42

IDENTIFYING PARTNERS AND ORGANIZATIONAL LOGICAL STRUCTURES FOR COLLABORATIVE CONCEPTUAL DESIGN

Antonio P. Volpentesta, Maurizio Muzzupappa
Università della Calabria, volpentesta@deis.unical.it, muzzupappa@unical.it
ITALY

Recently much interest has been devoted to novel distributed approaches which lead to the formation of collaborative networked organizations, e.g. virtual organizations, specifically oriented to generate an innovative product concept. Making use of logical-formal structures based on concepts related to directed hypergraphs, we formally represent competitive inter-organization and collaborative intra-organization relationships. Thanks to these structures, models for distributed processes which lead to the emergence of both design chains and functional architectures of an innovative product are formally described and then illustrated through examples from an applicative scenario.

1. INTRODUCTION

The main contribution of this paper is aimed to give an answer to new decision problems that arise in managing early lifecycle phases of a Virtual Organization (VO) which is specifically oriented to generate an innovative product concept. In particular, we focalize our attention on conceptual design and VO formation phases (fig.1). Referring to the product lifecycle, conceptual design is the creative phase which is placed between the product planning and the embodiment design phases (Pahl, 1996). Main goals are generation of concepts (ideas) and specification of function structure (architecture) of a product. Referring to the VO lifecycle, formation phase of a VO includes partners and organizational logical structure identification. In a collaborative conceptual design, partner companies should be able not only to provide information about resources and equipment for their part of the business, but also to share appropriate knowledge and technologies for a VO formation (Camarinha,1999).

The study of formation process of a VO oriented to collaborative concept generation is relevant for the following reasons:

- the knowledge of a single design office (or enterprise) is often not sufficient to let emerge the conception of an innovative competitive product.
- in principle, a large number of design offices may exploit a wider range of competences and knowledge.

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- high levels of creativity may be achieved through effective collaboration of many distributed DOs.
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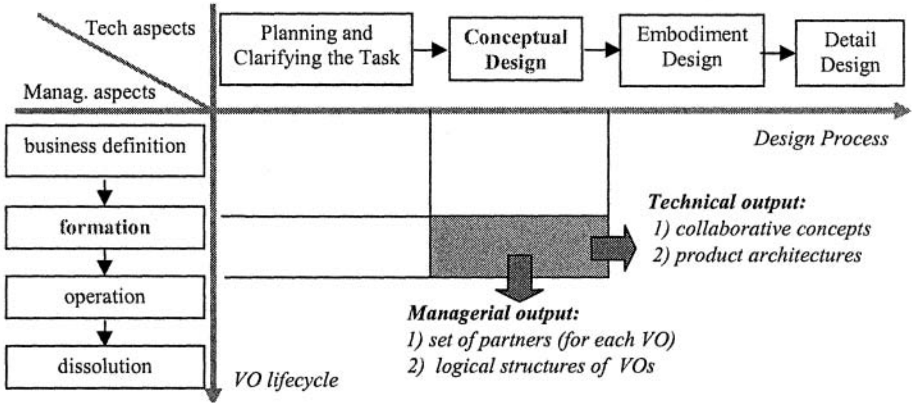

Figure 1 – Design Process and VO lifecycle

Due to interdependencies between managerial and technical problems, classical approaches (Frutos, 2004) for partners identification and VO formation are inadequate. As matter of fact, partners identification relies on the description of concept requirements but this knowledge is available only afterwards partners are already identified. Thus, knowledge and technologies cannot be well defined "a-priori". Moreover, VO partners rarely give away valuable concept design knowledge without expecting something in return. The formation process should utilize all and only information which is strictly necessary to define a VO architecture (members, their interactions and their roles in contributing toward the VO goal which is the generation of a new concept), but it could not rely on complete product part concepts description in order to not compromise enterprise private knowledge. In a previous paper (Volpentesta et al. 2005), we have outlined a combined approach where managerial and technical solutions are determined step by step in a circular way. In this paper, we introduce logical formal structures aimed to represent competitive inter-organization and collaborative intra-organization relationships in a Virtual Breeding Environment (VBE, for short) for conceptual design and we present formal process models for the formation of such structures.

