Holistic Design of Collaborative Networks of Design Engineering Organizations

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Abstract. The paper presents a visual knowledge-based approach for designing collaborative networks of engineering design organizations. The novelty of this holistic approach lies in integrated modelling of business, engineering, and learning processes. Distributed design tasks are easier coordinated due to explicit representation of management procedures as visual knowledge models of design flows and workflows. Furthermore, these visual models enable definition of design task patterns that can support design innovation management and learning across distributed teams. Proliferation of this approach in engineering communities is conditioned by availability of appropriate open platforms enabling distributed collaborative design and continuous learning processes in a frame of a collaborative engineering network.

Keywords: collaborative engineering network**,** holistic design, collaborative network modeling, active knowledge model, design house, design task pattern

1 Introduction

Network-based electronic system design becomes a common engineering paradigm, as a result of ubiquitous access to the broadband Internet and a progress in design engineering technologies [29]. The engineer's workplace gets more and more virtualized [28] with a global access to design resources. This virtualization process transforms both the individual working environment [28], a collaborative work in a distributed team [20], as well as it enables creation of virtual design organizations [6][7][31][32], and additionally networks of collaborating virtual organizations [2], as well as establishment of virtual engineering communities [4][9]. Network access has a predominant influence on enterprises that deliver design engineering, as a service. These enterprises, called *design houses* achieve a new dimension of flexibility related to the operation on the global market of design resources, partners with complementary competencies, continuous contact with clients, etc. Due to the access to the virtual infrastructures designers' teams from distributed design houses may undertake new innovative complex and heterogonous designs. New design approaches become feasible, like participatory design [13]. Traditional *Computer Aided Design* (CAD) and *Electronic Design Automation* (EDA) design disciplines have been especially influenced by the new network-based engineering possibilities [29].

Current systems, like cyber-physical systems [26] are complex and heterogeneous. Their design requires multidisciplinary and usually multi-organizational efforts [28] that integrate diverse design teams from different *design houses* (enterprises) into collaborative networks (CN) that encompass complementary engineering competencies. However, modern design methodologies like, platform-based design focus on system engineering design itself and rather neglect cross-organizational multidisciplinary issues in design flows. Further design challenges include: transformation and integration of models realized by multidisciplinary teams [10], *shared understanding* in distributed teams, engineering knowledge representation [27], as well as use in a design process of *enterprise knowledge* [25]. Due to a *dynamic character* of a design teams' membership, a need for agile learning of team new members becomes evident. Thus a requirement for a holistic and agile design approach that encompasses modeling of a design process of heterogeneous systems realized in networks of collaborating engineering organizations. This approach should comprise enterprise knowledge resources, their structure, business models, as well as feedback from users of designed products.

In the paper we point to the organizational context of complex distributed design processes. They are an essential part of design house knowledge. At the same time, we would like to underline that modeling and management of knowledge of a design house can influence design decisions and can contribute to agile design of more innovative products. In the presented work, visual knowledge models (AKM) have been used to represent multi-organizational, design, product, as well as infrastructural aspects of heterogeneous system design.

2 Design Engineering in Collaborative Networks

Design processes of cyber-physical systems (CPS) are usually conducted in multidisciplinary, often distributed, design teams [26]. Designers realising these design processes necessitate heterogeneous tools from different engineering domains. Mastering interdependencies between digital (cyber) and heterogonous (physical) domains, like: analog, mechanical, or optical design parts that are designed by teams with complementary design competencies constitutes a real challenge. In order to address it companies are motivated to *collaborative engineering,* especially in networks where trust among partners already exists. Inter-organizational collaboration requires an additional care concerning security.

Collaborative networks [2] or *collaborative engineering* networks [21][27][32] offer to engineers much broader spectrum of collaboration functionality enabling integration of design teams. The last ones are the most developed form of engineering networks, as they offer advanced engineering collaboration services for designers and tight cross-organizational integration of their tools. Through the evolution of the virtual organization concept [7] from the extended enterprises [3], virtual enterprises, and smart organization [6] concepts until collaborative networks [2], the available support for collaborative engineering was changing [32]. We have distinguished four categories of engineering networks [32]: digital engineering libraries, engineering brokers, engineering networks, and the most advanced collaborative engineering networks. Issues that are central to design engineering in collaborative engineering networks are shortly addressed below.

