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# Technological co-development competence: A longitudinal case of a software development spinout

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ABSTRACT

Through a single longitudinal case study of an Italian spinout, this paper develops the concept and processes of technology co-development competence (TCDC). The study adopts the market-as-network perspective for its theoretical framing. TCDC is developed in interaction with customers in a spinout's network. This competency is possessed by the firm and enacted for the development of its technology within its business network over time - from establishment to embeddedness. The TCDC concept is developed from the literature and case data and is made up of three elements – information and knowledge integration, multi-actor coordination, and interface management. The data collected comprises twenty eight interviews with twelve informants. The study also examines how TCDC evolves in interaction between the focal firm and its business network. It is found to evolve through four processes – technological frictions and tensions management, network-level relationship processes, product features development, and technological co-development enablement. The study outlines a model that presents how TCDC evolves over time in the spinout's network as it engages with an increasing number of different actors. The model highlights how the elements and processes of TCDC unfold.

## 1. Introduction

Universities' expertise in developing novel and innovative technologies can be exploited through spinouts. University spinouts have been found to enhance the economic performance of regions and have long interested policy makers keen to promote knowledge transfer from universities to industry (Mathisen and Rasmussen, 2019; Vohora et al., 2004). There are many upsides to spinouts for the economy, and for the research teams and institutions that create them. Benefits include employment and regional or national wealth creation (Huynh et al., 2017; Prokop et al., 2019; Vincett, 2010), financial and non-financial awards to inventors in universities (Holley and Watson, 2017), and IP returns to universities (Lockett and Wright, 2005). There are many risks and problems with the early stage technology development process for spinout firms (Ellwood et al., 2022; Grilli and Marzano, 2023; Walter et al., 2014). Two of these are of particular interest to the current research – continued university support, and reliance on a single development partner. Without a university founder's support, the ongoing technology development needed to support the nascent enterprise wanes, and as spinouts are often associated with research projects with an industry partner, reliance on this partner as a customer may make it lack the adaptability needed to fit to other potential customers. This article presents one solution to overcoming these problems through the development of a spinout competency in technology co-development.

The study develops the concept of technological co-development competence (TCDC). This is the competence possessed by the firm and enacted for technological development within its business network over time. The study positions technological development as interactive that is through the market-as-network lens (Håkannson and Snehota, 1995; Håkansson and Waluszewski, 2003). Therefore, the study explores how technological co-development evolves in interaction in the spinout's network. Technological co-development competence entails the skills or abilities enacted in the business network to develop new technologies in interaction with other actors, especially, customers in the case of a spinout (Atzmon et al., 2022; Johnsen and Ford, 2006; Murovec and Prodan, 2009). Technological co-development competence evolves in business interactions with network actors while developing new bespoke applications. The competence is enacted by the spinout to manage business relationships to develop the technology. In particular,

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the current research will focus on how this competence evolves, to support a spinout develop its core technology (computer software), in conjunction with buyers and key users.

Technological co-development differs from technology development by a single firm as it is not the result of one firm's effort but a reflection of networking (Nieto and Santamaría, 2007); hence firms need to develop competence, in terms of skills and abilities, to cope with technological development acknowledging the role of interactions within the network. The process of development takes time. While capabilities have been seen as a strategic resource for the firm (Afuah and Tucci, 2003; Teece et al., 1997), competencies have been defined as skills and abilities possessed by the organizations (and their people) enacted within business processes (Drucker, 1985; Prahalad and Hamel, 1990; Ritter and Gemünden, 2003). Competencies are firm-specific, not endowed but acquired and modified over time through their application, and have been deemed central to coping with change in the environment external to the firm (Malerba and Marengo, 1995). In particular, developing TCDC in the present study means skills and abilities for developing technologies in interaction. Hence, the paper focuses on interaction and collaborative activities unfolding during marketing processes that entail the development of new technologies for commercialization purposes. The study adopts the market-as-network lens as it recognizes that customers are central to co-developing value with suppliers (Möller, 2006); hence this theoretical perspective is relevant for interactive technological development processes. The market-as-network lens is suitable to study this phenomenon as Zahoor and Al-Tabbaa (2020) suggest that network theories are common in studying inter-organizational innovation processes. Möller (2006) suggests that the market-as-network approach is particularly relevant to capture processes through empirical investigations.

Studies of technology development and innovation collaboration have a long lineage in extant research in the new product and service innovation fields (Aarikka-Stenroos et al., 2012; Athaide and Klink, 2009; Håkansson, 1987; Lynch et al., 2016; Zahoor and Al-Tabbaa, 2020). This is also the case in the university spinout literature (Petruzzelli and Murgia, 2023; Thomas et al., 2020; Walter et al., 2006). Prior empirical work related to our topic has focused on aspects of innovation collaboration in networks and across company boundaries that has provided major impetus to our study. These include the role of boundary spanners in the acquisition and development of new technology (La Rocca et al., 2016; Leone et al., 2022), the mechanisms for involving a range of external actors in the technology development process (Mishra and Shah, 2009; Mu et al., 2017; Walter et al., 2006), and the identification of capabilities that enable a nascent venture to access relationships and networks before, during, and after it spins out (Aarikka-Stenroos and Sandberg, 2012; Ritter and Gemünden, 2003; Thomas et al., 2020). We extend these works by focusing on and conceptually developing a spinout's TCDC through identifying what its core components are, and critically, by taking a process perspective, through a longitudinal case study, to specify the processes through which TCDC emerges in a university spinout. Our research question is: how does technological co-development competence evolve in a spinout's network over time?

There are six main reasons why the study is important. Firstly, most of the works on technological development competence in the literature apply to large firms and SMEs rather than to spinout ventures. The empirical results for large firms and SMEs are not transferable to the new venture or spinout context, therefore, the study provides new knowledge on these neglected actors (Zahoor and Al-Tabbaa, 2020). Secondly, because new ventures lack resources and rely on the actors in their network to develop new technologies (Aarikka-Stenroos and Sanberg, 2012; Håkannson and Snehota, 1995), theoretical development on how to do this is important. Thirdly, relying on the actors of the network means coping with multiple actors simultaneously for technological development (Aarikka-Stenroos et al., 2014; Ritter and Gemünden, 2003). Therefore, new ventures need to understand how competence evolves in technological development processes in interaction with several actors over time. Fourthly, among the multitude of actors engaged, spinous need to identify "high-profile partners" that might support technological development and establish credibility (Aarikka-Stenroos and Sandberg, 2012). Fifthly, one of the risks of technological co-development for spinouts is the over-reliance on one particular or few customers and over-customization that can lead to technological dead ends that prevent engaging other actors. Hence, relational competencies are needed to avoid technological dead ends and identify future technological avenues (Mu and Di, 2012). Sixthly, new ventures need to be able to cope with technological development's processual and interactive nature (La Rocca et al., 2016). The technological development process can be long and characterized by friction and tensions among the network actors (Baraldi, 2008; Håkannson and Waluszewski, 2003). This calls for understanding how specific technological co-development competence evolves in the network over time.