2. RELATED WORK

Since the first appearance of the concept of VO much attention has been increasingly devoted to how to manage collaborative design in networked environment. Many researchers have tackled different aspects of this problem, from a technological and organizational point of view. In (Chiu, 2002), the authors provides a basic understanding of the role of organization in design collaboration and how it affects design communication and collaboration by empirical case studies.. An integrated environment for the coordination and management of worldwide-distributed multifunctional design teams (marketing analysists, engineering designers, suppliers, etc.) is proposed in (Tseng, 2004). A feature-based collaborative design system capable to support a distributed product development process in a virtual enterprise is presented in (Huifen, 2003). In (Baia, 2005), the authors introduce a Product Layout Feature model to resolve the problem of consistently maintaining a product scheme while collaborative activities among multi-teams from different disciplines are carried out. An approach to develop a knowledge repository as a basis for a domain ontology for conflicts is proposed in (Yesilbas, 2004). Specific studies are devoted to collaborative conceptual design. Haung and Mak propose a morphological chart analysis method to develop a set of Web-based design tools (Haung,1999). Extended reviews about methodologies and supporting technologies can be found in (Wang,2002;Roy,2000).

In order to study VO specifically oriented to the early stage of collaborative concept design, a key challenge is to determine how identify VO partners and product structure in a collaborative network environment. In (Haung, 2003) a prototype system embedding a Concept Base and a Solution Base is presented. Such a system is aimed to support synchronous/asynchronous collaboration in product concept definition. However, the authors don't face the problem of how to manage distributed knowledge to populate the system Bases. In (Chu, 2002), an integrated product design and partner synthesis process model is described. Such a model relies on the assumptions that "there is a master company which takes charge of selecting and managing its partner factories" and "the product development and production are distributed among the master company and all partner factories". This means that the product structure is always defined by a master company, so that it is impossible to achieve high levels of creativity by effectively taking advantage of distributed knowledge among many interacting design peers. Decentralized product design is considered in (Giannini, 2002), where "the emphasis is given to the product specification, and to the negotiation activity usually carried out to identify the right project partner and the final product configuration" in an enterprise network. The paper does not deal with the problem of which the network structure could be and how it can arise from a broader enterprise networked environment.

Our paper searches for answers to open issues related to the above-cited works. The main contribution consists in the introduction of a formal process model for the emergence of VO and product structures in a VBE oriented to collaborative conceptual design.

3. VBE FOR COLLABORATIVE CONCEPT DESIGN

Recently, the concept of VBE has emerged as the necessary context for effective creation of VOs. In (Camarinha-Matos, 2003) a VBE is defined as "an association of organizations and their related supporting institutions, adhering to a base long term cooperation agreement, and adoption of common operating principles and infrastructures, with the main goal of increasing both their chances and their preparedness towards collaboration in potential virtual enterprises". In our approach, VBE has the goal of blending collaboration contributions of a set of Design Offices (DOs) partners, in order to form a VE which is in principle capable of bringing new product concepts to life. In particular, a VBE for collaborative concept design consists of:

- a set of DOs which supply Requests for Concepts (RFCs), conditioned undertakings to respond to an RFC and RFC responses.
- a VO-planner that identifies a new collaboration opportunity and let it now to all DOs in the VBE (by launching an initial RFC). It selects necessary competencies and capacities for VOs capable in principle to seize the opportunity. Such a process may be carried out through managing RFCs, conditioned undertakings and RFC responses.

An RFC defines a set of requirements for a functional concept, by specifying characteristic parameters and their value range. These parameters generally refer to technical/functional requirements of a product element or part. However, they may also refer to requirements that a DO must satisfy when responding to the RFC, or to assessment criteria that may be used for ranking the concepts received from respondents to the RFC. Conditioned undertaking to respond to an RFC is an expression of interest to respond conditional on obtaining responses to other related RFCs. A response to an RFC consists of a functional concept description including, if necessary, other additional useful details. In the approach proposed in (Volpentesta et al., 2005), two main distributed processes (coordinated by VO-planner) take place in the VBE: *Conceptual Design Network Formation and Concepts Functionality and VOs Identification*. The first one defines a network consisting of all logical structures of VOs that rely on a collaborative minimal organization potentially capable of responding to the initial RFC coming from the VO-planner. The second one determines both concepts functionality and formal structures of VOs that are realistically able to generate the required product concept. In what follows, we give a formal representation of the two main processes necessary to identify partners and logical structures of VOs capable in principle to generate an innovative product concept in a VBE.