New techniques for management of distributed tools that support designers in creation of virtual design environments are required. These techniques should enable straightforward integration of engineering design tools and services, like: concept specification graphical tools, compilers, design verification and simulation tools, behavioural, architectural and logic synthesis tools, physical design tools, test generators, product data management systems, and/or databases of predesigned intellectual property components. All these tools and services can be distributed over different Internet sites and platforms. Issues of concern are: portable tool descriptions; management and control of access rights; configuration, registration, search, and invocation of remote tools.

Business aspects of engineering processes, like use of more cost effective technologies compromising some product parameters, like: power consumption, size or weight need to be addressed during the design process. Usually, business process management (BPM) is addressed by economists and managerial staff, who are not involved in design engineering. Integration of their BPM tools with engineering design workflow (WfM) technology is a challenging endeavour [14]. A common modelling paradigm is needed in order to address this challenge. Issues requiring special attention are related to distributed workflows definition, verification, and coupling. Further issues are related to collaboration among dispersed teams' members including synchronous and asynchronous communication, shared understanding, firewalls crossing, and assurance of robust Internet connection. Finally, we point to the need for open platforms that enable engineering in CNs.

3 Modeling of CNs of Design Engineering Organizations

The paper refers to the experiment in modelling of the engineering Collaborative Network (CN) which has been conducted by industrial partners of the MAPPER project (*mapper.eu.org*). It encompassed two design houses in complementary engineering domains, namely digital and analogue electronics. The industrial design spanned over two countries, Germany and Poland and involved dispersed branches of one company, and an additional academic enabling party responsible for maintenance of the used MAPPER virtual collaborative infrastructure [12]. MAPPER was extensively using the visual knowledge modelling approach based on Active Knowledge Models (AKMS).

The paper reports on the use of this approach to CN modelling that included integration of BPM and engineering WfM. The concept of Active Knowledge Models and its applications in various domains have been covered in the literature

[1][12][16][17][18]. Enterprise architecture modelling, IT governance and BPM are the most common applications.

The additional motivation of this paper is to demonstrate use of the AKM technology in the domain of electronic system design. AKM representation in principle is more general than workflow management. It can thus be applied to representation and modelling of various enterprise processes and products. Engineering processes, including EDA (Electronic Design Automation) ones, can be modelled using AKM. AKM-based design strategy enables capturing in a model, knowledge on: enterprise architecture, design processes, designers' competencies, used tools, IT infrastructure, products, and patterns of good practices. This knowledge is gathered in visual knowledge models, operational models [10], and patterns [23].

