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Dynamics of couplings and their implications in inter-organizational multi-actor research and innovation projects

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ABSTRACT

Publicly funded multi-actor research, development and innovation projects are a setting where a network of multiple organizational actors form a temporary consortium to jointly create new knowledge and market-upstream innovations. The couplings between the organizational actors and sub-groups of these actors represent joint work that leads to flows of knowledge and flows of activities. The dynamics of the couplings in this empirical context and their implications are not well understood yet. Using an inductive comparative multiple case study of projects funded in European Research and Innovation Programmes, we investigated 4 projects with 54 organizational actors, which produced 50 innovations. The evolutions of all couplings went through the same phases, although the temporality of the phases differed. We identified eight types of evolutions of couplings and their underlying generative mechanisms. These evolutions led to different, mostly negative implications on the planned collaborative innovations. Particularly, we observed a systematic degradation of the couplings that were planned to connect sub-groups of organizational actors. Over time, the projects became less collaborative than planned, and they have a tendency to fragment into isolated activities by subgroups of actors. Based on these findings, we propose an emerging process model which helps to better understand how and why the couplings evolve in multi-actor RDI projects.

1. Introduction

Over the past decades, public funding has shifted to support the generation of new knowledge and innovations in the context of collaborative research, development and innovation (RDI) projects with multiple organizational actors (e.g. Manning, 2017; Goldstein & Narayanamurti, 2018). Such projects, usually generating multiple collaborative outputs (Klessova et al., 2020, 2022), are implemented under numerous stringent boundary conditions and have characteristic properties that distinguish them from other inter-organizational projects, such as autonomy and heterogeneity of a considerable number of organizational actors, relatively rigid consortium membership and limited power of the project manager (vom Brocke & Lippe, 2015; Pinheiro et al., 2016). These projects are known to be difficult to manage (Lin et al., 2019; Söderlund & Tell, 2011).

The organizational actors in the inter-organizational projects are interdependent (Stjerne et al., 2019): they are connected by working relationships or collaborative links. In this paper, the terms 'working relationship' or 'collaborative link' are summarized under the concept of

'couplings', which reflect the interdependence between the involved organizational actors (Orton & Weick, 1990) and by extension between the project participants from these organizations. Couplings, their patterns and their implications have been extensively investigated in the literature on inter-organizational collaborations in different settings, such as ecosystems, projects, and networks, using different theoretical lenses. These studies mostly mobilized two related theoretical perspectives: a resource-based view to study activities and their coordination (e.g., Bakker et al., 2018; Browning, 2014; Shi & Blomquist, 2012), and a knowledge-based view to study knowledge integration (e.g. Rauniar et al., 2019; Tell et al., 2017; Berggren et al., 2017; Johansson et al., 2011), knowledge sharing and creation of new knowledge (e.g. Nahapiet & Ghoshal, 1998; Nonaka & von Krogh, 2009; Nisula et al., 2022; Stock et al., 2021; Marchiori & Franco, 2020; Dougherty & Dunne, 2011).

The dominating pattern of the couplings between the multiple interdependent actors (Capaldo, 2007) is often called architecture (e.g. Fjeldstad et al., 2012). Recent research (Klessova et al., 2020) provided empirical evidence that the couplings in multi-actor RDI projects relate to both flows of knowledge and flows of activities. The pattern of the

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couplings defines different types of project architectures. However, both, the architecture, or the ‘thing’, and the processes, should be analyzed when studying the organizational design (Aubry & Lavoie-Tremblay, 2018). Several authors pointed out that a better understanding of the organizing for knowledge creation in inter-organizational settings (Nisula et al., 2022), of the processes, i.e. of the dynamics of the couplings (Yang et al., 2021; Jakobsen et al., 2019; Sydow & Braun, 2018; Manning, 2017; Majchrzak et al., 2015; Davis, 2016), and of its implications on the collaborative innovations (Michelfelder & Kratzer, 2013; Hofman et al., 2016) are required. In the context of this paper, a specific question is how the dynamics of the couplings, defined here as a change in the couplings over time corresponding to the change of the pattern or intensity of relationships between organizational actors, happens under stringent boundary conditions.

The present paper addresses this research gap, complementing previous research (Klessova et al., 2020), and aims at shedding light on the ‘how’ and ‘why’ of the dynamics of the couplings and on its impact on the project outputs. We answer three inter-related research questions: (1) *How* do the couplings evolve in the multi-actor RDI projects? (2) *Why* do they evolve? (3) *How* do these evolutions influence the collaborative innovations generated by the projects?

We put in place an empirical inductive comparative multi-case study (Eisenhardt, 1989), and adopted a process view (Langley, 1999; Berends & Sydow, 2019; Cloutier & Langley, 2020) on the evolution of the couplings, using a grounded theory approach (Strauss & Corbin, 1990) at the intersection of the literature streams mentioned above. We selected and studied in detail the couplings, the processes behind their evolution, and the 50 innovations generated within four projects with 54 organizational actors, funded by the European Union’s Research and Innovation Framework Programmes. The material used was the extensive project documentations of the projects and data from 32 semi-structured interviews.

The study leads to a better comprehension of the evolution of couplings in the project and the underlying processes, and provides theoretical contributions to the literature on project management and on inter-organizational collaboration in the RDI setting. There are two main take-aways. First, the projects, although they have stringent external boundaries, have much less stringent internal boundaries, regarding the couplings. Some couplings evolve and others do not; the evolutions follow the same phases. These phases are different in the modules of the projects (i.e. independently acting sub-groups of organizational actors, working on specific applications or innovations) and at the interfaces, or inter-linkages that were planned to connect the modules. The study found that the couplings at the interfaces systematically erode or may even disappear, leading to the mostly isolated, fragmented activities instead of the planned collaborative pattern. Second, as a consequence, collaborative RDI projects with multiple actors, as well as their innovations, often turn out to be less collaborative compared to what was planned, and the value of collaboration may be lost, especially at the planned interfaces. Based on these findings, we propose an emerging grounded process model that explains the evolution of the couplings in multi-actor RDI projects.

The remainder of the paper is organized as follows. Firstly, a literature review is provided, followed by the exposition of the research methods used, the presentation of the findings, a discussion, and a summary of the theoretical and practical contributions. The paper concludes with a discussion of the limitations of this study and future research directions.

2. Literature review

2.1. Couplings in inter-organizational multi-actor RDI projects

Organizations increasingly engage into inter-organizational projects (Ahola, 2018; Bstieler & Hemmert, 2010; Stjerne et al., 2019), jointly

creating value while reaching their individual objectives (Dille & Söderlund, 2011; Bakker et al., 2016). These projects have been conceptualized as temporary organizations (Lundin & Söderholm, 1995); they have become bigger and more complex (Steen et al., 2018). Project-related constraints on the one hand and the independence of the actors on the other add complexity to such inter-organizational settings (Lundin & Söderholm, 1995; Gulati et al., 2012), and such projects are therefore difficult to manage (Söderlund & Tell, 2011; Lin et al., 2019).

Research and innovation in general have become more collaborative over the last decades (Chesbrough, 2005; Lundin et al., 2015). Collaborative innovation is a form of open innovation (Enkel et al., 2009; Chesbrough & Bogers, 2014): development of such innovations involves complementary technologies, knowledge, and other resources provided by collaborating organizations, in the variety of contexts, with external collaborators, including early customers, suppliers and competitors (Hurmelinna-Laukkanen et al., 2021; Oinonen et al., 2018; von Hippel, 1986).

Nowadays, public agencies allocate an important, if not the predominant part of R&D funding to inter-organisational research, development and innovation (RDI) projects (e.g. Manning, 2017; Goldstein & Narayanamurti, 2018; Spanos & Vonortas, 2012). They often deal with ambiguous, uncertain and complex problems (König et al., 2013) and contribute towards joint creation of project outputs: collaborative knowledge and innovations (Klessova et al., 2022; Manning, 2017). Collaborative innovations in such projects are market-upstream: they are created in a challenging collaboration context (e.g. Fernandes & O’Sullivan, 2021; Gretsch et al., 2019; Steinmo & Rasmussen, 2018; Steinmo, 2015), and may take very different forms (Kostopoulos et al., 2019), such as innovative products, technologies, methods, know how, processes, software, algorithms, tools. They are matured, or advanced, technologically, thanks to joint knowledge generation by peers (Nisula et al., 2022; Elmquist et al., 2016). For simplicity, this paper uses the term ‘innovations’ to describe the different forms of project outputs, including new knowledge. The maturation of innovations comes with increasing complexity, and required cost and efforts (Klessova et al., 2022; Olechowski et al., 2020; Héder, 2017).

Publicly funded multi-actor RDI projects are different from other inter-organizational settings, which makes their management even more challenging compared to the traditional project management approach (Fernandes et al., 2021). This is due to the autonomy and heterogeneity of a considerable number of organizational actors, the limited power of the project manager, multiple constraints due to relatively rigid project budgets, timelines and consortium membership (vom Brocke & Lippe, 2015; Pinheiro et al., 2016). As an example, the latest Horizon 2020 Framework Programme (FP) has allocated 39,64B€ in 2014-2021 to fund over 7000 such projects, with over 14 organizational actors per project in average (EC, 2021).

When studying inter-organizational settings and their structures, the key theoretical concept in the literature is that of collaborative links, also called ties, or couplings, which may evolve over time (Brusoni & Prencipe, 2013). The term ‘coupling’ here describes the presence of joint activities and exchange of knowledge between the elements (here, the organizational actors in the projects, represented by their projects participants), and can be described in terms of the intensity and strength of the connection (Orton & Weick, 1990), i.e. of the inter-organizational relationship. The intensity of couplings can be characterized by different types of interactions between connected elements: in case of low interdependence (comparing with high interdependence), ‘elements affect each other “suddenly (rather than continuously), occasionally (rather than constantly), negligibly (rather than significantly), indirectly (rather than directly), and eventually (rather than immediately)” (Weick, 1982, p. 380, cited from Orton & Weick, 1990, p. 203-204).

In the setting of large multi-actor RDI projects, often several simultaneous couplings between the organizational actors within the project exist, due to the large setting; organizations can be involved in several couplings in different configurations. These couplings enable flows of

activities and flows of knowledge (Klessova et al., 2020), which may be partially independent (Tell, 2011; Brusoni & Prencipe, 2006; Stjerne et al., 2019). Couplings in the inter-organizational setting, as well as their pattern, their evolution and their implications, have been extensively studied in the project management, innovation and knowledge creation literature streams. All three are relevant to multi-actor RDI projects. Below, we briefly highlight the main concepts and findings from these different conversations, which guided our study.

