Collaborative Engineering: A Review of Organisational Forms for Implementation and Operation

Goran D. Putnik\textsuperscript{1,2}, Zlata Putnik\textsuperscript{2}, Vaibhav Shah\textsuperscript{3,2}, Leonilde Varela\textsuperscript{1,2}, Luis Ferreira\textsuperscript{4}, Helio Castro\textsuperscript{5,2,6}, Catia, Alves\textsuperscript{1,2}, Pedro Pinheiro\textsuperscript{2}

\textsuperscript{1}Universidade do Minho, Department of Production and Systems Engineering, 4800-058 Guimarães, Portugal
\textsuperscript{2}ALGORITMI Research Centre, Universidade do Minho, 4800-058 Guimarães, Portugal
\textsuperscript{3}Universidade do Minho, Department of Information Systems, 4800-058 Guimarães, Portugal
\textsuperscript{4}2Ai—School of Technology, IPCA, 4750 - 810, Barcelos, Portugal
\textsuperscript{5}School of Engineering (ISEP) - Polytechnic of Porto, 4200-465, Porto, Portugal
\textsuperscript{6}INESC TEC, 4200-465, Porto, Portugal

E-mail: putnikgd@dps.uminho.pt

Abstract. A review of organisational forms for implementation and operation of Collaborative Engineering following the Collaborative Engineering organizational and management models based on complexity and semiotics frameworks, is presented. These forms are mainly the forms of communities, which are intentionally created for the purpose of Collaborative engineering. The paper presents basic definitions of three types of communities: learning community, community of practice and open design as the organizational environments for Collaborative Engineering. These communities usually take forms of complex networks of independent designers, and usually uses advanced internet based environments and platforms for communication, sharing, dialog, learning and operation in general. In the second part, some examples of the internet based platforms for supporting the Collaborative engineering communities are presented.

1. Introduction

One of the “keywords” of the Collaborative engineering definition is “community”. In fact, by our definition, any organisational form concerning the Collaborative Engineering addresses organisational form of a community. Is a “community” itself an organisational form? Yes and no. It is in the sense that any group of persons that have some relationship, and interaction, makes an “organization”. Even “crowd” could be considered as an organization if some patterns of behavior could be identified. From the other hand, if we consider that an “organization” should have some predefined form or structure, the Collaborative Engineering communities are considered as organisations as these, by the definition, are “intentionally developed”. Even in the case of their most “free”, or “open”, not constrained access and behavior, at least a participant has to register and, in fact, all behavior is controlled by some mediator or similar.
In that sense, communities that are oriented to engineering design activities and resources share, having an implicit or explicit, i.e. prescribed, organizational and management rules, would be considered as Collaborative Engineering organizational forms.

These forms could be classified by diverse criteria, including the purpose, tools, geography, etc. In the further text, we will refer to three organizational forms by the purpose, namely to the 1) learning communities”, 2) “communities of practice” and 3) “open design” communities. All of them share very similar organizational and management properties, in accordance with the Collaborative Engineering organizational and management features, or functional requirements for the design (of the Collaborative Engineering organizational and management forms), but their embodiment in the concrete (organizational forms) implementation (concrete design solutions) could differ in a number of details as well as in scope.

This paper presents in a way a continuation of the paper by the same authors [1]

The further text, is organized as follows: In the section 2, a definition of Collaborative Engineering is presented, following [1], including a list of the Collaborative Engineering organizational and management features, or requirements for design (of the Collaborative Engineering organizational and management forms), is presented. The section 3, will further present the three organisational forms for Collaborative Engineering: 1) learning communities”, 2) “communities of practice” and 3) “open design” communities. Finally, in Section 4, some conclusions, and suggestions for future work are given, following by the list of References.

2. Collaborative Engineering definition

The Collaborative Engineering definition follows from the “new engineering design organisation and management approach”, based on the complexity and semiotics framework, given in [1].

The definition, in its form presented in this paper, is adapted definition of the “learning community” in [2], especially taking into account that the “learning community” for design is considered as one of the Collaborative Engineering organizational forms. The Collaborative Engineering organizational forms are determined by the features, or by the organizational forms functional requirements, presented in [1].

