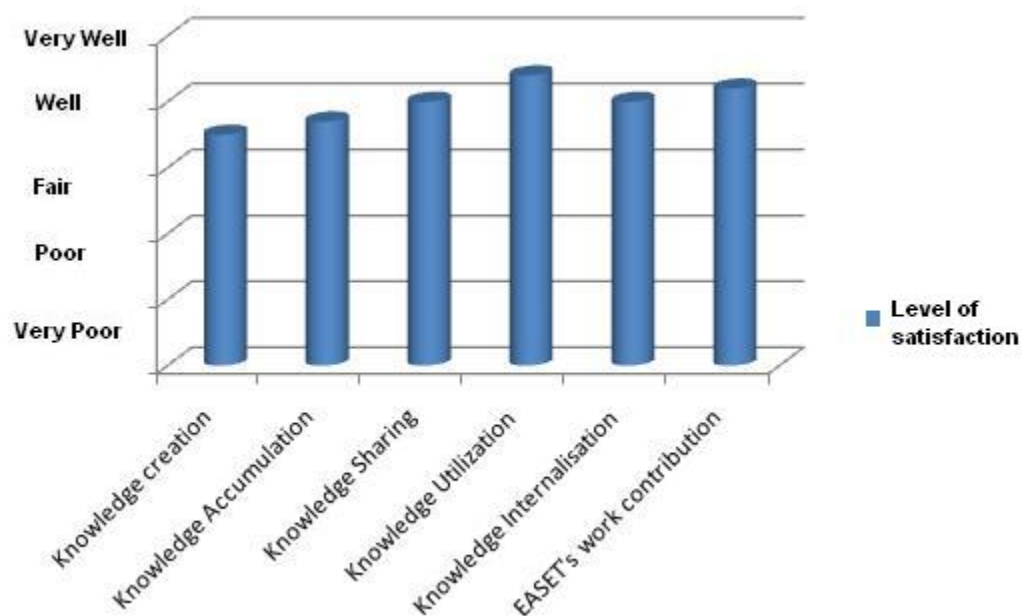


Figure 60 - EASET survey: Overall result

Analysing figure 60 it is possible to realize that the overall result of EASET is very satisfactory. These results show that EASET did in fact help EAS PVC members in their efforts for collaboration and dissemination of EAS paradigm. In terms of knowledge management EASET helped in all stages (creation, accumulation, sharing, utilization and internalisation) identified by Nonaka (detailed in chapter 3.2) which is considered as a major competitive advantage for organisations.

EASET creates a channel for distributing knowledge and fresh thoughts to community. EAS members and research community in general can now access EASET collaboration platform to share knowledge and opinions about EAS paradigm and manufacturing/assembly in general. The symbiosis of diversified actors of manufacturing/assembly field can result in numerous exploitation actions that can enhance greatly innovation and the quality of the future production systems.

This thesis addressed proving that a collaborative environment tool can facilitate this process endowing the actors with tools and mechanisms to collaborate in an effective way, raising critical mass support in the EAS paradigm and enhancing exploitation of knowledge.

This is in fact proved by the result of the analysis made to the use of EASET by its members. Members are satisfied with the collaborative environment created and agree that it is useful in their work developments. More, members agree that they improved their abilities and capacities with the usage of EASET which highly beneficiates the members and EAS paradigm evolution. Knowledge islands are reduced and a common base of knowledge is enhanced bringing advantages to EAS professional virtual community. At the same time EASET collaboration platform enhance the acquisition of more members to the community as well as enables knowledge to flow to other scientific communities. This benefice the scientific community in general since it facilitates the pursuit of the so desired modern production systems that are defined as a very important achievement by all recent roadmaps.

The EAS PVC does now possess a collaborative environment that endows members to share and acquire knowledge, have valuable discussions and have joint collaboration actions.

The goal of the collaborative environment tool proposed was to assist in the formation of a more extensive group of developers and users of adaptive assembly systems. The development and use of the Evolvable Assembly Systems paradigm was enhanced in several ways:

1. Scientific and commercial entities are more aware of what Evolvable Assembly Systems actually are, and why this paradigm is particularly well suited for highly dynamic production scenarios.
2. EAS PVC members are more updated regarding work developed, the commercially available solutions, future opportunities and the goals for the future.
3. EAS PVC member are working together in a collaborative environment and having positive results from this interaction.

The research hypothesis is validated by the mentioned facts and therefore it was hereby proved that EAS paradigm validation/falsification can be enhanced by the use of an accurate collaborative environment tool providing the required mechanisms for EAS dissemination and widespread consensus among the scientific community.

## 7 Conclusion and Future Work

To face current socio-economic adverse conditions enterprises must increase their efficiency and evolve to the requirements of customization and sustainability. Modern production systems need to deal with instability of markets and resource scarcity regarding an economical, ecological and social concern. The Evolvable Production Systems (EPS) aims at developing technological solutions and support mechanisms that may endow European assembly companies to fulfil these demands. EPS seeks highly adaptable control and mechanical systems enhancing re-usability and interoperability of modules, extending their life cycle and enabling short deployment times at shop floor level.

To help EAS paradigm evolution and dissemination a collaborative environment was developed. EAS professional virtual community does now possess a collaboration platform (EASET) to share and acquire knowledge, discuss important matters regarding manufacturing/assembly field and facilitate joint collaborative actions.

The collaborative environment has been useful in work developments and enabled improvement of abilities and capacities of users which is highly beneficent for the members and evolution of EAS paradigm. Knowledge islands among EAS PVC members are reduced and a common base of knowledge is enhanced. At the same time EASET collaboration platform enhance the acquisition of more members to the community as well as enables knowledge to flow to other scientific communities. This facilitates the pursuit of modern production systems, labelled as a very important target by all recent roadmaps.

The solution validation was accomplished and the analysis of the results in section 6 pinpoint areas of EASET that can be improved in order to improve knowledge management and collaboration activities to target optimal performance.

The Remote Monitoring and Control Tool and Emplacement Web Service of EASET are services that target integration of the shop floor with management level of companies. The better business tools can access the shop floor the better and faster an enterprise will be able to tackle problems, improve processes and attack new business opportunities. These tools are fundamental to EAS paradigm in the sense that they help improving agility and adaptability from management to shop floor level, as well as help improving processes and targeting sustainability of production systems.

EPS envisages achieving very adaptable, agile and sustainable production systems that can help enterprises dealing with instability of markets and resource scarcity while regarding an economical, ecological and social concern. The collaborative environment developed in this work has contributed to the evolution and dissemination of Evolvable Assembly Systems paradigm and will help in future EAS PVC efforts that will hopefully lead to obtaining production systems that can cope with the needs of tomorrow.

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