4. FORMAL STRUCTURES MODELS

In this section we introduce formal structures which are underneath concept design networks and VOs in a VBE. Such structures are based on concepts related to hyperpaths, hypernetworks and direct hypergraphs that are defined and studied in (Volpentesta, 2005; Nielsen, 2005).

In our context of reference, a Design Request Network is a triplet

$$\mathcal{R}=(\mathcal{H},O,\alpha)$$

where:

1. $\mathcal{H}=(\mathcal{N},\mathcal{E})$ is a directed hypergraph[1] in which
   - each node $n \in \mathcal{N}$ univocally identifies an *RFC* and where $s,d \in \mathcal{N}$ are two particular nodes: s is the "dummy" RFC for which no response is required, d is the initial RFC (say RFC_0) to which at least a response is required.
   - each hyperarc $e \in \mathcal{E}$ individuates an expression of interest to respond to the RFC identified by $h(e)$, conditional on obtaining responses to RFCs identified by nodes in $T(e)$;
2. O is a set of DOs in the VBE;
3. α: $\mathcal{E}\rightarrow O$, is a function from $\mathcal{E}$ to O, $\alpha(\mathcal{E})$ individuates the DO that has given the conditioned undertaking individuated by e.

Let $\mathcal{H}_\pi=(\mathcal{N}_\pi,\mathcal{E}_\pi)$ be a sub-hypergraph of $\mathcal{H}$ and let $\alpha_\pi:\mathcal{E}_\pi\rightarrow O$ be the restriction of α on $\mathcal{E}_\pi$. It is reasonable to identify a VO architecture with a triplet $\mathcal{R}_\pi=(\mathcal{H}_\pi,O,\alpha_\pi)$ where $\mathcal{H}_\pi$ is an hyperpath[2] from s to d, and we refer to it with the term *Design Chain* (DC). The fact that d is hyperconnected to s in $\mathcal{H}_\pi$ guarantees that initial RFC associated to d could receive a response by a means of recursive composition of responses to RFCs associated to nodes of $\mathcal{H}_\pi$. The fact that $\mathcal{H}_\pi$ is cycle free guarantees that stalemate situations in the *Concept Functionality Identification* phase do not happen. A stalemate situation occurs when some DOs are not able to respond to RFCs, even though they have expressed to interest to respond to it. A DC represents a formal model for a VO which, relying on a collaborative and minimal organizational structure in a Design Request Network, is potentially capable of responding to RFC_0 coming from the VBE. On the one hand it defines a decomposition of the RFC_0 in other less complex ones, on the other hand it identifies the DOs and information exchanges requirements necessary to respond to RFC_0. Of course, there exists a DC in $\mathcal{R}$ if and only if d is hyperconnected to s in $\mathcal{H}$. In such a case, we may consider the hypernetwork $\mathcal{H}_{\eta_{sd}}=(\mathcal{N}_{\eta_{sd}},\mathcal{E}_{\eta_{sd}})$ on $\mathcal{H}$, i.e. the union of all hyperpaths from s to d in $\mathcal{H}$, and we refer to the triplet $\mathcal{R}_{sd}=(\mathcal{H}_{\eta_{sd}},O,\alpha_{\eta_{sd}})$ with the term Conceptual Design Network. This network may be regarded as the union of all DCs in the Design Request Network. Within a DC its DOs collaborate to get a construction, in terms of functional elements, of the new product concept, required by the RFC_0, while, within the Conceptual Design Network, its DCs compete in order to be included among best VOs in developing a new product concept.

4.1 An applicative scenario

Let us consider a scenario in which VO-planner has forwarded an RFC_0 (i.e. d=RFC_0) for an innovative product concept of a jigsaw with lower cost and better easy-to-handle than the ones available on the market. The RFC_0 requires the design of an innovate jigsaw through an original and unusual re-combination of existing technologies and components. A Design Request Network may be represented by a set of tables and an hypergraph. All RFCs forwarded by DOs are described in table 1, where:

- columns are associated to RFCs,
- rows are associated to parameters considered in RFCs of jigsaw parts,
- the entry at place *(i,j)* contains the *j-th* parameter value ranges specified by RFC_i.

For sake of simplicity, we have simply restricted functional features exploration to the combination of a very limited number of parts, i.e. gear boxes, electric motors and crank mechanisms. The symbol x indicates that no specific constraints are required. The relation between RFCs and conditioned undertakings is represented by table 2, where:

- columns are associated to conditioned undertakings, denoted by $e_1, \ldots, e_{11}$;
- the entry in the first row at place *(1,j)* contains the index of the RFC for which e_j represent a conditioned undertaking to give a response,
- the entry in the first row at place *(2,j)* contains the indices of RFCs whose responses are declared in the conditioned undertaking e_j to be necessary.