2.2. Couplings related to the coordination of activities in inter-organizational settings

Couplings form the structure of the projects, which defines the way how the tasks in the projects are decomposed and coordinated (Mintzberg, 1979). Project management scholars, when studying couplings and their patterns, often adopted a resource-based view, and considered couplings from the angle of activities and their integration (Majchrzak et al., 2012; Okhuysen & Bechky, 2009; Wolbers et al., 2018) and coordination (e.g., Browning, 2014; Shi & Blomquist, 2012; Bakker et al., 2018). Scholars investigating collaboration in inter-organizational settings concur that the project architecture (or structure), and the couplings composing it, supports and significantly affects the success of the collaboration (Calamel et al., 2012; Dietrich, et al., 2010). However, extant research does not answer the question about the evolution of the project architecture and of the couplings over the project lifetime. The role of the project managers is to maximize the value creation in the project (Söderlund, 2013; Laursen & Svejvig, 2016), and RDI project managers shall be adequately equipped with relevant knowledge (Cunningham et al., 2021). This requires that the evolutions of the couplings in the multi-actor RDI projects and the related processes are understood so that they can be anticipated and steered.

Couplings and their evolution in the inter-organizational projects have been also addressed by scholars from the point of view of collaboration and its evolution. Nsanzumuhire and Groot (2020), after having reviewed 68 publications on inter-organizational settings of academia and industry, pointed out that these collaborations have been mainly investigated at the individual and organizational levels, but not at the collaboration (i.e. coupling) level, and have identified five types of barriers to successful collaboration, related to misalignment, motivation, capability of involved actors, governance and context of the collaboration.

The literature on the dynamics of collaboration investigated various multi-actor dynamics (Manning, 2017), e.g. changing strategic interests of the collaborating organisational actors (Majchrzak et al., 2015), as well as the evolution of collaboration relationships, adopting a process view on inter-organizational relationships and explaining their birth, development, adaptation and ending (Berends & Sydow, 2019). These relationships are often evolving in a sequence of stages which are not necessarily occur in a fixed linear order (Deken et al., 2018). Three causes of the dynamics of inter-organizational collaborations, leading to different direction and effects (Majchrzak et al., 2015) have been identified: differences between the organizational actors and their representatives in the project, external sources, and sources within the collaboration itself. However, this literature mostly concerns the unfolding of collaboration of the same organizational actors, i.e. within the same inter-organizational relationship (same coupling).

As mentioned above, couplings are not only related to flows of activities, but also to flows of knowledge, and have been extensively studied from this angle. This is described in the next section.

2.3. Couplings related to knowledge integration and creation of new knowledge in inter-organizational settings

The innovation and knowledge creation literature considers couplings from the angle of a knowledge-based view. In the inter-organizational setting, the generation of new knowledge and

combinatorial innovations (Obstfeld, 2005) results from knowledge integration, defined as “the purposeful combination of specialized and complementary knowledge to achieve specific tasks” (Tell et al., 2017, p.5); in some literature streams, the term ‘knowledge combination’ or ‘knowledge recombination’ are used instead of the term ‘knowledge integration’. Knowledge integration may reveal the need for unplanned interdependencies (Ben-Menahem et al., 2016); creation of new knowledge is supported by iterative processes, self-organizing groups, and dynamic participation of actors (Nisula et al., 2022).

Knowledge integration depends on the characteristics of the knowledge that is integrated (Brusoni & Prencipe, 2013; Johansson et al., 2011), requires strong internal capabilities for exploiting external knowledge and adequate knowledge integration mechanisms (Berggren et al., 2011) such as sequencing activities and others (Grant, 1996; Berggren et al., 2017; Canonico et al., 2017). This is often reflected in the architecture of the multi-actor projects: to avoid disintegration, modules are counterbalanced by integrative activities (Tee et al., 2019). Extant literature pointed out that both *coordination*, or the alignment and adjustment of the activities, actions and knowledge of the project participants (Gulati et al., 2012; Lawrence & Lorsch, 1967; Okhuysen & Bechky, 2009; Wolbers et al., 2018) and *cooperation*, or alignment of the interests of the organizations, their relationship and the commitment of the partners, are the key determinants of successful knowledge integration (Johansson et al., 2011; Tee et al., 2019). The more specialized the knowledge becomes, the more there is a need for dynamic knowledge integration for innovation: this is particularly critical in inter-organizational settings (Tell et al., 2017).

The knowledge creation literature pointed out the important role of knowledge exchange and combination mechanisms (Nahapiet & Ghoshal, 1998; Nonaka & von Krogh, 2009) to create new knowledge. Large multi-actor RDI projects offer a propitious setting for new knowledge creation and collaborative innovation, thanks to the variety of the knowledge bases. However, the possibilities for knowledge exchange and combination depend on a number of conditions: the opportunity to exchange or to combine knowledge elements, the anticipation of value through exchanging and combining knowledge, the motivation to be engaged in a collaborative effort that creates such value, and the combinatory capabilities, i.e. cognitive (i.e. shared codes, language, narratives), and relational (i.e. trust, norms, obligations) capabilities (Moran & Ghoshal, 1996; Nahapiet & Ghoshal, 1998; Miković et al., 2020; Rauniar et al., 2019). The couplings provide an opportunity for the activation of these combination mechanisms. An increase of the size and the diversity of the knowledge base is often considered to be beneficial for knowledge generation and innovation (Yayavaram & Ahuja, 2008; Cantner et al., 2011). However, the diversity of the organizational actors also can create problems: the technological relatedness of the knowledge base (Messeni Petruzzelli & Murgia, 2020) and the resulting cognitive distance may be detrimental for the combination of knowledge, especially if the diversity of accessible knowledge, capabilities and perspectives is high (Tiwana, 2008; Nooteboom et al., 2007).

In addition, combination and exchange are complex social processes: the larger the variety of the backgrounds and, the higher the complexity of the setting (Boisot & Mckelvey, 2010), the more difficult is the combination of knowledge. This suggests that couplings may be also influenced by the complexity of the inter-organizational setting with multiple actors; this also influences the breadth and depth of the information with which the involved individuals have to deal (Resch & Kock, 2021). Such complexity has cognitive and relational dimensions (Boisot & Child, 1999). Wang and von Tunzelmann (2000), with regard to the cognitive dimension, used the term ‘complexity in depth’, as it concerns the level of sophistication required to apprehend the phenomenon, versus the relational dimension, or ‘complexity in breadth’, as it concerns the level of heterogeneity and interrelations between distant domains required to seize the phenomenon. Applying this to inter-organisational RDI settings, small groups of organizational partners with closely related domains of knowledge may face mostly

cognitive complexity, or ‘complexity in depth’, while larger groups of organizational partners with more distant domains of knowledge may face mostly relational complexity, or ‘complexity in breadth’. Such complexities influence both intra- and inter-organizational dynamics (Patnaik et al., 2022).

Different combinations of couplings that enable flows of knowledge create different patterns of knowledge structures (Yayavaram & Ahuja, 2008), which affect the collaboration and the potential to generate new knowledge and innovations (Gulati et al., 2012; Tee et al., 2019; Rost, 2011; Michelfelder & Kratzer, 2013). However, how and why these patterns of couplings, and the architecture of complex projects, evolve, and what are the implications of these evolutions on the collaborative innovations, still remains to be understood (Michelfelder & Kratzer, 2013; Hofman et al., 2016).

2.4. The intersection of these literature streams and the motivation for the study

Planned couplings in multi-actor RDI projects lead to the coordination of activities and provide paths for knowledge integration, and are supposed to lead to project outputs. Answering the call for research at the intersection of project management and innovation literature (Sydow & Braun, 2018; Geraldi & Söderlund, 2018; Davies et al., 2018), specifically in inter-organizational settings (Berggren, 2019), and combining both an activity-based view and a knowledge-based view, Klessova et al. (2020) recently found that the interplay of the flows of activities and flows of knowledge, thus of the related couplings, forms the architecture of the RDI projects, and that multi-actor RDI projects are often characterized by the presence of *modules* (where couplings exist within small sub-groups of organizational actors), and *interfaces* (couplings inter-linking some or all of these modules). Different combinations of modules and interfaces form different types of modular architectures of multi-actor RDI projects, e.g. weakly coupled, grid and waterfall architectures, with different implications on knowledge creation and project management. This research advanced the understanding of couplings in multi-actor RDI projects, but it took a static approach. In addition, an investigation of the dynamic layer of the processes in the projects is also required (Aubry & Lavoie-Tremblay, 2018; Lundin & Söderholm, 1995). There are also multiple calls for research to explain the processual features of inter-organizational collaborations (Yang et al., 2021; Jakobsen et al., 2019; Sydow & Braun, 2018; Majchrzak et al., 2015), in particular in multi-actor RDI projects (Calamel et al., 2012; vom Brocke & Lippe, 2015) and to investigate how patterns of couplings influence collaborative innovation over time (Michelfelder & Kratzer, 2013; Hofman et al., 2016).

There is also an intriguing puzzle at the intersection of several research streams. From one side, the options for the structural evolution of the planned couplings in the multi-actor RDI project setting are limited because of multiple project constraints and requirements (vom Brocke & Lippe, 2015; Sydow & Braun, 2018). From the other side, many specifics of the multi-actor RDI projects considered here suggest that planned couplings might evolve and thus the realized couplings might be different. First, inherent technical and other uncertainties are present to a significant extent in the project planning phase (König et al., 2013), so the plans may turn out to be unrealistic, or opportunities may have been overlooked. Second, collaborating organizations may have different levels of commitment, or there may be a lack of trust or other barriers to collaboration (Nsanzumuhire & Groot, 2020). The planned innovations and the related planned couplings may have different priorities for the organizational actors who pursue both shared and own objectives (Mannak et al., 2019). So when shortages of resources or technical difficulties arise, the efforts may be refocused. Third, the dynamic project context (Bakker, 2010) may have an influence: “no project is an island” (Engwall, 2003, p.789), and the organizational actors in the RDI projects experience dynamics of their contexts (Manning, 2017). E.g., reorganizations of organizational actors or change of personnel may

have a significant impact. Forth, flexibility of some organizational actors may be enabled by the availability of resources, the context of urgency, and of trust between the participants in the projects and other factors (Lighthart et al., 2016). Fifth, with the involvement of organizational actors (and the project participants) in the modules and at the interfaces, the two dimensions of complexity described in Section 2.3 may manifest simultaneously and may influence the evolution of the couplings over time. Sixth, the organisations in the projects considered here are autonomous; the lack of an active project sponsor, the lack of a strategic integration on the portfolio level, and limited external intervention (vom Brocke & Lippe, 2015) may lead to an evolution of couplings.

A better understanding of the evolution of couplings is important also from the practitioners’ point of view, given the significant amount of public funding that is invested in such multi-actor RDI projects, and the need to equip the RDI project managers with an understanding of how to better manage projects leading to collaborative innovations (Cunningham et al., 2021).

