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A QFD-based method to support SMEs in benchmarking co-design tools

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ABSTRACT

Efficient collaborative product design is crucial for extended enterprises willing to develop complex products pursuing a short time to market. However, successful collaborative product design depends on the ability to effectively manage and share engineering knowledge and data throughout the entire product development process. Co-design software platforms aim to facilitate cooperation in distributed teams. In the context of Small and Medium Enterprises (SMEs) the advanced co-design software implementation to support the supply chain is not a trivial task. SMEs have peculiar characteristics such as flexibility, ICT skills and financial resources, which are difficult to be integrated within a structured design network. This paper presents a method to define and evaluate a co-design platform dedicated to SMEs in the mechanical product field. System architecture is defined by applying suitable metrics based on collaborative process characteristics in order to assess functionality performance of the available tools. Benchmarking is based on different levels of collaboration recognized in the typical product development process in SMEs. Correlation between process metrics, software functionalities and specific collaboration requirements is managed by adopting Quality Function Deployment (QFD) techniques. A practical case study allows the robustness of the proposed method to be verified and the main advantages and future developments to be discussed.

1. Introduction

Collaborative work is increasingly wide spreading into several product design processes to improve quality and reduce time and costs by integrating all partners and favouring data sharing. An interesting definition of collaborative product design can be found in Kleinsmann [1]: *the process in which actors from different disciplines share their knowledge about both the design process and the design content*. The creation of a shared understanding allows team participants to integrate and explore their knowledge and to achieve the new product design rapidly. Thus, the process is characterized by complex interactions among multidisciplinary teams which act in a distributed, heterogeneous and dynamic environment where the shared product and process understanding has to be optimized. Different expertise, individual knowledge and personal background of the actors participating in the collaborative product development (CPD) imply the creation of a shared workspace and the adoption of a common language.

Companies continuously evolve, extending their organization all over the world, and need to manage collaboration with a large number of different partners. These issues are particularly meaningful for Small and Medium Enterprises (SMEs), where supply (design) chain configuration requires high flexibility. It is worth noticing that design chain collaboration is complex for SMEs due to the following peculiarities:

- the interaction with a wide number of companies implies heterogeneity and multiplicity of design methods and tools adopted to support product development stages. System interoperability and interfacing with tools of leader companies are difficult to achieve. SMEs are mainly involved in specific design stages to face specific tasks (e.g. engineering simulations, mould design and production, equipment manufacturing, etc.);
- the low number or absence of internal operators dedicated to ICT system implementation and maintenance. Product designers are completely dedicated to the study and solution of technical problems;
- the limited budget available for investments on advanced technologies not focused on the core business.

In this context, many methods and tools have been studied to support collaborative activities. Techniques for computer supported cooperative work (CSCW) have been implemented in commercial collaborative Product Lifecycle Management (cPLM) systems. Main provided functionalities concern storing, management and control of data and processes. The available systems do not usually provide flexible and practical ways to capture and retrieve the design knowledge and expertise of SMEs. They are not

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easy-to use for non expert users and they generally require high cost for implementation. However, although cPLM potentialities are known, some issues are still unresolved:

- How can real collaboration requirements of the extended enterprise be recognized in a specific product development context?
- How can the most suitable easy to use collaborative tools for a specific low budget be identified?
- How can the necessary flexibility in dynamic enterprise networks be guaranteed?
- How can the achieved benefits for the extended enterprise be analyzed globally?
- How can a valid roadmap be defined to address optimization and improvements?

The present work tries to give some answers to these questions. It aims at defining a two-stage structured method which allows the determination of the proper co-design system for a specific SMEs context in the mechanical product field. It is based on a benchmarking protocol to design the collaborative environment as well as on an evaluation protocol which is able to assess tools during operational use within the extended enterprise. Both stages are based on the definition of a set of metrics, which are able to correlate collaboration requirements, software functionalities and process performance. Firstly QFD (Quality Function Deployment) technique is used to correlate companies CPD needs and software tool functionalities to select the most suitable system (benchmarking stage). Then it is use to quantify the achieved performance during different collaborative activities (evaluation stage). In particular, the evaluation is performed by diary study [2] to collect objective data and by post-hoc questionnaire [3] and VIA [4] (video interaction analysis) to gather subjective impressions. Data about the real performance is used to adjust metrics' weights for the first benchmarking phase.