Table.1. RFCs for a jigsaw

	Name of component	*Electric Power*	*Stroke Length*	*Load Speed (stokes/min)*	*Rotation (rpm)*	*Gear Ratio*	*Process requir.*
RFC_0	JigSaw						IGS format
RFC_1	Electric motor	300-500 (W)	x	x	2.500–3.000	x	"
RFC_2	Crank Mechanism	x	20-30 (mm)	2.000-3.000	x	x	"
RFC_3	Electric motor	500-750 (W)	x	x	5.000-7.500	x	"
RFC_4	Gear Box	x	x	x	x	0.5 - 1	"
RFC_5	Gearing	x	x	x	x	0.5 - 1	"
RFC_6	Eccentric	x	10-15 (mm)	2.000-2.500	x	x	"
RFC_{dummy}	x	x	x	x	x	x	x

For example, e_8 represents a conditioned undertaking to respond to RFC_4 (request for a gear box) provided that responses to RFC_3 (request for an electric motor) and to RFC_5 (request for a gearing) are available. Table 3 associates any conditioned undertaking to a DO.

Table.2. Conditioned undertakings/RFCs

e_1	e_2	e_3	e_4	e_5	e_6	e_7	e_8	e_9	e_{10}	e_{11}
0	0	0	1	2	2	3	4	5	0	3
1	1,2	3,4	dummy	dummy	dummy	dummy	3,5	dummy	1	4

Table.3 Conditioned undertakings /DOs.

conditioned undertakings	*Design Office*
e_1, e_3, e_6	DO_1
e_2, e_8, e_{10}	DO_2
e_4, e_{11}	DO_3
e_5	DO_4
e_7	DO_5
e_9	DO_6

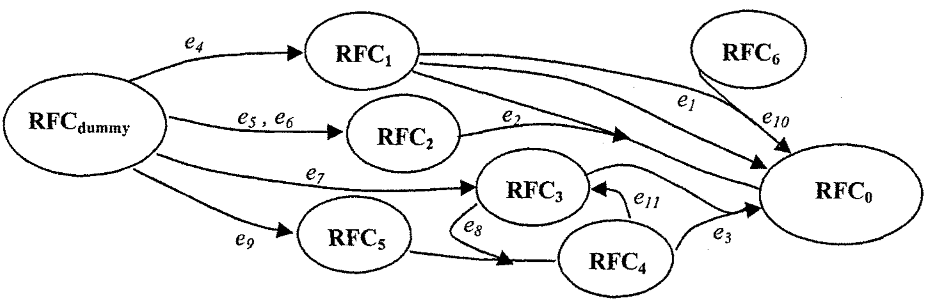

Figure 2 – The hypergraph $\mathcal{H}$ of the DRN

The three tables define a Design Request Network for a jigsaw concept. In particular, a graphical representation of the hypergraph $\mathcal{H}$ of such a Design Request Network is shown in figure 2. One may easily notice that RFC_6 is the only node which is not s-hyperconnected to s in $\mathcal{H}$. And that e_{10} and e_{11} are the only hyperarcs which do not belong to any hyperpath from s to d in $\mathcal{H}$. Their elimination determines the hypernetwork $\mathcal{H}_{\eta_{sd}}$ on $\mathcal{H}$. Such hypernetwork consists of the union of four hyperpaths corresponding to four DCs. Table 4 indicates the DOs involved in each DC.

Table.4 The Design Chains/DOs correspondance.

Design Chain	*Design Offices*
1	DO_1, DO_3
2	DO_2, DO_3, DO_4
3	DO_1, DO_2, DO_3
4	DO_1, DO_2, DO_5, DO_6

5. IDENTIFYING VO PARTNERS AND STRUCTURES

5.1. Conceptual Design Network formation

A request of a new product concept is represented by RFC_0 which is forwarded to the DOs in the VBE by the VO-planner. The problem we consider is how to individuate all DOs aggregations potentially capable of getting a collaborative construction of the product concept required by the RFC. In this section we describe a distributed process which leads to the emergence of a Design Request Network and, after that, lets the VO-planner determine the Conceptual Design Network. The process takes place in an established lapse of time during which each DO is able to:

- select an RFC, say r, amongst the ones which have been forwarded by the VO-planner,
- carry out a preliminary functional feature exploration to decide if it may respond to r and, in that case, let the VO-planner know the set $\mathcal{T}$ of all RFCs whose responses are considered sufficient and necessary to respond to r,
- send to the VO-planner an expression of interest to respond to r, conditional on obtaining responses to the RFCs in $\mathcal{T}$.

