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SIX INGREDIENTS OF COLLABORATIVE VIRTUAL DESIGN ENVIRONMENTS

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1. Introduction

Industrial operations are spreading around the whole globe. Not only marketing and production, but also design and development of products are influenced by globalization. New challenges and tasks are emerging unceasingly, which require genuine global solutions for geographically distributed product design, engineering, and realization. Communication and collaboration have got into the focus, calling for new approaches to activities such as concept definition, virtual prototyping, product review, and production planning. It is becoming more or less obvious that it is not possible to fulfil the new requirements solely based on conventional CAD/E systems and the present Internet facilities. The current Internet-based systems show poor functionality and performance compared to conventional standalone systems. New infrastructure, tools, methods and knowledge are needed in the form of collaborative virtual design environments (CVDEs). For instance, the American National Tele-immersion Initiative (NTII) will enable users at geographically distributed sites to collaborate in real time in a shared, simulated environment as if they were in the same physical room. CVDEs enable remote participants to share not only resources, but also knowledge and models, and carry out design and engineering actions concurrently. CVDEs represent holonically-integrated systems, therefore it is unimportant if the collaborating partners are co-located or remotely located. They have access to all kinds of resources that are available in the system, and can define product concepts and develop virtual prototypes of product variants in cooperation (Siddique, Z. et al., 1997). Each CVDE is tuned to specific design/engineering tasks as well as to the features of remote teams of designers/engineers.

Noteworthy progress has been reached in this direction. It is not a problem any more for geographically separated designers and engineers to work together forming virtual teams, to involve the potential customers in defining the requested individually customized products, or to implement knowledge and expertise brokering with suppliers. The global activities are supported by, among other things, enabling technologies such as blackboard systems, videoconferencing, e-business systems, engineering service hubs, distributed knowledge bases, outsourcing/servicing management systems and telemanufacturing systems. Nevertheless, the paradigm of CVDE is in its infancy and there are still many open issues related to the architectures, functionality, methodology and implementations. Therefore, intensive theoretical and methodological research, technology and tool development as well as practical implementations and testing through applications are needed.

The requirements for and the functionality of CVDEs always depend on the application. Nevertheless, there are some functions that are common and fundamental for such distributed environments. That is, we cannot talk about a complete implementation of the CVDE concept without establishing (i) distributed virtual office for remote teams, and supporting (ii) synchronous communication and interaction, (iii) genuine three-dimensional imagining and simulation, (v) interactive collaboration based on virtual presence, (iv) creative conceptualization and modeling of parts, assemblies and entire artifactual systems, as well as (vi) sharing the knowledge assets and putting them into work, and (vii) brokering knowledge and expertise for virtual enterprises. In our Integrated Concept Advancement research program, we have been investigating the issues concerning the architecture, functionality and realization of such all-inclusive CVDEs, in order to fulfill the fundamental requirements by our pilot implementation. We also intended to identify components that can be common in several implementations. In this paper we report on the first phase of the research in which we have developed our architectural model, and have investigated both available and emerging technologies enabling realization in the industry. We also indicate some of the open issues for further research.

2. The build-up of collaborative virtual design environments

According to our understanding, CVDEs represent the fourth generation of CAD/E systems covering the entire product development and environment. Based on the generic requirements and functionality, we identified six basic components (ingredients) that are vital for the implementation of distributed CVDEs. Figure 1 shows these components as well as the onion-like structure that we propose as a standard architecture of a collaborative virtual design environment.

