Collaborative Engineering definition: Distinguishing it from Concurrent Engineering through the complexity and semiotics lenses

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Abstract. A contribution to the definition of Collaborative Engineering (CoE), together with the definition itself, are presented. The need for a more rigorous definition is due to the fact that the Collaborative Engineering (CoE) definitions in literature within the so-called “classical” discourse in fact could be reduced to the Concurrent Engineering (CE), making synonymy between the two terms. However, the need for distinguishing the semantic contents of the two terms and concepts, Collaborative Engineering and Concurrent Engineering, could be understood to be driven mainly by new, emergent, organizational and management concepts that refer to new features required for the engineering design organizational and management approaches. The two new, emerging theories and paradigms, that inform design and practice of new, emerging engineering design theories, approaches and practices, and based on which the definition of the Collaborative Engineering is proposed are the complexity theory and semiotics, in particular the complexity management in organizations and organizational semiotics.

1. Introduction

The paper’s objective is to contribute to the definition of Collaborative Engineering (CoE). The need for this definition is due to the fact that the definitions (of CoE) that could be found in the literature are many times confusing referring to the same features as the Concurrent Engineering (CE) features, meaning that for the same concept two different terms are used. While this situation is acceptable in some contexts, other contexts require clear distinction of meanings by two terms.

The need for distinguishing the semantic contents of the two terms, CoE and CE, could be understood to be driven mainly by new, emergent, organizational and management concepts that refer to new features required for the engineering design organizational and management approaches.
These new, emergent, organizational and management concepts, that open new space for defining new approaches to engineering design, are mainly based on two main sources.

The first source of the need for definition of a new engineering design organizational and management approach is emerging complexity thinking paradigm, that is, in its model oriented to “chaos and complexity in organizations” called Chaordic System Thinking (CST). The second source of the need for definition of a new engineering design organizational and management approach is semiotics, that is, organizational semiotics. Organizational semiotics is closely related to the complexity thinking paradigm, i.e. both share a number of similar and/or equal concepts.

One of the questions is how to name this new engineering design organizational and management approach. The authors propose, that this new engineering design organizational and management approach to be named Collaborative Engineering.

In this paper a definition of CoE through the lenses of Complexity thinking and Semiotics will be presented, which will make a clear distinction from well-known CE. In this due, the paper will present the related concepts, as well as the features of the CoE, as a new engineering design approach.

2. Collaborative Engineering (CoE) and Concurrent Engineering (CE) are synonyms within the “classical” discourse

Considering the differences between the semantic contents of the terms CoE and CE, i.e. between their definitions, the first step is to recall the definitions of the term definition itself. Historically, the perception of the meaning of the term definition has evolved within the areas of logic and linguistics.

The “classical” approach considers that the role, or function, of a definition of some concept, phenomenon, object - denominated by a term or syntagm (such as the terms and/or syntagms for denominations of the concepts we are addressing in this paper, i.e. of the concepts of "concurrent" and "collaborative", "concurrent engineering", "collaborative engineering") - is to describe precisely that concept, phenomenon, object. This type of definition is called "normative" or “prescriptive” definition (the first discussion on the topic by the authors of this paper is published in [1]). The normative, or prescriptive, definitions are those in which it is prescribed how something should be in reality. Normativity denotes theory, ordering and truth.

As described in [1], when analyzing the descriptions, their semantics adopted in common language, of the terms “concurrent” and “collaborative” taken from the commonly used dictionaries, namely from the on-line Merriam-Webster’s dictionary [2], it is easy to see that the terms “concurrent” and “collaborative” are usually considered as synonymous.

Consequently, the syntagms “Simultaneous Engineering”, “Concurrent Engineering” and “Collaborative Engineering” should be considered to denominate the equivalent concepts, i.e. the respective terms/syntagms are synonymous, see [1].