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” [3]

The community, taking form of a complex network of independent designers, usually uses advanced internet (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

3. Three organisational forms for Collaborative Engineering

In this section three organisational forms for implementation and operation of Collaborative Engineering are presented. These are 1) learning communities, 2) communities of practice and 3) open design communities.

The presentation of each form will include the presentation of the definitions, selected from the literature, followed by some examples of implementations.

It could be said that all definitions (for all three forms) are not accepted universally, but depend on authors and other contexts, i.e. the definitions could be classified by the criteria such as purpose, geography, technology, type of community, etc. For example, the situation with the definitions is well
described in [4]: “The term learning communities is used variously within the literature, often without explicit definition.” Concerning the criteria by which the definition is determined, or by the focus of each definition in particular, these (criteria) are multiple, such as: human element of communities, purpose, curricular structures, geographical-boundaries, institutions (educational, government bodies, industry partners, public, private and non-profit organizations), community groups.

Although the cited finding is related to the definitions of “learning communities” it could be said that the same is valid for other forms (or community types) as well.

It is worth to remind that, in accordance with the discussion on the concept of definition in general [1], all definitions presented could be considered as “descriptive”, rather than “prescriptive”.

3.1. Learning Communities (LC) for Design
Definitions of Learning Communities (LC) are multiple and differ in details, that is, in considering or not some specific features.

A very good generic description of the main features of the learning community is given is [5], which summarized well the definitions from different sources, i.e. from [6], [7], [8] and others. The learning communities are characterized by the capacities for

“self-regulation as a critical human capability to deliberate knowledge sharing and collaboration with others through the interactions among individuals and groups. (…) monitoring the cognition, motivation, and behavior in pursuing their personal mastery and prosocial goals, members can effectively learn and share knowledge in the knowledge communities. This may in turn foster a high level of professional ability to collaborate with others and efficacy to emotionally and instrumentally help others.” [5].

What is indicative in the above description is what makes the qualitative difference from Concurrent Engineering. This is the feature of “to emotionally and instrumentally help others”. The keyword is “help”, with all implications on specifications and distinguishing between the Concurrent Engineering and Collaborative Engineering.

Also, an indicative characterization is given by [9], following [10]:

“… at least two challenges exist when we try to create our own learning communities. First, they must stand for something, meaning they must have a boundary that defines who is and is not a member. People will join a learning community because of its unique identity, mission, goals, or opportunities. But we also know that students often join learning communities to escape other aspects of the university. The challenge, therefore, is to create communities that have strong identities without being elitist, that are defined by their goals and missions rather than by who they exclude.

Second, a learning community must be large enough both to accomplish its goals and to include all members who wish to join. It cannot be so large, however, that an individual is lost within it. When we define a community as a group of individuals committed to shared values and goals, who purposefully come together and work together to reach these goals, then diversity is encouraged not just for ideological reasons but also because different perspectives, experiences, and backgrounds contribute to the collaborative efforts to achieve the community’s goals. Unlike formal organizations, which are designed and constructed around well-defined hierarchies and roles, community members and roles evolve over time through a sense of shared commitment, obligations, and resources. Finding the right mix of roles, tasks, and number of members is an ongoing process of trial and error.” [9]

Also:

“any group of people, whether linked by geography or some other shared interest, which addresses the learning needs of its members through proactive partnerships. It explicitly uses learning as a way of promoting social cohesion, regeneration and economic development.” [11] (cited in [4])

or similarly (based on [11] but using the word “collaborate”):
“Learning communities are developed where groups of people, linked geographically or by shared interest, collaborate and work in partnership to address their members’ learning needs. Learning communities facilitated through adult and community education are a powerful tool for social cohesion, community capacity building and social, cultural and economic development.” [12] (cited in [4])

More explicit definition of the Learning Communities found in literature are mostly related to the education domain (the above referred description (definition), by [9] and [10], refers to educational settings as well), referring both to the students’ and teachers’ learning communities. 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!” [2].

