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# Virtual environments for dynamically reconfigurable Concurrent/Collaborative Engineering "virtual" teams

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ABSTRACT

The paper presents a hypothesis, and its experimental validation, on virtual environments, i.e. Virtual Reality based interfaces, which hide the real appearance of their interlocutors, as enablers, or facilitators, of performance of dynamically reconfigurable "virtual" teams in Concurrent/Collaborative Engineering. Design teams' dynamic reconfiguration may either be a need for (1) their structural and functional optimization (e.g. for improving their productivity) or (2) to support dissipatedness of the design teams in Chaordic Manufacturing Systems. The effect that virtual environments have on reducing the "set-up" time when switching from one interlocutor to another during the communication process is evaluated. The proof of the hypothesis is presented through a statistical evaluation of the experiment.



## 1. Introduction

Virtual environments (VE), with Virtual Reality (VR) as the underlying technology, are proposed as one of the tools for enabling the highest levels of dynamic reconfiguration and "virtuality" of Manufacturing Systems (MS) or organizations [1–3]. Dynamic reconfigurability is one of the most important requirements nowadays and for future MS. Two perspectives are widely recognized by the community: (1) the MS "traditional" approach perspective—as an approach to their structural and functional optimization and (2) the Chaordic Manufacturing System perspective—in order to support the dissipatedness requirement [4]. Additionally, in the European 7th Research Framework Programme (FP7) dynamic reconfigurability of "new production" is already declared as one of the research policy goals [5] (Section 1.3, Activity 4.3, new production, pp. 28–35).

This paper also focuses on VE for processes inherent to dynamic reconfiguration of Concurrent/Collaborative Engineering (CCE) teams, as well as for the processes inherent to dissipatedness in Chaordic MS. This is due to the fact that in the context of MS dynamic reconfiguration, the design should be as quick and as innovative as possible. The CCE teams could use dynamic reconfiguration and VE as a mechanism to effectively and efficiently achieve (1) design solutions for reconfiguration of MS, or (2) dissipations within Chaordic MS.

The research focus on VE for dynamic reconfiguration of CCE teams implies conception, development and evaluation of VE for "enhancement of human being interactions" and "optimization of processes to be executed effectively and efficiently" in "collaborative, interdisciplinary and multicultural design/analysis" [5] (which – human interactions, collaboration, interdisciplinarity and multiculture – are CCE intrinsic features [6]).

This paper presents a VE concept for CCE teams (Sections 2 and 3), the research hypothesis on the effect of VE on reducing the "set-up" time when switching from one to another interlocutor during the communication processes inherent to dynamic reconfigurations of CCE "virtual" teams in (Section 4), the results of experimental validation of the research hypothesis (Section 5) and conclusions (Section 6).

## 2. "Virtuality", virtual environments and dynamic reconfiguration of CCE teams

Two general approaches could be found in the literature concerning the implementation of "virtuality". The first approach implies powerful computer-generated environments based on VR technology. VR is "creating substitutes for real-world objects, events or environments that are acceptable to humans as *real* or *true*. The terms 'virtual environments', 'artificial environments' and 'synthetic environments', are often used interchangeably when the subject of VR is discussed" [7]. This approach, applied mainly for design and control of machines and MS, is widely reported in literature, e.g. [8–10].

In the case of our research, we are interested in the second approach, which uses VR technology to connect the real system to a VR based user-interface. In this case VR does not simulate but *emulate*, i.e. duplicate the real system in another (VR) representation. The user controls the real system even though he/she cannot see it. The user only sees the real system's VR representation. In other words, the real system is hidden (from the user) even though the user has full on-line control of it. Consequently, VE are defined as environments that provide full "virtuality" in the above terms.

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This approach implies a three-level architecture, i.e. *user–emulator–real system*, or *client–emulator–server*, see Fig. 2, in which the role of the ''emulator'' level is to hide the real system and to represent it to the user in some other representations, e.g. VR representation. A much less number of cases have been reported this approach (e.g. it is informed in [11] and an application is presented in [12]). It is important to notice that the studied cases have addressed VE for integrating the equipment, i.e. machine tools and workshops.

In the literature, we did not find any proposal for the use of VE in communication among human actors or amongst enterprises within the inter-enterprise and production networks business processes, and, in particular, among the partners/members of a CCE team and as a tool for enabling dynamic reconfiguration (of the enterprise networks and CCE teams).

Actually, our proposal is to use VE as one of the enablers of dynamic reconfigurability of enterprise/production networks as well as in CCE teams. The motivation is as follows: Every reconfiguration of the system implies some non-productive reconfiguration time (and costs too), which we call the *reconfiguration ''set-up'' time*. The higher the frequency of reconfigurations, i.e. higher reconfiguration dynamics, the higher is the total non-productive time (the sum of reconfiguration ''set-up'' times).

In the case of CCE teams, the basic (human) communication model is characterized by a dialog, meaning each communication party (agent, interlocutor, CEE team member) acts as a sender and as a receiver (of message). The ''non-productive'' communication time ($t_s$) is the time between the end of the reception of the message (e.g. a question) and the beginning of sending the message (e.g. answer).