The “common features” referred to both CE and CoE are e.g. 1) approaches oriented to, we would call it, “conventional” engineering/design environment, which is a company. The “company”, as the organizational, management and phenomenological environment implies 2) the common goal, meaning practically without exception the common product, to the (members of) engineering/design team. In other words, the goal product is given. 3) Another implicit engineering/design feature implicit to “company” is that the main management goal is some kind of “efficiency”, e.g. coordination, or conflict resolution in engineering/design activities [1]. Phenomenologically, whenever “multifunctional teams”, or “stakeholders along the product life-cycle” within the “company” are referred, “conflicting interests”, the CoE could be, virtually, reduced to, or interpreted as synonymous to CE [1] (we should not forget that we are talking about the definitions within the “classical” approach/discourse).

One of the typical examples of using two different terms for the same concept is in [3]. Citing from [1]: “in [3], the CoE is defined as ‘A Formal Definition of Collaborative Engineering facilitates the

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1 When discussed the feature of the “common goal” and/or “given goal” one of the international experts, participant in discussion, said that he never participated in any engineering/design meeting without “common” or “given” goal.
communal establishment of technical agreements among a team of interdisciplinary stakeholders, who work jointly toward a common goal with limited resources or conflicting interests2, and (specifying the decision making methodology) “Engineering Collaboration via Negotiation (ECN)”. However, the suggested ‘new’ decision making methodology ‘negotiation’, is just a tool for conflict resolution in CE.

3. Non-“classical” discourse for distinction between the Collaborative Engineering and Concurrent Engineering definitions

However, today, it is known that the semantics of the terms, or syntagms, of the concepts by itself is not sufficient, but it (the semantics) should be considered within the context in which it has been defined and in which (context) it is used, considering that each phenomenon is context sensitive, and changing the context the semantics could (but not necessarily) change as well. This is especially notable when considering new scientific discoveries, research results and technological developments and innovations, especially in engineering sciences. These new discoveries, in fact, generate motivations, and needs, to change the semantic contents of the previously “established” definitions, and, consequently, their change or defining new definitions.

This reality led to "abandoning" of “normative” or “prescriptive” approach to definition of definitions, and to the formulation of, so called, "descriptive" definitions. The descriptive definitions are those in which the reality is described and analyzed in different “spheres” (domains, fields, use, applications and circumstances) and contexts [1].

Actually, a number of problems arise. These could be resumed as follows [1]:

1) keeping the same denomiating term, or syntagm, for different semantic contents, implying different definitions, and
2) using different denomiating term, or syntagm, for the same semantic contents, implying same definitions.

Both situations happens in relation with the terms/syntagms: "concurrent" and "collaborative", i.e. with the "concurrent engineering" and "collaborative engineering", see [1].

Is this situation acceptable?

From the point of view of the co-called “classical” (normative, prescriptive) approach this is not acceptable. From the other side, from the non-“classical” (descriptive) approach this is acceptable, and even desirable. In fact, we need both approaches.

The theory “behind” this position, that we need both approaches, could be the view from semiotics on development of “signs” [4]. Paraphrasing Guiraud’s (1975) scheme [5], Figure 1 presents an explanation of the sign, i.e. the definitions, changes and creation and changes of ‘fields of observations’, or ‘information fields’, and influence of the ‘individual/community’ and ‘society’ on the “collaborative (engineering)” paradigm definition, through the enrichment or ‘impoverishment’ of the potential for innovation and novelty of the “collaborative (engineering)” definition and of the potential for the “collaborative (engineering)” effectiveness or efficiency.

The scheme from the Figure 1 in fact means that the needs for the knowledge and “codification”, i.e. it could be said, the needs for the “normative” definitions, grows with the need of society, i.e. for the communication within the society, while when there are needs for change, originality, innovation, novelty, the need for the “normative” definitions diminish and the need for learning and “de-codification” grows.