Both the identified literature gap, the puzzle highlighted above, and the practical needs provided the motivation for conducting this study, i.e. analyzing ‘why and how’ the couplings evolve in multi-actor publicly funded RDI projects, and how do they influence the collaborative innovations generated by the projects. The evolution of the couplings is understood in this paper as the reconfiguration of the planned couplings within the project over time: either in terms of their pattern (this includes a reduction or an increase of the number of contributing organizational actors involved in the same coupling) or in terms of their intensity. Implication on collaborative innovation is understood from the point of view of the innovations actually being realized and of the number of contributing organizational actors comparing with plans. Adaptations of the technical content without a change of the configuration of the coupling are not considered as evolutions of couplings in this paper, so the analysis is content-agnostic.

3. Research methods

3.1. Research design

This research is part of a larger study that takes a deeper look into multi-actor RDI projects. The research design is an exploratory comparative inductive multi-case study (Eisenhardt, 1989). Exploratory case studies (Yin, 2017) are needed when there is a lack of detailed preliminary research and hypothesis to be tested (Mills et al., 2010). We adopted a process view, which is appropriate to illuminate the dynamics of inter-organizational collaborations (e.g. Berends & Sydow, 2019; Brunet et al., 2021), investigating how “phenomena emerge, change, and unfold over time” (Langley et al., 2013, p. 1) as well as the generative mechanisms behind these changes (Cloutier & Langley, 2020; Abdallah et al., 2019).

The study mobilizes grounded theory approach (Strauss & Corbin, 1990): it is one of the “valuable methodological approaches for shedding light from new and decidedly fascinating angles...” (Pinto, 2022, p. 4), and may be one of those “alternative lens through which new insights into projects and project management practice can be generated” (Cicmil et al., 2006, p. 684). The theory is generated inductively, it is ‘grounded’ in the field data and thus reflects the lived experience of the interviewed project participants.

The field data included project documents and interviews. The analysis was inductive and was supported by the coding process, with three main stages: (1) open coding, with systematic comparison of the quotes of the informants in order to group them as the codes of 1st level, close to the field data; (2) abstraction process of open coding (Strauss & Corbin, 1990, adapted by Gioia et al., 2013); (3) elaboration of data structures. During the abstraction process, leading to the codes of 2nd degree, we regularly iterated with the existing literature, which helped to make sense of data and perform an informed analysis, e.g. about complexity, cognitive distance, technological barriers and other aspects.

The data collection and analysis were conducted at the project level. To answer the first and the second research question, the unit of analysis was the couplings (planned and realized) within the modules and at the interfaces. To answer the third research question on the implications of the evolution of the couplings, the unit of analysis was the innovations that were (planned to be) generated in the projects. Details on data collection and analysis are provided in Sections 3.3. and 3.4 below.

3.2. Research setting

The research setting is defined as multi-actor inter-organizational RDI projects in the engineering domain funded on the basis of competitive calls by the European Commission (EC) through its two latest Research and Innovation Framework Programmes, Horizon 2020 and its predecessor, FP7. These projects usually last three to four years, and comprise multiple organizational actors usually from academia and industry, often combined in several sub-groups to undertake market-stream research, development and innovation.

This setting is particularly compelling for project management scholars to study the dynamics of couplings, due to two reasons. First, complex, large EC-funded projects with multiple and diverse organizational actors exhibit a large variety of couplings and their combinations, which are planned in the proposals. The couplings reflect substantial working links, leading to project outputs. Second, the period of proposal preparation, when the organizational actors agree on their collaboration and the couplings, is usually short, commonly a few months. If the proposal is granted, the public funds are allocated to each individual organization and the funding is expected to continue as planned until the project ends. This lack of structural flexibility constrains the evolution of the couplings, however, as discussed in Section 2.4, on the other hand evolutions of couplings should be expected.

The paper builds on the previous research mentioned in Section 2.4 (Klessova et al., 2020) which analyzed the architectures (patterns of couplings) of six projects. A typical example of such a project architecture is shown in Fig. 1a. From these six projects, four¹ were selected for this paper, with anonymized names HERCULES, PEGASUS, PERSEUS and ORION (Appendix 1). These four projects were selected because they satisfy the criteria of (1) availability of data, (2) homogeneity and (3) comparability in terms of (a) thematic: all projects concerned industrial applications and IT technologies; (b) the type of the project architecture: all four projects were modular (see Fig. 1b), and were planned with parallel modules (related to specific applications) that were connected by interfaces, often throughout the duration of the project; (c) the relatively high number of organizational actors from academia and industry: 10 to 17 organizations; (d) the collaboration antecedents (50-60% of the participants in each project had experience of collaboration with some organizations in the project before the project start). Two criteria of variety were also taken into account: (a) the four selected projects represent different types/sub-types of project architectures (Fig. 1b): three projects (PEGASUS, ORION, PERSEUS) were planned as *grid*-type projects with planned interfaces connecting modules; the activities at the interfaces were of different intensity with different sizes of the sub-groups involved. In contrast, HERCULES was a *waterfall*-type project, with a strong activity at the interface with an output that was planned to be used in a subsequent “waterfall” of different modules; (b) the PEGASUS project was mainly driven by the interest of several research teams while the other three projects were largely driven by industrial needs. The selected projects constituted theoretical sampling: the selected cases were “particularly suitable for

¹ Initially, also two workflow-integrated projects were analyzed, but the research showed that they are very similar to new product development projects, they lead to one main innovation and their couplings do not evolve, except under force majeure circumstances; such projects were therefore not considered in the analysis reported here.

illuminating and extending relationships and logic among constructs” (Eisenhardt & Graebner, 2007, p.27). Each of the projects and their couplings were unique, but looking at the whole sample contributed to theory building, by enabling the recognition of patterns of the evolution of couplings and their implications, and a comparison between them.

3.3. Data collection

For this paper, we distinguished and observed: (1) Couplings in modules, where work was done in small sub-groups of a few (up to 5) organizational actors, with significant amounts of efforts invested per organization, leading to specialized outputs; and (2) Couplings at the interfaces; some of them were planned to provide input to modules (for example, work at the interface leading to the development of generic innovations to be applied in several modules), while others were planned to collect input from modules in order to generate generic outputs on this basis. We also analyzed the generated innovations in terms of the contributing actors and to which extent they conformed to the planning. The research focused on those couplings which evolved; for completeness, in section 4.3 (Table 5) we indicate not only the planned and evolved couplings, but also the couplings which did not evolve comparing with planning.

We firstly used the project documentation and then performed and analyzed interviews with project actors. The project documentation included over 740 pages, and allowed us to identify the planned couplings, the realized 50 innovations (45 innovative technologies, methods, tools, algorithms etc., and 5 creations of new knowledge), and the contributing organizations. The innovations ranged from physical devices to software platforms, algorithms, tools, know-how or human-computer systems. In all projects most innovations had to be embedded into larger systems (e.g. machines, processing equipment, transport units, IT systems...). The innovations can be characterized as non-radical as their development departed from existing foundations.

To trace and understand the evolution of the couplings, we analyzed how the couplings were planned at the beginning of the project, how they changed during the execution of the project, and what the realized (“lived”) couplings were at the end of the project. Planned couplings in the modules and at the connecting interfaces were identified in the grant agreements, which defined the contributing organizational actors and the planned input of resources. For example, text in the grant agreement might read “tool A will be applied and tested by Partners B C D”. Many organizations were planned to contribute both in modules and at the interfaces, with different roles. An overview of the numbers of planned modules and interfaces in the studied projects is provided in Appendix 1, columns G-H. The project documentation made it possible to identify the *realized* modules, interfaces, innovations, and to trace the evolution of the couplings (planned versus realized collaborations).

A break of a coupling was defined as an abandoning of the planned joint work; weakening of a coupling was defined as a retreat of some organizational actors from the planned work, but with other organizational actors remaining, and thus with conservation of the related module or interface. We also identified the number of organizational actors that contributed to the innovations, and compared it with the plans. After the initial identification of the innovations and the evolutions of the couplings, we reviewed and validated the data with the project coordinator or with one of the key participants in each project.

The data from 32 semi-structured interviews with 24 project participants resulted in over 33 hours of recording and 585 pages of transcripts (Tables 1 and 2). This data was used to confirm the couplings and to gain insights about their evolutions. In each project, representatives of between 40% and 65% of the participating organizations were interviewed. Informants were from large industry, technological SMEs, and research organizations. We selected mostly experienced informants who had been involved in the collaborative work: over 80% of them were CEOs of SMEs, team leaders within large corporations, or tenured university professors.

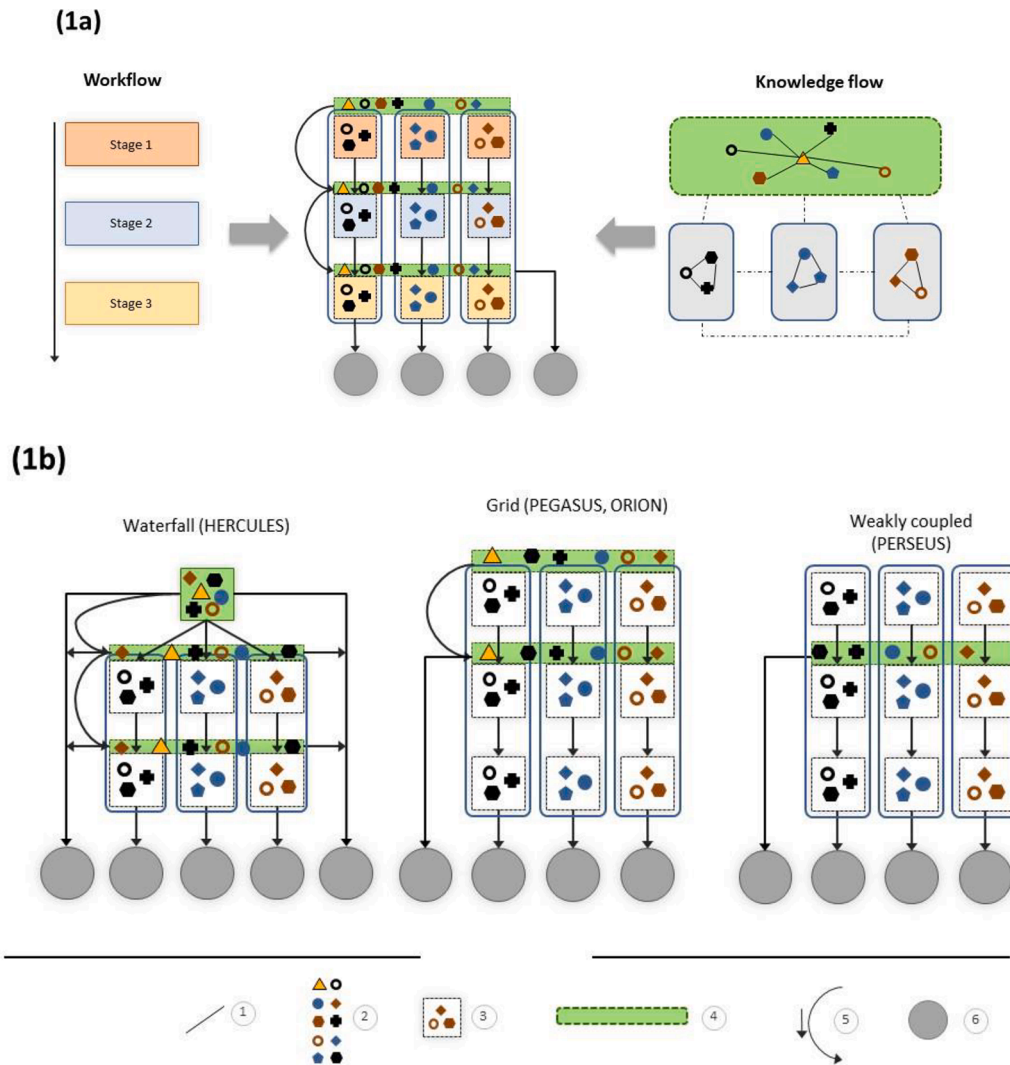


Fig. 1. Conceptual representation of project architectures: (1a) example of a project with planned three parallel modules (involving small sub-groups of organizational actors) and one interface involving a large sub-group of organizational actors; (1b) Architectures at the beginning of the four projects under study. Legend: 1: planned couplings (Fig.1a); 2: collaborating organizational actors; 3: planned module; 4: planned interface; 5: dependencies; 6: planned outputs (innovations). Adapted from Klessova et al. (2020).