The paper is structured as follows: Section 2 illustrates the research background. Section 3 focuses on the overall approach, while Section 4 shows the benchmarking method in detail. Through an experimental case study (Section 5), where the approach has been successfully applied, the evaluation stage is described. In particular the architecture of the collaborative platform developed and the practical results of its use in the context of a complex and heterogeneous extended enterprise are reported. Finally, after a discussion on the experimental data (Section 6), in Section 7 conclusions and future developments are provided.

2. Research background

Nowadays horizons have moved from the single organization towards a multi-company context. As a consequence, the success of collaborative actions basically involves the management of a complex network of dependency among individual organizations which aim to achieve a common goal. This framework is generally called extended enterprise, which can be defined as "a temporary network of independent companies which cooperate in order to exploit the fast evolving business opportunity with the assistance of information technology to share expenses, skills and access to global market" [5]. In Ref. [6] a complete classification of typological issues of enterprise networks is reported.

Collaborative product development is widely studied by the research community to improve decision-making in extended enterprises carried out more and more often by design teams, which are geographically and temporally distributed. A set of issues has been taken into account in the development of CPD systems, e.g. information system architecture, communication tools, engineering applications, product geometric representation, etc. [7].

Among the different kinds of industrial cooperation, product design collaboration is the most complex [8]. Shen et al. [9] has recently presented a review of the literature concerning computer supported collaborative design. After a complete analysis of the technological state of art, they have identified the main areas for future research opportunities and challenges. One of these topics is to provide methods and tools which allow users to choose favourite software tools according to their experience and preference as well as to their product typology (product centric design methodology).

Collaborative product design typically requires interaction of competencies to achieve final product design. Specialists, within and outside the company, have to share knowledge in a multidisciplinary teamwork where communication problems can emerge due to the different skills involved and the different representational tools adopted. Information needs to be shared in order to make the process efficient and guarantee the coherence between specified requirements and results achieved. Exchanged data mainly concerns 2D drawings, 3D CAD models, product structure and configuration data, manufacturing and engineering procedures, etc. However, in early phases data is not structured enough and does not dynamically change as the design evolves. Process must be flexible, accommodating to emerging situations and requirements caused by collaborating partners who may join or quit the alliance [10]. This is particularly evident for SMEs that are single entities teamed up with other companies to support product design and manufacturing. SMEs are viewed as the seeds of a vital entrepreneurial economy: recent statistics show that 99.8% of European firms is represented by SMEs [11].

The organization in SMEs is mainly characterized by a management group consisting of few people who are generally the owners of the companies. Formalized in-house knowledge base is limited as well as human and financial resources dedicated to support the design of different products and to manage interactions respectively. Flexibility and specialization are additional features in SMEs. SMEs work with many different companies to develop a new product or a productive process. They are involved in different product development stages, from technical feasibility to manufacturing. They have to adopt design methods customized on specific product requirements in order to quickly meet particular needs. Moreover, they usually use different software tools and representation modalities to perform specific tasks which do not necessarily correspond to those adopted by the teamwork partners. The interoperability of systems and models developed is not always supported [10]. Efficient data sharing implies formalization and management of knowledge in the designed product models and proper use of file formats to exchange data preserving all generated information [12,13]. All the differences mentioned lead to the idea that SMEs should not change their traditional way of working, both operational and organizational and replace it with systems able to increase speed and fluidity of information flows, to synchronize demand with supply and to help manage transactions in a more accurate way. All these aspects limit their involvement into LMEs' (large manufacturing enterprises) processes. On the other hand, several researches point out the need to develop specific co-design tools in order to maintain SMEs' traditional methods and tools while supporting networking efficiency [14].

In order to face the cited problems, supporting tools should meet technical requirements and communication needs. The quality of collaboration actually depends on the capacity of technological solutions to allow the functional objectives to be reached and of collaborative virtual space to support team interaction and shared decision-making [15]. In this context,