“Learning communities, according to Lieberman, are ‘places in which teachers pursue clear, shared purposes for student learning, engage in collaborative activities to achieve their purposes and take collective responsibility for student learning’ (Sparks, 1999, para. 1)” [13]

The question that could be raised is: what is the relationship between the Learning Communities in education and the engineering design and Collaborative Engineering? First it could be related to the education of (engineering) Design, e.g. [14]. From the other side, students working within a Learning Factory environment (for the concept of Learning Factory see e.g. [15] and [16]) are supposed to interchange directly with companies and in that way to participate in real-life engineering design problems solution.

When referring to the professional domains other than education, learning communities could be referred as “professional learning communities” (PLC) [17] (although many times the professional learning communities are related to the communities of teachers, i.e. to the education domain as well e.g. [18]). The professional learning communities are “groups of people who share a concern, a set of problems, or passion about a topic, who deepen their knowledge and expertise in this area by interacting on an ongoing basis” [19] (cited also in [17])

Many times, the learning communities, and professional learning communities, are also, referring to the community of practice [17].

3.2. Design communities of practice (CoP)
Communities of practice (CoP) are another form of communities, distinct from the learning communities mainly by the purpose. As the name says, the purpose are improving practices. However, interconnections within the communities of practice generates learning too. In this sense both forms, shares the most of the features, which is in accordance with the assumptions that all these types of the communities are different organisational and management forms of Collaborative Engineering. In many cases, and discourses, the communities of practice are related, or even connected to the communities of learning.

Definitions are multiple as well, basically descriptive, as there is no one definition accepted universally. In one of the most cited works on community of practice these are described as follows [19]:

“Communities of practice are groups of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis. Engineers who design a certain kind of electronic circuit called phase-lock loops find it useful to
compare designs regularly and to discuss the intricacies of their esoteric specialty. (…) Frontline managers running manufacturing operations get a chance to commiserate, to learn about upcoming technologies, and to foresee shifts in the winds of power. These people don’t necessarily work together every day, but they meet because they find value in their interactions. As they spend time together, they typically share information, insight, and advice. They help each other solve problems. They discuss their situations, their aspirations, and their needs. They ponder common issues, explore ideas, and act as sounding boards. They may create tools, standards, generic designs, manuals, and other documents—or they may simply develop a tacit understanding that they share. However they accumulate knowledge, they become informally bound by the value that they find in learning together. This value is not merely instrumental for their work. It also accrues in the personal satisfaction of knowing colleagues who understand each other’s perspectives and of belonging to an interesting group of people. Over time, they develop a unique perspective on their topic as well as a body of common knowledge, practices, and approaches. They also develop personal relationships and established ways of interacting. They may even develop a common sense of identity. They become a community of practice.” [19]

As it is easy to see, a number of properties are in accordance with our definition of the Collaborative Engineering, e.g. the learning is one of the most important effects, or outcomes, the participants in the community of practice usually do not belong to the same company, they do not have a common goal product. But, again, one word there makes the most qualitative distinguishing form the Concurrent Engineering: “help”. Other word for “help”, in this context, could be (to) “give”. Some other descriptions, including the definitions, are also interesting to consider. For example:

“While CoPs were initially conceptualised as a spontaneous phenomenon, marked by informal nature and lack of regulation, shortly afterwards it has become clear that they should be cultivated and managed [...]. Nowadays, they are considered as key components of systematic and deliberate KM strategies [...]. In particular, CoPs can be regarded as a manifestation of a human-oriented approach to KM [...] that sees knowledge as constructed through the joint experience in social networks and, thus, as characterised by a prevalently tacit dimension. In this view, the potential of ICT applications is not neglected (indeed, without ICT, it would not be possible to connect professionals working globally, nor to store and share large amounts of information), but their role is somewhat seen as “ancillary”: what is deemed vital is the implementation of appropriate organisational structures, processes, and mechanisms that facilitate the sharing of experience, ideas, and suggestions among individuals.” [20]

“Communities of practice are systems of collective critical inquiry and reflection focused on building a shared identity and collective intelligence garnered over time.” [21]

Design is also of concerns by the Communities of Practice.