Table 1
Overview of informants and number of interviews.

Profile	Informants, number		Interview; number
	Total	incl. those participated in two or more projects under study	
Research/ university	9	2	15
Industry	15	5	17
incl. large industry	8	4	10
incl. tech SMEs	7	1	7
TOTAL	24	7	32

7 informants participated in more than one project from our sample, and the project manager was the same in 2 projects, thus adding to this research a comparative multiple-case dimension (Bakker et al., 2016). A detailed interview guide was developed, all interviews were recorded, with prior consent in line with the European General Data Protection Regulations.

3.4. Data analysis

The data analysis, based on open coding and abstraction (see Section

3.1), was organized in three sequences, as described below, firstly ‘within-case’ and then ‘across-cases’.

Sequence 1. Study of the evolutions of the couplings and of the phases in the modules and at the interfaces. The evolutions of the couplings were very similar across the projects, but different within the modules and at the interfaces. The cross-project data structures 2A and 2C of the types of evolutions are presented in Appendix 2 and helped to identify 8 types of evolutions of couplings: 5 in the modules (see data structure 2A: 18 1st order codes grouped into 5 concepts of the 2nd order) and 3 at the interfaces (see data structure 2C: 9 1st order codes grouped into 3 concepts of the 2nd order). For example, the quotes below suggested the code of the 1st order “dropping the planned collaborative work”

“It became apparent that in some cases it will not work because requirements do not fit the possibilities... And that was after one year... we had to stop it” (ID31_PERSEUS_res).

“We had the clash between partners and the subsequent abandoning of the application”. (ID5_ORION_coord)

And the quotes below suggested the code of the 1st order “No alternative options”:

“They don’t want us to extract the data from their database... for confidential reasons.... they need to approve our software but the IT did not allow. So we cannot do anything...” (ID38_ORION_SME)

Table 2
Overview of interviews per case study.

Anonymous project name	Partners (organizations), number	Interviewed organizations per case		Interviews, informants per case, number	Number of interviews per profile of informants			Recording, min.	Transcripts, pages
		Number	%		Research	Industry			
						Large	SME		
HERCULES	10	4	40	6	3	2	1	443	130,3
PEGASUS	12	6	50	7	3	3	1	384	109,1
PERSEUS	15	7	47	8	5	2	1	527	145
ORION	17	11	65	11	4	3	4	639	201,1
TOTAL				32	15	10	7	1993 (33.2 hours)	585,5

“There were troubles down the line because the use case had to change. And although it is frustrating, it did set our work back, there’s nothing that anybody could have done about that”. (ID25_ORION_SME)

Combined with other relevant codes of the 1st order, this led to the theme of the 2nd order “Abandoning” (see data structure 2A).

Some evolutions were clearly marked by documented decisions, while others took place more informally, but in both cases, there was a result: evolution of the couplings. The quote below illustrates how a planned coupling slowly split without clear decision.

“At the beginning they came to us, and said, yes we can do this or that... We had a lot of discussions with them, ... you couldn’t reach him by mail or by phone or whatever, and he only answered shortly before the next plenary meeting to get some information to do his slide desk, and at one point in time we said okay this is not giving us any benefit... They were not interested to help us to reach the project goals. They were just interested to develop their (output) with the EU funding.” (ID 40b, ORION_large ind)

Then we compared and studied the evolutions of the couplings from a process perspective in the modules and at the interfaces, and identified the decomposition into phases of evolutions of couplings, or temporal bracketing (Langley, 1999), i.e. how the evolutions unfolded over time. Similar phases, but of different durations, were found for different evolutions of the couplings in all four projects.

Sequence 2. Study of the generative mechanisms. We followed the same process of open coding and abstraction to build the data structures to identify 10 generative mechanisms behind the evolution of the couplings: 8 generative mechanisms in the modules (see Appendix 2, data structure 2B: 66 1st order codes grouped into 17 concepts of 2nd order and 8 aggregate dimensions) and 3 generative mechanisms at the interfaces (see Appendix 2, data structure 2D: 13 1st order codes grouped into 6 concepts of 2nd order and 3 aggregate dimensions). Similar generative mechanisms were found in the four projects. By the analysis of documents and data, we also identified potential facilitating elements which help to maintain the interface coupling in place. For instance, the following quotes from ORION defined the code of the 1st order “Too many partners”; in combination with other codes, this led to the 2nd order theme “Flaws in project design and planning” and then to the 3rd order aggregate dimension “Flaws in the proposal”:

“Seventeen partners...too many, it was just impossible to synchronize... I was making distinction between learning and actively doing things together... learning of course you can learn from everybody... to do things together is very different... almost inevitably, you form subgroups.” (ID24_ORION_SME)

“There were many people... What happened... the island of the people who do topic 1 and the island of people who do topic 2...” (ID5_ORION_coord)

Sequence 3. Analysis of the consequences of the evolutions of couplings.

This is the descriptive part of the study, in which we juxtaposed the plans with the results, and identified implications, e.g. whether the planned innovation was realized or not, or whether it was realized collaboratively, with the same or less contributors comparing to the planning, or individually.

Thanks to the combination of the interview data and the documents and the verification with the informants, it was possible to triangulate the data, and the insights gradually emerged from the analysis. For example, the project proposal mentioned two collaborators, organizations A and B, in the description of the project module, and the final project report mentioned only one contributor to the output of this module, organization A. The informant from the organization B explained this evolution:

‘We offered A to come here and to do everything they need... They have to ... check and discuss with people and get this data. We can’t have one guy here internally just providing all the information to A... They were not ready to do that. We gave up... They were not interested to help us to reach the project goals. They were just interested to develop their (technology).’ (ID40b_ORION_large ind)

Based on these results, we propose an emerging grounded model of the evolution of the couplings over time in multi-actor RDI projects.

4. Results

This section focuses on the ‘across-cases’ analysis, following Eisenhardt (1989) and Berends and Deken (2021). We firstly present the phases, types and generative mechanisms of the evolution of the couplings in modules, and then at the interfaces. Then we show the resulting architectures of the projects with a comparison to the planned architectures. Then we discuss the implications of these evolutions on the collaborative innovations, and finally present the emerging grounded process model.

4.1. Evolution of the couplings in the modules

4.1.1. “How”: phases and types of evolutions in the modules

The study identified 3 phases of the evolution of couplings in the modules, which were abstracted into 5 types of evolutions (see Appendix 2, data structure 2A).

During *Phase 1, “exploration”*, the evolutions of the couplings in the modules resulted from deeper investigations of the needs and requirements, confirming (or falsifying) the feasibility of the planned collaborative innovations and of the couplings. This phase concluded either by a validation of the coupling and its lock-in, or by two possible decisions corresponding to two types of evolution of couplings: *abandoning*, i.e. dropping the planned collaborative work completely, or *consensual refocusing*, i.e. consensual reconfiguration of the couplings, forming a different coupling compared to the planning. In addition, *splitting*, i.e. bifurcation of work, with partners following own paths, resulting in individual work instead of planned collaborative work

already started in this phase, but without explicit decisions.

“It became apparent that in some cases it will not work because requirements do not fit the possibilities... And that was after one year...” (ID31_PERSEUS_res).

Phase 2, “adaptation”, started when the main R&D work towards the development of the collaborative innovations advanced, facing obstacles of different nature and characterized by multi-actor dynamics. This phase, after an attempt of adaptation, concludes either by validation and lock-in of the coupling, or by several types of evolutions: similar to phase 1, abandoning, continuation of splitting or new occurrences of splitting, *consensual refocusing*, or *restoration*, often as a result of response actions of the project management to previous tendencies of abandoning.

“We had one point in the project were one partner ... was going in a direction which was relatively unrelated to the rest of the project, we corrected that, had a discussion, and they refocused that work.”-ID2_PEGASUS_coord (example of restoration; phase “adaptation”)

Only one *bottom-up integration* – the formation of an additional, unplanned coupling – was observed. So all but one of these evolutions across all four projects pointed in the non-increasing direction, either the coupling was confirmed and locked-in or there was abandoning or weakening of couplings.

Phase 3, “lock-in” was characterized by stability of the couplings in all projects: the reconfigurations had already taken place during the previous phases.

The work in the modules started early in all projects, so in the beginning and at the end of the projects the phases were synchronized, while in-between the duration of the phases varied depending on the project context, e.g. the nature of the projects, research-driven or industry driven, on the previous collaboration experience, on organizational factors, on the depth of planning and knowledge at the proposal stage... For instance, Phase 1 in PEGASUS for all couplings took three months, while in PERSEUS and ORION for several couplings it lasted almost a year; the new bottom-up integration in ORION took place and was locked only within the last year of the project.

Table 3 provides an overview of the phases and the related types of evolutions of couplings in the modules of the projects, as well as findings about related attitudes or/and actions of the involved organizational actors, and implications on those involved in the couplings. On-line Appendix A provides illustrations from the projects.

4.1.2. “Why”: generative mechanisms in the modules

The study found six generative mechanisms that were activated in the modules, resulting in the evolution of the couplings (see Appendix 2, data structure 2B): four disintegrative and two integrative ones. Disintegrative mechanisms are those which lead to negative evolutions of couplings comparing to what was planned (i.e. a coupling either was weakened or dissolved); integrative mechanisms are those which lead to positive evolutions of couplings (e.g. a new coupling evolved, or reinforcement of a previously weakened coupling). We also observed that in all projects knowledge integration mechanisms were used to a large extent, especially technical exchanges in the modules, and, according to the project actors, significantly influenced the level of the resulting innovations in terms of their quality and maturity, but did not prevent the negative evolution of couplings.