The study provides three main contributions to the literature. First, it aims to fine-tune the conceptualization of TCDC for the spinout venture. This conceptualization is developed in an inductive way from the empirical data from our spinout case and the literature. Second, it aims to identify the core elements of TCDC. The study posits that technological co-development competence is made of three elements enacted concurrently. Finally, the study aims to provide a longitudinal perspective of how TCDC evolves at the network level. It identifies four processes that comprise TCDC unfolding in interaction. These findings will contribute to the theoretical understanding of technological co-development processes and managerial understanding of how TCDC is enacted within business-to-business marketing processes for a spinout firm.

Based on a longitudinal case study, the study gathers empirical data from a software spinout already in the network because of the founder's previous university-industry ties. The case firm has developed unique software that still needs the support of the actors of the business network to develop certain components through the collection of specific knowledge, information and insights about several processes to deliver the designed for value. The paper is organised as follows: section 2 outlines the theoretical background of the study, then the methodology is outlined in section 3, comprising the research design, case selection and case description; section 4 outlines the findings which includes the data coding and structure. Section 6 presents the discussion of our model of TCDC's evolution. Section 6 presents the implications, and section 7, the study conclusions, also offers a description of the limitations and further research suggestions.

## 2. Literature review

### 2.1. University spinouts

Although there are many conceptualizations of a university spinout (Huynh et al., 2017; Mathisen and Rasmussen, 2019; Prokop, 2021), the study takes Lockett and Wright's (2005: 1044) version to define spinouts as "new ventures that are dependent upon licensing or assignment of the institution's intellectual property for initiation, or directly related to intellectual assets created from research funded by government or industry" where the founder is a faculty member and the technology-based idea has been developed within the university (Nicolaou and Birley, 2003; Smilor et al., 1990). In other words, spinouts are a sub-category of new technology-based firms that are established by scientists or researchers to commercialize scientific knowledge developed within academic institutions sometimes in association with lead customers as commercialization partners (Mathisen and Rasmussen, 2019; Zhou and Minshall, 2014).

University spinouts have been classified into three categories: orthodox spinouts, where both technology and academics spin out from the university; hybrid spinouts, where the key technology is spun out but the academics retain their position in academia; technology spinouts,

characterised by the spinning out of the technology alone where the academics do not hold any connection, or little connection, with the new company (Holley and Watson, 2017; Nicolaou and Birley, 2003; Sulej and Bower, 2006). The case study presented in this paper is of an orthodox spinout with the addition of a joint venture of shareholders in the company. The latter is "a new venture in which technology is assigned or licensed to a company that is jointly owned by the university and the industrial partner" (Wright et al., 2004: 288) with the original scientist/entrepreneur who created the IP also taking a shareholding. The advantages of this configuration are related to the credibility transferred, and the ease of access to resources that can be provided by the industrial partner, both in terms of technological knowledge and network relationships. The joint venture spinout can be a faster, more flexible, less risky and cost-effective business venturing route for university spinouts (Wright et al., 2004). However, they can also have dark sides too, such as the risk of dependence on a single partner (Lubik et al., 2013). All of these features can be seen in the empirical case study presented in this paper.

Key features of spinouts are their focus on continuing the research and development on their technology (Sulej and Bower, 2006) given that their parent institution is a university or research institute and the entrepreneur is a scientist or researcher (Mathisen and Rasmussen, 2019). Spinouts are similar to start-ups but face a different set of challenges (Huynh et al., 2017). University spinouts need to deal with a large network of actors. Not only universities but also interacting with institutions, industry and investors become crucial to ensure their survival (Mathisen and Rasmussen, 2019). Moreover, spinout founders need to transform their academic network ties into the initial relationships needed for the spinout's success (Mathisen and Rasmussen, 2019).

Studies on spinouts have shed light on the role of capabilities and competencies of both the spinouts and their entrepreneurial teams (Huynh et al., 2017; Lockett and Wright, 2005; Mathisen and Rasmussen, 2019; Thomas et al., 2020; Zhou and Minshall, 2014). Capabilities and competencies possessed and developed by successful spinouts support the creation of wealth and spread of technological innovation as these are particularly focused on technological commercialization (Lockett and Wright, 2005). Vohora et al. (2004) suggested that technical and market capabilities should be developed to ensure product-market fit (Mathisen and Rasmussen, 2019). However, there is still the need understand the role of capabilities and competencies in how high-technology spinouts reach economic sustainability (Liao et al., 2020; Ziaee Bigdeli et al., 2016). Longitudinal empirical studies have been called for to delve into the processes and the underlying challenges that can be overcome through competency development (Zhou and Minshall, 2014).

### 2.2. Market-as-network approach to technological co-development

The study draws on the market-as-network approach which has a long tradition of studies on technological development in interaction since the seminal studies of Håkansson (1987) and Håkansson and Snehota (1995). These authors highlighted how technological development takes shape through the interaction between many actors within the business network. Laage-Hellman et al. (2014) depicted the role of customer involvement in product development, highlighting the relevance of interactions during technological development and how competencies enable the actors' effective participation in the process. La Rocca et al. (2016) showed how sales competence is mobilized to develop technology by acting as a bridge to the network. They suggest that orchestrating customer involvement and the respective pattern of interactions in technological development requires particular sales capabilities and competencies. Lind and Melander (2019) found that interfaces between actors during technological development are related to competence development. The study evidences that developing competencies is challenging for small firms that can be tackled by developing long-term relationships with key actors.