In other words, with the development of new approaches to the engineering design, new organizational and management forms emerges and the need for changing the semantic contents of the terms and syntagms of the "collaborative" and "collaborative engineering" usually considered within the “classical” approach, or within the “classical” discourse, especially in relation to the terms and syntagms "concurrent" and "concurrent engineering", emerges as well.

So, to define “Collaborative Engineering” as distinct from “Concurrent Engineering” (because ‘nomen est omen’), the question is which are the new, emerging engineering/design theories, approaches

2 Bold letters by the authors of this paper
or practices where there is no “competing/concurrent/conflicting interests” over the common goal product to the group of engineers that “collaborate”? [1]

![Figure 1. Influence of the ‘individual/community’ and ‘society’ on the paradigm characterisation and definition [4].](image)

4. Chaordic System Thinking (CST) and Semiotic frameworks for defining a new engineering design organizational and management approach

The new, emerging theories and paradigms, that could inform design and practice of the new, emerging engineering design theories, approaches or practices, and that could represent an instrumental framework for their development, are without doubts those that are changing, and transforming the “traditional” view in many other areas. These are, at the first place, the complexity theory and semiotics, in particular the complexity management in organizations and organizational semiotics. From the other side, both complexity and semiotics paradigms, or theories, serve as well as the explanatory frameworks for a number of emerging practices in the area of engineering design not yet “codified” as the theoretical models.

4.1. Chaordic System Thinking (CST) and Complexity Management framework for new engineering design organization and management systems

Chaordic System Thinking (CST) is a model of complexity thinking and of complexity science applied to the complexity management in organizations. Complex systems are distinguished from the “classical” Newtonian systems by a number of features. At the very high level of abstraction, the complex systems are characterized by [6][7]:

“a great many independent agents are interacting with each other in a great many ways, (...) [in which] systemic interactions can lead (...) to spontaneous self-organization, [and] learning which takes place through feedback.” [7]

These features, together with more detailed features of CST, are critical for design of the new engineering design organizational and management approach. All these features, of the systems’ complexity and CST, are well presented in a number of references, especially in [6], [8], [9].

A CST based system, has the capacity for creation of true novelty, whether novel products or novel technologies. The capacity for creation of the “novel” product is one of the main requirements for the new engineering design organization and management systems. From the other side, the capacity for creation of the “novel” technologies refers to the completely new forms of work and management of the engineering design organizational system. The term “novelty” is defined as something completely new. The basic idea is that both the what (Goal) (the subject matter to be created) and how (Path) (the process by which the subject matter is to be created) are unknown, in advance [10]. This is just another description of the above referred feature of the capacity for “spontaneous self-organization”.

To provide this capacity for novelty creation (for novel ideas), the new engineering design organization and management system should implement the CST five chaordic properties: Consciousness, Connectivity, Indeterminacy, Dissipation, and Emergence. These are presented in more
details, including the implicit design rules for the new engineering design organization and management system, in [11], [9] (cited in [9]).

Selected features of the complexity / CST based approach to inform the design of the new engineering design organization and management system are given in the first part of the Table 1.

4.2. **Semiotic frameworks for new engineering design organization and management systems**

The second fundamental and qualitatively new feature of the new engineering design organization and management system is employment of semiotics as an instrument.

A view on use of the semiotic-based approach for manufacturing systems, in particular for the manufacturing systems integration / interoperability, together with an overview of the semiotics basic properties, is presented in [4]. The proposed semiotics-based framework for Manufacturing Systems Integration and interoperability (S-MSI) in [4] considers a number of S-MSI determinants with their values on two main levels: syntactic-semantic level and pragmatics level. Although the referred framework was proposed primarily for MSI, referring in fact to interoperability, its two aspects – 1) generality and paradigmatic nature of semiotics, making it applicable virtually to any system, and 2) the interpretation of the system “integration” as the system design – or features, make various determinants of the framework characterizing and explanatory, instrumental and applicable, for the new engineering design organization and management system.

It is worth referring to [5], [12], [13] (cited also in [4]) which give excellent descriptions of the consequences based on the semiotics-based view on system, i.e. on engineering systems, and in particular, on the engineering design organization and management systems.