As DOs express their interest to respond to RFCs, a Design Request Network emerges. At the VO-planner side, its representation is obtained by adding RFCs and instances of both relations between RFCs/conditioned undertakings and conditioned undertakings/DOs, from time to time, until the time deadline is reached. In what follows the process, aimed to generate a Design Request Network, is formally described. Let:

d: the initial RFC forwarded by the VO-planner,
t_0: the moment in which d has been forwarded to the DOs in the VBE,
$t^{\wedge}$: the deadline by which the Design Request Network should be generated,
s: the "dummy" RFC whose response is not required,
O: the set of DOs in the VBE,
$t_1, t_2, \ldots, t_m$ (with $t_0 < t_1 < \ldots < t_m \leq t^{\wedge}$): the moments in which a DO (say o_i) sends to the VO-planner an expression of interest to respond to an RFC (say n_i), conditional on obtaining responses to RFCs, each of which is represented by a node in the set $\mathcal{T}_i$.

The process consists of the following steps :

- (inizialization at time t_0) set $\mathcal{N}^0=\{s,d\}$, $\mathcal{E}^0=\emptyset$, $\alpha^0=\emptyset$;
- (iterative updating at time t_i) for $i=1, \ldots, m$,

  $\mathcal{T}_V = \mathcal{T}_i \cap \mathcal{N}^{i-1}$; $\mathcal{T}_V$ represents the set of RFCs forwarded before time t_i and whose responses are necessary to o_i to respond to n_i;

  $\mathcal{T}_N = \mathcal{T}_i - \mathcal{T}_V$; $\mathcal{T}_N$ represents the set of new RFCs forwarded at time t_i and whose responses are necessary to o_i to respond to n_i;

  $\mathcal{N}^i = \mathcal{N}^{i-1} \cup \mathcal{T}_N$; $\mathcal{N}^i$ represents the set of all RFCs forwarded in the interval $[t_0, t_i]$;

  e_i: the hyperarc defined by setting $\mathcal{T}(e_i)=\mathcal{T}_i$, $h(e_i)=n_i$. It represents the conditioned undertaking given by o_i at time t_i

  $\mathcal{E}^i = \mathcal{E}^{i-1} \cup \{e_i\}$; $\mathcal{E}^i$ represents the set of all conditioned undertakings given by some DO in the VBE;

  $\alpha^i=\alpha^{i-1}$ on $\mathcal{E}^{i-1}$, $\alpha^i(e_i) = o_i$; it represents the functional relation between conditioned undertakings and DOs.
- (process end at time t^*) set $\mathcal{R}=(\mathcal{H}, O, \alpha)$, with $\mathcal{H} = (\mathcal{N}, \mathcal{E})$, $\mathcal{N}=\mathcal{N}^m$, $\mathcal{E}=\mathcal{E}^m$, $\alpha=\alpha^m$.

Once the Design Request Network, denoted by $\mathcal{R}=(\mathcal{H}, O, \alpha)$, has been generated, the VO-planner may verify the hyperconnection of d to s in $\mathcal{H}$, by means of a hypergraph traversal algorithm that runs in polynomial time on the size of $\mathcal{H}$ (Nielsen, 2005; Volpentesta, 2005). Thus, the VO-planner is able to know if there exists at least one VO potentially capable of generating a product concept required by the RFC_0. Moreover, under some reasonable assumptions that reflect the reality of collaborative concept design, the hypernetwork $\mathcal{H}_{\eta_{sd}}$ on $\mathcal{H}$ may be found in polynomial time on the size of $\mathcal{H}$ and all the hyperpaths $\mathcal{H}_\pi$, $\pi \in \Pi(s,d)$ may be found in polynomial time on the cardinality of $\Pi(s,d)$, (Volpentesta, 2005). Thus, the VO-planner is able to determine $\mathcal{R}_{sd}=(\mathcal{H}_{\eta_{sd}}, O, \alpha_{\eta_{sd}})$ and $\mathcal{R}_\pi=(\mathcal{H}_\pi, O, \alpha_\pi)$, with $\pi \in \Pi(s,d)$, i.e. the Conceptual Design Network and all its DCs, respectively.