In fact, developing technologies demands the application of competencies in interaction with the network actors to change the technology according to users' and buyers' specifications and information (La Rocca et al., 2016). The market-as-network approach posits that firms cannot control the network but influence the actors through relationships (direct and indirect) (Håkannson and Snehota, 1995; Möller, 2006; Ritter and Gemünden, 2003). It also argues that the sequential view of technological development theories is outdated and unsuited to studying actual technological development processes (cf. Cooper, 1983, 1998). The market-as-network approach views technological development as dynamic, not a simple sequence of activities but as patterns of interactions and decisions that have varying pace and timing (Katzy and Crownston, 2008; Tian, 2019) as it can suddenly take new directions and move back and forth over time (Lind and Melander, 2019). It can entail a trial and error approach for a spinout (Huang, 2011), is interactive, continuous, non-linear and evolutionary, where several actors are engaged to develop and adapt technical solutions (Håkansson and Waluszewski, 2002; Munksgaard et al., 2012). Managing technological development in the network means considering the firm's goals and resources that are linked and interdependent with the other actors. Hence, friction and tensions might arise during technological development processes at the interfaces developed to interact with the actors (Baraldi, 2008; Håkansson and Waluszewski, 2007). These frictions and tensions are not negative per se but demand the firm's attention to obtain positive outcomes (Håkansson and Waluszewski, 2002).

### 2.3. Technological co-development competence

TCDC is a type of network competence. Network competencies entail the skills and abilities possessed by organizations and people to manage business relationships and their interdependencies within the business network (Ritter and Gemünden, 2003, 2004). Possessing network competencies enables the firm to develop technology-oriented relationships with actors that have critical resources (Ritter and Gemünden, 2004). Ritter and Gemünden (2003) introduced technological competence as the ability to use and exploit state-of-the-art technology for internal purposes. Technological competence is owned by a firm at a point in time for developing new products, processes, or services (Ritter and Gemünden, 2003).

The present study extends earlier notions about technological competence by introducing TCDC as an interactive competence enacted with external network actors for technological development over time. Therefore, TCDC extends previous technological competence into the network. Hence, technological co-development competence is owned by the individual firm but enacted in the network. In line with Malerba and Marengo (1995) suggestion about the nature of competencies, TCDC is developed in interaction with the network and possessed by a firm. The interactive nature of the competence, highlighted in the study with the term "co-development", is grounded in the long tradition of technological development studies in the market-as-network approach (Håkansson and Snehota, 1995; Håkansson and Waluszewski, 2003).

Now that technological co-development competence has been defined, we draw out its key elements that are further clarified with the data obtained from the case as we are introducing TCDC as a new concept to the literature on technology development in interaction. TCDC entails the abilities and skills of the firm to co-develop technologies in interaction with the network actors over time. Technological co-development competence comprises three main elements. First, the ability to integrate information and knowledge from multiple actors in the network as the "state-of-the-art technology" mentioned by Ritter and Gemünden (2003, 2004) into new technology. Also, the ability to manage relationships with the network's actors and particularly manage their prioritization (La Rocca et al., 2019). Finally, according to the market-as-network studies mentioned, technological co-development competence entails the creation of several interfaces to ease the interaction and collaboration with several firms at once (Håkansson and

Waluszewski, 2002; Lind and Melander, 2019). These three elements comprise the concept of TCDC are discussed in the following section.

### 2.4. Elements of technological co-development competence

As outlined, TCDC entails three components: information and knowledge integration, multi-actor coordination and interface management. These three elements, derived from the literature and from the empirical case data, are discussed below.

Information and knowledge integration into the new technology is the skill and ability to identify, transform and make use of the "state-of-the-art technology" obtained in interaction with the network (Ritter and Gemünden, 2003) to develop new technology. The study extends the previous definition by adding that this information is not applied to an internal new product development project but is deployed interactively with multiple actors in the network to combine and integrate their contribution to the ongoing process of technological development. At the technological level, information and knowledge are identified for product requirements, production processes, materials, features, algorithms, and methodologies that can be transferred to the focal firm or between firms to be embedded into their activities. In addition, information and knowledge gathered from the network can be used for relational purposes; actors' information and knowledge regarding sector information, other actors, and similar technologies that might help the firm manage technological development.

Multi-actor coordination is the ability of the firm to develop co-development relationships and prioritize those ones that matter the most for developing the new technology (La Rocca et al., 2019). Multi-actor coordination ability to develop multiple co-development relationships is related to the ability to engage a considerable number of actors to contribute to the new technology. These co-development relationships are often managed by creating multi-party working teams populated by the actors of the business network working together around specific technological development tasks (Möller, 2006). Market-as-network studies highlight the relevance of managing a portfolio of relationships to support the growth of a start-up (La Rocca et al., 2019). In the same manner, TCDC entails managing a portfolio of technological relationships and prioritizing those actors with critical resources that are relevant and consistent with the technological development roadmap of the focal firm. Finally, multi-actor coordination entails an ability to "jump" from relationship to relationship to find the most valuable one for technological development.

Finally, interface management entails the skill and ability to create physical and digital touchpoints to engage multiple actors for technological development. The study extends previous technological competence studies by highlighting the role of competence in creating technological development interfaces to support multi-actor interaction (Baraldi and Strömsten, 2006; Dubois and Araujo, 2006; Lind and Melander, 2019; Håkansson and Waluszewski, 2003). Interface management involves the firm establishing physical or digital touchpoints to meet the actors and obtain their technological contributions. Interface management is enacted when the firm co-develops these touchpoints to support the interaction with the actors. The touchpoints can be identified in the technology itself, its components, in trial and testing beta-products deployed to validate the new features, or in formalised innovation projects developed in interaction with many actors. These interfaces are deployed to multi-actor interactions between the spinout (focal firm), the network actors, and among the network actors themselves for technological co-development.

## 3. Methods

### 3.1. Research design

The study adopts a qualitative case methodology. The paper focuses on how TCDC unfolds in interaction between the focal software spinout (named Alpha) and the actors in its business network. A longitudinal case study of technology development was been deemed suitable given the theory development objectives of the research (Eisenhardt, 1989; Halinen and Törnroos, 2005; Yin, 2014). Case study methodology is particularly suitable for studying business relationships in long-term interactions (Håkansson and Waluszewski, 2016). Case studies have become the primary methodology for industrial market-as-network research (Dubois and Araujo, 2004; Halinen and Törnroos, 2005; La Rocca et al., 2017) because they allow researchers to observe the interaction between a phenomenon and its context over time (Dubois and Gadde, 2002). Thus, the study adopts a processual perspective (Pettigrew, 1992), which allows us to "catch reality in flight" (Pettigrew, 1990: 268) to understand how events unfold over time (Langley, 1999) and capture interaction patterns through the observation of the phenomenon (Aaboen et al., 2012; Hutt et al., 1988).