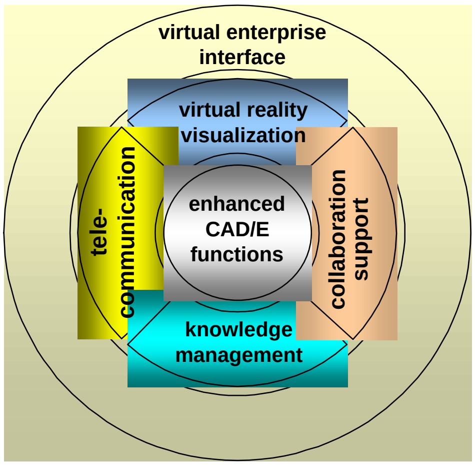

Figure 1. Components of a collaborative virtual design environment

The enhanced CAD/E functionality represents the kernel of a CVDE. On the one hand, it provides us with advanced design techniques; on the other hand, it facilitates exchange of ideas, advanced interaction, multi-site imaging as well as team partnership. Virtual reality-based advanced visualization, support of creative collaboration and virtual presence, networking and multi-channel telecommunication, along with knowledge processing and asset management form a layer around this kernel. Although shown as distinct ones in the architectural scheme, these components are not only integrated, but also work together holonically both from a methodological and from an information technological point of view. On the one hand, a CVDE provides a virtual enterprise (VE) with the hardware, software and brainware infrastructure that is necessitated by global product development. On the other hand, it contributes to product development by utilizing functions such as knowledge brokering, outsourcing, capacity acquisition, service management, etc. of the VE. The interface that makes it possible forms the outmost layer of the CVDE architecture.

3. Enhancement of CAD/E functionality

The currently typical CAD/E functionality is shown in Figure 2. Commercial systems are normally built around a 3D geometric modeling engine, which enables solid, boundary, surface, nonmanifold or feature modeling, or a combination of these techniques. They still follow the classical workstation concept, although communication through the Internet has been added to the list of functions. The leading CAD/E systems support detail design, assembly design, physical analysis, behavioral simulation, manufacturing process planning, numerical control manufacturing, and other downstream applications of product development and engineering. Computer support of conceptual design is still a stepchild, because the representations proposed by academic research are usually abstract, and the tools based on them are difficult to streamline with and interface to commercial CAD/E systems. In general, problem solving based on the capabilities on individual designers and development of aspect models are more in the focus than creative collaboration of a team of designers and multi-aspect collaborative synthesis.

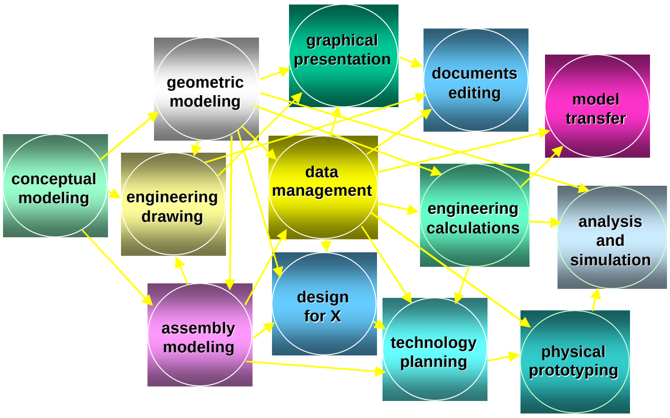

Figure 2. Topography of CAD/E functions

Nevertheless, there are several opportunities for enhancement of CAD/E functionality to better support distributed product conceptualization, design, development, simulation and manufacturing by CVDEs. For instance, conceptualization of artifacts can be supported by (1) less restrictive shape modeling techniques allowing for incompleteness, vagueness and impreciseness, (2) using natural verbalism in modeling processes, (3) allowing shape specification by hand movements and hand gestures, (4) application of evolving multi-resolution product models, (5) involving physical principles and effects in concept models, (6) using qualitative and situational reasoning in modeling, (7) associative management of product variants, and (8) application of editable and reshapeable physical prototypes. The vague discrete shape modeling technique realized in the ICA research program is a good example of the possibilities (Figure 3) (Horváth, I. and Rusák, Z., 2001).