The four disintegrative mechanisms were: (1) cooperation issues, such as selfish interests, misalignment of interests; (2) technical barriers; (3) actors-related attributes at the organizational or individual level; (4) external pressure.

“It was seen later on... They underestimated the technical challenge... (ID28a_PERSEUS_large_ind) (example of technical barriers)

“We have talked about organizational issues ... very often in all these projects it boils down to individuals. You know, how open how

willing they are to work together...” ID24_ORION_SME (example of actors-related attributes)

Combination of different mechanisms led to different types of evolutions, especially to abandoning or splitting.

The underlying issue in the modules often was flaws in the proposal, such as ill-designed use cases of industrial organizational actors, unrealistic plans, imprecisions or too high expectations. However, according to the project participants, some overestimations of the opportunities are a typical ingredient of proposals for pre-competitive public funding and a certain degree of imprecision also help to adapt to new developments.

Two generative mechanism activated evolutions of couplings in a positive direction in the modules, leading to either their adaptation or preservation: (1) *pressure*, both internal (especially action from the project management) and external (sponsor); (2) *new opportunities* combined with proactive actions of one of the involved actors, motivation and an open-minded attitude of those involved in the couplings, their organizations and the project manager, a relatively broad description in the technical proposal that enabled to react flexibly, the availability of the right competences required for the reconfiguration to be put in place.

“I had to intervene and threaten them, because many people other partners were depending on their work, and if they stopped working ... then we wouldn’t achieve our goal. Well the only option I have to make pressure on them” (ID11_PERSEUS_coord) (example of pressure from the project manager)

When promising reconfiguration opportunities were present, some organizational actors did not seize them: the project participants were either under too much pressure to “have their eyes open”, did not had enough power within their organization to push options forward, or were newcomers to the funding scheme and lacked understanding that adaptations are possible. This might be a reason for only one bottom-up integration taking place in all studied projects.

4.2. Evolution of the couplings at the interfaces between modules

4.2.1. “How”: phases and types of evolutions at the interfaces

The evolution of the couplings at the interfaces included only two phases, in which two types of evolutions unfolded (see Appendix 2, data structure 2C): **Phase 1, “exploration”**, and **Phase 2, “erosion”**, which was commonly characterized by fading away of enthusiasm. At the end of three projects (PEGASUS, PERSEUS and ORION), many planned interfaces had eroded significantly. The evolution was different at the two types of the interfaces. When the interfaces were planned to provide input to modules, they were often not connected to the modules to the extent planned, in spite of their high technological relatedness, and planned couplings at the interfaces were abandoned, often in favour of couplings in modules, so the project became fragmented into isolated activities in the modules. When the interfaces were planned to receive input from the modules, the contributions did not meet the expectations.

“It (NB: interface activity) partially indeed happened, let us say fifty percent” (IDsupp5_PEGASUS_coord)

Only in HERCULES (waterfall-type project), the degradation of the interface was minor, it survived until the end and generated significant documented knowledge, even though some organizational actors downscaled their contributions.

“At the beginning of the project it seemed for a while that they were just doing their own thing...because it wasn’t very much in their interest at the beginning. In the end it turned out, with a bit of pressure I would say from the management team... in the end they did work” (ID6_HERCULES_large_ind)

The interfaces in all four projects went through these two phases, but

Table 3

Overview of the phases and types of the evolutions of the couplings in the modules; attitudes, actions of the involved organizational actors, implications on the actors and actions of the project managers, as observed in the studied projects.

Project phase in modules	Decisions at the end of the phase (and type of evolution)	Changes in the <i>pattern</i> (configuration) or in the <i>intensity</i> of coupling	Projects where evolutions were observed	Attitude/action of the organizational actor-initiator regarding the planned coupling (work)	Attitude/action of other involved organizational actors, and implications	Attitude/ action of the project manager
Phase 1: exploration	Abandoning	Disappearance of couplings (<i>pattern</i>)	PERSEUS ORION	Abandoning of work	Receive information. Accept abandoning of planned coupling.	Intervention or laissez-faire – accept abandoning of planned coupling.
	Splitting	Separation (dissolution of couplings (<i>pattern</i>))	PERSEUS ORION	Work done individually instead of collaboratively or by less collaborators	Receive information. Loss of collaboration opportunity.	Intervention or laissez faire
	Consensual refocusing	Replacement of some couplings by others (<i>pattern</i>), often accompanied by downscaling (intensity)	PERSEUS ORION	Effort refocused on promising directions. Not promising planned topics may still be dealt with, but with reduced effort	Contribute to the extent possible. Look for other topics. Re-assign efforts	Participates actively.
	Validation and lock-in	No change	All projects	No deviation	No deviation	No deviation
Phase 2: adaptation	Abandoning	Disappearance of couplings (<i>pattern</i>)	PERSEUS ORION	Abandoning of work	Receive information. Accept abandoning of planned coupling.	Accept abandoning of planned coupling.
	Consensual refocusing	Replacement of some couplings by others (<i>pattern</i>), often accompanied by downscaling (intensity)	ORION	Effort refocused on promising directions. Not promising planned topics may still be dealt with, but with reduced effort	Contribute to the extent possible. Look for other topics. Re-assign efforts	Participates actively.
	Splitting	Separation (dissolution of couplings (<i>pattern</i>))	PEGASUS PERSEUS ORION	Work done individually instead of collaboratively or by less collaborators	Receive information. Loss of collaboration opportunity.	Intervention or laissez faire
	Bottom-up integration	Formation of new, unplanned couplings (<i>pattern</i>)	ORION	Search of new opportunities	Search for new opportunities. Possibly reallocation of resources.	Support, enco-uragement, or intervention
	Restoration (response to abandoning or splitting)	Restoration of couplings, after temporary abandoning (<i>pattern</i>)	PERSEUS, ORION (response to abandoning), PEGASUS (response to splitting)	Reducing efforts, then returning to plans	Active management and counterbalancing. Coupling stay in place	Active management, counterbalancing
	Validation and lock-in	No change	All projects	No deviation	No deviation	No deviation
Phase 3: lock-in	No deviation, continues as locked-in in the previous phases					

timing depended on the timing of the planning of the interface in the projects. In most cases, it was not possible to identify the exact separation between these two phases, as the erosion took place gradually; often one organizational actor continued to work independently at the interface on own innovations but the connection between the interface and the modules was weakened or lost.

The durations of the phases of the evolution of the couplings were dependent on the timing of the work in the interfaces, but the sequence was always the same.

Table 4 provides an overview of the phases and the related types of evolution of couplings at the connecting interfaces of the projects, as well as attitudes and actions of the involved organizational actors, and of the project managers. On-line Appendix B provides illustrations from the projects.

4.2.2. “Why”: generative mechanisms at the interfaces

At the level of connecting interfaces, there were two generative mechanisms of disintegration (see Appendix 2, data structure 2D): (1) relational complexity at the interfaces versus cognitive complexity in the modules, leading to the reluctance or inability of the project participants to contribute to different topics in different groups simultaneously; and (2) internal and external pressure (e.g. of the main organization, of the project constraints such as time and budget), which drove the organizational actors to prioritize the key activities in the modules, paying less attention to or abandoning contributions at the interfaces.

With regard to complexity, it was difficult for the project participants to simultaneously deal with the relational complexity ‘in breadth’ (at the interfaces) and the cognitive complexity ‘in depth’ (within the modules). At the proposal writing stage, large consortia with many organizational actors were created, following the implicit expectation of the calls of dealing with a significant number of specialized applications. The projects were structured in modules that were driven by the interests of small groups of organizational actors. In order to demonstrate the value of the partnership, connecting interfaces were introduced. At the project implementation stage, the work at the interfaces generated a high relational complexity, and the cognitive complexity took its toll: under the pressure from the project constraints, the partners prioritized their work and focused on the couplings in the modules that provided tangible benefits to them.

“It’s like adding balcony to the house, you know... you can live in a house without a balcony, but it looks nicer... with a balcony (smiles).

These were balconies, these tasks... Balconies are nice to sit and have a broader view. However people are more concerned with digging in the soil to plant...” ID43_PERSEUS_acad

The interfaces were planned because the consortium and specifically the usually small group of people involved in the design of the proposal believed in their value, and because they were needed to tie the work together and present it as one proposal, thus demonstrating the added value of the partnership. Then, in the implementation phase, it was realized that the potential was sometimes overestimated, and the difficulties were underestimated; most actors preferred to respond to their immediate needs in the modules. So their enthusiasm faded away as soon as the difficulties appeared, and their effort was diverted away from the interfaces.

Other factors concerned the interfaces which were supposed to provide input to the modules. In some cases, the results were ready too late for embedding them; in other cases, the developments were mostly driven by interests of the developers that reflected customers outside of the project; and sometimes, there were barriers to the implementation.

“Partners have ecosystem of software tools... it’s hard to connect all these tools. I think the tooling creates walls, and it’s not that people don’t want to collaborate, it’s just that the only thing that they can exchange, is data... and they can’t work with each other tools very easily, some tools are licensed, and some tools you have to know quite a bit about... this sets limitations (supp1_ORION_SME)

We also identified generative mechanism leading to the preservation of couplings (fluctuation, instead of downscaling), especially internal pressure from the project manager or from key project participants contributing to the interface (Appendix 2D).

Overall, we observed that the interfaces were the first elements that were dropped under pressure:

“When you struggle (NB: with the main work) then you’re not so concerned (NB: about other work). And that was the case ... then you fight with technical problems” (ID4_PERSEUS_acad)

The evolution in the modules influenced the evolution in the interfaces, but not vice versa. The more there was refocusing, adaptations, and pressure in the modules, the stronger was the tendency to reduce the efforts that are spent on the activities at the interfaces, and the interfaces which were not critical to the project systematically eroded when pragmatism took over from enthusiasm, frequently with the interface

Table 4

Overview of phases, related types of evolutions of couplings at the interfaces; attitudes and actions of the involved organizational actors and the project managers, as observed in the studied projects.