### 3.2. Case selection

The Alpha case has been selected for its revelatory potential (Coviello and Joseph, 2012; Siggelkow, 2007) and its match to the research aim of the paper (Eisenhardt and Graebner, 2007). The case is of an Italian spinout emerging from a medium sized university. Alpha developed a new software that only became successful when the company started to co-develop it with multiple network partners. We focus on this period of growth to answer our research question but also present the story of the spinout from the beginning. In addition to the revelatory potential of the case, the direct access to the new venture through the university's innovation support programme and its local proximity also contributed to granting preferential access to the key informants (Yin, 2014). All the companies and product names are concealed for confidentiality reasons. Alpha is an academic spinout firm established in 2011 that develops innovative software for design-to-cost. The software supports manufacturing designers and buyers in the costing and the optimal manufacturing process selection for producing parts and components. The Alpha case is described in-depth in section 3.4.

### 3.3. Data collection

Data was collected through semi-structured interviews with key informants (Corbin and Strauss, 2015; Eisenhardt and Graebner, 2007; Yin, 2014). The study encompasses 28 interviews with the actors selected from Alpha's business relationships (Eisenhardt and Graebner, 2007). Data collection from January 2017 to June 2018 involved 12 informants from 5 firms and the university (see, Table 1). Data collection consists of more than 20 h of interviews, validated through triangulation with secondary data provided by the actors who took part in the data collection process.

### 3.4. The case of Alpha and AlphaCost software

Alpha was established in 2011 as an academic spinout company. It developed software to perform design-to-cost analysis, called AlphaCost, by establishing relationships with different actors. The first version of the software was completed by integrating Actor 1's information and knowledge. Then, Alpha began commercialising it more broadly, looking for new buyers. It encountered many technology development challenges in growing to over a hundred customers and a €2 million turnover at the end of 2019, 13 years later (see, Fig. 1 for Alpha's chronological milestones). Alpha's growth only really took-off in 2014/5 when its development of TCDC really started to lead to increased turnover. Between 2014 and 2019 the company's performance was stellar - its employee numbers have grown from 2 to 27, its sales from €360,000 to €2million, and its jump in profitability also has been spectacular.

2006 - The beginning.

The story of Alpha began in 2006 when a group of young researchers

**Table 1**
Data collection Overview and actors' roles.

| DATE | INFORMANT | ROLE OF THE INFORMANT | FIRMS | LENGHT (min) | DATA |
|---|---|---|---|---|---|
| 25-Jan-17 | 1 | ALPHA CEO & Founder | Focal firm | 60 | interview notes (IN) |
| 06-feb-17 | 1 | ALPHA CEO & Founder | Focal firm | 40 | Recorded transcript (RT) |
| 31-mar-17 | 1 | ALPHA CEO & Founder | Focal firm | 30 | RT |
| 14-Jul-17 | 1 | ALPHA CEO & Founder | Focal firm | 40 | RT |
| 19-Jul-17 | 2 | UNIV - TTO director | Engineering University | 30 | RT |
| 19-Jul-17 | 3 | UNIV - focal firm's board of directors member | Economics University | 25 | RT |
| 25-Jul-17 | 4 | APLHA Founder | Focal firm | 45 | RT |
| 31-Jul-17 | 1 | ALPHA CEO & Founder | Focal firm | 25 | RT |
| 23-oct-17 | 4 | ALPHA Founder | Focal firm | 40 | RT |
| 13-nov-17 | 5 | ACTOR 1 - CIO | Actor 1 | 60 | IN |
| 11-dec-17 | 6 | ALPHA CTO & Founder | Focal firm | 30 | RT |
| 11-dec-17 | 6 | ALPHA CIO & Founder | Focal firm | 30 | RT |
| 26-Jan-18 | 7 | ACTOR 1 Product cost engineer | Actor 1 | 90 | RT |
| 06-feb-18 | 1 | ALPHA CEO & Founder | Focal firm | 20 | RT |
| 21-feb-18 | 1 | ALPHA CEO & Founder | Focal firm | 30 | RT |
| 23-Feb-18 | 8 | ALPHA Sales specialist | Focal firm | 80 | RT |
| 07-mar-18 | 7 | ACTOR 1 Product cost engineer | Actor 1 | 20 | RT |
| 08-mar-18 | 9 | ACTOR 2 Technical Sourcing | Actor 2 | 45 | RT |
| 09-mar-18 | 10 | ALPHA Founder & former sales specialist | Focal firm | 90 | RT |
| 12-mar-18 | 8 | ALPHA Sales specialist | Focal firm | 80 | IN |
| 12-mar-18 | 11 | ACTOR 3 Procurement | Actor 3 | 45 | RT |
| 13-mar-18 | 8 | ALPHA Sales specialist | Focal firm | 30 | IN |
| 16-mar-18 | 8 | ALPHA Sales specialist | Focal firm | 10 | IN |
| 22-mar-18 | 12 | ACTOR 4 Product engineer | Actor 4 | 45 | RT |
| 16-may-18 | 8 | ALPHA Sales specialist | Focal firm | 35 | RT |
| 25-may-18 | 1 | ALPHA CEO & Founder | Focal firm | 20 | RT |
| 04-jun-18 | 10 | ALPHA Founder & former sales specialist | Focal firm | 45 | RT |
| 26-jun-18 | 8 | ALPHA Sales specialist | Focal firm | 90 | RT |

