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## ► To cite this version:

Svetlana Klessova, Sebastian Engell, Catherine Thomas. The interplay between the contextual conditions and the advancement of the technological maturity in inter-organisational collaborative R&D projects: a qualitative study. *R&D Management*, 2023, 53 (5), pp.778 - 800. 10.1111/radm.12598 . halshs-04314148

**HAL Id: halshs-04314148**

**<https://shs.hal.science/halshs-04314148>**

Submitted on 29 Nov 2023

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# The interplay between the contextual conditions and the advancement of the technological maturity in inter-organisational collaborative R&D projects: a qualitative study

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**This paper analyses the evolution of the contextual conditions during the advancement of the degree of technological maturity of innovative technical solutions and their interplay with the R&D processes in the setting of collaborative inter-organisational publicly-funded R&D projects. Extant literature investigated the role of contextual conditions for the development process of technologies across *different* settings, but the evolution of their role has not yet been analysed in detail during the *same* development process over different levels of maturity. It has also not been investigated how the inter-organisational collaboration is affected by this interplay. To address this gap, we put in place exploratory qualitative research in the empirical setting of collaborative inter-organisational R&D projects that were funded by the EU's Research and Innovation Framework Programmes. Such projects often advance the maturity of *several* new technical solutions in different constellations of partners within the same project and therefore provide rich data for our analysis. The research design is a comparative multiple case study. We studied 5 projects that developed 49 innovative technical solutions, adopting a grounded theory approach, through the analysis of the project documentation and semi-structured interviews. The evolution of the non-technical contextual conditions and their interplay with the R&D processes and the inter-organisational collaboration were found to be similar across different technologies, but their role was significantly different at different stages of the advancement of maturity. Medium TRLs constituted a watershed for inter-organisational cooperation, whereas**

when going to higher TRLs, the role of the intra-organisational context became dominant. As a consequence, the changes of the contextual conditions should be anticipated by project planners and project managers to avoid that the R&D processes get stuck at medium technology readiness levels. We also discuss the implications for policy interventions when reaching higher TRLs is intended.

## 1. Introduction

Contextual conditions, ‘the particular set of conditions within which the action/interactional strategies are taken’ (Strauss and Corbin, 1990, p. 96) are known to strongly influence R&D processes. These processes depend on different contexts, such as the type and domain of the technologies (e.g. Héder, 2017), prior R&D work (Belderbos et al., 2018), leadership style (Turner and Muller, 2005), etc.

Extant literature investigated the role of contextual conditions in R&D processes across *different* settings (Daniel and Klein, 2014), but it has not yet been analysed yet how, why, and to which extent the advancement of the degree of technological maturity, which is usually measured by the Technology Readiness Level (TRL) scale (Mankins, 2009; Héder, 2017; Olechowski et al., 2020; Klessova et al., 2022b), interplays with the evolution of the non-technical contextual conditions during the R&D process of the *same* technology involving the *same* organisational actors.

During the last decades, R&D has become increasingly more open and collaborative, providing multiple opportunities for collaborating organisations from industry and academia (Gubbins and Dooley, 2014; Dooley et al., 2016; Fernandes et al., 2020; Ferreira et al., 2022). Many public agencies nowadays fund collaborative R&D in the form of inter-organisational projects which are a specific form of open innovation (Enkel et al., 2009). The goal of the projects is to collaboratively advance the maturation of innovative technical solutions or technologies which are still market-upstream. The development processes in such projects take place *via* joint activities or ‘couplings’ of collaborating organisations (Klessova et al., 2022a). It has so far not been analysed in depth how and why the different stages of the maturation process interplay with the contextual conditions. A better understanding of the evolution of these conditions and of their influence on the collaboration in the projects also helps in tailoring the management of such projects to the needs (vom Brocke and Lippe, 2015; Fernandes et al., 2021).

This paper contributes to reducing this research gap. Our two connected research questions are: *How do the non-technical contextual conditions evolve*

*with the advancement of the level of technological maturity and how do they influence the collaborative development processes in inter-organisational R&D projects?*

We investigated these research questions by empirical qualitative research in the setting of multi-actor R&D projects funded by the European Union’s Research and Innovation Framework Programmes. In these projects, under the umbrella of one project, often various new technical solutions or technologies are developed (Klessova et al., 2020). The R&D work aims at bringing the technologies closer to the market or to permanent applications by partner-organisations in the project. Therefore these projects provide a rich collection of examples of collaborative development processes at various levels of maturity. The research design is a comparative multiple case study (Eisenhardt, 1989), using a grounded theory approach (Strauss and Corbin, 1990). We selected 5 projects and studied the maturation processes of 49 innovative technical solutions which were based on previous R&D efforts and the evolution of the contextual conditions, based upon the project documentation and 49 semi-structured interviews with internal project actors. The technologies and technical solutions developed in the projects were of a non-radical nature. In what follows, we do not differentiate between a technology (which we understand as being of a broader nature) and a technical solution (which is more specific for a given context).

The paper provides a theoretical contribution to the R&D management and project management literature: it highlights that the advancement to higher TRLs leads to changing contextual conditions which have different influences on the collaborative development processes at different targeted TRLs. A key aspect when progressing to high (7 and 8) TRLs is the need to involve a significant number of additional actors in particular within the end-user organisations who were not directly involved in the work at lower TRLs. We empirically identify the ‘watershed’ targeted TRL resulting from the intra-organisational context within the end users as TRL7, while for the inter-organisational cooperation, the critical phase where changing collaboration patterns were observed was when targeting TRL 5–6. For promising technologies that are intended to be pushed to high TRLs,

**Table 1.** TRL scale used in the EC-funded project (EC, 2014)

TRL9 – Actual system proven in operational environment
TRL8 – System completed and qualified
TRL7 – System prototype demonstrated in operational environment
TRL6 – Technology demonstrated in relevant environment
TRL5 – Technology validated in relevant environment
TRL4 – Technology validated in lab
TRL3 – Experimental proof of concept
TRL2 – Technology concept formulated
TRL1 – Basic principles observed

the required context *needs to be created proactively* as a prerequisite to further pursue their maturation. The findings also have practical implications for funding policies at higher TRLs in the context of inter-organisational multi-actor collaborative R&D projects, and provide further directions for research.

## 2. Literature review

### 2.1. Advancement of the maturity of innovative technologies: the R&D phase

R&D activities shall meet the criteria of novelty, creativity to advance existing knowledge and transferability; they are characterised by uncertainty with regard to cost, time and output (OECD, 2015). During the R&D phase, the maturity of technologies or innovative technical solutions is advanced. The concept of “advancement of maturity” describes the progress of the development of a technology starting from first ideas to demonstrations and validation in the real environment and then to a final implementation (Pavitt, 2005; Cooper, 2017).

The maturity of a technology is often described by the so-called TRL scale, which consists of 9 levels and describes how ready (mature) a technology is on its way towards the final use (Peters et al., 2017). It was introduced by NASA in the late 1980s, with the vision of a funnel-like process, where many projects are started at low TRLs (basic research) and then the most promising ones are matured further with increased investments of resources (Mankins, 2009): abandoning certain developments is thus expected. The TRL scale is relevant to the topic of this paper because it helps to define the degree of the maturity of a technology at different periods of time, which is central to our research.

The maturation of technologies requires increasing efforts to deal with the embedding into the real environment, requirements for robustness, reliability and user-friendliness, etc. when going to higher TRL

(Mankins, 2009; Olechowski et al., 2020). For the same targeted TRL, the relative increase of the efforts is comparable across different technologies in similar domains (Klessova et al., 2022b). Maturation implies changes in the implementation environment but also a decrease of the technological risk (Mankins, 2009), an increase of the time needed for maturation (Kenley and El-Khoury, 2012), the need for user involvement (Bogers and Horst, 2013), an increasing dependency on the socio-technical infrastructure, markets, policies and regulations (Nakamura et al., 2012) and leads to a different balance of cost and risks (Cooper and Kleinschmidt, 2007; Héder, 2017; Webster and Gardner, 2019). It usually is more complex to ‘push’ a physical and digital technology towards higher levels of maturity compared to developing a purely digital one (Klessova et al., 2022b).