Project phase At the interfaces	Type of evolution	Changes in the <i>pattern</i> (configuration) or in the <i>intensity</i> of coupling	Projects where evolutions were observed	Attitude/action of the organizational actor-initiator regarding the planned coupling (work)	Attitude/action of other involved organizational actors	Attitude/ action of the project manager
Phase 1: Exploration	Downscaling	Slow decrease in <i>intensity</i> , may lead to full retreat of actors and thus decomposition	HERCULES PERSEUS leading to decomposition in Phase 2, see below	Some planned collaborators retreat (do not provide input)	Laissez-faire. Continuation, with input from some partners	Laissez-faire
	Fluctuation (response to downscaling)	Temporary changes in <i>intensity</i> or <i>pattern</i>	ORION PEGASUS HERCULES ORION PEGASUS	Collaborating partners silently retreat but then are re-investing efforts	Continuation even if some partners retreated	Active management, counterbalancing
Phase 2: Erosion	Downscaling	More significant decrease in <i>intensity</i>	HERCULES PEGASUS ORION	Some planned collaborators retreat (do not provide input) or do not apply the technology	Laissez-faire. Continuation, with input from or collaboration with fewer partners	Laissez-faire
	Fluctuation (response to downscaling)	Temporary changes in <i>intensity</i> or <i>pattern</i>	HERCULES PEGASUS ORION	Collaborating partners silently retreat but then are re-investing efforts	Continuation even if some partners retreated	Active management, counterbalancing
	Decomposition	Erosion of couplings until full disappearance (<i>pattern</i> , <i>intensity</i>)	ORION (partial decomposition) PERSEUS (full decomposition; no remaining interfaces)	No initiator: all planned collaborators retreat	Withdrawal or continuation, individually	Laissez-faire

leader continuing to implement the planned work individually, but connections between the modules were lost.

4.3. Summary of the findings about the evolution of the couplings

Table 5 provides an overview of the number of planned and of the realized couplings in the four projects, this includes planned couplings that evolved (studied in Sections 4.1 and 4.2) and also those that did not evolve. In the modules of all four projects, *non-evolving* couplings went directly from exploration (Phase 1) to lock-in (Phase 3), but *evolving* couplings went through all three phases; some of them were initially considered as being ‘locked’ after Phase 1, but then experienced evolutions and again lock-in.

The project architectures are mostly defined by the number and the strength of the interfaces (Klessova et al., 2020): these are the ‘gluing’ part connecting the project altogether. Table 6 analyses the consequences of the evolutions of couplings on the project architectures, and outlines that in the three projects, with the evolution of the main interfaces, the modular project architectures evolved as well, *systematically in one direction*, towards erosion and decoupling of the modules from the interfaces.

Only in HERCULES (waterfall-type project), the evolution of the architecture was minor: the main interface connecting different modules survived until the end. It also became the “anchor point” of the project and shaped its identity.

“Within the (HERCULES) project, I think, there was a real progress ... some of the partners tried to develop specific ... solutions, others like us, we developed generic solutions.... but there was an anchor point. And we don’t have an anchor point like this in ORION... the approaches are totally different (ID26_compar_SME)

“There was a bigger block of work where an unknown problem had to be solved... we had to develop this thing, and create a joint understanding... virtually all partners had to get involved in the creation of something... the creation of concepts and ideas brainstorming about them... it went through the project from day one to day final” (ID36_HERCULES_compar_acad)

The interface in the HERCULES project exhibited the following characteristics: (1) It was planned in the proposal and started from the

Table 5
Overview of planned and realized couplings in the studied projects.

Evolution of couplings (planned versus realized)	Number of couplings			
	PEGASUS	HERCULES	PERSEUS	ORION
MODULES				
Planned, total	6	6	9	15
From them:				
Not evolved: planned and realized	4	5	5	11
Evolved: realized with unplanned additional coupling(s)	0	0	0	1
Evolved: realized with loss of coupling(s)	2	1	2	1
Evolved : planned but not realized	0	0	2	2
Not planned but realized	0	0	0	1
INTERFACES				
Planned, total	3	3	3	9
From them:				
Not evolved: planned and realized	0	0	0	0
Evolved: planned and realized with erosion of different degree	3	3	3	7
Evolved : planned but not realized	0	0	0	2
Not planned but realized	0	0	0	0

beginning of the project, with regular interactions with modules; (2) Significant resources were allocated to the organizational actors at the interface; (3) The result of the work at the interface was needed and not a “nice to have” element; (4) The work at the interface did not include high-risk tasks; (5) There was not a too large number of organizational actors involved at the interface; (6) The interface has a close technological relatedness with modules; and (7) There was sufficient pressure from the project manager to counterbalance tendencies for erosion at the interface, and sound knowledge integration mechanisms were put in place. This suggests that couplings at the interfaces seem to have higher chances to last until the end of the project if several of these potentially facilitating elements are present in the planning of the project and in its implementation.

4.4. Implications of the evolutions of the couplings in the modules and at the interfaces on the planned collaborative innovations

The evolution of the couplings had different implications on the planned innovations in the modules and at the interfaces. A summary of the findings, linking the evolution of the couplings and the implications on the collaborative innovations, is reported in Table 7. We classified the implications into negative, moderately negative (individual innovation instead of planned collaborative innovation, collaborative innovation as planned, but with less contributing organizational actors; or downscaled innovation, due to reduced input, but with the same contributors as planned), neutral (another innovation resulted, or it was preserved as planned with the same contributors) and positive (new, unplanned collaborative innovation), which we observed as a result of one bottom-up realization of a coupling. Because of the challenge of the relational and cognitive complexity (Section 4.2.2), and because the organizations (and their project participants) gave priority to the work in the modules, especially the collaborative innovations at the interfaces suffered.

However, as shown in Table 7, despite the observed general trend towards negative evolutions of couplings (for instance reduction of the number of planned couplings) and their either negative or moderate negative implications, the number of planned innovations compared to the plans remained stable in three projects out of four (except PERSEUS), despite the fact that the innovations became less collaborative than planned in all studied projects, especially at the interfaces. In many cases, the project participants were not overly concerned about this:

“In my experience the proposals are always based on 100% success rates, you say that you’re ...going to develop something ..., and then the ... evaluation is based on the fact that you would ... reach all your goals...the system works that way. It’s not so bad because in the end you still ... do have (innovations) but maybe not all that was promised when you wrote the proposal.” (ID31_PERSEUS_res)

According to the project participants, some slack in the plans to react to unforeseen difficulties and to grasp new opportunities helped to reconfigure the couplings and to avoid loss of collaborative innovations, although they were sometimes different comparing to initial plans.

“You come up with a project description... at some point you find out that ... it might be more worthwhile to rather work on that topic that on the others, but you are limited by what is written in the description of work”. (ID40a_HERCULES_large ind)

4.5. Summary of findings: an emerging grounded model of the evolution of the couplings in multi-actor RDI projects

Based on the previous findings about the ‘how’, ‘why’, and about the consequences of the evolutions of the couplings, we propose an emerging process model of their evolution and its influence on the planned collaborative innovations in multi-actor RDI projects, see Fig. 2.

In the modules, *the first phase*, “*exploration*”, is characterized by

Table 6

Evolution of couplings, modules and interfaces, and of the architectures in the projects under study.

Project/ phases	Evolution of couplings: level of modules	Evolution of couplings: level of the interfaces		Project architecture	
		Evolutions	Explanation	Planned in the proposal	Realized, at the end of the project ¹
Phase 1	1. HERCULES No deviation	Some downscaling; Fluctuation Minor downscaling, Fluctuation N/A	Minor negative changes in the pattern: Phase 1,2	Grid	Waterfall
Phase 2	No deviation				
Phase 3	No deviation				
Phase 1	2. PEGASUS No deviation	Downscaling Downscaling; Fluctuation N/A	Negative change in intensity: Phase 2	Grid	Weakly coupled
Phase 2	Splitting; Restoration				
Phase 3	No deviation comparing to Phase 2				
Phase 1	3. PERSEUS Abandoning; Consensual refocusing; splitting	Downscaling Downscaling; decomposition N/A	Negative changes both of the pattern and of the intensity: Phases 1 and 2, until full decomposition in Phase 2	Weakly coupled	Decomposed
Phase 2	Splitting; Consensual refocusing; Restoration				
Phase 3	No deviation comparing to Phase 2				
Phase 1	4. ORION Abandoning; Consensual refocusing; splitting	Downscaling Downscaling; Fluctuation, bottom-up integration N/A	Mostly negative changes both of the pattern and of the intensity: Phases 1,2	Grid	Partial grid
Phase 2	Splitting; Consensual refocusing; Bottom- up integration; Restoration				
Phase 3	No deviation comparing to Phase 2				

¹ This was found in the previous study and used here for comparison.

significant evolutions of some planned couplings in the modules (abandoning, splitting, consensual refocusing), resulting from a deeper understanding of the needs and of the technical feasibility and prioritizing the ambitions of the project. Organizational attributes play an important role (confidentiality issues, changes of individual priorities...). *The second phase, "adaptation"*, is characterized by the presence of disintegrative mechanisms with cooperation issues and technical difficulties being the major drivers. This leads to a variety of evolutions, mostly with negative implications on planned collaborations. Bottom-up integration, with appearance of new couplings or even modules, generating unplanned collaborative innovations, may appear, however it is rare. *The third phase, "lock-in"*, is characterized by stability of the couplings. In contrast to what happens in the modules, at the connecting interfaces, the evolution of the couplings has two phases: they usually start as planned in the first phase, "*exploration*", which is relatively short in this case, and then already have a tendency to downscale. During *phase 2, "erosion"*, the interfaces degrade; in the extreme case, this may lead to fragmentation or even full decomposition of the project and loss of planned collaborative innovations, often with replacement by individually developed innovations. The restoration of the couplings in the modules and the degree of fluctuation at the interfaces depend on managerial actions and the integrative mechanisms put in place. The interplay between the evolution of the couplings in the modules and at the interfaces is uni-directional: additional efforts that are needed in the modules or pressure related to the technical work and deadlines accelerate the erosion at the interfaces, but not vice versa, i.e. reducing the inputs of the organizational actors to the interfaces does not lead to their disengagement from the modules.

5. Discussion

5.1. Theoretical contributions

The result of this research suggests an empirically grounded emerging process model (Cloutier & Langley, 2020; Langley, 1999)

which helps to better understand how and why the couplings, or the collaborations, reconfigure in multi-actor RDI projects, and the implications on the planned collaborative innovations. It enriches and complements the extant literature in two essential directions:

The first and main contribution of the paper is the enrichment of the literature on inter-organizational collaboration and its dynamics (e.g. Yang et al., 2021; Jakobsen et al., 2019; Manning, 2017; Davis, 2016), by exploring the 'how and why' of the evolution of the couplings in the inter-organizational setting, and more specifically, in multi-actor publicly funded RDI projects (e.g. vom Brocke & Lippe, 2015; Goldstein & Narayanamurti, 2018; Spanos & Vonortas, 2012), which are often implemented in a challenging collaboration context with academic and industrial participation (Fernandes & O'Sullivan, 2021; Gretsches et al., 2019; Steinmo & Rasmussen, 2018) and usually generate multiple collaborative outputs (Klessova et al., 2020, 2022, Kostopoulos et al., 2019). Several scholars called for research on the collaboration dynamics in inter-organizational settings (Sydow & Braun, 2018; Manning, 2017; Majchrzak et al., 2015), and pointed out the importance of organizing for knowledge creation in inter-organizational settings (Nisula et al., 2022), but multi-actor publicly funded RDI projects have not been investigated deeply yet. The literature on the dynamics of inter-organizational collaboration studied the unfolding of the collaboration between specific organizational actors, within the same coupling, and the nature of such dynamics (for a literature review, see Majchrzak et al., 2015), while our research extends to the overall organizational setting of the project, i.e. the full pattern of couplings at the project level, including couplings between the actors within subgroups (modules) and couplings between the subgroups of actors (interfaces).

