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Modularizing for a community: enabling new product development and innovation supported by collective intelligence

Carignani G. (University of Udine)
Andriani P. (Durham Business School)
De Toni A. F. (University of Udine)

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Giuseppe Carignani*

University of Udine, Via delle Scienze, 208, 33100 Udine (UD) Italy
Tel: +39 0432 558273 – Fax +39 0432 558251
E-mail: giuseppe.carignani@uniud.it

Pierpaolo Andriani

Durham Business School, Mill Hill Lane, Durham, DH1 3LB, United Kingdom
Tel. +44 191 334 5385, fax +44 191 334 5201,
Email: pierpaolo.andriani@durham.ac.uk

Alberto Felice De Toni

University of Udine, Via delle Scienze, 208, 33100 Udine (UD) Italy
Tel: +39 0432 558273 – Fax +39 0432 558251
E-mail: detoni@uniud.it

* Corresponding author

Abstract: Can a web-based community of peers autonomously engage in architectural innovation, develop a tangible product and manage the subsequent diffusion process? After discussing briefly the relevant background we present a theoretical framework exploiting the idea of product modularization as a knowledge management tool enabling community collaboration. The theoretical framework core is composed by a community meta-model and by a product meta-model, described using a semi-formal modelling language (UML); a few mechanisms enabling community collective innovation are also exposed as part of the framework. We also apply the theoretical framework, and in particular the product metamodel, to the real case of a high-performance human powered watercraft. Finally, we present a new possible development of the research suggested by early empirical evidence form the users.

Keywords: bill-of-materials, collective intelligence, human powered boats; innovation, modularity; open source software; product architecture; user innovation; user community; UML

1 Introduction

This paper describes a research in progress exploring the possibility for a web-based community of peers to autonomously develop a new physical product and manage the subsequent innovation.

We present both the theoretical and the experimental part of the research: the paper is therefore organized as follows:

- In chapter 2 we present the relevant background;

- in chapter 3 we outline a theoretical framework, necessary to drive the experimental part of the research

- in chapter 4 we describe a web-based experiment, in progress at this moment;

- in chapter 5 we briefly expose some preliminary empirical evidence suggesting a new development in our research

2 Background

Modularity and modularization

Modularity[1] can be regarded as a strategy deliberately pursued in order to cope with the complexity of new product development, thus organizing efficiently and smoothly the processes associated (Baldwin, Clarke, 1997).

Two definitions are particulary relevant for our purposes.

In his seminal works Karl Ulrich (Ulrich, 1995) defines a modular product architecture, in opposition with an integral one, as a scheme in which each component (module) is associated with a well defined single function.. In Ulrich's view a modular architecture is based on:

- a one-to-one mapping connecting physical components and function;
- standardised interfaces which decouple the modules.

Baldwin and Clarke, by contrast, in their extensive work (Baldwin, Clarke, 2000) while criticizing Ulrich's definition propose a powerful concept based on deliberate modularization formalized by visible 'design rules'.

A traditional well-known representation of the modular structure of a product is the Bill of Material. A new model, GBOMO (Generic Bill of Material and Operations) has been proposed for integrating product, process & supply chain and supporting variety (Jiao at al., 2000). Their proposal is aimed at enabling mass customization.

The modular architecture of the product, in turn, has a strong connection with the organizational structure of its industry, which tends to mirror the product architecture in terms of the correspondence between organizational units and product's modules (Fixson, 2005).

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[1] The concept of modularity has been investigated in several knowledge domains (e.g. Fixson, 2003) whose complete review is well beyond the scope of this paper.

Modularity, however, is not a binary attribute of a product architecture; on the contrary it is clear that a product architecture can be more or less modular even if measuring it could be tricky (Mikkola, 2006).

In general, manufacturing firms face a trade-off in defining the degree of modularity of their products: a highly modularized design, while leading to a more predictable development of the product, could end up making the firm prisoner of its modular architecture. Radical innovation which involves a change in the basic architecture, becomes more difficult, whereas component innovation (more incremental in nature) tends to become more dominant (Fleming and Sorensen, 2001).