Again, paraphrasing Guiraud (1975) [5] (see [4]), the new, semiotics-based, engineering design organization and management system, could be seen as — the generator of the creative power in the design systems, i.e. as the ‘maker’ and ‘inventor’ of the new, semiotics-based, engineering design organization and management system, providing higher levels of coherence with the environment, and social reality, and promoting space for the individual and community-based generation and interpretations of signs. Figuratively, semiotics is the poïëte (‘maker’) of the new engineering design organization and management system. In other words, ‘making’, and the ‘inventing’ of the new engineering design organization and management system, is grounded in pragmatics.

Implications of the semiotics-based view on the system design and management, are that actually it is hardly possible to exist an ‘absolute’, common and universal, interpretation of reality, but, rather, there are multiple interpretations by multiple communities and in different times. It means that semiotics inform us that the new engineering design organization and management system is conditioned by, and employing at the same time, multiple interpretations of the same reality in the same and in different times, differently by different communities. In other words, rooted in the social process of communication, as excellently described by Saludadez and Taylor in [12].

A similar position is expressed by Moor and Weigand in [13]: information systems should be approached “much more as communication systems than computation systems (…) . The information systems built on the information field paradigm do not produce sterile data, but aim to generate and communicate information that can lead to knowledge that helps people to perceive, understand, value, and act in the world”. This position is well summarized in two tables presented in [13], and cited in [4], which we will use for our presentation of the new engineering design organizational and management approach, i.e. for the new definition of Collaborative Engineering.

Selected determinants, adopted from the S-MSI framework [4], and from [13], of the semiotics-based framework for 1) guiding the development of the new engineering design organization and management system, and 2) for evaluating a concrete engineering design organization and management system solution’s compliance with the semiotics-based paradigm, are given in the second part of the Table 1.
5. Characterization of the new engineering design organization and management approach

5.1. The new engineering design organization and management approach characterization

The new engineering design organization and management approach characterization, as indicated in the Section 3, follows the characterization of any systems that could be considered as a complex one, and which employs instruments of complexity management and semiotics based framework for system development, design, management and evaluation.

Table 1 presents a list of the features that characterize CoE as the new engineering design organization and management approach and comparison with the “classical” design engineering approach represented by CE. The list of features in Table 1 is a compilation of the CST and semiotics frameworks features for systems development, design, management and evaluation presented in the Section 4, including as well features referred in [1].

| Perspective | Feature | “Classical” engineering design organization and management approach – (CONCURRENT ENGINEERING) | The new engineering design organization and management approach – (COLLABORATIVE ENGINEERING) |
|-------------|---------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| **Complexity** | A great many independent agents are interacting with each other in a great many ways | Yes | No |
| | Systemic interactions | Yes | No |
| | Spontaneous self-organization | Yes | No |
| | Learning which takes place through feedback | Individual learning | Generative learning, Collaborative learning |
| | Collective aspirations are set free | Yes | No |
| | Planning | a mean for priority setting in the present | device for controlling the future |
| | Dissipation - active dissolving of winning design teams, and agile unlearning | Yes | No |
| | Self-organization, self-reference, and self-transcendence | Yes | No |
| | Complexity | To be eliminated | To be nurtured |
| | Organization structure | Fixed, stable structure | “Flow” - as a dynamical process that is traveling an attractor- basins’ landscape |
| | Capacity for true novelty (path and goal unknown in advance) | Yes | No |
| **Semiotics** | Focus | Information | Communication |
| | Support | Transaction process | Communication process |
| | Design objects | Clear specification | ‘Fuzzy’ process definition |
| | Development process | Single project | Continuous project |
| | Developers | Elite development team | Many stakeholders |
| | Change | Static | Dynamic |
| Responsibility | Anonymous | Individual responsibilities |
|----------------|----------|----------------------------|
| Design process | Representation | Interpretation |
| Objective      | Control | Perceive, understand, value, act |
| Control Logic  | Rules | Norms |
| Environment    | Static, linear | Dynamic, non-linear, ‘chaotic’ |
| Process        | Computation | Semiosis |
| Cognition      | Knowledge | Learning |
| Performance measure | Efficiency | Efficacy, creativity, novelty |
| Design paradigm / process | Prescriptive | Descriptive, co-design, co-creation |
| Semiotic field focus | Semantics | Pragmatics |