However, the ''non-productive'' time is higher in the case of the system, i.e. CEE team, reconfiguration. CCE team reconfiguration consists of introducing new members in the team. This is due to fact that the cognitive ''load'' is higher when communication is established with an already known interlocutor. Additional time is necessary when establishing a new relationship. In other words, this phenomenon is a disabler of higher reconfiguration dynamics, as there is a trade-off between reconfiguration frequency (dynamics) and the CCE communication process efficiency, and, consequently, overall Time-To-Market.

Considering the above, the use of VE can eliminate that additional non-productive communication time since the message receiver only sees one, chosen, virtual representation of the real message sender (interlocutor), and eliminates the cognitive overload when the message senders (interlocutors) change, or switch, i.e. when the CCE team reconfigures. In this sense, VE could be considered dynamic reconfigurability enabler.

## 3. Elementary architectures for CCE teams' communication and their dynamic reconfiguration

There are two elementary communication architectures for CCE teams.

The first one is designated as the DCA (Direct Communication Architecture). This is a two-layer architecture, in which the CCE team members (agents, interlocutors, message senders/receivers) see each other ''eye-to-eye'', directly in person (''collocated''), or through video-conference when remote (or distributed).

The second architecture is designated as the VCA (Virtual Communication Architecture). This is a three-layer architecture. In this architecture, the CCE team members do not see each other, they see a VR representation of the other CCE team members (see Fig. 1).

In the case of CCE team (dynamic) reconfigurability communication architectures are a bit more complicated. It is necessary to add an element, i.e. an agent, which will perform the reconfigurations (''switches'').

In the case of the DCA, the elementary architecture has the form of a two-level binary tree, meaning that the interlocutor (receiver/sender) is represented as a tree ''root'' which can ''switch'' between two interlocutors (senders/receivers) that are represented as tree ''leaves''. The reconfiguration agent could be ''embedded'' in the interlocutor himself or can be an external entity that acts only when reconfiguration is required. During the communication, the CCE team members see each other and the reconfiguration agent does not participate.

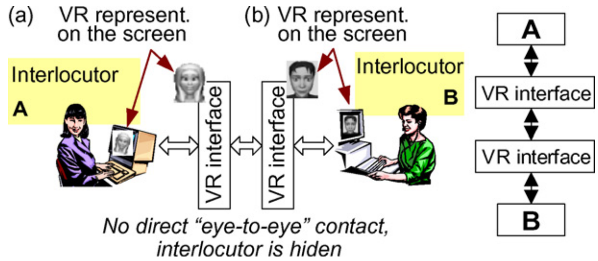


**Fig. 1.** (a) Informal and (b) logical representation of Virtual Communication Architecture (VCA) for CCE team.

In the case of the VCA the architecture is a bit different. It is still a three-level architecture, however, the reconfiguration agent is embedded in the second level between the VR interfaces belonging to the actual and potential CCE interlocutors (see Fig. 2). The role of this agent is to provide reconfiguration from one physical structure to another in a way that the communication and cognitive process of the CCE agents is not affected. The reconfiguration agent participates all the time, during operation as well as during reconfiguration. In this sense, the agent can also be called an ''agent of virtuality''. We designate this agent as a ''broker'' or a ''mediator''. In the case of CCE

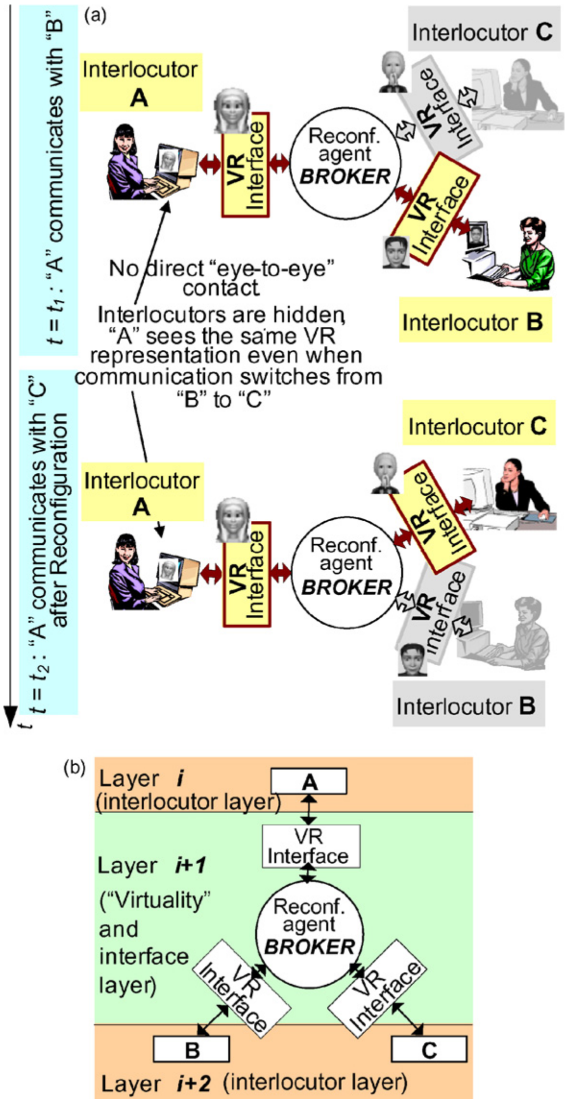


**Fig. 2.** (a) Informal and (b) logical representation—of VCA with reconfiguration of CCE ''virtual'' teams and dissipatedness in Chaordic MS.