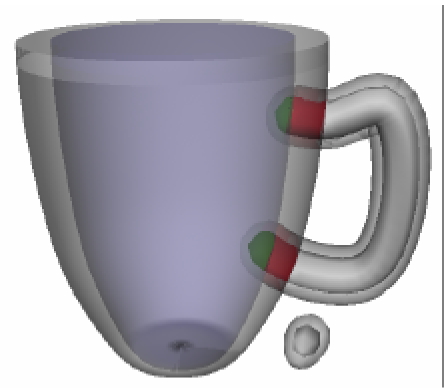

Figure 3. Application of vague discrete modeling

Nonetheless, detail design of artifacts can be supported by (1) multi-site solid and assembly modeling, (2) multi-aspect and multiple-context oriented product modeling, (3) multi-level constraint satisfaction, (4) management of design intents and design contexts, (5) complex real-time behavioral simulations, (6) explicit handling of product-related knowledge, (7) use process modeling and prediction, and (8) distributed supplier and change management. Intensive research is concentrated on new geometric modeling for conceptual and detail product design. It is to be seen that realization of some of these functions cannot be achieved without the involvement of the other ingredients of CVDEs. The most crucial issue is how to forward the present syntactic product modeling towards a more semantic one?

4. Advanced interaction and visualization

Efficient human-computer interaction and advanced imaging are aimed at for a long time in CAD system development. However, tabooing keyboard and mouse, and being skeptical towards the emerging interactive means froze everything. Recently, both interaction and imaging have received new impetus from the results of research into virtual reality (VR) technology (Bochenek, G. M. and Ragusa, J. M., 1998). To have a full thrust, the technological development needs to be combined with design methodological ones. The main aspects of current VR technology are interaction, imagination, immersion and integration of these. Thus we typically talk about interaction, imagining and hybrid VR systems. New ways of interaction are being implemented by advanced verbal, gestural, visio-spatial, physical and other means. The emerging tools have the potential to handle input from several users (designers, customers, etc.) concurrently (Chu, C. P. et al., 1997). The typical interactive input means for IVRs are: (i) three dimensional eyes and head tracking devices, (ii) data gloves or 6D pointing devices, (iii) haptic/tactile/force feedback interfaces, (iv) kinesthetic motion feedback interfaces, (iv) action-at-a-distance (AAAD) selectors, (v) gesture scanning and interpretation interfaces, (vi) speech recognition and processing interfaces, and (vii) virtual/real object collision (VROC) detectors (Hand, C., 1997). These technologies lend themselves to a more natural, ingenious, and effective externalization of the designers' ideas, achieve higher level of flexibility and collaboration, and exempt the designers from the necessity of doing everything definite and final for the first time. Unfortunately, these technologies are hardly used together with the current product modeling systems.

In a VR system the experiences of the individual encounters are created by computers and performed in such a way that the virtual experiences are to some degree real experiences by the user. Imagining virtual reality systems create a cyberspace around the designers and engineers and append it to their natural sensorial and cognitive image spaces. Three generations of imagining VR systems can be distinguished from which the first and second-generations are commercially available and used. The first generation is represented by fully immersive virtual reality (FIVR) technologies, the second by semi-immersive (SIVR), and the third by non-immersive (NIVR) technologies. FIVR systems include (i) head/helmet mounted displays (HMD), (ii) binocular omni-orientation monitors (BOOM), (iii) stereographic monitor (SGM) systems, and (iv) stereoscopic shutter-glasses (SSG). These means are oriented to stereographic visualization for individuals; therefore they do not typically support collaborative actions of a group of designers. The inherent shortcoming with 2D generated and projected images is that they do not provide us with a true immersion in a 3D environment.

SIVR systems use immersive projection technologies (IPT) (Cruz-Neira, C. et al., 1993). Typical SIVR technologies are provided by room-sized and -shaped CAVE (computer augmented virtual environment) and WPS (wall projection system). The high-resolution projectors, 3D video and audio imagining facility, allow multiple individuals wearing stereoscopic glasses to concurrently view a virtual product or system model, as well as to use simultaneously highly interactive input means, and maintain near-natural human communications. In this way, multiple viewers can share virtual experiences and become capable to act collaboratively in the virtual environment. A CAVE configuration best supports "being inside, looking out" type of visualization. A WPS configuration is for "being outside, looking in" type of visualization. In the car and airspace industry they are alternately used, e.g., to design exteriors and interiors. The third generation of the VR imagining systems, which does not need additional viewing means to experience with a true 3D image, is just evolving in these days. Holography-based systems are intensively studied and used in the development of NIVR systems. Holography is a technique, which uses the interference of light waves for producing three-dimensional imagery. Holographic true imaging workbenches (TIW) multiplied at all sites of remote collaborating designers allows them to interactively create, visualize and manipulate a true 3D virtual model of a product and combine real parts with virtual ones. An advantage of using SIVR and NIVR technologies is the opportunity to synchronously project the same 3D image of the model in 1:1 scale in each connected remote locations. Nevertheless, current geometric modeling principles do not sufficiently support interactive modeling in these environments. Implemented with digital audio, verbal communication is gaining popularity in dispersed NIVR systems, but the opportunities are far not explored yet.