Source: Authors

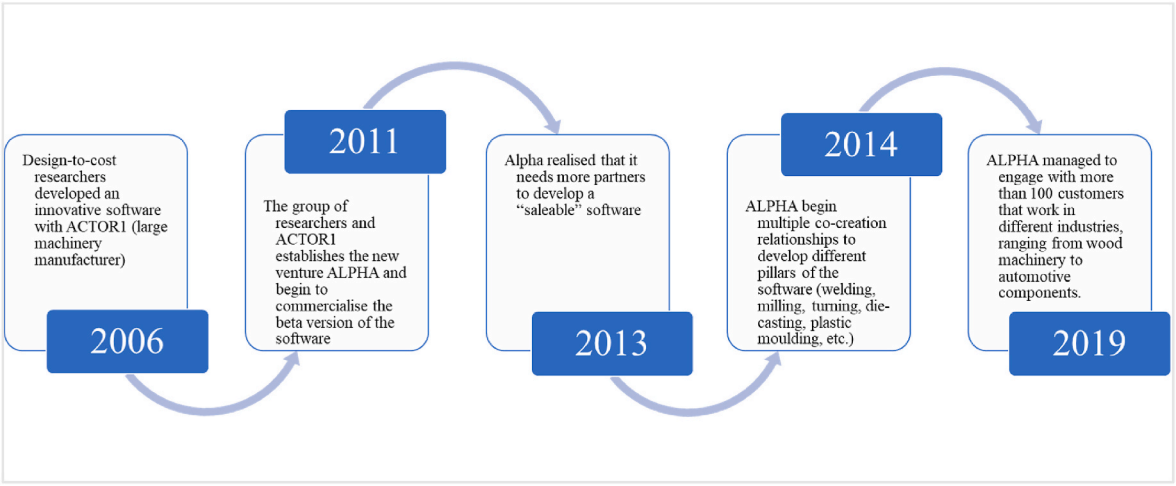



**Fig. 1.** Chronology of Alpha's development. Source: Authors.

from the Faculty of Mechanical Engineering began to study new methodologies to evaluate production costs. Initially, they carried out a project financed by the Italian Minister of Economic Development to create new methodologies to support software innovation in industrial components in production processes. Five large companies led this project. Actor 1, one of those five companies, became the leading partner with the researchers, allowing them to work directly with the firm to analyse how they design and produce components. It is worth noting that the researchers and Actor 1 have actively collaborated since the early 2000s through minor academic activities. However, five years after the initial project, the researchers worked with Actor 1 to develop new design-to-cost methodologies. At this point, the researchers thought their work might be exploited more broadly. Therefore, supported by Actor 1 and the university, the researchers formally founded Alpha in 2011 as an academic spinout. The new venture has five academic founders, the participation of ACTOR 1 and the university. However, as per University terms, it has sold its shares after five years in 2016. The software which lays the basis for Alpha's development was named AlphaCost. This software stems from Alpha's experiences studying design-to-cost methodologies, CAD (computer-aided design) software, and the knowledge gathered and formalised with Actor 1.

2013 - The drawback.

After Alpha was established, it took two more years of development with Actor 1 before commercialising the first version of the software. However, as soon as they began the commercialization at the end of 2013, Alpha realised the technology was too specific to Actor 1's requirements. It is worth considering that Alpha exploited its university network of relationships and reputation as an expert on design-to-cost and mechanical design to commercialize the software. Almost two years after the launch of the AlphaCost software, Alpha CEO realised that the software's potential buyers were reticent to buy and adopt AlphaCost. He realised that the software was too focused on Actor 1

needs and not fully compatible with other firms' requirements even though some were operating in the same industrial sector and with similar industrial processes already codified into the software.

2014 - Reborn through multiple relationships.

The CEO understood the need to establish new business relationships besides Actor 1. These relationships should support technology development and make the software more suitable for broader adoption. These relationships often begun as a usual buyer-seller relationship. However, as soon as Alpha's salesperson recognizes the need to develop new technologies for new potential buyers, they offer a development partnership, where the software is provided for free to harness the user's commitment to obtaining its information and insights. This approach led the new venture to the rapid and robust development of the software's underlying technology.

2019- The software development and the different contributions of the actors.

AlphaCost is co-developed due to the nature of the software itself, that is, it needs data and information gathered directly from the users. The AlphaCost software comprises four elements. These are user experience, in terms of the software's ease of use; knowledge library database, in terms of all the information about materials, processes, components and industry specifications gathered from users and customers to allow the software's algorithm to work; the software integration with other software used by designers and producers within the firm; and algorithms, which are the core calculations developed by the researchers that integrate their knowledge on design-to-cost software development and the other elements described (see, Fig. 2).

Alpha initially exploited existing personal contact relationships of the CEO & Founder to begin co-development collaborations. These technological co-development relationships unfold with a continuous exchange of information, data and insights about software and industrial processes between Alpha and the actors of its business network. These relationships were developed concurrently with buyers and potential new customers. While co-developing the software, Alpha offers the opportunity to use beta versions of AlphaCost. During co-development, Alpha also delivered consultancy to the users. This activity aimed to improve users' proficiency in the use of the software. The users provided Alpha with specific industry knowledge and information about production processes, materials, and machines. Alpha develops its TCDC while commercialising the software and developing new business relationships.

In the initial period (post 2014), the AlphaCost development process involved more than 20 actors in developing more than six industrial processes and twelve industrial applications (see, Fig. 2). These numbers highlight the technology development complexities Alpha has managed simultaneously with many actors operating in different industries. However, this technological co-development process was essential for AlphaCost's development as it needed to be more generalised and suitable for wider use across industrial processes and industries.

## 4. Results

### 4.1. Coding and data structure

The data analysis process, developed inductively using Gioia et al.'s (2013) guidelines, classified 116 first-order codes, 13 s-order themes and four processes (see, Table 2). The data is presented in Table 2 according to the type of informant(s) whom are colour coded.

### 4.2. Four processes of TCDC

#### 4.2.1. Technological frictions and tensions management process

During the process of technological co-development, the spinout had to deal with several tensions and frictions in engaging with the other network actors. This process of TCDC entitled "technological frictions and tensions management" refers to the potential for conflicts, mismatches between actors' expectations, or divergence of aims between the spinout and the network actors during the development of TCDC. In particular, Alpha focused on managing three main aspects of frictions and tensions: the roadmap development priorities, managing users' expectations, and managing the actors' feelings of neglect.

Firstly, frictions and tensions emerge when the spinout implements a technological development roadmap that does not satisfy every actor involved. Not all the actors have the same preferences; besides, Alpha needed to steer the technological development process according to its perspective. The threat lies in the possibility of not engaging some actors with different needs or preferences: "*We are prone to Alpha development map unless we want to use those hours of customization to implement these*