User innovation

In the recent years a new way of thinking about innovation has gradually emerged. Labelled as Open Innovation, it shows that innovation doesn't occur only within the boundaries of the firms, but on the contrary, external actors play a fundamental role in nearly every stage of the innovation process (Chersbrough et al., 2005).
A particularly important external actor is represented by innovation communities of users, which under certain conditions, play a central role in the development of new products and in the generation of new ideas (Von Hippel, 2005). There is ample an unequivocal evidence of the importance of users and users communities in innovation (von Hippel, 1988).

This phenomenon has been investigated and ascertained in several cases, including sports equipment (Baldwin et al., 2006), professional tools (Luthje, 2004), specialized machinery (von Hippel, 2005). Among the population of user-innovators there exist a particular type, called lead–users, who happen to be at the leading edge of important market trends and can therefore be of great value to the manufacturing firm.

User innovation may be highly cost-effective in comparison with traditional in-house product development because users usually test their innovation in the real environment in which they use the product (low-cost laboratories) and can exploit directly their knowledge without the costly process of transferring it to the manufacturer, that usually involves a time-consuming and ineffective iterative process (Thomke & von Hippel, 2002). In other words, the experience of how a get used lies with the users and not with the manufacturers. Hence, users are more capable than manufacturers to develop new products around the winning applications. The nature of the innovators, the users, take care of the traps of the 'technology-push' model.

Unexpectedly, most users willingly disclose their innovation and share their knowledge with others (von Hippel, 2005).

Innovation communities

In this paper we propose a model of an innovation community, which shares many features with other well known models, notably the 'communities of practice' concept (Wenger, 1998), the 'KBS communities paradigm (Santoro and Bifulco, 2006), the concept of 'innovation community' (von Hippel, 2005).

The community of open source and free software developers is of particular relevance here, because Open Source Software is the most successful example of community-supported product innovation and one of the few in which the viability of integral product development has been ascertained.

The economics of Open Source has been researched and a framework of external incentives (Lerner and Tirole, 2002) has been proposed as a explanation of the Open Source projects success.

A more complex structure of hackers'[1] motivations, reaching beyond economics, has been recently researched: according to Lakhani and Wolf (2005) intrinsic motivation, both enjoyment-based and community-based is at least as important as external incentives in determining partecipation and effort in Open Source communities.

3 Theoretical framework

The theoretical framework is supported both by the literature and preliminary empirical evidence. It exploits the idea of product modularization as a knowledge tool enabling community collaboration and possibly triggering an emergent process of product innovation.

A community meta-model and a product meta-model have been developed.

The metamodels are collection of high-level "concepts" (e.g. in our case community, member, role, product, interface) and their connections; they are aimed at building correct models, in our case models for specific products.

We adopt a semi-formal graphical language (UML, Uniform Modelling Language) for describing the meta-model; UML is therefore our meta^{2}model.

UML is a standardized visual specification language that includes graphical notations used to create an abstract model of different aspects of a system; while used especially in software engineering, we adopt it here also as a conceptual tool. Anyway, these high level diagrams are also part of the design of the prototype web-application. The derivation of specific product-centered models is straightforward, as we will show with an example in section 4.

Community metamodel

We describe in figure 1 the structure of the community, showing the main entities and the relationships between them.

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[1] The term 'hacker' used within the Open Source community has a positive connotation; it is not a synonim of 'malicious meddler' as in common language