Many funding agencies and other organisations worldwide adopted the TRL scale. For instance, the EU has defined and generally applies the TRL scale according to Table 1 in the Horizon 2020 Programme (EC, 2014) and in the current Horizon Europe Programme (EC, 2021). Public funding agencies often issue calls for projects that aim at reaching middle to high TRLs, i.e. 5–6 resp. 7–8 (e.g. EC, 2022) in order to transfer promising research results into real applications and to pass the so-called “valley of death” (e.g. Ellwood et al., 2022).

### 2.2. Inter-organisational collaborative R&D in the context of publicly-funded projects

Over the last decades, R&D activities have become more open and more collaborative (Dooley et al., 2016; Fernandes et al., 2020, 2021) and are often project-organised (Tiwana, 2008). Collaborative R&D projects provide multiple opportunities for the contributing organisations not only to advance their development thanks to complementary expertise and resources but also to benefit from knowledge transfer (Alexander et al., 2016) and organisational

learning (Scandura, 2016; Fernandes et al., 2020), especially in the international context (Gubbins and Dooley, 2014; Ferreira et al., 2022).

Such R&D projects receive significant public funding (Perkmann et al., 2021). As an example, the previous European Research and Innovation Framework Programme (FP), Horizon 2020, has allocated 39.64 B€ in 2014–2021 to fund over 7000 projects (EC, 2022), aiming at the advancement of the degree of maturity (especially to medium and high TRLs) of technologies and technical solutions in collaborative settings. These projects usually are performed by a significant number of heterogeneous and autonomous organisations, including technology developers (research organisations, SMEs) and end users that provide the application context and act as early users (Ritala and Hurmelinna-Laukkanen, 2009). The projects are characterised by complexity and interdependence of R&D collaborators (e.g. Bogers and Horst, 2013; Klessova et al., 2020; Fernandes et al., 2021), face technical uncertainties (König et al., 2013), and have multiple constraints in terms of e.g. budgets and timelines (vom Brocke and Lippe, 2015; Pinheiro et al., 2016).

When studying collaboration – joint work to achieve a common purpose – the key theoretical concept is that of “couplings”, or interdependencies between collaborating actors (Orton and Weick, 1990). In the context of inter-organisational publicly funded R&D projects, the couplings between the organisations which are jointly pursuing the advancement of maturity of a technology relate to flows of knowledge and flows of activities and to their interplay (Klessova et al., 2020). With the advancement of the targeted technical solutions, these couplings are subject to the pressure of various disintegrative mechanisms, especially technical difficulties and cooperation issues and overall have a tendency to weaken (Klessova et al., 2022a).

With the advancement of the technological maturity, the validation and demonstration environment is changing (e.g. Cooper and Kleinschmidt, 2007; Mankins, 2009; Webster and Gardner, 2019; Klessova et al., 2022b), this is implicit in the definition of the TRL scale, and consequently the organisations involved experience dynamics of their contexts (Manning, 2017).

### 2.3. Contextual conditions in R&D processes

R&D processes and their management are context-dependent (e.g. van der Duin et al., 2014; Primus, 2017; Fernandes and Araújo, 2019).

Contingency theory suggests that an organisation is an adaptive system that is reacting and evolving under the influence of its surrounding environment (Lawrence and Lorsch, 1967): the context creates the requirements. Contingency theory underscores the importance of contextual conditions, which have been studied by scholars in different settings (Aubry and Lavoie-Tremblay, 2018). Organisational learning influences the ability of the organisations to react to the changing contextual conditions (Argote and Hora, 2017) and to anticipate them.

The contextual conditions that influence the performance of R&D projects (Chiesa et al., 2009; Pinto and Pinto, 2020) are multifold. Balachandra and Friar (1997) identified over 70 critical factors that influence the success of R&D projects, related e.g. to organisation, market, technology, supportiveness of the environment, and noted that the amplitude and the direction of the implications of these factors vary depending on the context. Specific sets of conditions have been extensively studied across different settings; see, for example Daniel and Klein (2014). Scholars have identified three main groups of interrelated contextual conditions, which may influence collaborative R&D projects and thus are relevant to this paper.

The first group of contextual conditions relates to the *technical factors and to the technology itself*. This group includes, for example the domain and the characteristics of the technology and its applications (Olechowski et al., 2020) – this especially concerns the complexity of the integration of the solution or technology into the environment which changes for different targeted TRLs. Gretsch et al. (2019) identified the degree of innovativeness as a major factor that influences many others.

The second group is related to the *non-technical contexts surrounding the R&D processes*. This includes organisation-related characteristics and context e.g. the size of a firm (Dooley et al., 2016), organisational structure, allocation of human and other resources, sector of activity, geographic area (Fernandes and Araújo, 2019), the culture of the organisation, business-related factors such as strategy, horizon of implementation (Becheikh et al., 2006; Daniel and Klein, 2014; Dziallas and Blind, 2019), knowledge management capabilities (Ferreira et al., 2022), and characteristics of the involved persons involved, such as their leadership style (Turner and Muller, 2005), their motivation and competences (Hemmert et al., 2014; Bstieler et al., 2015). Legal and regulatory elements are important as well (Becheikh et al., 2006).

Third, the contextual conditions related to *collaboration* play an important role in inter-organisational collaborative R&D, notably the quality and the

depth of the collaboration (e.g. Dietrich et al., 2010; Calamel et al., 2012), which builds on antecedents, especially on prior R&D collaboration (e.g. Laursen et al., 2011; Belderbos et al., 2018). Barriers to collaboration in the setting of inter-organisation R&D projects include, for example deficiencies in alignment of interests, motivation, capability of involved actors, planning and governance of the collaboration (Nsanzumuhire and Groot, 2020), and lack of clear collaborative mechanisms and distribution of the roles of the actors (Hemmert et al., 2014; Canhoto et al., 2016; Wit-de Vries et al., 2019). The literature also highlights the importance of the intra-organisational aspects for technology management and organisational learning (Argote and Hora, 2017), in particular in collaborative settings (Fernandes et al., 2021), and the advantages of adaptation capabilities and flexibility for collaborative innovation (Davis and Eisenhardt, 2011).

The focus of the published research so far has been mostly on the role of contextual conditions at the individual and organisational levels (Nsanzumuhire and Groot, 2020), and *across* different cases, elements and settings, comparing for example different types of organisations (e.g. high-tech and low-tech), teams, cultures, leadership approaches, and so forth. However, a detailed analysis of the influence of the non-technical contexts on the *same* development process with the *same* organisations so far is lacking, which motivated our empirical investigation. It is also not clear how this evolution influences the R&D process itself; the development phase of R&D processes has so far been insufficiently studied in the literature (Dziallas and Blind, 2019). From the project management side, in collaborative R&D, complexity, uncertainty, and often multi-disciplinarity, pose challenges (Fernandes et al., 2021). Therefore R&D managers need to be adequately prepared to manage collaborative R&D projects (Cunningham et al., 2021) as the managerial challenges are context-dependent (Fernandes and Araújo, 2019); for this an understanding of the evolution and the influence of the non-technical contextual conditions on the development processes is important.

To address this gap, we investigate how the non-technical contextual conditions evolve with the advancement of the level of technological maturity and how they influence the collaborative development processes in inter-organisational R&D projects.

### 3. Research setting

The research setting is defined as inter-organisational collaborative multi-actor R&D

projects in the engineering domain, specifically projects funded through competitive open calls by the European Commission through its Framework Programmes of Research and Innovation, and specifically its LEIT (Leadership in Enabling and Industrial Technologies) Programme (EC, 2020) in Horizon 2020 and its predecessor, FP7. These projects, which usually comprise research organisations (universities, Research and Technology Organisations (RTOs)) and industrials (SME technology providers, large firms, often as end-users), perform market upstream R&D, and often are aiming at developing several innovative technical solutions that are tested or deployed in pilot applications at project partners or test customers. The projects often build on previous work that has already led to certain levels of maturity of the technologies, usually they start at least at TRL3.