For example, in [22] the authors investigated “whether the traditional team is in fact the most effective methodology for distributed design projects”. The conclusions are that “It is clear from these empirical studies that the concept of distributed CoP’s can offer insight into the way distributed design teams function” and that “However within present practice the authors observe that there are often barriers to the development of a productive social learning environment”.

In [23] the authors analyzed “the biases and barriers of two different types of design communities: communities of practice and communities of interest.” The conclusions are that

“...<...> substitutes the references used by [20], which may be consulted through [20].
focused on the needs of individual users. Our research has evolved from (1) empowering individuals to (2) supporting CoPs with domain oriented design environments to (3) creating shared understanding among CoIs with the Envisionment and Discovery Collaboratory and the Evolving Artifact approach.”

3.3. Open Design (OD)
Open design is the third Collaborative Engineering organisational and management form considered in this paper. Differently from the Learning Community and Communities of Practices, that could be applied to virtually any application domain, the Open Design approach as the name itself says, is directly and exclusively oriented to Design.

Following we are rewriting some considerations from the authors’ earlier publication [24]. As a continuum process [25] of design, adjustment and redesign, that could lead to transformation, Open Design (OD) have a direct relation with the involvement of the community. Collaboration, sharing and learning processes [26] among members of a specific community is a must in order to leverage OD, that is supported by a digital platform. Using these premises and based on technical development and dialogue practices, OD is a generative process with a potential high growth rate. Some open initiatives and movement, such as Open Source Initiative [27] and Open Source Hardware [28], can be considered as high-level sharing initiatives, without boundaries (time, place), applying a commitment with a community, in particular, and with the society, in general.

The concept of Open Design (OD) is based on open-source design and in redefining the intellectual and industrial property and rights, through internet, to facilitate collaborative development of hardware and systems [29]. Considering the existing number of projects/platforms, it is notorious that the development in open-source software design is more active and proliferated than hardware design.

One of the few examples of an OD hardware is the additive manufacturing printing machines. The emergency of affordable 3D printing is leading to the spread of open source physical products, to the involvement of communities related to this type of equipment, and to the democratization of design, manufacture and innovation [30]. Moreover, open-source design is playing an important role in research (the development of research papers in open access is leading for an easier, faster, and more cost-effective research output [31]), the cost for making scientific equipment is being reduced drastically, with an estimation of 90-99% reduction of the traditional costs [32].

As for the previously presented concepts, there are multiple definitions of the Open Design. For example:
“Open Design as the adoption of tools, processes and principles from Open Source software development in the Design discipline” [33].
“Open source hardware is further defined as “hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design” [34].

4. Some platforms for creation and operation of the communities
Communities today are created and operate mostly over internet based platforms. Simple search over internet would inform of hundreds, if not thousands, of platforms for supporting communities, including the communities for Collaborative Engineering.

These platforms are owned by the commercial companies or by the interest groups or by institutions (public or private) or by other type of owners, using the variety of business models that provide the users practically free access and use of services. Depending of the complexity of the platforms supporting software, the users could, or not, create their own services. There is a number of forms the communication among the communities’ members is implemented. These forms comprises blogs, forums, hubs, events, repositories (based on cloud or not), etc. Table 1 presents just a small number of internet based platforms, which are well known within the community(ies), without any further classification and/or analysis (that would be the task of a future work). The majority of platforms presented in Table 1 are oriented to the communities in general but with the capacity to, and examples of, supporting the Collaborative Engineering communities.
### Table 1. Selected platforms for operating Communities of Practice and Open Design