Figure 1 Community metamodel static view (UML class diagram)
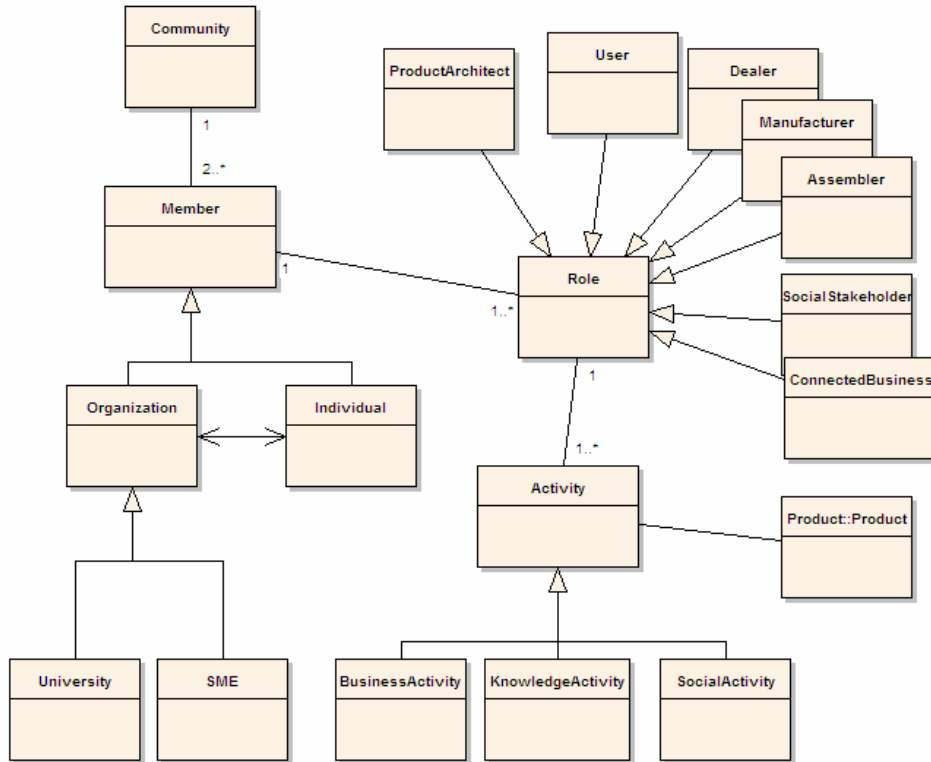
As it is shown in figure 1, the members of our community of peers can be both organizations and individuals; each member is associated to one or more roles, each of which is associated to one or more activities.

These expected activities, which should be supported by any webapplication aimed at implementing this model, are described in high-level aggregate form in figure 2 (user case diagram). This is a type of UML diagram which presents a graphical overview of the functionality provided by a system in terms of interactions with roles and of dependencies.

Figure 2 Community metamodel (UML use case diagram)
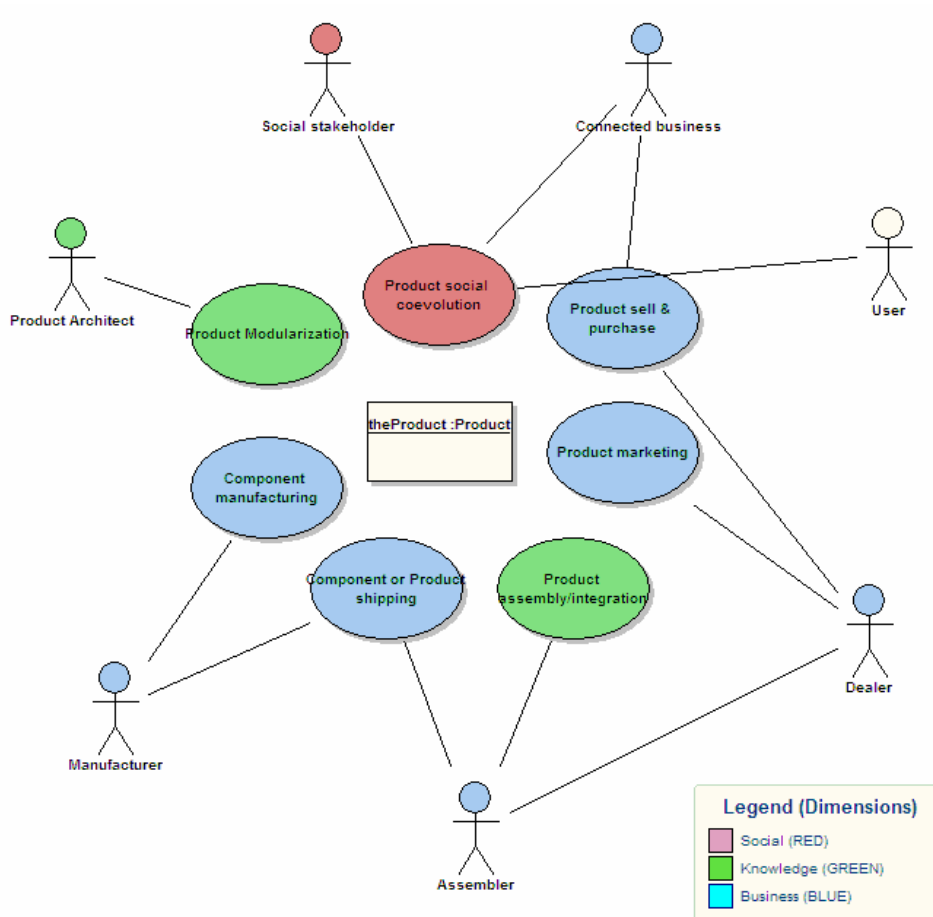
We start by introducing some traits of our community meta-model. We will justify the reasons that lead to the choices of the traits in a subsequent section.