With regard to 'how' the evolution of the couplings happens, the study provides evidence that it follows several phases, dependent on the role of the couplings in the project architecture. In the specialized modules, there are three phases of the evolution, exploration, adaptation and lock-in, sometimes with sharp boundaries between the phases. At the interfaces that connect (or were planned to connect) the modules, there are two phases, exploration and erosion, with blurred boundaries

Table 7
Evolution of the couplings and implications on the planned collaborative innovations.

Modules/ interfaces Phases	Type of evolution	Implication on the planned collaborative innovations	
MODULES			
Phase 1: Exploration	Abandoning	Negative: Loss of planned collaborative innovations (PERSEUS, ORION)	
	Splitting	Moderately negative: Individual innovations instead of planned collaborative innovations (PERSEUS, ORION)	
	Consensual refocusing	Neutral: Equivalent outcome on the project level (PERSEUS, ORION)	
	Phase 2: Adaptation	Abandoning	Negative: Loss of planned collaborative innovations (PERSEUS, ORION)
		Consensual refocusing	Neutral: Equivalent outcome on the project level (ORION)
Phase 1: Adaptation	Splitting	Moderately negative: Individual innovations instead of planned collaborative innovations (PEGASUS, PERSEUS, ORION)	
	Bottom-up integration	Positive: Increase of collaborative innovations unless other promising directions are not realized any more (ORION)	
	Restoration (response to abandoning or splitting)	Neutral: Preservation of planned collaborative innovations (PEGASUS, PERSEUS, ORION)	
	INTERFACES Phase 1: Exploration	Downscaling	Moderately negative: collaborative innovations generated as planned but with lower no. of contributors: ORION (planned innovation with less contributors); ORION (downscaled innovations); restored (HERCULES, PEGASUS)
Fluctuation (response to downscaling)		Neutral: Preservation of planned collaborative innovations, with lower no. of contributors (HERCULES, ORION, PEGASUS)	
Phase 2: Erosion		Downscaling	Moderately negative: collaborative innovations generated as planned but with lower no. of contributors: ORION (planned innovation with less contributors); PEGASUS, ORION (downscaled innovations); restored (HERCULES)
		Fluctuation (response to downscaling)	Neutral: Preservation of planned collaborative innovations, with lower no. of contributors (HERCULES, ORION)
		Decomposition	Negative: loss of collaborative innovations (PERSEUS, ORION). Moderately negative: Individual innovations instead of planned collaborative ones (PERSEUS)

between the two phases. The phases of the evolution occur in a fixed order: this is fundamentally different from other, more open settings, where it has been found that inter-organizational relationships are often evolving but do not follow a fixed sequence of phases (Deken et al., 2018). Our study uncovered eight types of evolutions of couplings, all following the phases described above: five types in modules (abandoning, splitting, consensual refocusing, restoration and bottom-up integration), and three types at the interfaces (downscaling, fluctuation and decomposition). All but one of these evolutions point in the non-increasing direction, at best resulting in the maintenance of the planned couplings, at worst leading to abandoning. Thus, through empirical exploration and induction, our study complements the

literature on processes in inter-organizational settings and on the evolution of the project architecture (Majchrzak et al., 2015; Berends & Sydow, 2019; Lighthart et al., 2016; Aubry & Lavoie-Tremblay, 2018; Sydow & Braun, 2018).

In all projects, there was a systematic degradation of the couplings at the interfaces; this happened without major concerns of the organizational actors, as long as their own objectives were reached (Mannak et al., 2019). We found that preservation of the interface is easier for projects of waterfall architecture (Klessova et al., 2020) because of the stronger, anchoring role of the interface which also helps in creating a common base of understanding (Calamel et al., 2012) and a project identity.

The study also found that, in spite of some possibilities for adjustments and the presence of a large number of the diverse organizational actors, which is considered beneficial in other more open settings (e.g. Nahapiet & Ghoshal, 1998; Ahuja & Katila, 2001), appearance of a new coupling (bottom-up integration) is not happening often in this context because of the project boundaries.

With regard to 'why' the evolution of coupling happens, we found that, while these projects are implemented with stringent boundaries (vom Brocke & Lippe, 2015), they often have a large 'networked' setting, face technical and other uncertainties (König et al., 2013), lack an active project sponsor, are characterized by the lack of a strategic integration on portfolio level and the lack of active external intervention and control instances (vom Brocke & Lippe, 2015): this is what opens up the possibility of evolutions of couplings. We identified the generative mechanisms which explain the evolution of couplings, activated depending on contextual conditions (Strauss & Corbin, 1990): among others, by the project preparation, the level of uncertainties and the appearance of technical barriers (König et al., 2013), and also depending on the level of cooperation of the organizational actors in the project (Gulati et al., 2012; Johansson et al., 2011; Nsanzumuhire & Groot, 2020). The coordination of the activities (e.g. Caniëls et al., 2019; Majchrzak et al., 2012; Gulati et al., 2012; Wolbers et al., 2018) played an important role. It is known that knowledge integration mechanisms (e.g. Berggren et al., 2011; Tell et al., 2017), and the quality of the collaboration (Belderbos et al., 2018; Engwall, 2003) are critical in the inter-organizational setting, but we did not find evidence that they prevented the evolution of the couplings during the phases when the couplings were not locked yet, and especially they did not prevent the evolution at the interfaces. The particularity of the collaborative RDI projects (Fernandes et al., 2021) is that their couplings are planned, but do not exist yet in this specific context, and may evolve, even if the organizational actors collaborated already in another context. In other words, the evolution of couplings in such projects is not only related to the multi-actor dynamics and iterative processes (Nisula et al., 2022), but also conditioned by the context of the project (Engwall, 2003).

The degradation or even decoupling at the interfaces was in some cases favored by the diversity of accessible knowledge, capabilities and perspectives of the project participants (Tiwana, 2008; Nooteboom et al., 2007). In addition, the difficulty to deal simultaneously with both relational and cognitive complexity (Boisot & Child, 1999; Wang & von Tunzelmann, 2000) within the project boundaries, including the breadth and depth of the information with which the involved individuals have to deal (Resch & Kock, 2021), was salient, especially in large groups of organizational actors at the interfaces; such complexities influenced the inter-organizational dynamics (Patnaik et al., 2022).

In addition, we also enrich the literature on management of inter-organizational RDI projects: our study provides an important finding for the RDI project managers who should anticipate negative evolutions of the collaboration (see also Cunningham et al., 2021), especially at the interfaces, and understand the reasons for such evolution in the inter-organizational setting which are challenging to manage (Söderlund & Tell, 2011; Lin et al., 2019; Fernandes et al., 2021), in order to maximize value creation in the projects (Söderlund, 2013; Laursen & Svejvig, 2016).

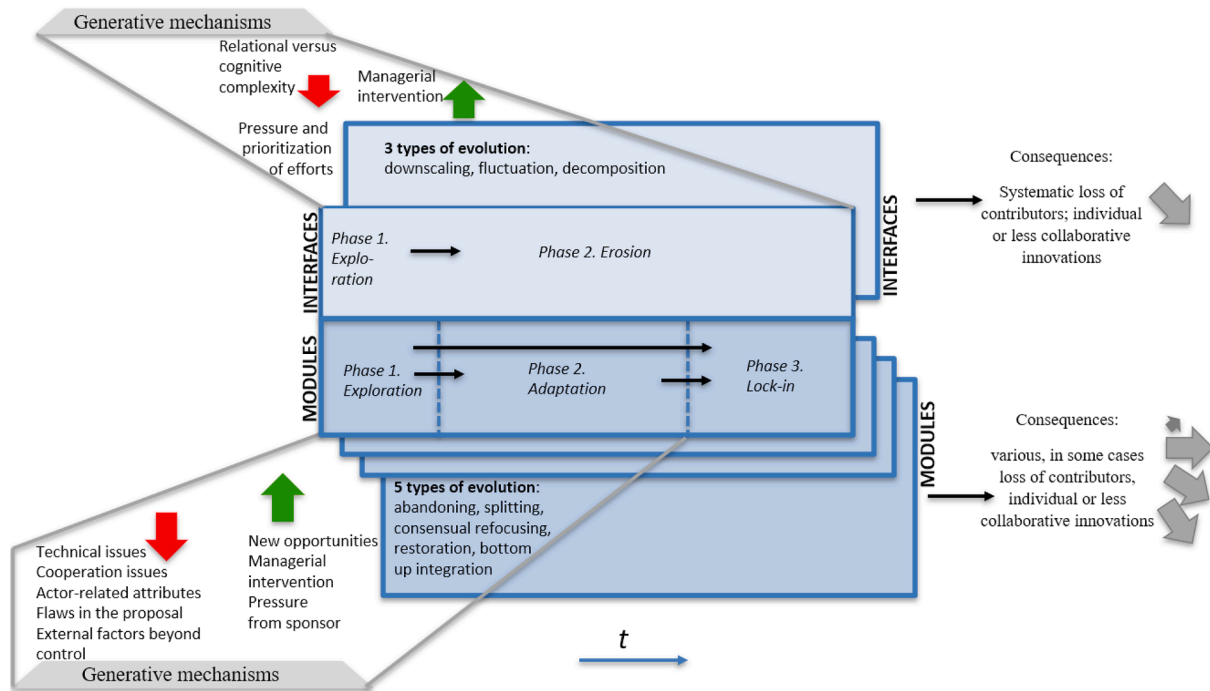


Fig. 2. Evolution of the couplings and implications on the collaborative innovations in multi-actor RDI projects: a process model. Black arrows between phases show the temporal progression in the modules and at the interfaces. Red arrows show disintegrative generative mechanisms, green arrows show integrative generative mechanisms. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The second contribution of this paper is complementing the literature on the implication of the evolutions of the couplings and their pattern on the planned collaborative generation of knowledge and innovations, also responding to the call of multiple scholars (Michelfelder & Kratzer, 2013; Hofman et al., 2016; Yang et al., 2021). Our study found that, because couplings systematically decrease or even disappear at the interfaces, and, more rarely, also weaken in the modules, this is mirrored in the generated innovations: in general they are less collaborative than planned, or are even generated individually. However, the effect on the outputs in many cases was minor, if any, as in most cases the number of generated innovations remained similar to the planning. This points to the conclusion that the necessity and the degree of collaboration were systematically overstated in the project proposals.