| Common goal – PRODUCT | Yes | No |
|-----------------------|-----|----|
| Common goal – LEARNING, NOVELTY CREATION | No | Yes |
| Simultaneous processes | Yes | Yes |
| Development effort focused on the initial phase of the product development life-cycle | Yes | Yes/No |
| Relationship graph or network type | Complete / regular network | Complex network |
| Group type | Team (common goal product) | Community (no common goal product) |
| Conversation type | Discussion | Dialogue |
| Principle engineering/design process Management objective | Conflict Resolution | Learning |

5.2. Naming the new engineering design organization and management approach as “Collaborative Engineering”

If the new engineering design organization and management approach is clearly characterized, or defined in the generic form, the following question is: how to name it?

That is, what is the name of the concept we are defining?

This is a very important question (reminding the proverb: ‘nomen est omen’), which is already addressed in the Section 3. At the moment we have several terms/syntagms in use that refers the engineering design approaches. These are: Sequential Engineering (SeqE), Simultaneous Engineering (SE), Concurrent Engineering (CE) and Collaborative Engineering (CoE) (see [1])\(^3\). As the definitions of SeqE and SE are not critical (although many authors use the term/syntagm ‘simultaneous engineering’ as the synonymous for the term/syntagm ‘concurrent engineering’, see [1]), we have to decide on terms/syntagms of ‘Concurrent Engineering’ (CE) and ‘Collaborative Engineering’ (CoE). As already discussed in Section 2, in common use the ‘Collaborative Engineering’ could be, virtually, reduced to, or interpreted as, synonymous of ‘Concurrent Engineering’. However, we cannot ignore that the two terms/syntagms of ‘Concurrent Engineering’ (CE) and ‘Collaborative Engineering’ (CoE) are different,\(^3\)

\(^3\) There are some other terms/syntagms related to the engineering design approaches, such as Set-based Engineering, Design Thinking, etc., but these will be not discussed in this paper as it could be shown that these follow the principles of one of the approaches referred in this paper, usually follows the principles of concurrent engineering, which could be the subject of another paper.
and therefore, it is expected to denominate different concepts. This observation is of interest for naming of the new engineering design organization and management approach.

So, we have to decide if the new engineering design organization and management approach will be named Collaborative Engineering (CoE) (removing the usual synonymy with the Concurrent Engineering) or to define a new term.

The hypothesis in this paper is that the new engineering design organization and management approach should be named Collaborative Engineering (CoE).

Proving this hypothesis is based on literature review on collaboration theories, i.e. on selected definitions of what does it mean “collaboration”.

It is important to say, that a unified theory on “collaboration” does not exist (see a review in e.g. [14]). This fact could justify the practice identified in the Section 2, the practice that created synonymy between CE and CoE. However, there are other models of “collaboration”, we would say, more in accordance with emergent system thinking and with other social phenomena, especially related to learning.

For example, in [15] (although not considered as a scientific text) the author clearly stated what “collaboration” is not, addressing the message to the “classical” use of “collaboration”, and presented a description of “collaboration”, which is almost totally in accordance with the “new engineering design organization and management approach ” identified in Sections 4 and 5.1 above):

“But what is collaboration? Many people prefer the idea that collaboration is “working together to do something.” While this is a reasonable starting point, the problem is that there are many different forms of working together. (…) Collaborating involves substantial organizational commitment, a very high level of trust, and extensive sharing of turf. The qualitative difference between Cooperating and Collaborating is that collaborating partners demonstrate a public enthusiasm for—and commitment to the value of—learning from each other to become better at what they do collectively. (…) Collaborators are clear that the importance of their partners’ success is as great as their own and that their own success depends on their partners’ success. Collaborating partners willingly share the risks, responsibilities, resources, and rewards of the work” [15].