- we consider equal members of our community both individuals and organizations;

- we separate the concept of member from the roles a member can assume within the community: members are intended to model physical entities while roles are effectively connected with activities;

- we propose seven community roles to model the behaviour of community members. These roles cover different dimensions of the innovation community (business, knowledge, social);

- members can perform more than one role (e.g. user-manufacturer, user-dealer); we can therefore model the most innovative community members, whose behavior and whose impact on product innovative evolution has been researched and ascertained.

Product metamodel

The product meta-model exposed in figure 3 is aimed at describing modular architectures of physical assembled products; it resembles a Generic Bill Of Material and Operations, but is aimed at describing the diversity of community-driven components rather than the variety of products.

We briefly introduced earlier the central concept of interface[1] in product modularization; we propose and discuss a new concept of component interface (triple interface) in order to enable manufacturer-innovators incremental innovation.

Figure 3 Product metamodel: triple interface (UML class diagram)
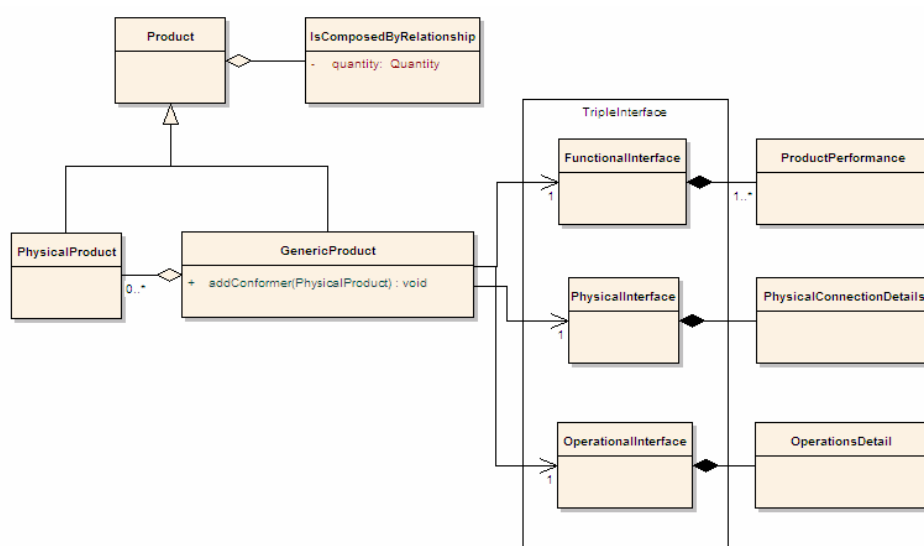
We think that the metamodel we propose needs a 'triple interface' to take into account three different types of interactions:

- a functional interface defining the component performance;

- a physical interface defining the geometrical and technological constraints of physical assembly;

- an operational interface defining the supply chain detail needed for sourcing the component;

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[1] the concept of interface has as many facets as the concept of module, and discussing it is well beyond the scope of this paper

Our model is based on a typical engineering (manufacturer's) perspective of product, ('a complex assembly of interacting components' (Fixson, 2003)); this is necessary for giving manufacturers the opportunity of introducing innovative components (addConformer method in figure 3)

However, our metamodel supports also the typical user view, which sees modularity as 'a bundle of attributes'. In particular, the product performance at top level describes the user's view of the product enabling meanwhile the 'option value' mechanism described in the following paragraph.

Connecting product and community

A few mechanisms enabling community collective innovation are also exposed as part of the framework, addressing central questions about the behaviour of the community of peers, including the mechanisms driving community activities without any central authority.

The challenge here is to understand why members should be interested in giving their time, skills and energy to the community.

Two mechanisms are exposed:

- product appeal, providing collective overall motivation;

- option value, giving members the motivation for improving modular performance.