This setting is very suitable for exploring the research question of this paper: the advancement of the TRL of the solutions is reported at different points in time and thus identifiable; each project usually develops a set of innovative technical solutions with different start and end levels of maturity, often some of the participating organisations are involved in the development of more than one technology in different constellations. By studying a limited number of projects, it is therefore possible to have access to data about the evolution of different technologies and the related contextual conditions.

## 4. Research method

### 4.1. Research design

This research is part of a larger study that takes a deep dive into multi-actor R&D projects (Klessova et al., 2020, 2022a, 2022b). The research design is an exploratory multiple case study (Eisenhardt, 1989). Multiple case studies provide a stronger base to build theory (Yin, 2017), enable comparison and demonstration of replication (Eisenhardt, 1991) and create more robust theory (Eisenhardt and Graebner, 2007). We adopted the grounded theory approach (Strauss and Corbin, 1990): the theory is generated inductively, 'grounded' in the field data and thus reflecting the lived experience of the interviewed project participants. For the purpose of this paper, we grouped the maturity of the technical solutions into three levels: low (TRLs 3–4), medium (TRLs 5–6) and high (TRLs 7–8): a more detailed discussion about the advancement of the maturity of the technologies in the projects under consideration and refined TRLs

can be found in (Klessova et al., 2022b), but for this study, a coarse TRL scale is sufficient.

The selection of the projects was done at the initial phase of the larger study. At that stage, we used 4 selection criteria: homogeneity, variety, comparability and availability of data. Each of the projects and their technologies were unique, but the whole theoretical sample (Eisenhardt and Graebner, 2007) contributes to theory building. For the studies, we selected up to 6 projects of 3 to 4 years duration each, involving 67 organisations overall and resulting in the advancement of 54 technologies or innovative technical solutions at different stages of maturity. We gave them the names of celestial constellations: HERCULES, PEGASUS, GEMINI, PERSEUS, and ORION (Table 2). GEMINI developed and matured purely digital technologies, while the other studied projects included a mix of digital and digital/physical solutions. The technologies developed by the projects differ in terms of their elements (physical devices, industrial systems, tools, models, developments of software and algorithms and the integration into larger systems, ...), the TRLs reached during the projects, the development approach, the applications, the profile of the technology developers, the sizes of the collaborating organisations, the experience of participants, and the collaboration antecedents.

The innovations pursued in these projects can be characterised as non-radical. In all studied projects the solutions had to be embedded into larger systems with a high degree of technical complexity and many human actors involved; the existing environment consisted of specific hardware (e.g. machines, processing equipment, transport units) and/or IT systems, and the interfaces to physical systems, IT systems and human users were important elements of the development. All technologies belong to the engineering domain with a strong digital element, all of them concern new *elements* of operational systems rather than completely new large-scale systems. The reliability of the solutions needed to be high, for routine and in most cases daily industrial use but not ultra-high as, for example if rolled out in cars or aircrafts. The starting points of the developments were at least TRL3, usually higher, that is they built on existing foundations created by previous work, and the goal was to advance their technological maturity.

The field data consisted of project documents and semi-structured interviews. The data collection and inductive analysis were conducted at the project level, the unit of analysis was the technology under development. Details are provided in Sections 4.2 and 4.3. The advancement of the maturity of the technologies has been put in the focus of this paper for two main reasons: first, the informants highlighted

Table 2. Overview of the studied projects

	Organisational actors (number)					Technologies (number)	Thematic	Overall maturity of the innovation technologies at the end of the projects (low: TRL 3–4, medium: TRL 5–6, high: TRL 7–8)	Implementation (type of technology and application)
	Total per project	Research (universities, RTOs)	Large industry	SME	Others (incl. consultants)				
1 HERCULES	10	3	4	2	1	7	Energy efficiency, ICT System management, ICT	Medium	Physical and digital
2 PEGASUS	12	5	4	2	1	7		Low to medium	Physical and digital
3 GEMINI	13	3	3	4	3	9	ICT (purely digital)	Medium to high	Digital
4 PERSEUS	15	4	8	2	1	10	Hardware technologies, ICT	Low to medium	Physical and digital
5 ORION	17	5	5	6	1	21	Production, ICT	Medium to high	Physical and digital

it as a key *systematic* factor that evolved during the project and had a major influence (see Section 4.3); second, because the interplay between the advancement of development processes (maturity) and the non-technical contextual conditions in collaborative inter-organisational R&D had not been studied in depth before.

### 4.2. Data collection

We firstly collected empirical data about the technologies, their advancement and the related inter-organisational collaboration, using over 330 pages of project proposals and over 780 pages of confidential reports and other internal documents. Additionally, we performed 49 semi-structured interviews with 31 project participants. Representatives of between 50% and 60% of the participating organisations of each project were interviewed, in most cases 1 informant per organisation (see Table 3). To select the informants, we used theoretical sampling with two main selection criteria: different profiles of the organisations, and contributors to the advancement of technologies with different maturity levels. Over 80% of the informants were CEOs of SMEs, team leaders within large corporations, or tenured university professors. They all were deeply involved in the development of the technical solutions. Additional informants were developers and managers. Most informants took part in more than one development process. We developed a detailed interview guide to stratify the scope and the depth of the interviews. The interviews were organised in line with European General Data Protection Regulations. All interviews were recorded and transcribed verbatim (Table 3), resulting in over 850 pages of transcripts.

For this paper, we did not consider 5 out of the 54 technologies because they were developed largely independently by single organisations from which we did not interview a representative. The distribution of the remaining 49 technologies over the projects is shown in Table 4. The innovative technical solutions were developed in the different projects between 2014 and 2020; the interviews were conducted in 2018–2021.

### 4.3. Data analysis

We identified the relevant contextual conditions of the development processes in the studied projects which were systematically mentioned by the informants, interacting with the literature, and clustered them into five main groups (for details see Appendix 1): (1) *Intra-organisational factors*: *Organisation-related characteristics*: company

**Table 3.** Overview of interviews per studied project

Anonymous name	Partner organisations involved in the development of innovative technologies, including project management (number)	From them, profile of organisations				Interviewed organisations, number				Interviews <sup>1</sup> : profile and number of informants				
		Industry		Consultants	Number	%	Total, number	Industry		Research	SME	Consultant	Recording, min.	Transcripts, pages
		Research	Large					Large	SME					
HERCULES	8	2	4	2	0	4	50	9	3	4	2	0	548	168.8
PEGASUS	10	4	4	2	0	6	60	7	3	3	1	0	384	109.1
GEMINI	10	2	3	4	1	6	60	7	1	1	4	1	447	134.1
PERSEUS	12	4	6	2	0	7	58	11	6	4	1	0	638	189.0
ORION	16	5	5	6	0	9	56	15	5	5	5	0	787	258.6
Total								49	18	17	13	1	2,804 (46.7 hr)	859.6

<sup>1</sup>49 semi-structured interviews were done with 31 project participants. There was more than one interview with some informants, in case additional information was needed; from some organisations two informants were interviewed, for example when they worked on different technologies.

**Table 4.** Studied technical solutions and their TRL at the end of the projects

TRL scale (as per Table 1): achieved level at the end of the projects	Number and TRLs of technical solutions recorded at the end of the project					
	Hercules	Pegasus	Gemini	Perseus	Orion	Total
TRL8 – System completed and qualified	2	0	0	0	5	7
TRL7 – System prototype demonstrated in operational environment	2	0	4	0	3	9
TRL6 – Technology demonstrated in relevant environment	2	3	5	6	7	23
TRL5 – Technology validated in relevant environment	1	2	0	2	5	10
Total	7	5	9	8	20	49

size, procedures, number of staff and level of qualifications, organisational units involved.... (2) *Intra-organisational factors: Business strategy-related context:* business needs, payback requirements, existence of clear business goals and an intended time to market, prioritisation with respect to other goals, accepted horizon of implementation and so forth. (3) *Personal characteristics* of the participants directly involved in the projects: availability, experience, open mind, managerial level, personal links to other units in the firm and so forth. (4) *Collaboration antecedents:* R&D collaboration before the project and established personal relations. (5) *Technology-related and application-related specificities.* The latter group was included for completeness, but it was not analysed in detail as we focus on the non-technical factors. Illustrative quotes concerning these factors are provided in Appendix 2. There were also other contextual elements which were mentioned, such as safety regulations, need for legal advice, IP specificities, but these factors were excluded from the further analysis as they were mentioned infrequently.