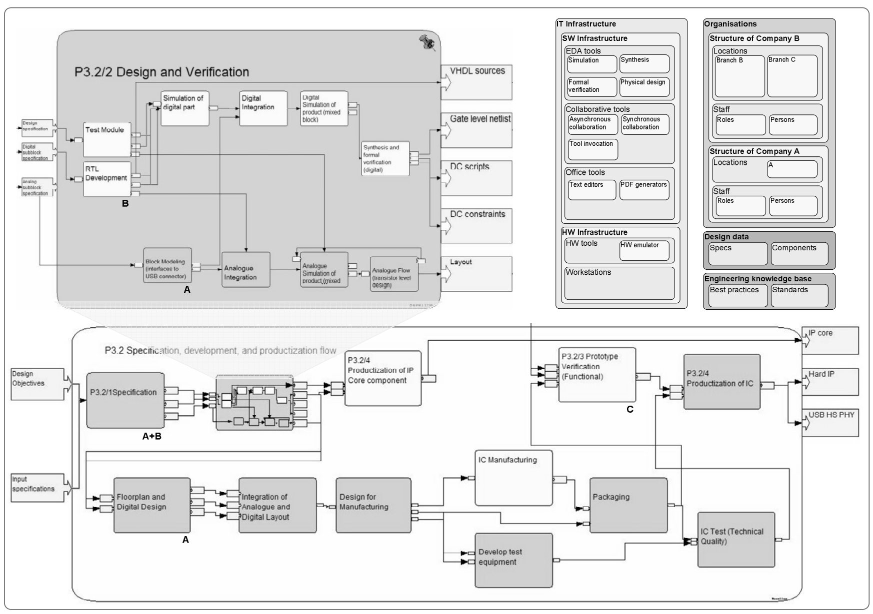

Fig. 1 - A visual design of a collaborative network of two design companies

Active knowledge models (AKMs) [18] are visual representations of unfolding and dynamic business knowledge. The models, when supported by an appropriate platform, can be used to *actively* customize the underlying IT infrastructure. AKM models are executed through process enactment and rule engines provided by that infrastructure. In the context of engineering design processes, AKMs can be applied as an active and systematically unfolding knowledge model of the design process and its environment. This knowledge model can integrate: relevant design processes, required human resources with engineering expertise profiles, and appropriate design tools. Such a model, if systematically updated, can simplify transfer of design knowledge concerning a particular design phase to new employees. It supports design knowledge accumulation and transfer through learning patterns around the distributed teams. Furthermore, AKMs can model families of *electronic products* at various levels of abstraction well managing various configurations of product functionality.

Fig.2 consists of the top view of a design house model comprising such components as: design flows, design documents, design house organization and infrastructure.

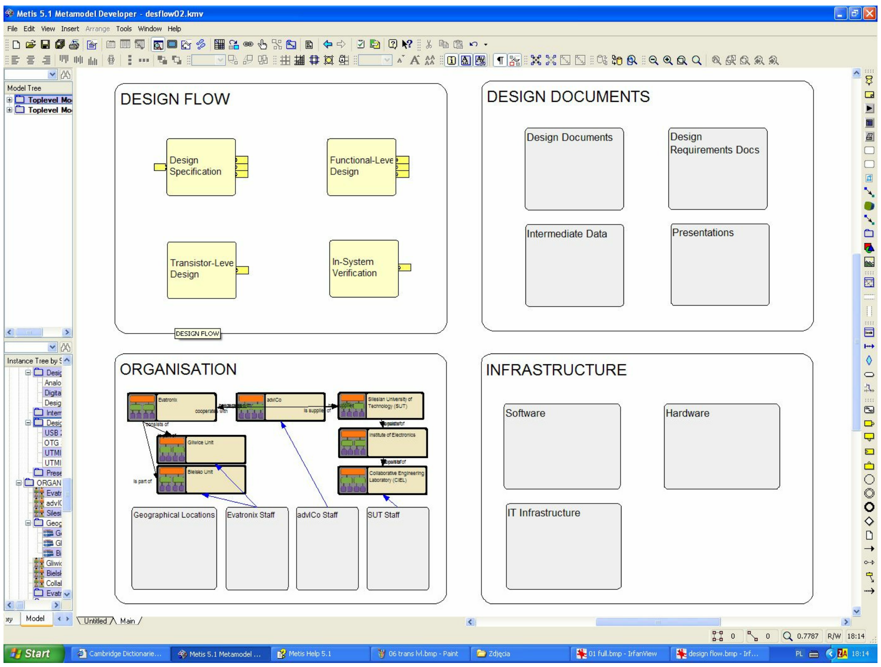

Fig. 2 - The design house representation as AKM.

4 Towards Holistic Design of CNs of Design Houses

Models of collaborative engineering networks are generally defined as explicit representations of some portions of design houses reality, i.e. their resources in terms of available tools, human experts' profiles, design and verification processes, as well as organizational structures, and collaborative links. Developed knowledge models are actively used during the operation of the system. Models need an appropriate IT infrastructure in order to be developed, managed, stored, and executed. The MAPPER infrastructure [12] has been used in below shortly reported experiments. The infrastructure applies active model configuration in the following ways:

- Model-configured *workplaces* constitute simpler means of interacting with information and knowledge, adapted to the designers' preferences, competences, roles, and responsibilities;

- Portal *navigation* structures reflect model structures;
- Portal and web *services* from other tools can be invoked using general plug-in mechanisms, mapping data from the models to the parameters of the service;
- *Task execution* is used for plugging together solutions for a particular process or task pattern, invoking parameterized infrastructure services for each step;
- *Intellectual property rights* can be protected using a model-configured access control mechanism, as defined in [11].