5.2. Concepts functionality and VOs identification

In what follows, we assume that there exists at least one DC in $\mathcal{R}=(\mathcal{H}, O, \alpha)$, i.e. d is hyperconnected to s in $\mathcal{H}$. The process is divided in two phases: a) functional description phase; b) functional concept and DC evaluation.

a) In this phase, a recursive composition of Functional Description Tasks (FDTs), carried out by DOs along the Conceptual Design Network, takes place. The aim is to obtain functionality descriptions of the concept required by the RFC_0. Any FDT is associated to an hyperarc e in $\mathcal{E}_{\eta_{sd}}$, i.e. a conditioned undertaking in the Conceptual Design Network; the responses to RFCs identified by nodes in $\mathcal{T}(e)$ are the input of such FDT, while the response (eventually, a "null" response) to the RFC identified by $h(e)$ is the output. The FDT consists of a more or less detailed description (functional schemes, CAD models, delivery time, ...) of a new product part concept in accordance with requirements established by the RFC. A FDT is executed as many times as the number of DCs where the conditioned undertaking associated to the FDT occurs. This is due to the fact that FDT could be carried out according to some distinctive organizational, economical and technical criteria depending on the particular DC. Hence, executions of a FDT may take place only after the Conceptual Design Network has been individuated, since they depend on information which are available only after DCs have been individuated. Let $\mathcal{R}_{sd}=(\mathcal{H}_{\eta_{sd}}, O, \alpha_{\eta_{sd}})$ and $\mathcal{R}_{\pi}=(\mathcal{H}_{\pi}, O, \alpha_{\pi})$, with $\pi \in \Pi(s,d)$, be, respectively, the Conceptual Design Network and all its DCs. Set:

$$\Pi(e)=\{\pi \in \Pi(s,d): e \in \mathcal{E}_{\pi}\}, \text{ for any } e \in \mathcal{E}_{\eta_{sd}}$$

and, for any $\pi \in \Pi(e)$, denote by $q_{\pi,e}$ the response to the RFC associated with $h(e)$ and given by $\alpha_{\pi}(e)$ when participating to the DC represented by $\mathcal{R}_{\pi}$. Of course, such a response may be a "null response" (say $q_{\varnothing}$), i.e. a message attesting no response will be given. For any $e \in \mathcal{E}_{\eta_{sd}}$, set:

$$Q(e)=(q_{\pi,e}),\ \pi \in \Pi(e)$$

and let $$Q=(Q(e)),\ e \in \mathcal{E}_{\eta_{sd}}$$

This phase is aimed to determine Q and, in what follows, we will see how it can be carried out. Since $e \in \mathcal{E}_{\eta_{sd}}$ and $\pi \in \Pi(e)$ if and only if $\pi \in \Pi(s,d)$ and $e \in \mathcal{E}_{\pi}$, we have

$$Q=(q_{\pi,e}),\ \pi \in \Pi(s,d),\ e \in \mathcal{E}_{\pi}$$

Therefore the phase may be divided into sub-phases $\mathcal{P}_{\pi}$, $\pi \in \Pi(s,d)$, each of which leads to the determination of

$$Q_{\pi}=(q_{\pi,e}),\ e \in \mathcal{E}_{\pi}$$

As it is shown in (Volpentesta, 2005) we have that $\forall\ n \in \mathcal{N}_{\pi}$, with $n \neq s$, $\exists_1\, e \in \mathcal{E}_{\pi}$ such that $h(e)=n$; hence, by setting $q_{\pi,n}=q_{\pi,e(n)}$, where $e(n)$ is the element of $\mathcal{E}_{\pi}$ such that $h(e)=n$, we have

$$Q_{\pi}=(q_{\pi,n}),\ n \in \mathcal{N}_{\pi}-\{s\}$$

This means that a response to any RFC, different from s, in $\mathcal{N}_{\pi}$, may be determined by recursively composing executions of FDTs along the DC represented by $\mathcal{R}_{\pi}$. As matter of fact, the FDT associated with $e(n)$ in $\mathcal{R}_{\pi}$ may be modelled as a computation of a function $f_{\pi,e(n)}$ which depends on the RFC individuated by n and on the responses $(q_{\pi,m})_{m \in \mathcal{T}(e(n))}$. Thus we have:

$$q_{\pi,n}=f_{\pi,e(n)}(n, (q_{\pi,m})_{m \in \mathcal{T}(e(n))}),\ \forall\ n \in \mathcal{N}_{\pi}-\{s\}$$

where $q_{\pi,n}=q_{\varnothing}$, if $q_{\pi,m}=q_{\varnothing}$ for some $m \in \mathcal{T}(e(n))$.