We organised the data according to the targeted level of maturity of the technologies (low, medium, high) in the different phases of the development for each identified group of contextual conditions. We found strong similarities across the development processes of different technologies at the same TRLs in the different projects. To coarsely quantify the influence of the advancement of the maturity of the technologies, we introduced qualitative constructs of “low”, “moderate”, “high” and “very high” influence on the contextual conditions that were derived from the qualitative judgements of the informants, for example “it was so important”, “fortunately we had...” “this blocked...” and so forth.

## 5. Results

This section is organised as follows: first, we analyse the evolution of the generic challenges that accompany the advancement of maturity as observed by the informants (Section 5.1), then we analyse the related main implications and consequences (Section 5.2), the evolution of collaborative couplings and inter-organisational challenges (Section 5.3), and the interplay between the advancement of maturity and the role of the contextual conditions, focusing on the non-technical ones (Section 5.4). We conclude with an overview of our findings (Section 5.5).

### 5.1. Evolution of generic challenges accompanying the advancement of maturity and related contextual conditions

With the evolution of the targeted maturity of the technical solutions, we observed the evolution of generic technical and intra-organisational challenges (see on-line Appendices A and B). ‘Generic’ means that these challenges were reported in all observed advancements of technologies, when they required changes of the deployment environment (e.g. lab or industrial site) and of the temporality of implementation (temporary or permanent).

The increase of *technical challenges* concerned both technology providers (SMEs, research organisations) and end users, and was related to the increased technical complexity of the implementation in the different environments. At TRLs 3–4, the development was mainly done by research organisations, sometimes by SMEs, the problems and case studies were inspired by the end users, but were abstracted and simplified, which led to innovative solutions and publications, but the real context was not taken into

account in detail. Targeted TRLs 5–6 were technically the critical stage: many new aspects came up such as complex technical integration into existing systems, necessity to deal with data availability, acceptance by users, technical robustness and reliability, safety aspects, affordability issues, legal and regulatory issues, including data security, data privacy, and others. Such technical challenges continued when TRL7 was targeted. When targeting TRL 8, the development was less challenging from a technical point of view, the issues were known for the most part, but significant work on details was needed.

(at lower TRL) “we modeled the reality ... in a limited universe ... on computer. You make them as complex as you like ... (at medium and high TRL) The problems (was) may be not complex but difficult ... we needed to deal with a lot of issues ... like not availability of data .... ID46\_compar\_res

The third difficulty is installing and training the pilots. And that requires time ... and effort and patience in order to set up the software, train the people, develop the user manuals ... in a language that is user-friendly, so the others understand. ID14\_GEMINI\_SME

There was a non-trivial stage from one (pilot) to multiple (pilots), because with one (pilot) you can fool yourself that you have a product while really you have a solution for a particular customer. So there is a critical step, so, to go from one to multiple. ID51\_ORION\_SME

*Intra-organisational challenges*, mainly within the end-user organisations, but sometimes also at the technology developing SMEs, were of multiple dimensions: at low TRLs, the organisational specificities (e.g. the willingness to provide data) defined the feasibility of some planned developments, but did not play an important role for the R&D process itself. With the advancement of maturity, needs evolved to interact with more units within the organisations, to involve external (with respect to the project) actors (managers, technicians, business units, production units, IT units, legal departments etc.) who had their own agendas and priorities. The contribution of these external actors was critical for the further advancement and so their prioritisation of work became a bottleneck. Business-related elements also became more important, related to the assessment of the technology, as well as external influences, both affecting the assignment of resources. At lower maturity levels, with the R&D work done at small scale and mostly by research organisations or research departments in companies, these challenges were low. The challenges and the workload of the end

users increased significantly when targeting TRL 6 and further significantly increased when targeting high maturity, especially TRL7, associated with the change of the environment from “relevant” but protected and decoupled from the real processes to the implementation of pilots in an industrial environment. The “watershed” regarding these intra-organisational challenges was observed when TRL7 was targeted. Below are exemplary quotes both from end users and from a technology developer:

We realised it is too big in terms of number of people that we should involve. And it would not be manageable. ID29\_PEGASUS\_large ind

People have jobs to do and (ORION) is seen as something extra ... everybody works for the same company but really they're all compartmentalized and you know working on their own things' ... you'll have one department do something that's really good ... (and for others) it's just seen as ... it's not my job. ID25\_ORION\_SME

We had more variety of resources. At the end, it could be, if you put the number of FTEs (NB: *full time employees*), I needed two FTEs ... but instead of being two people, it's 20 people ... the more meetings were needed to have to agree and to align. ... there were more and more people involved, but every individual has only a small amount of the time that they put in the project. ID28\_PERSEUS\_large ind

## 5.2. Main implications and consequences of the evolution of the challenges for the development process

The increase of the challenges, as described in Sections 5.1, strongly affected the resources that are necessary to raise the maturity level (TRL), as described in (Klessova et al., 2022b), the time needed for the advancement, leading to the need to cope with business decisions of the end-users and thus with prioritisation of developments.

1. *Increase in the amount of efforts* (input of human resources). This depended not only on the complexity level of the development but also on the need for the involvement of external actors – other units, management, suppliers and so forth.

More people were involved. So, more employees. It's not just the developer, it's also the guys who ... have more contact to the customers, who do the installation for proof of concepts, other people.... ID54\_ORION\_SME

2. *Increase in the amount of time needed to progress.*

This was not only related to the increase of efforts due to the increased technical complexity, but also due to the number of external actors involved, the need of their synchronisation, and other factors requested significantly more (calendar) time to handle these elements.

The increase of efforts and development time led to *prioritisation of developments* in the projects by industrial firms. The developments plans were initially agreed upon by the technology providers and by the end users, but at TRL 6, new business factors appeared related to the technology, they had not been considered at the early stages, such as other projects competing for the same internal resources, implementation horizon, business strategies. As a consequence, some developments slowed down or were frozen:

It was quite difficult to get something really into productive operation in the end ... companies wanted to know how much how long would it take and would it give ... money or resources.... Talking is always quite easy, but as soon as you have to commit resources then it becomes much more limited. ID9\_PEGASUS\_SME

I had two developments in parallel. One is in TRL 3, and one is maybe in TRL 6 and 7. And ... just limited resources. I ... pushed more the development which is already in TRL 6 or 7. ID54\_ORION\_SME

Of course ... we saw the potential value (when joining the project), but it's not proven yet. So, the potential value shows that you need to carry on and get to the next level, but it's not giving you 100% confidence that things are going to work.... ID57\_ORION\_large ind

We decided that to make a last performance or a last production run but ... this cost us .... the management director decided that we will skip this. ID19\_PERSEUS\_SME

... in other cases, positive results of the development process and urgent needs combined with reasonable requirements of time and efforts fostered the advancement to the market or inhouse utilisation; the motivation of the industrial actors sharply increased, developments were pushed, even with internal investments from outside the project.

The business need was matching very well ... so it was not difficult to convince (internal units) ... it was very clear what we needed, we knew exactly what we needed ... we want to accelerate ... we want to

even go faster, to prove the case internally. ID28\_PERSEUS\_large ind

Prioritisation was relevant to all private companies interviewed: not only to the end users, but also to technology providing SMEs. When going from TRL7 to TRL8, the end users noted a decrease of the attrition from their side because of already demonstrated benefits of the technology at TRL7.

5.3. *The evolution of the collaborative couplings and the inter-organisational cooperation challenges accompanying the advancement of the level of maturity*

According to the project actors, with the intended advancement of the degree of maturity, the challenges described in Section 5.1 evolved, and led to *inter-organisational* cooperation challenges. The targeted advancement and the associated challenges significantly affected the degree of interdependence, thus the strength and intensity of cooperation, and impacted the R&D process and by extension the whole project. For instance, in PEGASUS, the research actors were practically independent at TRL4, the end-users just supported the process and observed it.