**Figure 4** 'Appeal' conceptual map: connecting product with community
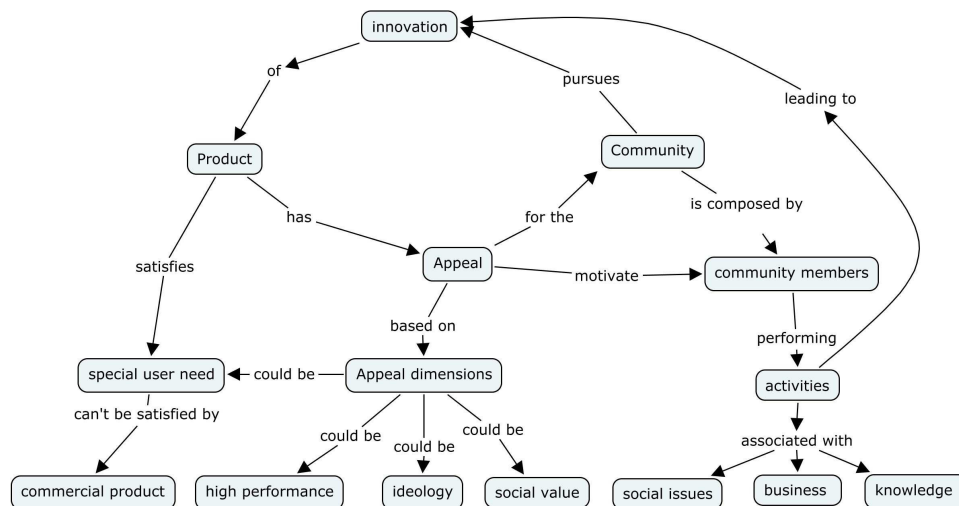
As shown in figure 4 the concept of 'appeal' is an abstraction of real users needs (e.g. high performance, social value, special needs unsatisfied by commercial products) whose importance for motivating user innovation processes has been researched.

We don't expect any of the community members to pursue deliberately product innovation; community members perform various activities, according to their own

motivations and goals. Innovation could emerge as a collective behaviour (figure 4, outer circle).

Figure 5 Option Value (conceptual map)
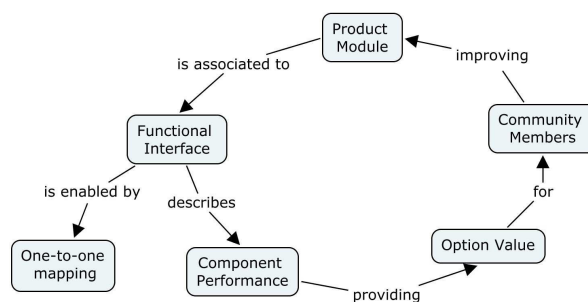
The connection within modularity and community-driven product development has been recently researched in the case of Open Source Software (Baldwin, Clarke, 2005). The 'option value' provided by the opportunity of improving the performance of a module has been proposed as a powerful force able to increase the incentive of developers to join an innovation community.

We see no reason why this mechanism should not work for physical products, too; the managerial suggestion here is to deliberately pursue a 'one to one' mapping in modularizing the product.

4 Web based experiment

The experiment specializes our theoretical framework to a specific product, a high-performance human powered watercraft. There are several reasons behind the choice of such a product:

- sports equipments have a well documented history of user-innovation cases,

- preliminary empirical evidence suggests that the social-coevolution within the community might drive could the evolution of new niches for this product.

The first experiment, which is in progress at this moment (www.openwaterbike.com), is based on the architectural model developed for the prototype, and aimed to start an evolving process of community-driven incremental innovation.

We deliberately start from a modular architecture for this product; a working prototype of the product has been built.

The measure of the performance of the prototype (Zamparo et al, 2008) shows an outstanding performance in term of speed and efficiency. This results, which is confirmed by the successful partecipation to sporting events, should put the the reputation of the prototype on a firm basis, thus providing an appealing start-up modular architecture to the community, as required by the our theoretical framework. In fact, the role of user architect, who carries the responsibility for product modularization, is in this case played by a community of individuals. In other terms, it becomes a collective role based on consensus rather than on authority. One of the main goals of our experiment is to test the hypothesis that communities can play the role of user architect, thereby confirming the viability of open innovation approaches in setting architectural standards.