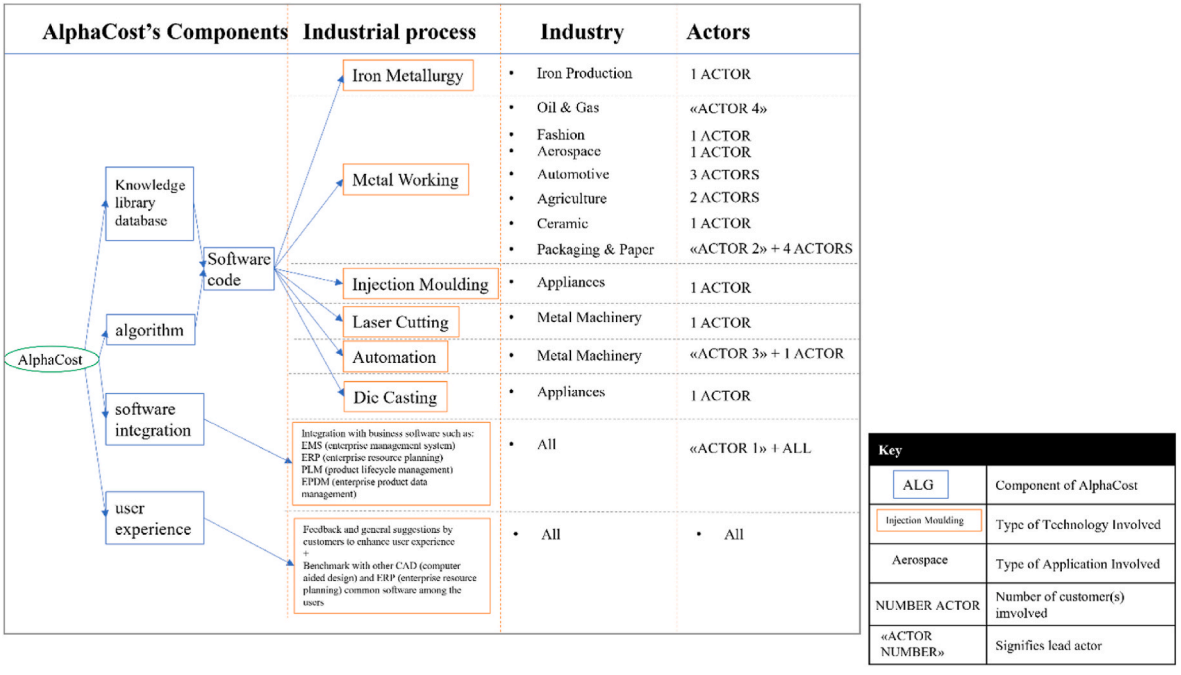



**Fig. 2.** Overview of Alpha's co-development relationships and AlphaCost's software components. Source: Authors.

*technologies or improve some environments. They live on their priorities; for us, it could be more priority to improve the painting environment, which at the time had been treated more simply, and therefore enhance the algorithms; maybe for them, it is more important to prioritize the development of other things within the software or improvement of other processes*" (ACTOR 1 Product cost engineer).

Secondly, TCDC requires maintaining actors' collaboration to develop the technology over time, even when their expectations might have been disappointed. The focal firm shifting its attention towards other actors that are more relevant for developing the technology might cause this disappointment: "*Initially, there was more cooperation from their side and more attention to our requests, but then it went downhill. The last release of the software, now I do not remember the number, but last year, we asked them to solve certain problems that are not being solved*" (ACTOR 3 Procurement).

Thirdly, potential tensions emerge when technological development fails to meet some actors' expectations but favours others. Hence, these actors perceive that they receive less attention than others. Thus, TCDC also requires the focal firm to manage the tensions that emerged when actors felt neglected or not considered a point of reference for technological development: "*We asked for a thing that was instead developed immediately with 'Ceramic machinery firm', and we were sorry because we found ourselves unhappy. This bad feeling spread within our firm, and even though I was slightly happy in either case, some of my colleagues were not. So, within the company, there has been discontent between Alpha and us, and it has been difficult to let it go away over the years.*" (ACTOR 1 – Product cost engineer).

#### 4.2.2. Network-level relationship process

In the "network-level relational process", TCDC required Alpha to expand into new business relationships for technological development and commercialization of the new software. Here, this process comprises four different themes: leveraging academic background; addressing users' needs; leveraging network relationships; and, managing relationship dynamics.

Firstly, the prior social background of the focal firm plays a crucial role. The network of academic relationships facilitated the initiation of new business relationships. At first, thanks to the academic background, the spinout engaged several actors quickly due to pre-existing relationships and trust for developing the new technology: "*Actor4 is the only one that came to look for us for skills that they knew at the university level, and in that case, we started more from academic relationships and then also moved on to a commercial relationship.*" (ALPHA CEO & Founder).

Secondly, addressing users' needs supports the spinout's business relationship development. Technological development is easier when the focal firm understands the actors' needs and helps them understand

**Table 2**
Coding of the technological co-development competence (TCDC) processes.

| 1st order codes | 2nd order themes | Processes |
|---|---|---|
| Early customers believed in the solution even though the system was weak | manage development roadmap priority | Technological frictions and tensions management |
| Roadmap priority caused a lack of involvement | | |
| The software has been generalised in 3 years and is still at 50% | | |
| They have more customers and their development does not match with our needs | | |
| Actor1 invested in maintaining the solution and not for its development | managing users' expectation | |
| In the beginning, they were more attentive to our needs | | |
| Customer collaboration is rewarded with royalties | | |
| Customers do not want to pay for improvements and customisation | | |
| From collaborator to customer | | |
| The improvements we develop together should be free | | |
| Lack of collaboration | | |
| Lack of commercial support from the founding firm | | |
| Support the development to avoid adoption failure | | |
| Software (Sw) does not fit our needs | | |
| Sw useful to reach new suppliers | | |
| The time they give us is less than before | | |
| Buyer expectation toward Sw release | actors' feeling neglected | |
| Other actors are developing the product now | | |
| There are more attractive customers issues to solve before our requests | | |
| Actor1 invested in the development of the research activity on design to cost | leveraging previous background | Network-level relationships development |
| Actor1 needed specific skills to develop a solution | | |
| Alphacost is the result of 30 years of research | | |
| The core business is the commercialisation of research | | |
| Internship to create a link between the firm and the university | | |
| Lack of experience and far from real field problem | | |
| Maturity of the software | | |
| Fit between the firm's needs and the university's knowledge of engineering Sw solutions | | |
| Previous academic relationships | | |
| Previous research group relationships | | |
| Team's academic background credibility | | |
| Theory needs to be operationalised | | |
| They begin from a profound mechanical abstract knowledge | | |

| | | |
|---|---|---|
| Through internships, we developed some areas of the SW that have been subsequently commercialised | | |
| University internships supported the adoption of the software | | |
| Few similar solutions | addressing users' needs | |
| Other solutions have been tested before | | |
| Sw development stems from actor1's need to have a single tool for costing | | |
| Sw develops through customers' needs | | |
| The Sw stems as the answer to a specific need in a specific industry | | |
| The Sw was the answer to a specific need | | |
| We have understood the potential of the Sw since the beginning | | |
| Actor 1 brought relationships. | leveraging network relationships | |
| Commercialise in the industry already developed in the Sw | | |
| Engage with other users or customers | | |
| Extant personal links were crucial for Sw development | | |
| Host meetings with other actors | | |
| Looking for firms operating in filed not yet covered by the Sw | | |
| Other customers add value to the SW | | |
| Sharing knowledge and relationships | | |
| The relationships developed allowed us to be recognised and engage with new customers | | |
| The Sw develops through customers' contributions | | |
| Users gathered information through their network | | |
| Competitor awareness | managing relationships dynamics | |
| Customers are different in terms of support provided for Sw development | | |
| Even though the relationship is more formal, founders continue to have a tight exchange of information | | |
| Formalise requests | | |
| From customer to collaboration | | |
| Relationship's detachment | | |
| Relationships have always been good | | |
| The collaborative feeling of the beginning is gone | | |
| The nature of the relationship change | | |
| The relationship becomes formal but with informal relationships among those developing the Sw | | |
| We consider strategic customers those with a strong brand and those who are supporting the development of the Sw | | |