| Title + WWW | Description |
|-------------|-------------|
| **Communities of Practice** | |
| General question answer-forum: Quora | “question-and-answer website where questions are asked, answered, followed, and edited by Internet users, either factually or in the form of opinions” ([https://en.wikipedia.org/wiki/Quora](https://en.wikipedia.org/wiki/Quora)); “It allows users to create social networks and follow topics that interest them” ([https://learn.g2.com/what-is-quora](https://learn.g2.com/what-is-quora)); “Quora is a top-ranked question and answering community that can form the basis of a successful marketing campaign” ([https://www.searchenginejournal.com/what-is-quora-why-should-you-care/379341/](https://www.searchenginejournal.com/what-is-quora-why-should-you-care/379341/)) |
| Subjectwise question answer and knowledge exchange platform Stack Exchange | “Launched in 2010, the Stack Exchange network comprises 173 Q&A communities including Stack Overflow, the largest, most trusted online community for developers to learn, share their knowledge, and build their careers” |
| Community for coder and developers Stack Overflow | “Stack Exchange network has grown into a top 50 online destination with Stack Overflow and our technical sites serving more than 100 million developers and technologists every month” |
| Engineering & Technology community platform by IET EngineerZone | “… inspire, inform and influence the global engineering community to engineer a better world. As a diverse home across engineering and technology, (…) share knowledge that helps make better sense of the world in order to solve the challenges that matter.” |
| National Instruments' forum for LabVIEW developers' community | “The NI Community is part of the (…) NI Ecosystem. This is (…) place to network, ask questions, and collaborate on code with users all over the world” |
| **Open Design** | |
| Open Design initiatives – Farmbot FarmBot | FarmBot is an open source precision agriculture CNC farming project consisting of a Cartesian coordinate robot farming machine, software and documentation including a farming data repository. The project aims to "Create an open and accessible technology aiding everyone to grow food and to grow food for everyone.” FarmBot is an open source project allowing hardware, software and documentation modifications and additions from users ([https://en.wikipedia.org/wiki/FarmBot](https://en.wikipedia.org/wiki/FarmBot)) |
| Open Systems Lab | “Open Systems Lab is a non-profit R&D lab working on open digital innovation to tackle systemic social, economic and environmental issues.” |
5. Conclusions

The definition of the Collaborative Engineering presented in [1], based on the complexity theory and semiotics frameworks, provides the capacity of completely new approaches to engineering design organizational and management models. It is interesting that it is not only the proposal for the future but it is already the reality. This new reality many times is not recognized explicitly as the new engineering design organizational and management models. In these terms, this paper contributes to this recognition and the potential, and needed, future renewals of the companies and their design functions.

Looking through the lenses of complexity management in organisations, the Collaborative Engineering, based on the complexity theory and semiotics frameworks, could be considered as an emergent approach with potential for leading to a system New-Thinking, New-Doing, i.e., to a real novelty.

An interesting position concerning renewals (reinventing) of companies is presented in [35]: “Not so long, companies were reinvented by teams. Communities of practice may reinvent them yet again – if managers learn to cultivate these fertile organizational forms without destroying them”. Paraphrasing the referred statement, we could say that the Collaborative Engineering will renew, or reinvent, the engineering design organization and management approaches and models.

Concerning the future work, besides the usual directions towards more detailed studies, one of the important issues is the dynamics of the communities. In all definitions of diverse types of communities, although these are descriptive, including our definition of the Collaborative Engineering, the communities are referred as “static”, i.e. as the collaboration will always remain in communities. However, the nature of conversation, or communication, which is basically a dialog in the Collaborative Engineering, permits, of course, that the participants in the Collaborative Engineering community could establish business or project partnerships with the defined goal product. In this case, these participants are creating the design project team which starts to behave as the “classical” Concurrent Engineering
team. And contrary, it doesn’t mean that the participants of a Concurrent Engineering team could not go “back” to join again the Collaborative Engineering community, or to act as the participants of both the Collaborative Engineering community and the Concurrent Engineering team in parallel. Supposedly, this dynamics, which was not found to be referred in the literature, is a virtual source of confusing the concepts / terms / approaches of Concurrent Engineering and the Collaborative Engineering. Consequently, research of this dynamics is identified as one of the important issues of the future work.

Finally, we would like to underline once more the keywords that characterize and distinguish the concept of Collaborative Engineering, and that we have already referred in the above text:

(to) “help”, and (to) “give”,
and to add one more (for which our colleague Prof. C. Brown always call for attention). This third word is
(to) “serve”.

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