They were kind of just providing a case study and being a discussion partner, it was not about implementing something really. ID3\_HERCULES\_res

But for the same development, the coupling became stronger at TRL5 and even more stronger at TRL6.

When targeting TRL5-6, there was more need for integrated work, complaints about the collaboration were made from both sides, dependencies from industrial partners were salient, tensions, obstacles due to the technical and organisational context were regularly mentioned. This was a critical step for inter-organisational cooperation as observed in different collaborative development processes:

They had a number of questions ... very complicated to answer and very problem-specific, so you have to know a lot about these problem to actually answer these questions. ID37\_supp1\_ORION\_SME

We heavily, heavily depend on the others ... a nightmare (speaking about external actors). ID44\_GEMINI\_SME We were iterating what is the real setup of the problem that the industrial partners had, and we were tailoring our developments to that, but also we were getting quite some feedback. ID20\_PEGASUS\_res

We noted less complaints about dependence and inter-organisational cooperation issues when targeting TRL7-8. The related challenges decreased: cooperation was already established, or the commercial partners (technology providers and/or end-users) worked alone.

In addition, *personal* factors (geographic proximity of the collaborator, ability to travel, personal bureaucracy, communication issues both in terms of language and technically...) played an important role for the inter-organisational cooperation throughout the advancement of maturity, at all stages of advancement but especially at medium and high TRLs:

When I wrap up everything, 80 percent was industrial culture and company culture and personal feelings and personal decisions, and only 20 percent were technical issues. ID15\_PERSEUS\_res

You need, and that's what's much more important, to see each other, and the other one was 2,000 kilometres away, not speaking the same language, it was not helpful. ID38\_ORION\_SME

Sometimes the contextual conditions *changed abruptly* (e.g. appearance of competition, staff replacement, reorganisation of end-users, new business strategies...). These abrupt changes, externally imposed, strongly influenced the intra-organisational contextual conditions and led to inter-organisational challenges. These were considered as “force majeure” by the informants.

The case was cancelled because of business reasons. So then what can you do. ID36a\_ORION\_res They (large firm) went quickly into internal reorganisation ... then the pilot was not available anymore, and all the rules changed ... it was a surprise. ID31\_PERSEUS\_res

Figure 1 summarises the previous findings, showing the interplay between the advancement of maturity, challenges, implications and influence of contextual conditions on the development process. This figure covers all maturity levels, more specific findings for different TRLs are shown in Figure 2.

#### 5.4. The interplay between the advancement of maturity and the evolving roles of contextual conditions

By comparison between the different technologies developed in the different projects, we observed that the advancement of maturity systematically changed the importance of the contextual conditions: depending on the targeted TRLs, the non-technical

contextual conditions played a more or less important role. For *different technologies*, digital or physical, the interplay between the advancement of maturity (the development process) and the influence of the contextual conditions followed a *similar* pattern and the implications were of *similar* nature for the same TRLs, although the strength of the implication varied.

##### 5.4.1. Low maturity (targeted TRLs 3–4): Strong influence of collaboration antecedents (Group 4) and personal characteristics (Group 3)

TRLs 3 and 4 were often the starting or first targeted levels in the developments. The technology providers were mostly ‘solo developers’, while the collaborating partners, usually the industrial end users, supported the process and provided feedback; details did not have to be taken into account much. Comparing across the technologies, the main influencing contextual conditions at this stage were collaboration antecedents, especially the historic experience, pre-knowledge of the context and the challenges, established patterns of joint work before the project that facilitated a quick start and a smooth unfolding of the collaboration, and personal factors. However, as the implications on efforts and time were relatively low, in comparison with the implications of the context at the more advanced stages of development, major consequences were usually not observed, only in rare cases R&D processes got stuck already here usually because of technological issues or lack of alignment of interests.

The connection ... have been on personal grounds before the projects, and have been turned into a strong official collaboration. ID6\_HERCULES\_large ind

We built on existing projects and existing experiences. ID7\_ORION\_large ind

We did test but then we had other issues that destroy the whole setup, and, yeah, it was a little bit disappointing, but it shows that the principle works. ID19\_PERSEUS\_SME

##### 5.4.2. Medium maturity (targeted TRLs 5–6): strong influence of intra-organisational characteristics (Group 1), personal factors (Group 3), and technological specificities (Group 5); some influence of collaboration antecedents (Group 4)

At this stage, the role of both the technological and the inter-organisational contextual conditions peaked

and shaped the developments, with new aspects popping up, and the context facilitating or impeding the progress. Interdependencies between collaborators increased significantly, non-technical contextual conditions started to interfere more intensely with the development process, significantly more when going to TRL6 than to TRL5: this was an observed “watershed” for inter-organisational cooperation. Notably, availability of data and organisational bureaucracy had a significant importance; the personal ability to mobilise external project actors within the industrial firms led to significantly quicker advancement. Some developments, even some that were not initially planned, were rated as very promising, and the necessary context was created to pursue them, while others were slowed down.

We showed in project reports that in principle we have the impression that it helps ..., but you can only demonstrate it, if you have a real application ... you need to convince people that they say, okay, you are allowed to spend the engineering hours to progress on this project. ID48\_ORION\_large ind

5.4.3. High maturity (targeted TRL 7): the interplay of intra-organisational organisational (Group 1) and business strategy-related context (Group 2), technological (group 5) and personal (Group 4) factors

At this level, the “scenery” was known; but the project actors had to cope with it. This level was the

watershed for intra-organisational issues: context and content of the development process became strongly intertwined, contextual conditions interplayed, business-related factors became decisive, drop out or ‘freeze’ of the developments materialised before or at this stage in many cases. Similar to when going to TRL6, the personal ability to get support from external project actors played an important role when going to TRL7. We did not observe importance of collaboration antecedents here anymore: this phase took place at a late stage in the studied projects, and the partners had already acquired collaborative experience, they would not have undertaken to progress to TRL 7 if the collaboration had not worked out.

They really took the lead (in the development) and they really wanted to go forward ... they had really a high interest, which in my opinion means that they also had big problems to solve.... ... The message that they were sending, the work ... is very important for us, we want to have it tomorrow (laughing). ID31\_PERSEUS\_res

5.4.4. Targeted TRL8: strong influence of intra-organisational business strategy-related context (Group 2)

At this level, the perspective of bringing the technology to the market or to long-term productive internal use moved into the focus, the visibility of the development increased internally within the involved end-users or technology providers, the pressure on the project actors increased, the probability of attrition