This modular architecture (figure 6) deliberately pursues a 'one-to-one' mapping, connecting each components to a single well-defined function. The aim of this managerial choice is to enable the 'option value' circle described earlier on.

Figure 6 Displacement buoyancy waterbike modular architecture (UML component diagram)
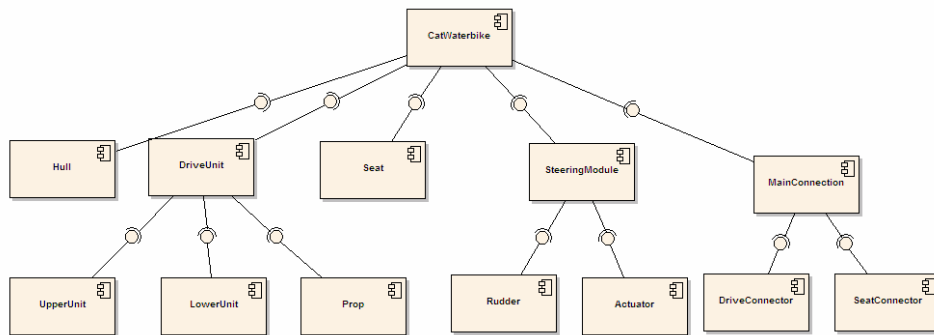
A second experiment, supported by the same theoretical framework but with a different product architecture, is aimed to ascertain the possibility of triggering a process of 'technological-driven' radical innovation, based on an overturned product core concept, recombining most of the pre-existing components.

Figure 7 Submerged buoyancy waterbike modular architecture (UML component diagram)
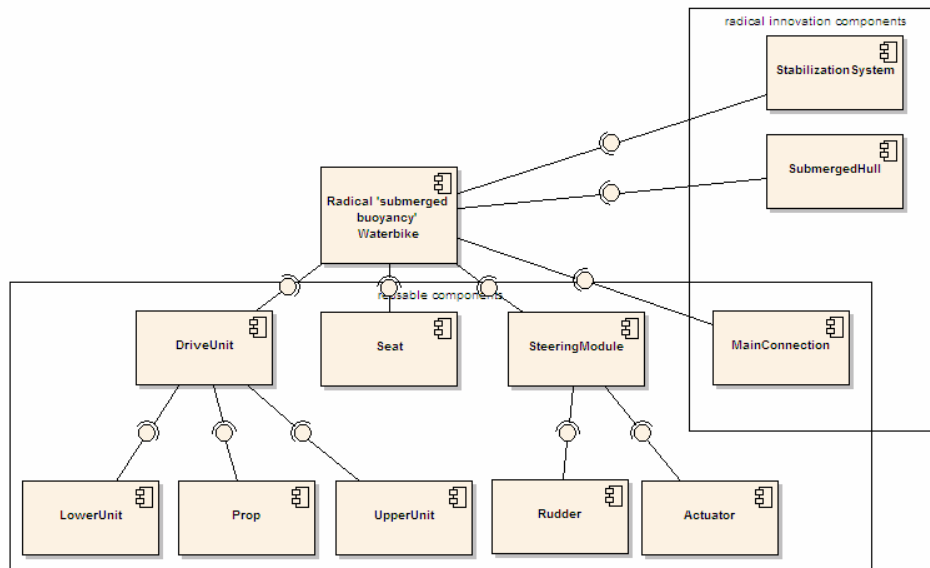
5 Conclusions: enabling user-generated radical innovation

We gathered some preliminary informal empirical evidence from early users in the form of emails sent to our pilot website. From these documents we can easiliy recognise the emergence of the roles described earlier in our community metamodel, namely user, dealer, social stakeholder, connected business, etc. We think that each of them gives some confirmatory hints about our theoretical framework.

What emerges is that different users have different agendas for product innovation, thus suggesting the preliminary idea that communities of innovators can engage not only in incremental/component innovation on the basis of a predefined architecture, but also in architectural innovations on the basis of a consensus-based emergent architecture.

While this initial evidence opens up several opportunities for extending the theoretical framework, it also poses new conceptual problems.

We think that, by stretching the role of communities toward architectural/radical innovation, our framework (and experiment) has the potential to extend the currently accepted realms of open innovation.

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