4.1 Tool Invocation Workflows in TRMS

The Tool Registration and Management Services (TRMS) [15][24] system comprising three main components: Global Tool Lookup Service (GTLS), Tool Servers (TSs), and Client Applications has been used for tool invocation workflows in the conducted design engineering experiments [23].

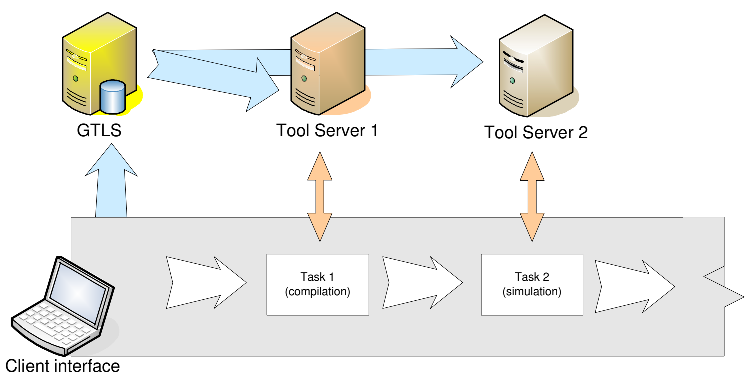

Fig. 3 - Tool invocation workflows in TRMS.

Fig. 3 illustrates a simplified design scenario based on TRMS. A designer executes a workflow that constitutes a sequence of design tasks. The TRMS Client interface enables a designer to define in a graphical way the workflow of tasks. The simplified workflow consists of two design tasks, namely design compilation and simulation. The first Tool Server is responsible for execution of compilation, whereas the second one executes simulation. Both tool servers have been identified by the GTLS service. A task, being a part of the workflow available at the GUI level, is a representation of a service that is executed at the specified Tool Server.

EDA tools operating in the “batch mode” can also be supported by TRMS which enables their encapsulation and flexible execution. Design data transfer to the tool servers can be facilitated, either through the TRMS Client or through the consecutive use of tools, like CVS.

4.2 Model-Configured Task Execution

The mapping of the high level knowledge models of design flows onto the concrete tasks and workflows that are available through TRMS requires that the atomic tasks of the knowledge models are connected to the TRMS specific workflows or tasks. In consequence, the AKM task execution engine will be able to invoke a particular lower level tool for each process task. The parameterised URL interface of the TRMS applet is used for handling interactive tasks, while automatic workflows may be invoked using the TRMS web service interface. Both these integration mechanisms are supported by the AKM task execution engine.

From the AKM models data and parameters are extracted that are needed as input to TRMS. Definition of mapping between model elements as well as, service input and output parameters, assures that any kind of modelled content may be used by lower level services. Different types of models concerning: documents, organisations and people, design processes and tasks, or product structures can be configured to be used by services. The integration of AKM and TRMS is thus flexibly model-configured, and may be dynamically adapted to meet particular designers' requirements. This assures designers' freedom that in consequence supports creative design.

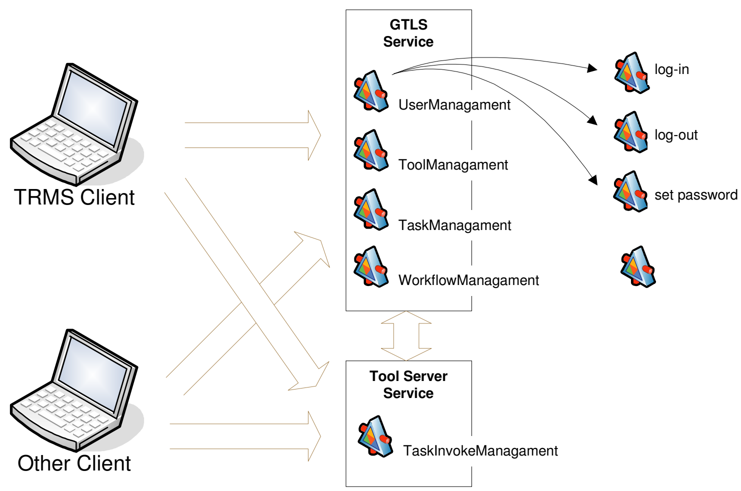

Fig. 4 - Model-configured task execution in the MAPPER platform [12].