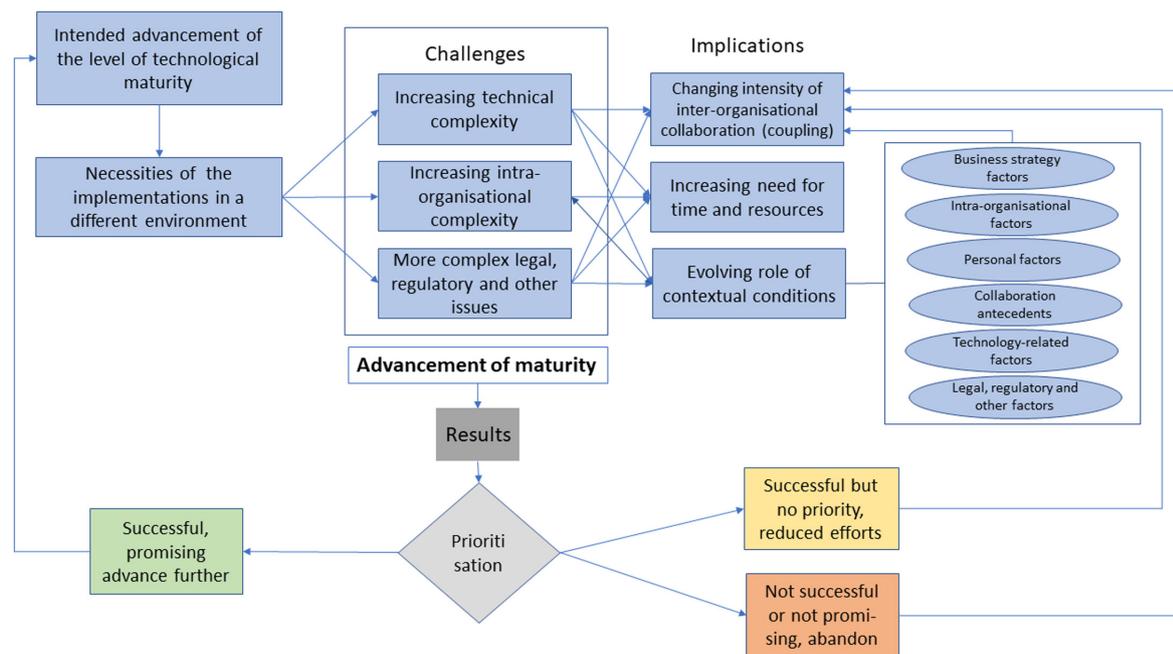
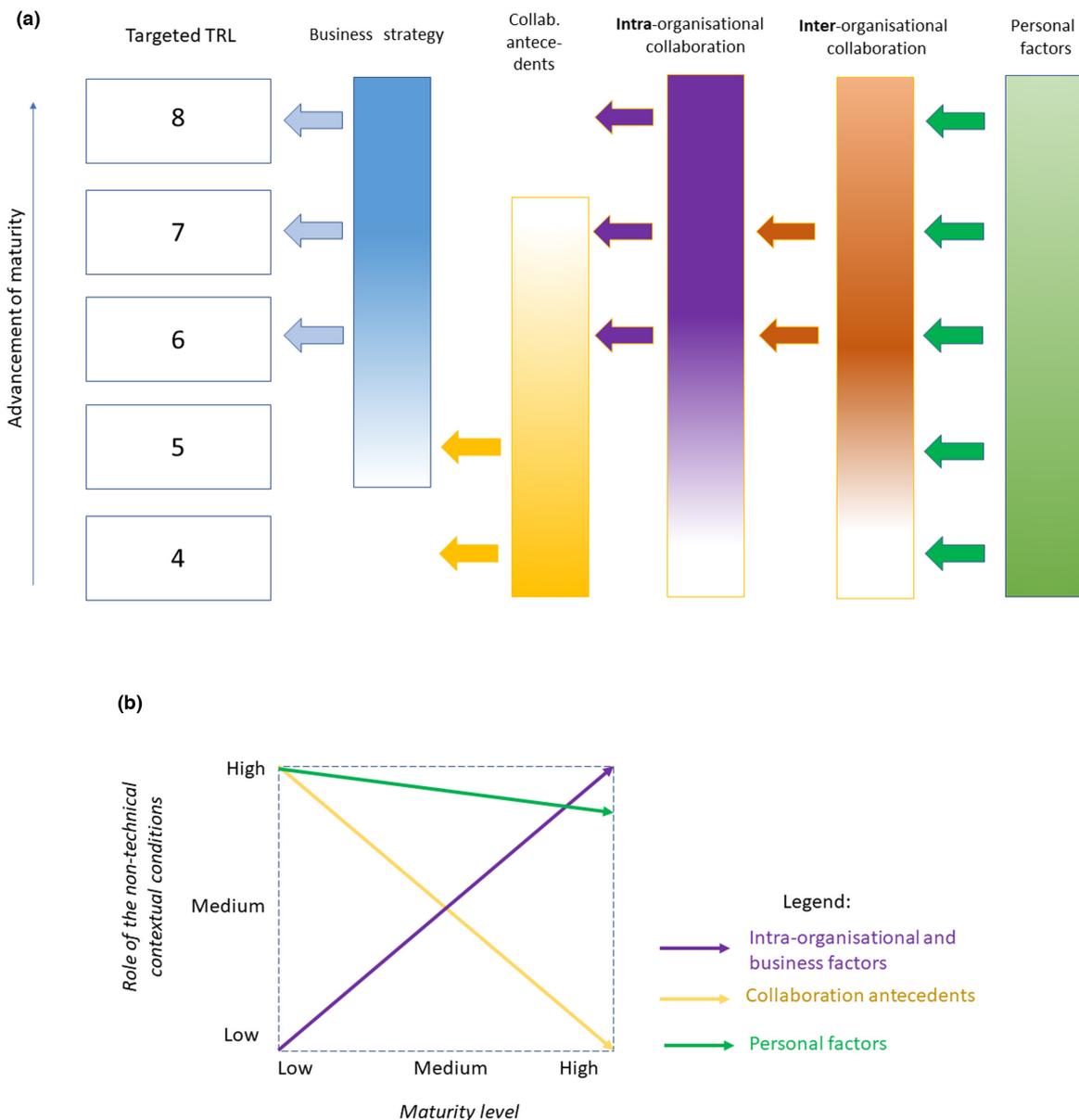


Figure 1. The intended advancement of maturity: challenges, implications and influence of contextual conditions.



**Figure 2.** The influence of non-technical contextual conditions on the collaborative development process, at different TRLs. (a) Strength of the influence at different TRLs. (b) Evolution of the importance of the non-technical factors.

decreased after TRL 7 was reached successfully: the organisational strategy and pressing business needs favoured a quick advancement at this stage.

There was a system developed to operate (many) plants. So, it was possible to implement the (technology). But this required testing and developing for all plants. They did it for a few, but then they ran out of people, they never finished that. ID56\_HERCULES\_compar\_res (describing end-user)

The fact that it worked well in the (first plant), it created a lot of momentum and appreciation, and

we got high level of support from management to continue on that, because they saw the value.... when we demonstrate it ... this is where you start seeing the value. So you need to really get into real data, into a real demonstration. ... (to show) the business value ... we managed to do this.... ID57\_ORION\_large ind

The importance of personal factors was highlighted by the informants predominantly in the first phases of the projects, i.e. at lower TRLs. There are several possible explanations for this: (1) at higher TRL, personal factors have less

influence *comparing to the other elements* of the contextual conditions, and this is the reason why the informants especially highlighted other elements; (2) the collaborators got used to the personal characteristics of the people involved or “when things get serious, people have to behave”, as one informant said; (3) when at the personal level the technical collaboration did not work well at all, the collaboration was given up and did not reach a higher TRL – e.g. in one case, one the organisations focused on its individual development, without further involvement of the original collaborator. So personal factors played a less important role at high TRLs in the studied development processes.

### 5.5. Summary of the findings

The findings are summarised in Table 5; Figure 2 visualises the main findings dependent on the evolution of the TRL. The targeted advancement of the maturity of the technologies, independent from the project or technology, was accompanied by the evolution of technological and non-technological challenges; thus, progressing to the next TRL *requires* a certain set of contextual conditions which evolves when the next level is targeted. The evolving context had strong implications for the inter-organisational collaboration within the projects. At lower TRL, the couplings between the actors tended to be much less intense than at middle or higher TRL. At medium TRL, the technological contextual conditions become much more complex, many elements had to be considered, and an intense collaboration was needed to progress to TRL 6. In parallel, the intra-organisational context both for end-users and for technology providing SMEs became more complex, more actors that are external to the project needed to be involved. If either the intra-organisational collaboration or the inter-organisational collaboration did not materialise as needed, delays were encountered and often the development was slowed down and stopped at TRL 5 or 6. Slowing down or freezing some developments was not too much of a problem from the point of view of the projects, as the results could be reported to document the stage that was reached in the project. However in these cases, we noted that usually no follow-up after the termination of the projects happened. Overall, the main attrition of the developments happened between TRL 6 and 7. At high TRLs, the intra-organisational complexity increased significantly. If the context was not provided, the development could not progress as intended or planned. On the other side, *because*

some developments were rated as very promising, the context needed to bring them to higher TRLs was created, even if not initially planned. The necessary inter-organisational collaboration was found to play a minor role here as a limiting factor.

When studying different development processes, we did not identify major differences in the nature and in the dynamics of the contextual conditions across the different studied technologies (physical/digital, or purely digital). This can be explained by the fact that during the demonstration of technologies, connecting to existing IT systems, access to data, and collaboration with a broad set of stakeholders are equally important for both types of technologies and these are crucial factors.