The same definitions, in support to our hypothesis, are also found in the scientific literature. For example, in [16] “collaboration” is defined as:

“Collaboration is the process of shared creation: two or more individuals with complementary skills interacting to create a shared understanding that none had previously possessed or could have come to on their own. Collaboration creates a shared meaning about a process, a product, or an event. In this sense, there is nothing routine about it. Something is there that wasn’t there before. Collaboration can occur by mail, over the phone lines, and in person. But the true medium of collaboration is other people. Real innovation comes from the social matrix… [and] is a relationship with a dynamic fundamentally different from ordinary communication (40–41)” [16].

Additionally, important sources to support our hypothesis are presented in a vast literature on “collaborative learning”, especially as in CST learning is one of the most important processes and instruments. For example:

“A learning community is a small group or cohort of students who share common academic goals and work collaboratively in the classroom with one or more professors. At (…), we offer First Year Learning Communities for entering students and Collaborative Learning Communities for all students. When you enroll in a learning community, you will be part of a cohort of 22-24 students. Together, you will take courses that are either “linked” thematically or enhanced by peer learning. By taking classes together and/or engaging in peer-to-peer learning, you get to know each other better, learn from each other, and support each other. And because classes are limited to 22-24 students, you and your instructors will get to know each other better, too!” [17].

In conclusion, “Collaborative Engineering” is the new engineering design organization and management approach, informed by the emerging system thoughts, namely by the complexity management and semiotics.
6. Collaborative Engineering definition

The Collaborative Engineering definition follows from the “new engineering design organization and management approach” description by the features from requirements for it, and their implementation forms.

The definition, in its form presented in this paper, is inspired by the definition of the “learning community” in [17], especially taking into account that the “learning community” for design represents one of the ColE organizational forms (see [18]).

Definition:

“Collaborative Engineering is the engineering design process (practice) within an intentionally developed community as a complex network, created to promote and maximize the individual and shared learning of its members, through ongoing interaction, interplay, dialogue and collaboration among the community’s members to achieve common goals of collaborative learning on design and creation of novel design” [19].

The community, taking form of a complex network of independent designers, usually uses advanced web based environments and platforms for communication, sharing, dialog, learning.

Concerning the common goal, it is important to notice that the common goal is not a particular product (or the product portfolio) “given” by a company, typical for the CE, but the common goal is learning on design and creation of novel design.

7. Conclusions

The definition of the ColE presented is based on the complexity theory and semiotics, in particular the complexity management in organizations and organizational semiotics. This definition is needed as the ColE definitions in literature within the so-called “classical” discourse in fact could be reduced to the CE, making synonymy between the two terms. This situation is not satisfactory because we are witnessing the new, emergent, organizational and management concepts that refer to new features required for the engineering design organizational and management approaches. For these new design organizational and management approaches to design practices, the definitions of the ColE within the “classical” discourse couldn’t be used. Therefore, it was necessary to invent a new term/syntagm for these new practices or to redefine the definition of the ColE. The paper’s hypothesis was that the term/syntagm Collaborative Engineering is fully adequate. This position was justified by the definitions from the collaboration theory.

The future work will address, in the first phase, a consolidation of the proposed definition of the Collaborative Engineering through investigation of the emergent organizational and management forms and practices in accordance with the definition proposed, investigation of their properties through the lenses of the relevant theories, and in the second phase, development of new organizational and management forms and instruments, using design theories, for example, Axiomatic Design (AD) and other design theories, for designing these new forms and operational instruments, including advanced information/digital technologies. Of course, addressing Industry 4.0 in both phases is understood.

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