| | | |
|---|---|---|
| Buyers finance the Sw development by buying something that does not exist yet | demonstration and trials | Product features development |
| Demo | | |
| Demo and pilot project to engage with several potential customers | | |
| The demo is crucial because it is both commercial and technical | | |
| Demo license to obtain feedback for bug improvement | | |
| Development licenses support autonomous Sw development | | |
| The technical demonstration is the key to engaging with buyers | | |
| The Sw is validated from use and free pilot project | | |
| Trials and demos can last for more than one year | | |
| Trials on customer components to engage buyers | | |
| The aim is to cover the needs of several industries | avoiding dead end | |
| The software has been generalised after the commercialisation and meeting with the market | | |
| Too customised on actor1 needs | | |
| Auto-detection of 3d model is the uniqueness of the software | developing software capabilities | |
| Creation of bug fixing and improvement database | | |
| Cad interface | | |
| Collaboration begins when the Sw has no capabilities for a specific process or industry | | |
| Sw has unique features | | |
| Sw is continuously developed and validated | | |
| Sw support for massive information upload | | |
| The collaboration begins with industry data and information input | | |
| Agreement for Sw development | openness for collaboration and customisation | Technological co-development enablement |
| Customers perceived other Sw providers as less keen on customisation | | |
| Customisation persuade purchase | | |
| Development licenses and bug improvement activities persuaded customers | | |
| Software developed through multidisciplinary and multi-organisation team | | |
| External actors supported the Sw development through their needs, knowledge, data and solutions | coding information & knowledge | |
| Field experience is reported in a book by integrating theoretical background | | |
| Industry information begins with the relationship with specific customers | | |
| Information collected has been transcribed into the basic logic of the software | | |
| Knowledge is continuously growing as it expands with further technologies mapped during use | | |
| The knowledge library is continuously evolving. | | |

| | | |
|---|---|---|
| Models have been developed after knowledge exchange | | |
| Sw industrial knowledge limits the commercialisation | | |
| The book was developed by a multidisciplinary team | | |
| Translate and transferring field experience and production processes to highly theoretical personnel were the first challenge | | |
| A job was done with "4 hands." | engage actors for co-development | |
| Being flexible and providing customisation is a plus | | |
| Collaboration for Sw integration with other Sw | | |
| The different firms brought different information on different industries or production process | | |
| Every user continuously adds feedback and knowledge. | | |
| Joint work with other actors for Sw logic development | | |
| Small fix and customisation are concurrent | | |
| Sw development is rewarded with free Sw licenses | | |
| Sw logic development as a training experience | | |
| The Sw success with large players is the proof of our good job | | |
| Training is mandatory for Sw adoption | | |
| Users' feedback allows a continuous development | | |
| We can continue developing together | | |
| We needed their coordination to begin the development of the software | | |
| Willingness to make a development agreement to develop and distribute a new version | | |
| Willingness to participate in Sw development | | |
| Willingness to provide what is needed to enhance the Sw | | |

Source: Authors

*Informant typology colour Key:*

| | | | | |
|---|---|---|---|---|
| Founders = red | Early collaborator = green | Later collaborators = blue | Alpha employees = purple | University = orange |

the role of the new technology. The actors are advised about how they might contribute to technological development. Furthermore, understanding users' needs was made easier for Alpha as it shared a common technological background, which in turn also supported the beginning of further business relationships: "*Mechanical abstraction, which guaranteed a deep knowledge of the technique, computer science for the management of the development of the software.*" (ALPHA CIO & Founder).

Thirdly, the engagement of the actors supported the focal firm in leveraging network relationships. Alpha nudged their partners into the technological development to engage their network of actors to participate in the software development of AlphaCost. Hence, the actors who participated in developing the new technology engaged other actors within their network. Thus, the technology also developed due to the continuous engagement of new actors bringing new perspectives, knowledge, and further contributions: "*Actor 1 has made available networks of knowledge and distribution. It brought knowledge and external contacts.*" (University - Board of Director Member).

Finally, Alpha recognised that not all relationships are the same and have the same outcome. Over time, every relationship had its highs and lows. Managing business relationship dynamics develops through continuously fine-tuning the relationships with the actors. Nevertheless, some relationships began with a technological ethos and later became formalised customer-buyer relationships, while others began as a customer-buyer relationship and, over time, developed into profound partnerships for technological development: "*Everything started with a customer-supplier relationship, with presentations of the platform, after which it became a continuous collaboration to exploit the knowledge of Alpha, who has a strong knowledge of the theoretical part.*" (ACTOR 2 – Technical sourcing).

#### 4.2.3. Product features development process

This process of TCDC is labelled "product features development" and refers to the software's intrinsic and tangible technological characteristics and specifications that allow embedding and integrating the contributions gathered from the actors of the business network. Product features highlight the new technology itself as an interface to integrate the actors' contribution to the software. The product features development themes that were important in the case are demonstration and trials, avoiding dead ends, and developing software capabilities.

Demonstration and trial activities refer to all the activities deployed to show the new technology to the actors of the business network and engage them in effectively using and validating it. Moreover, through demonstration and trials, the users can test the technology with their components and decide to buy it. These activities are still crucial for building engagement with new actors and identifying future business opportunities: "*We gave free licenses on trial working on bugs and improvements as a way of developing and growing the system. This process has been replicated with both small and large enterprise customers.*" (ALPHA Sales Specialist).

Secondly, one of the focal firm's main drawbacks was when it recognised the software was too customised to Actor 1's preferences. Alpha had to rebuild the software and the technology from scratch; the software was re-designed to avoid future dead ends. Thus, Alpha developed software open to receiving contributions from new actors, which in turn facilitated the technological applicability across industries and supported the continuous development of the coding and algorithms: "*The first problem was generalising a solution born on a project that was too specific. This theme is still the main theme today, that is, developing many technologies that meet the needs of a generic company—ranging from the sector, cars, air transport, maritime, and plants. Each of these has specificities on the processes they carry out, to which today Alphacost does not respond in full. The goal is to have a satisfactory platform for all industrial sectors.*" (ALPHA CEO & Founder).