## 6. Discussion and conclusion

### 6.1. Theoretical contributions

To the best of our knowledge, this is the first time when the influence of the contextual conditions and their evolution throughout the R&D processes are analysed in inter-organisational R&D projects *via* a multi-case study. The extant literature focused on the role of contextual conditions at the individual and organisational levels (Nsanzumuhire and Groot, 2020), and thus *across* different cases, elements and settings, not within the same development process.

The main contribution of this paper is the finding that, depending on the targeted TRL the contextual elements that have already been identified in the literature (e.g. Daniel and Klein, 2014; van der Duin et al., 2014; Primus, 2017; Belderbos et al., 2018; Olechowski et al., 2020) play more or less important roles in the R&D process, and interplay with it. The targeted degree of maturity of the technologies is a key contextual factor in collaborative R&D projects which amplifies or decreases the role of other contextual conditions. The evolution of the maturity goes hand in hand with an increased complexity of the implementation (Cooper, 2017) and therefore organisational and technical challenges evolve. This leads to changing influences of contextual factors and to evolving requirements on the context. The findings of this study underpin the findings in (Klessova et al., 2022b) by pointing out key factors for the increase of the required time and effort when targeting different TRLs. Extant literature already highlighted that the R&D processes and project management practices are influenced by their contexts (Daniel and Klein, 2014; Dziallas and Blind, 2019; Fernandes and Araújo, 2019). We

**Table 5.** Summary of findings, linking the advancement of the technological maturity, the observed generic challenges, their implications and consequences, the influencing groups of contextual conditions, and their indicative degree of influence on the development processes

Systematically observed non-technological challenges and their level of importance		Implication and consequences of the advancement of maturity			Main influencing contextual conditions on inter-organisational collaborative R&D		
Intra-organisational: dependence on external project actors (not involved in the projects but staff of the organisations participating in the projects)	Intra-organisational: business-dependence	Inter-organisational cooperation issues	Efforts needed	Time needed	Prioritisation of developments (and related attrition)	Contextual conditions	Indicative degree of influence
Degree of maturity: targeted TRL level							
TRL 3–4	Not observed	Not observed	Minor	Increase significantly, from low to high, especially from TRL 6 onwards	Increase, from low to high, especially from TRL 6 onwards	Not observed, work is funded by the project	Some
TRL 5 TRL 6	Increase significantly according to the advancement of the targeted TRL	Low at TRL 5 Increases sharply at TRL 6 and 7 After success on TRL 7, was not a critical factor any more	Critical		Not critical when targeting TRL 5, increasing when targeting TRL 6	Influence of technological, intra-organisational and personal factors; some influence of collaboration antecedents	Moderate high
TRL 7		Lower (established patterns at this stage)			Very critical when targeting TRL 7	Interplay of intra-organisational business-related factors, technological, and personal factors	Very high
TRL 8					Lower influence and attrition after TRL 7	Strategy of commercial partners	High

have shown how, and why, these contextual conditions are more or less critical at specific targeted TRLs, enriching the literature on R&D management and project management.

The study also provides a better understanding of the challenges accompanying the R&D processes in collaborative R&D projects (Fernandes et al., 2021) at different stages of maturity of technologies, and their influence on the collaboration in the projects, thus helping in tailoring the management of such projects to the needs. The intra-organisational contextual conditions, both organisational and business related, have a sharply increasing role when targeting TRL 7 which is why we mark this TRL as the watershed TRL. When progressing to high maturity (TRLs 7–8), in particular within the end-user organisations that provide the application context and act as early users (Ritala and Hurmelinna-Laukkanen, 2009), the need to involve a significant number of additional actors that are external to the projects became critical. Also, the business strategy of the end users has little influence at the lower TRLs, but its influence is growing with the maturity and becomes critical at high TRLs. This significantly influences the resulting TRLs: internal resources are limited, and how scarce the resources are and what projects are competing for them at a given point in time is an important contextual factor that strongly influences the development process.

We have shown that the strength of the collaborative couplings (Klessova et al., 2022a) and the interdependence of the collaborating actors (Bogers and Horst, 2013; Klessova et al., 2020; Fernandes et al., 2021) increases with the increase of the targeted degree of maturity, and how the intra-organisational context influences the inter-organisational context: the interactions between the actors and the dependency on the end users, become stronger with the progress on the TRL scale. This in turn significantly affects the R&D processes. We have empirically identified the ‘watershed’ targeted TRL 5–6 for the inter-organisational collaboration, as it requires an intense collaboration where the technology providers have to address the technological contextual factors of the end-user organisations fully. From the other side, progressing to higher TRLs requires a certain set of contextual conditions especially on the side of the end-users, and thus quality of the leadership and flexibility in resource allocations within the organisation (Davis and Eisenhardt, 2011), especially at high TRLs.

Extant literature also highlighted the importance of the intra-organisational aspects for organisational learning and technology management

(Argote and Hora, 2017), in particular in collaborative settings (Fernandes et al., 2021). At high TRLs, due to the required contextual conditions, the solutions developed by the projects compete with other demands for scarce resources. As the technical success of the developments and the business priorities cannot be anticipated with certainty at the beginning of a project, this calls for an agile reallocation of resources within the organisation (Davis and Eisenhardt, 2011) according to the prioritisation of the development processes. To succeed in this competition becomes a crucial factor for the advancement of the solutions that are developed by the projects. In turn, this requires reinforcement of organisational learning for better technology management (Argote and Hora, 2017) vis-a-vis of future collaborative projects.

## 6.2. Managerial contributions and policy implications

Our exploratory qualitative study also leads to conclusions for the project partners involved in the R&D processes, for the project management and for the funding institutions. Up to TRL 6 technological issues are dominant and both intra-organisational and inter-organisational collaboration are focused on technological aspects. Project management should anticipate the need for much more intense collaboration on middle TRLs and prepare for this stage by going beyond the minimum exchange that is needed on lower TRLs early in the projects, to generate a common understanding of the innovative technologies and of the technological contextual conditions that emerge with applications in a relevant environment.

When deciding to go beyond TRL 6, intra-organisational factors within the commercial partners play a decisive role; only those developments are carried further that fit into the business priorities well so that scarce internal resources are assigned and the required contextual conditions are provided, notably related to the involvement of additional actors within the partner-companies. Also the factor of time, independent of the need for more workforce, becomes important. The need for the involvement of additional actors and the related consultations leads to delays where the progress may be blocked temporarily, up to the point where the project ends before the implementations in the real environment can be realised. Such change of the contextual conditions should be anticipated and the necessary steps should be planned and to some extent already implemented before TRL 6 has been reached, if the business-related factors are

positive. This would help to prevent delays due to organisational issues. This again points towards the need for organisational learning, especially regarding the flexibility of intra-organisational resource allocation.

This also leads to conclusions about project planning and funding policies. As the contextual conditions are quite different between going up to TRL 6 and targeting TRL 7 and 8, going to higher TRLs must be planned carefully within the projects, which implies that the technologies under consideration should have reached a degree of maturity of at least TRL5 before the start of the project so that realistic planning is possible. Reflecting on funding policies, the funding institutions could consider a staggered funding mechanism: Standard projects then would go up to TRL 6 or occasionally to TRL7 and might develop and mature a set of innovative technical solutions for various applications up to this level. Going to higher TRLs would be supported by additional funding of the maturation of *only the promising technologies* to the same core consortia, or to those partners who contribute to the development of the promising technologies, based on a detailed planning of the further maturation and with a reduced percentages of co-funding. This would match the original idea behind the TRL scale, that not all technologies will make it to the final stage and still provide enough incentives for R&D collaboration – up to TRL 6 – between RTOs and industry.

Besides this, projects should be given more freedom to advance some technologies even further than originally planned, and to reduce the investment of resources into others. The total outcome of a project, especially in terms of technologies that were pushed to higher TRLs, should be more important in evaluations than the adherence to the project proposal which was based on the knowledge that was available several years before the end of the project. Such adaptation and redistribution of efforts within the project, adapted to the maturity of the technologies and the ability and willingness to create the necessary contextual conditions, should be encouraged, rather than requesting to present results that were planned but are not anymore of relevance to the end-users.