4.3 Integration of Task Execution and TRMS Workflows

The web services-based architecture of TRMS enables straightforward integration with other web service-based systems. A set of services offered by TRMS includes: search for a predefined task or workflow (group of tasks), as well as task control and execution. Two TRMS Clients independently invoking services from the GTLS server and from the Tool Server are illustrated in Fig. 4. The TRMS Client enables the complete control over the TRMS environment. It supports management of users and tool properties. A designer is supported in building his own visual representation of the environment based on the available web services.

4.4 Design of Virtual Electronic Components in the CN

A distributed collaborative design process aiming at a virtual (Intellectual Property) IP component required for hardware implementation of standard serial communication protocols is shortly described in this section. This design process integrated two electronic design companies from Germany (Recklinghausen) and Poland (Fig. 1) (two branches in Gliwice and Bielsko-Biała). This design process was realised in the collaborative engineering network that was enabled by the MAPPER project infrastructure [12]. The network integrated engineers' workspaces with design tools and remote specialized tools that processed automatically design data upon invocation through the TRMS environment (Fig. 2 and Fig. 3).

The IP component design process begins with an informal specification that is agreed upon by both partners. Once a precise specification is defined, both companies precise their design flows and workflows as visual models (AKMs), and agree upon appropriate analogue-digital interfaces. The AKM-based design flows and workflows cover: specification, synthesis, verification, and product preparatory phases for both digital and analogue design flows. Consecutively, designers responsible for particular design phases and tools to be used are defined. The common design workflow defines all design steps at both companies that are needed for designing and production of the designed IP component for standard serial communication. This common design workflow is a result of numerous negotiations between designers and also managers of both companies that are performed using collaboration services of the MAPPER infrastructure (e.g. CURE environment).

The active knowledge model developed for the IP component design integrates a wide spectrum of information and knowledge related to the joint product, namely: the companies' structures, human resources including their competencies, the available IT infrastructure, the project organisation with assigned responsibilities, the detailed structure of the joint product, as well as the project planning with management and design workflows. Fig. 2 presents the top-level view of this model for one design organization (design house). The detailed model comprises a very large number of elements, i.e. objects and their relationships that are not easy to comprehend all at once. It is therefore necessary to focus only on the portion of the model at the time. The AKM model browser enables control of visibility of model elements by creating different views with selected model components only.

Further details of the discussed distributed collaborative design process are available in: [22][23][25], as well as from *mapper.eu.org* (D15).

Acknowledgments. The authors acknowledge MAPPER project partners and the SUT TRMS team: Paweł Fraś, Tomasz Kostienko, Piotr Penkala, and Marek Szlęzak.

5 Conclusions

Modeling of collaborative networks that includes: modeling of partition of design tasks onto different design houses, designers' and resources' allocation enables verification of correctness of design decisions, and in general it supports distributed design processes. The use of active knowledge models has been demonstrated in modeling of organizational, process, product and system aspects of collaborating design houses.

The experiments conducted during the MAPPER project and later the MADONE network [19] have confirmed that Active Knowledge Models constitute an innovative approach to holistic design of CNs due to their support for:
- Multidimensional modeling and management of design house knowledge,
- Integration in a model of organizational, process, product and system aspects,
- Virtual collaboration of designers and their continuous learning processes,
- Creation of meta-models,
- Modeling and generation of configurable model-driven workspaces that support collaboration in multidisciplinary design teams,
- Representation of design task patters, and
- Automation of selected design tasks with appropriate infrastructures.

Practical realization of the holistic design methodology depends on the availability of the underlying IT infrastructure for all design houses that are involved in the collaborative network. Community efforts are thus required towards development of open platforms enabling collaborative engineering [19].

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