Now, let $q_{\pi,s}$ be the "dummy" response to the "dummy" RFC associated with s and let $k=|\mathcal{E}_{\pi}|$. It follows that $|\mathcal{N}_{\pi}|=k+1$, (see footnote 2); the values in Q_{π} may be computed according to any sequence $s=n_0, n_1, \ldots, n_k=d$ such that $\mathcal{T}(e(n_i)) \subseteq \{n_0, n_1, \ldots, n_{i-1}\}$, for $i=1,\ldots,k$. The existence of at least one of these sequences is proved in (Volpentesta, 2005), and therefore the sub-process $\mathcal{P}_{\pi}$ can be actually carried out.

b) Once all responses in Q_{π}, $\pi \in \Pi(s,d)$ have been determined, the pairs $(\mathcal{R}_{\pi}, Q_{\pi})$, $\pi \in \Pi(s,d)$, may be ranked according to an evaluation function $v(\mathcal{R}_{\pi}, Q_{\pi})$ which is based on assessment criteria previously established by the VO-planner of the VBE. A model of such a function may take into account various organization factors (costs and time for the concept generation, relationship trust, coherence and cohesion, ...) with respect to a DC, as well as technical aspects (innovation level, consistency, feasibility, ...) with respect to concept functionality. Such an evaluation allows the VO-planner to identify those DCs that may constitute into VOs.

6. CONCLUSIONS

The shifting of the companies' attention from the necessity of "what to design" to the idea of "how to design", has led to the rising of new organizational models which can support innovative design paradigms such as co-design and concurrent engineering. In keeping with the viewpoint above, we have formalized an approach by which new concept function architectures and VO structures take shape in a circular way in a VBE for collaborative concept design. Hypernetworks and hyperpaths have been proposed as meaningful tools to represent logical structures underlying Conceptual Design Networks and Design Chains, respectively. This has allowed us to present a formal model of a process which identifies DO partners and their knowledge exchanges in a VO devoted to generate an innovative concept.

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[1] A *directed hypergraph* $\mathcal{H}$ is a pair $(\mathcal{N},\mathcal{E})$ where $\mathcal{N}$ is a non empty set of nodes and $\mathcal{E}$ is a set of hyperarcs; a hyperarc $e \in \mathcal{E}$ is defined as a pair $(\mathcal{T}(e), h(e))$, where $\mathcal{T}(e) \subseteq \mathcal{N}$, with $\mathcal{T}(e) \neq \emptyset$, is its *tail*, and $h(e) \in \mathcal{N} - \mathcal{T}(e)$ is its *head*.

[2] Let $\mathcal{H}=(\mathcal{N},\mathcal{E})$ be a directed hypergraph and let $s,d \in \mathcal{N}$. $\mathcal{N}' \subseteq \mathcal{N}$ is *s-hyperconnected* in $\mathcal{H}$ if $\mathcal{N}'=\{s\}$ or $\exists e \in \mathcal{E}$ such that $\mathcal{T}(e) \subseteq \mathcal{N}'$ and $\mathcal{N}'-\{h(e)\}$ is *s-hyperconnected* in $\mathcal{H}$. We also say that n is *hyperconnected* to s in $\mathcal{H}$ if $\exists \mathcal{N}' \subseteq \mathcal{N}$ *s-hyperconnected* in $\mathcal{H}$ and $n \in \mathcal{N}'$. A *sub-hypergraph* $\mathcal{H}_\pi=(\mathcal{N}_\pi,\mathcal{E}_\pi)$ of $\mathcal{H}$, with $s,d \in \mathcal{N}_\pi$, is a hyperpath in $\mathcal{H}$ from s to d if $\mathcal{N}_\pi$ is *s-hyperconnected* in $\mathcal{H}_\pi$ and d is not *hyperconnected* to s in $(\mathcal{N}_\pi,\mathcal{E}_\pi-\{e\})$, $\forall\ e \in \mathcal{E}_\pi$. It's immediate to see that a hyperpath is cycle free and that one plus the number of its hyperarcs is equal to the number of its nodes.