This study has analysed projects that were funded by the previous Framework Programmes (FP7 and Horizon 2020), but its findings are also very relevant for the new European Framework Programme Horizon Europe. Horizon Europe funds similar projects, as far as the size and the topics and the targeted TR levels are concerned, with a shift of the emphasis to higher TRL levels and large

projects. Thus the role of the contextual conditions becomes even stronger and the anticipation of the required contextual conditions becomes even more important.

### 6.3. Limitations and future research directions

There are of course limitations of this exploratory study. We only studied engineering projects with rigid boundaries in terms of time-frame, budget and partnership, developing non-radical technologies. Also, we focused on publicly-funded projects with multiple autonomous organisational actors where several developments were pursued simultaneously. There may be other contextual conditions in other types of technologies or R&D settings.

Future research should investigate the evolution of contextual conditions and their implications in other settings, for instance in privately-funded inter-firm inter-organisational projects and for different technological domains and applications. Also how the contextual conditions evolve and affect the development of technologies that lead to radical innovations needs to be studied.

In this paper, we only briefly mentioned the organisational dimension and organisational learning related to technology management. This presents another important avenue for future research.

The projects considered in this study ended before or at the beginning of the Covid crisis, so the study does not reflect the changes in the contextual conditions for and ways of R&D management due to Covid (Mortara et al., 2022). To explore the differences to projects that were executed in 2020–2022 would be a very interesting research topic.

### Acknowledgments

We thank the partners of the projects that were included in our investigation as case studies and who volunteered their time to contribute to this research. Encouraging comments and suggestions of the participants of the R&D Management 2021 conference, track “Contextual specificity in R&D Management” and of the track chair helped us to shape the presentation in the paper.

### Data availability statement

The data that supports the findings of this study are available in the supplementary material of this article.

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## Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's web site:

## APPENDIX 1. MAIN IDENTIFIED GROUPS OF CONTEXTUAL CONDITIONS DURING THE DEVELOPMENT PROCESS

Identified contextual conditions: examples	Abstracted terms	Group of contextual conditions
Dynamic organisations, “carte blanche” for the project development from the managers Organisational bureaucracy	Organisational culture	1. Intra-organisational factors: organisation-related characteristics
Availability of organisational units dealing with required data Availability of legal units and non-technical support	Organisational setting	
Ambiguity, clarity and certainty of the level of needs Driven by the interest to explore new options/technologies or by pressing needs	Pressing needs	2. Intra-organisational factors: business strategy-related context
Implementation horizon Payback expectations Prioritisation comparing to other developments	Business strategy	
Level of personal bureaucracy Degree of personal interest Ability to communicate in English	Personal characteristics	3. Personal characteristics
Degree of experience Degree of availability Managerial level of the involved staff Personal links to other units in the organisation	Professional characteristics	
Continuation of previous R&D work in the project Knowledge about the collaborating organisation: available data, equipment, procedures etc.	Professional knowledge about collaborators	4. Collaboration antecedents
Personal knowledge of collaborators Personal knowledge of capabilities of collaborators	Personal knowledge of collaborators	
Physical technology Digital technology Related legal requirements Related safety requirements Related regulatory constraints	Specificities of the technology and domain	5. Technology-related and application-related specificities
Small or large size of the deployment application Low or high business criticality of the application	Specificities of the application	
Known or less known technology Strong or weak need for collaboration	Specificities of approach taken for development	
Use of predominantly commercially available components re-combined or enhanced in a novel way, or development of new components		

*The interplay in inter-organisational collaborative R&D projects*

APPENDIX 2. MAIN IDENTIFIED GROUPS OF CONTEXTUAL CONDITIONS DURING THE DEVELOPMENT PROCESS – ILLUSTRATIVE QUOTES

Groups of contextual conditions in the study	Illustrative quotes
1. Intra-organisational factors: organisation-related characteristics	<p><i>“The problem is that it is a very big company (partner)... They do not want to collaborate with other software development SMEs that we have in the consortium. ... So they are pushing me, pushing me ... to help them in software development activities, because they have to do this alone” ID34_ORION_res</i></p> <p><i>“They involved legal department, and as soon as company of the size has their legal department involved, ... it slows everything down” ID25_ORION_SME</i></p> <p><i>“They (the unit at the large company involved in the project) do not have electricians, they do not have safety people.... they have to come into contact with the service groups ... this is too far away from each other ... ID15_PERSEUS_res</i></p>
2. Intra-organisational factors: business strategy-related context	<p><i>“As long as they only had to invest research, I mean they are sort of researchers within the company and they want to do some research they are interested in it, and they only have to invest manpower, they do not have to invest any significant funds, it’s fine” ID9_PEGASUS_SME (intra-organisational, observed from the outside)</i></p> <p><i>“I had to consult locally that time, and my senior management made a decision, they thought it is a good idea, let us pursue it... my senior management said, “Will be get money? It fully covers what we want to do ... anyway? So let us try it”. ID6_HERCULES_large ind</i></p> <p><i>“We have to prioritise all other projects because the money that this project brings is not enough to cover the costs.” ID44_GEMINI_SME</i></p> <p><i>“We have a lot of customer work to do although we get money for that (in the project), it does not help with the fact that this customer work that needs to be done, for the development side is not so straightforward flexible ... it’s just difficult for small companies to balance their normal customer work and a project like this”. ID25_ORION_SME</i></p> <p><i>“the output ... is business critical, so you need to convince people that they trust in the results you have there, otherwise you have to reschedule production...” ID48_ORION_large ind</i></p> <p><i>“We still do not have the implementation on site.... we have it in our plan ... but at some point of the list there is a cut, this is something that all the companies do ... we have to be up in a priority list.” ID40a_HERCULES_large ind</i></p> <p><i>“We had the vision of what we wanted.... This (development in the project) was matching or fitting very well with that vision... matching perfectly” ID28a_PERSEUS_large ind</i></p> <p><i>“... They give good inputs ... but if you were trying to sell to some production manager this kind of stuff, they would be much less nice, because they would be much more focused on what would actually cost them.” ID9_PEGASUS_SME</i></p>

Groups of contextual conditions in the study	Illustrative quotes
3. Personal characteristics	<p><i>“These persons we work with, they have a position, if they want, really want to do something, they could have it more or less easy ... this was the case (in HERCULES). Some people, they are not so open-minded, it does not matter what kind of position they have. And others, I would say, were they open-minded, but they have no chance right now, in the position they have right now.” ID26_HERCULES_SME</i></p> <p><i>“This (manager) did not want to make something wrong. So, it was a step in his career ... he could not judge about these things, and he was frightened to do something wrong ...” ID15_PERSEUS_res</i></p> <p><i>“Not speaking the same language, it was not helpful.” ID38_ORION_SME</i></p> <p><i>“The manager (had connections within the company), he said ‘oh we’ll be fine we’ll manage’. ID33_ORION_large ind</i></p> <p><i>“A certain person was not very interested in that because he was more comfortable with his previous system... he delayed things.” ID56_ORION_res</i></p>
4. Collaboration antecedents	<p><i>“We were cooperating in different projects and initiatives” ID16_HERCULES_res (explaining work at low TRL)</i></p> <p><i>“(fortunately) we knew (them) ... they had done a lot of projects with (us)” ID6_HERCULES_large ind</i></p> <p><i>(explaining that there was no antecedents) “We spent a lot of time educating them...”. ID31_PERSEUS_res</i></p>
5. Technology-related and application-related specificities	<p><i>“(We needed) to be compliant ... to make sure that the data security is uphold...” ID53_HERCULES_large ind</i></p> <p><i>“They were good in (domain X) but not in the specific application and specific technology.” ID31_PERSEUS_res</i></p> <p><i>“There was technical part to answer the question (explain technical question) ... And this actually took six months ... this was very problematic because we could not start ... And then they could not (send us a sample), they told us it’s totally complicated ... and it’s a very dangerous ..., and we cannot do this (at our lab), we can only do it at their premises, and so on, and so on, and then we really had to got the (ingredient) ourselves. So it was very expensive to buy it”. ID15_PERSEUS_res</i></p>