5. High-speed communication on multiple channels

CVDEs utilize wired and wire-less telecommunication networks as well as satellite systems as mediums to distribute CAD/E functionality and to connect collaborating parties. Today's ISDN-based teleconferencing technology does not typically lead to satisfying interaction among the participants. The two factors are the speed of communication and the number of available channels. The results are even worse when communication is realized on computer webs. This is the reason why the expectations are so high towards the results of the recent Next Generation Internet Initiative (NGI) and University Corporation for Advanced Internet Development (UCAID) program (with the Abilene and Internet2 projects), that promise 100-times and 1000-times faster communication. This leap is needed not only in terms of the speed of transfer (expected is 256 Gb/s), but also in terms of the number of communication channels.

Typically three forms of communication need to be supported in CVDEs: (i) asynchronous communication, (b) synchronous communication, and (iii) participatory communication. For asynchronous communication, document-centric transfer means such as e-mails, bulletin boards, discussion databases, information-sharing tools, Intranets, and group calendaring are used presently. It can be foreseen that the significance of these means will decrease in fully featured CVDEs. On the other hand, the technologies of synchronous communication, which are based on meeting-centric interactive means such as text chatter, phone conversations, audio conferencing, shared whiteboards/sketch-boards, application sharing, screen sharing, ISDN-based and IP (net-based) video conferencing, and multi-site video phoning, will play a more dominant role in CVDEs.

The issue of reliability of transfer couples with the issue of security of communication. In CVDEs, security must be achieved not only in terms of the access to and manipulation of data and knowledge, but also in terms of communication channels. In a CVDE, there are multiple input and output signal streams from and to the users respectively. These signal streams, together with the related actions, are called channels. For instance, primary input channels for a CVDE are verbal communication, digital sketching, gestural movements, computer command-based model generation, digital scanning, and/or conversion of virtual images. The main forms of output channels are screen display, wall projection, CAVE, holographic imagery, and/or sound. Similarly to asynchronous transmission and synchronous communication channels, the direct interaction channels need various authorization and security levels. They can be public, that is, open to any participants, or private, that is, available to people with sufficient authorization, or open and accessible only to distinguished participants. Future information highways are supposed to support more advanced forms of participatory communication.

6. Collaboration support and virtual presence

Specific interactions and activities of remote participants in order to solve tasks are often referred to as collaborative functions. Among other things, typical collaborative functions are (i) discussion with customers and users, (ii) management of chains of suppliers, (iii) collaborative definition of products, (iv) collective ideation and modeling of products concepts, (v) shared dynamic construction of product models, (vi) concurrent multi-view design reviews, (vii) multi-aspect behavioral simulation, (viii) manufacturability analyses, (ix) assemblabitity and disassemblability analyses, (x) environmental and sustainability evaluation, (xi) outsourcing planning, (xii) development progress reviews, and (xiii) product life-cycle investigations. In these days, the typical basis of collaborative functions is videoconferencing. However, as the examples of leading aerospace and automotive manufacturers show, solving complex, multi-disciplinary problems, and making the necessary knowledge and capacities available, need more effective support of collaboration. The reason is simple: current teleconferencing facilities have been developed for communication, rather than for virtual co-location and collaboration.