5.2. Practical contributions

Our research also provides practical contributions. The type of projects that we analyzed here poses challenges to the funding agencies and project managers in terms of ensuring that the funds are spent according to the so-called grant agreement and that the promised goals are reached, to the extent possible: the funding of the contributing organizations depends on providing the corresponding deliverables, prototypes etc. This is obviously in conflict with the nature of funded pre-competitive research and innovation which involves risks and not all planned developments may be feasible, or they may turn out to be of less value than anticipated. Our study shows that most evolutions of couplings were caused by technical, organizational, and personal attributes that could hardly be changed. Flexibility in the execution of the projects enables the actors to respond more effectively to unforeseen difficulties, also by reconfiguring couplings, and thus to generate more collaborative innovations. Thus, some slack in the project planning, and some structural flexibility are advantageous to maintain the collaboration pattern in reaction to unplanned circumstances. Therefore the projects should be enabled to be executed in a more flexible and adaptive manner, with accountability. This makes it more difficult for the funding agencies to monitor the execution of the project. However, producing relevant

results that are different from what was planned, is better than producing weak or less relevant results because they were planned.

Without interventions, the collaborative innovations systematically erode at the interfaces compared to the plans. When the projects get under pressure, which almost inevitably happens, downscaling at the interface level is imminent, but with the weakening of the interfaces and the fragmentation of the activities, some of the value of the project gets lost. The connections between the work in the modules are an important element of the justification of performing a multi-actor RDI project and not separated smaller projects with fewer organizational actors. The waterfall architecture (Klessova et al., 2020) makes the erosion of the interfaces less likely to happen, compared to projects with little coupling between the modules. Managers of multi-actor RDI projects shall thus especially pay attention to the work at the interfaces between the modules from the very early project stages on. Management of the interface level is an important issue also for the funding agencies, if the connection between the modules, the creation of generic knowledge, and broad collaboration within the projects are desired. This leads to the question about the priorities of the funding agencies, regarding the relative importance of the activities in the modules which are more specialized and often have a more immediate impact than the work at the interfaces which on the other hand creates more generic knowledge and fosters broader collaborations. To put the focus on innovations in the modules rather than on work at the interfaces would imply that it is preferable to support smaller focused projects. Calls asking also for generic outputs at the overlaps between the innovations would contribute to broader knowledge creation and possibly be more beneficial in the long term.

6. Conclusion

This research complements our paper on the architecture of inter-organizational, collaborative RDI projects with multiple organizational actors and multiple boundaries (Klessova et al., 2020) and intends to improve the understanding of the dynamics of inter-organizational couplings, or inter-organizational collaboration, in such projects, and

of its implications on the planned collaborative innovations. By performing an inductive multiple case study, we unveiled the evolution of the full pattern of planned and realized couplings in the projects, and not only the evolution of the couplings between specific actors. As a result, we proposed an emerging process model of the evolutions of couplings and their implications in multi-actor RDI projects. We found that the evolution of couplings is of different types and happens in distinct phases, depending on the place of the couplings in the project architecture. Most evolutions led to a decrease or loss of envisioned collaborations and to less collaborative input to the planned innovations. In particular, we observed a systematic degradation of the couplings at the planned interfaces between the specialized modules. We also identified the generative mechanisms behind the evolution of the couplings. Our research also put in evidence the specificities of such multi-actor RDI projects comparing with other inter-organizational settings, notably the distinct phases of the evolutions of the couplings and the limited amount of knowledge recombination. In addition, we conclude from our observations that publicly funded collaborative RDI projects with modular architecture and multiple actors, as well as their innovations, have a tendency to develop into being more fragmented and less collaborative than anticipated and promised.

This research is limited to inter-organizational multi-actor collaborative RDI projects funded by the European Union Research and Innovation Programmes, which have specificities such as a large number of organizations and complex patterns of couplings. We studied a set of engineering projects with modular architectures and a strong application dimension. Our typology of evolutions of couplings may not be complete, but it can be expected that the observed evolutions are of a general nature. Additional generative mechanisms, factors and interactions may be observed in other projects or domains. The impact of the abandoning of some planned work was not quantified in the study, as the innovations are not comparable. We did not analyze the interplay of the dynamics of couplings with the progress of the maturity of the innovations throughout the projects. Also, we did not investigate more deeply the specific role of the project leadership and the reasons why bottom-up integration of couplings (recombination of knowledge) rarely happened in spite of the large number of involved actors and opportunities for collaboration, and we did not analyze whether the couplings at the interfaces led to new collaborations between the organizational

actors outside the projects.

In terms of future research avenues, the specific role of the project leader and of the key persons merits attention: it would help to better understand the evolution of couplings and the related implications in this specific setting and how to manage this process. A qualitative approach to study the project innovations and to investigate whether the decrease of the number of organizations contributing to the innovations comparing to plans is in general detrimental for the innovations could provide a deeper understanding of such publicly funded multi-actor RDI projects. Analysis of the projects in other domains, of projects without a strong application dimension might bring additional insights. Future research could also analyze whether knowledge recombination is triggered by the projects but happens outside the projects. Research on knowledge integration mechanisms that are adapted to this large inter-organizational project setting would also be of great importance. Finally, there is a need for better understanding of the role of the project size, in terms of the number of the organizational actors, in this specific setting, i.e. whether the current trend towards large projects is correlated to an increase of the productivity of the projects, compared to a set of smaller, more focused projects.

Declarations of Competing Interest

None.

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Appendixes

Appendix 1. Overview of projects under study

N°	Project name	Applications of the innovations	EC Programme	Thematic of the project	Project architecture at the end	Organizational actors, number	Planned couplings, number		Generated outputs, number	
							Modules	Interfaces	Innovations	New knowledge
	A	B	C	D	E	F	G	H	J	K
1	HERCULES	Medium term	FP7	Production/ICT	Waterfall	10	6	3	7	2
2	PEGASUS	Long term	FP7	ICT/Production	Weakly coupled	12	6	3	7	2
3	PERSEUS	Medium term	H2020	Production/ICT	Decompo-sed	15	9	3	10	0
4	ORION	Short to medium term	H2020	Production/ICT	Partial grid	17	15	9	21	1

Appendix 2. Data structures

Appendix 2A: Data structure: types of evolutions in the modules

1st order codes	2nd order themes
Dropping the planned collaborative work No alternative options	Abandoning (Phase 1, 2)
Reorganization of work needed Actors found other opportunities Options possible with other actors Actors formed a different collaboration compared to the planning Consensus between actors to reorganize work	Consensual refocusing (Phase 1, 2)
Actor did individual work instead of collaborative Actor shifted needs Actor had unrealistic expectations Actor has another understanding of the obligations Actor did not want to invest in collaboration	Splitting (Phase 1, 2)
Actor dropped contributions Actor returned back and provided contributions	Restoration (Phase 2)
Persons seized opportunities Decision makers from own organization supported persons Actors had available budget Actors started unplanned collaboration	Bottom-up integration (Phase 2)

Appendix 2B: Data structure: generative mechanisms in the modules

1 st order codes	2nd order themes	3rd order aggregate dimensions
Actor focused on own developments Actor had lack of interest to collaborate Actor lacked “deep digging”	Selfish interests	Negative: Cooperation issues
Collaborators had different interests Collaborators had different timeline Collaborators had different skills	Misalignments of interests and skills	
Lack of quality data Lack of access to data Integration issues High complexity of work Impossible to test the technology	Unexpected technical difficulties	Negative: Unexpected or underestimated technical barriers
Underestimation of time Underestimation of efforts Wrong initial choice of the application or approaches	Underestimation of time and efforts	
Lack of managerial support Confidentiality issues Inertia/bureaucracy Too limited involvement Changes of project staff	Actors-related attributes: organizational level	Negative: Actors-related attributes at the organizational or individual level
Language difficulties Lack of motivation Overload at permanent work Too formal approach Inefficiency Lack of open minded attitude Lack of willingness to “dig deeper”	Actors-related attributes: personal level	
Internal reorganization affecting availability of the equipment or staff Change of the strategy of the organization Withdrawal of organization	External circumstances related to the main organization	Negative: External factors (force majeure)
Appearance of competition within the consortium Negative evolution of the market potential	External circumstances related to the market	
Project coordinator did not act Project coordinator did not see options	Laissez faire, no intervention	Negative or positive: Action and attitude of project manager
Project coordinator proposed ideas Project coordinator was supportive Project coordinator exercised pressure	Proactive support or pressure	
Lack of deep analysis Technical challenges not analyzed properly Description of work at a too high level Ill-designed use cases of industrial partners Lack of definitions of the extend of contributions Confusing selection of the applications/their content Too different approaches, difficult to integrate Some departments of the large firms not consulted Misjudgment of importance of project work Overestimation of capabilities	Flaws in project content preparation	Negative: Flaws in the proposal
Too many partners Given set of partners Too specialized applications	Flaws in project design and planning	

(continued on next page)

(continued)

1 st order codes	2nd order themes	3rd order aggregate dimensions
Unrealistic plans Lack of technological relevance between the applications Integrating activity not strongly planned		
Pressure from a close collaborative partner to maintain planned work Pressure from the project manager Pressure of key people or other partners in the project	Internal pressure from the project management and key team	Positive: internal and external pressure
Pressure from the reviewer/funding agency Pressure from the main organization Pressure of the legal context Pressure of the “political” and status context	Pressure from external project actors Pressure of the project context	
Matching skills Matching interest of actors Open-minded attitude of actors Proactivity of actors Availability of actors	Conditions offered by the project actors	Positive: availability of new opportunities for recombination
Exchange opportunities Flexibility offered by broad description of work	Conditions offered by the project setting	

Appendix 2C: Data structure: types of evolutions at the interfaces

1st order codes	2nd order themes
Actor retreated completely from planned work Actor provided reduced contributions Some contributions were formal, to fulfill the obligations	Downscaling (throughout the project): erosion
Responsible for the interface activity continued individual work All actors retreated except the responsible Disconnection of work in contrast to what had been planned	Decomposition (Phase 2): erosion
Collaboration intensity changed over time Actors decreased their input and then increased again Number of contributing actors changed over time	Fluctuation (Phases 1 and 2)

Appendix 2D: Data structure: generative mechanisms at the interfaces

1 st order codes	2nd order themes	3rd order aggregate dimensions
Pressure of project boundaries Prioritization of key own activities Lack of immediate application Need to dig deeper Barriers to implementation	Inability to contribute to different topics simultaneously Fading away the enthusiasm	Negative: Challenges of relational versus cognitive complexity
Person did not have time for the project Person had to concentrate on the priorities given by own organization Lack of time; input received too late Lack of budget	Pressure of the main organization not related to the project Pressure of project constraints	Negative: pressure of the main organization and the project boundaries
Project coordinator put the work on planned path Project coordinator regularly pressed for planned contributions Project key people put the work on planned path	Pressure of the project manager	Positive: pressure of the project manager or of the key people
Project coordinator encouraged contributions Project coordinator initiated discussions	Active management of the project manager	

Supplementary material

Supplementary material associated with this article can be found, in the online version, atdoi:[10.1016/j.ijproman.2022.05.003](https://doi.org/10.1016/j.ijproman.2022.05.003).

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