Experience has learned that a large part of communication is spent on trying to agree on a set of terms to describe the artifacts, the used methods, processes, tools and other means, that obviously hinder effective collaboration (Rogier, J., 1999). In like manner, using several aspect models and representations does not favor to efficiency. In addition, with teleconferencing systems, participants do not become involved in a shared 3D space therefore they cannot feel presence. It makes it difficult to see the participants' intentions, reactions and especially emotions. In each of the above-mentioned collaborative functions, the solution is a kind of virtual presence of the remote participants. Consequently, collaboration support in CVDEs decomposes to three fields: (i) facilitating team understandings and creativity, (ii) execution of collaborative functions based on shared models, and (iii) virtual presence at remote locations.

Endorsement of team creativity is a specific issue for collaboration in CVDEs. In the conventional design offices, the frequent exchange of ideas and purposeful interactions increase the creativity of designers. If in a distributed environment the models rather than the ideas are telecommunicated, creativity for sure suffers. Therefore, there is a strong need to magnify creativity by real time involvement of the distributed teams. Research relating CSCW has recently inclined towards this point with the ultimate aim of providing creative techniques for remote participants (Zhuang, Y. et al., 2000). CVDEs must be equipped with a suite of means for creative collaboration. It is still unclear how can we develop comprehensive artifactual system models in a collaborative manner, especially if they not only orientated to the artifact, but also to the realization environments, the use environments, and the related humans.

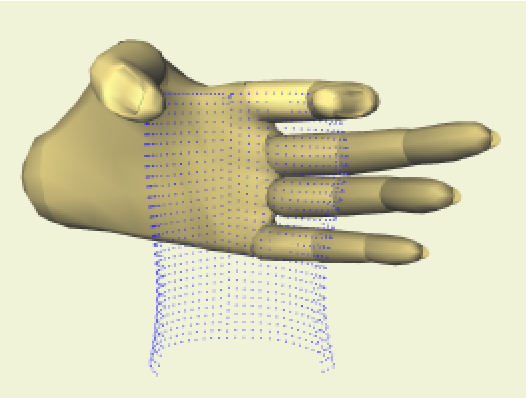

Figure 4. Hand as a partial avatar

Virtual presence makes it possible in principle to each participant to have a representation of himself at each remote location and interact with the model. The representation means that the remote participants are emulated in purposeful human-like models by means of which they have the abilities to fulfill certain actions. In very simple applications, remote designers or engineers have been symbolized either by digital photos or camera-pictures, or by three-dimensional geometric or kinematics models. These do not make it possible for the remotely located designers to dynamically exist and carry out actions in the virtual environments. To provide this capability, the concept of digital human replicas, called avatars, has been proposed. An anthropomorphic avatar is a fully featured model of the human body or a part of it. Obviously, full-body avatars are needed to represent all possible body functions of the remote participants. Partial avatars (e.g., hands, heads, legs, etc.) are sufficient when body functions are localized to an area of interest (Figure 4). The first generation avatars provide realism in believable appearance, but not in human-like movements. The presently evolving second generation (telecommunicated) avatars mimic user's movements by tracking a few sensors attached to the user and by fuzzy computing body deformations and movement trajectories based on body behavior patterns. The ultimate goal of research into anthropomorphic avatars is emulating human presence in virtual environment both from a physical and from an intellectual point of view.

7. Knowledge asset management

Solving product development by human designers or by intelligent agents strongly relies on information and knowledge management. Collaborative virtual design environments are supposed to achieve the best utilization of all kinds of knowledge that are available for the virtual enterprise at all (Rodgers, P. A. et al, 1999). The issue of knowledge management in CVDEs appears in the context of:

(i) making the knowledge needed for solving complex product development problems available, and (ii) formally processing the available knowledge and knowledge assets in the collaborative virtual design environments. In the former context the issues of (i) sharing the knowledge of the individual designers and engineers, and (ii) brokering with the available but unbounded (mental) product development capacities come into view. In the latter context (i) elicitation and formalization of knowledge for processing by knowledge-intensive systems and intelligent agents, and (ii) archiving knowledge assets in the VE's warehouse for contemporary or future uses are important issues.

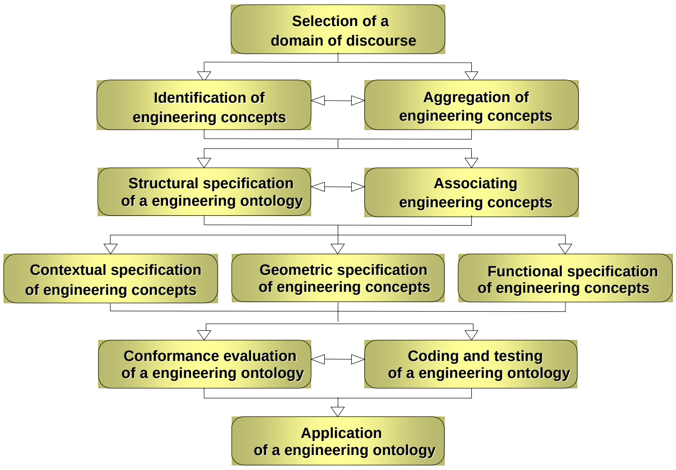

Figure 5. Process of design ontology specification

The collaborating designers who activate their knowledge sets whenever they take part in a joint product development task implement knowledge sharing. The knowledge engineering tasks in this respects are related, but not limited to involvement of the needed experts, stimulation of joint thinking, extending the platform of reasoning and harmonizing multiple views of experts with the aim of shortening the time needed for solving the problem, and increasing the value and quality of the solution. The term "knowledge brokering" has been coined recently to express the form of utilization of knowledge, which considers the genuine knowledge owners as service providers for solving global product realization tasks. Although they need to be supported by formal methods and tools, both concepts contribute to a compelling vision for the future. In order to support knowledge sharing among dispersed locations and experts as well as to facilitate the interoperation of knowledge-intensive agents and systems, the development of concept ontologies as common vocabularies have been proposed. Figure 5 shows a general process of development of a design concept ontology.

The same can be claimed for knowledge-intensive system development and "knowledge warehousing". The necessity of development of knowledge intensive systems and intelligent agents originate in the need for a virtual enterprise to reduce the incurred labor cost through the application of smart problem solver or solution supporting software tools wherever it is possible, as well as to defend themselves against the loss of problem solving knowledge whenever human experts are in shortage. In the wake of mass globalization and the birth of the virtual organizations, the strategic thinking of enterprises is unconsciously shifting from tangible to intangible knowledge assets. Knowledge asset management is not a trivial task since the knowledge spreads over all domains of enterprise operations, and can appear in explicit (formal) and/or in implicit (tacit) forms. Knowledge asset warehousing means not only the use of the CVDEs infrastructure to explore, formalize, structure, validate and archive knowledge, but also educating designers and engineers on the creation, sharing, and use of knowledge. A multi-layer asset ontology has been proposed for warehousing knowledge assets of various knowledge domains (Owen, R. and Horváth, I., 2002). This structured ontology incorporates descriptions of units of knowledge as elements. Rather than pursuing a unique axiomatic characterization of the units of knowledge, it targets a semantic structuring of the entire ontology. On the highest level, it categorizes company knowledge as product-, production- and business-orientated knowledge. These generic classes are further decomposed to various units of knowledge according to their kinds. A web of relationships is defined by links that are annotated with the description (the semantics) of the relationship. The links show not only the relationship in terms of content, but also give indication of the context.

8. Amalgamation in virtual enterprise

A virtual enterprise is a proper combination of specialized marketing, designing, manufacture, assembling, distributing and other servicing components. It operates as a decentralized dynamic network with cooperation brokers stimulating the cooperation through servicing. From a system theoretical point of view, a virtual enterprise is a system of open and flexible components, called holons, which are similar in structure and task execution. The holons must be integrated in a unified production infrastructure, a management infrastructure as well as in an information and knowledge infrastructure. Consequently, on the one hand, that a collaborative virtual design environment must be designed to fit as a holonic component, on the other hand, it has to be amalgamated in the above mentioned infrastructures of a virtual enterprise. Part of the problem is integration of models ranging from product models through process models to geographically distributed site models with those of the VE. Providing scientifically supported solutions is the most challenging task for future research and technology development.

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