Thirdly, TCDC requires engaging actors to develop several new software features and capabilities from scratch; actors' effort in validating, fixing bugs, and improving the software using field data. Data

gathered from several industries and production processes were crucial to expanding the software capabilities toward a wider range of actors: "*It is a continuous validation; it is constantly evolving. There is no precise moment; it was done directly for the company's use. In particular, stress was on the following areas: Features required to* support *daily work; Data reliability, knowledge-based tool: first verification obtained by comparing Alphacost data with the company's current data*" (ALPHA CTO & Founder).

#### 4.2.4. Technological co-development enablement process

TCDC entails "Technological co-development enablement" process between the focal firm and the network actors. These interactions are mainly technical and require collaboration in developing all the details of the new technology. The data analysis identified three themes in this process: the openness for collaboration, the coding of information and knowledge, and the engagement of the actors for co-development.

Firstly, technological co-development enablement begins with the openness of the focal firm to the contribution of several actors and toward the collaboration and the exchange of information for technological development. Alpha's openness for collaboration and technology customization unfolds by allowing the actors to ask for customised front-end and back-end functions. Several standard software functions were initially developed as custom components but these have met the specification of other actors within the business network over time: "*They saw our Competitor 1 software, but many of our customers felt that because Competitor 1 is a larger company, it will be less suitable to develop specific features and customised functions. Our users believe that Competitor 1 is more suitable for production on large numbers, but we are more eager to customise solutions for them.*" (ALPHA Sales Specialist).

Secondly, technological enablement aims to codify the information and knowledge gathered from the actors into software functions or repositories. For example, the report of bugs and improvement or interviews with machine operators and technologists as the technology is used. A further complexity also lies in the need to integrate different sources of information and knowledge into different production processes and industries' software logic: "*They elaborated while we gave much information. Then, slowly they got this information and began to integrate everything and structure the activity for analysis. So, what it consisted of, what was needed or how a quote had to be made, they carried it out with us. Every day we discussed topics such as carpentry, and there, we dealt with everything related to the technological and production processes regarding that process, starting from laser cutting and what can be done with laser cutting. From this first point, we generated the logic that is the software's basis, then the algorithms."* (ACTOR 1 Product Cost Engineer).

Thirdly, the software has developed in continuous collaboration with many actors over time. Most software parts have been jointly developed between the focal firm and the users. Alpha deployed several concurrent joint-development projects according to the part of the software, industry information or production process-specific algorithms that needed co-development. This joint work in developing and testing the software unfolds with many actors, each with a different industry and process background. The software is still under development with the collaboration of several actors: "*It is a product in continuous evolution thanks to the feedback of users, even after adoption.*" (ACTOR 1 CIO).

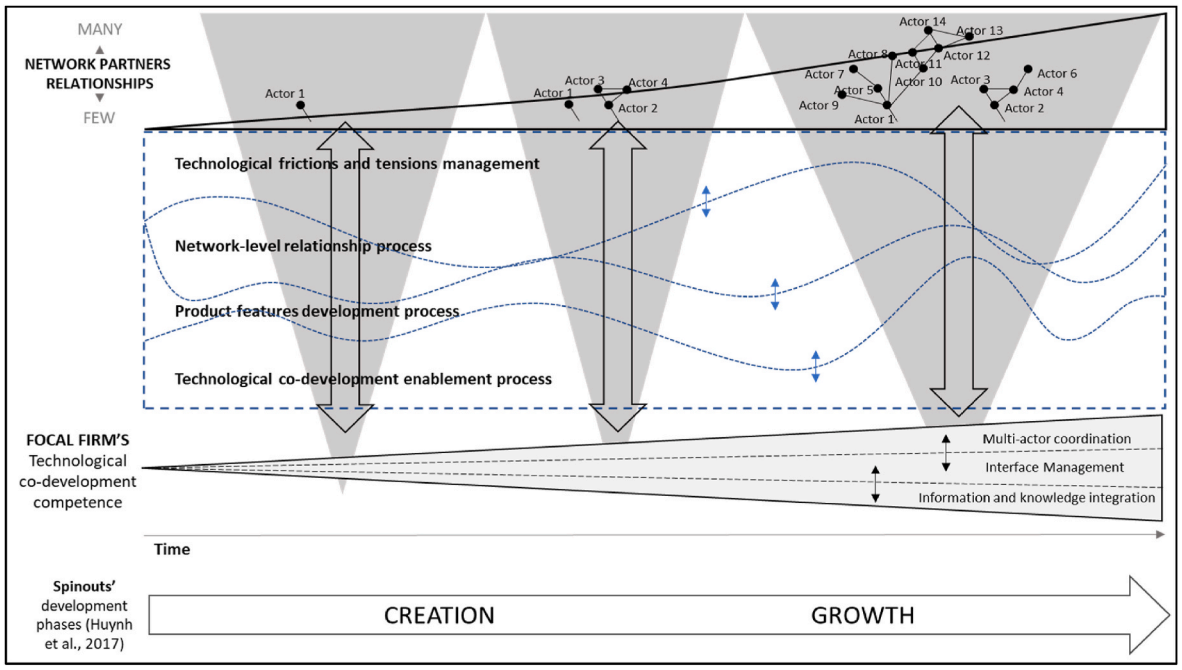
## 5. Discussion: Conceptualizing a model of TCDC's evolution

Fig. 3 diagrammatically conceptualizes our model of how TCDC is developed by the spinout firm in an interactive way in its network. It uses the four processes derived from our data and presented in Table 2, combined with the three elements of TCDC identified in our literature section, mapped with Alpha's development of TCDC over time through its creation and growth phases (Huynh et al., 2017). The model's design is an interactive and processual description of TCDC's evolution over time of a university spinout. Therefore, the study is consistent with the market-as-network tradition of processual studies (e.g., Medlin and Törnroos, 2014; McGrath et al., 2019; McGrath et al., 2018). The model is similar in assumptions to La Rocca et al. (2016)'s model of customer involvement in innovation and the role of sales in the boundary spanning processes as it presents the technological development phenomenon in the business network but ours has a different focus. Fig. 3 shows the relationship between the spinout and its network partners. It also shows how Alpha developed TCDC in interaction with the network over time, and presents the four processes of TCDC as they evolved (see, Table 2 for data coding and structure). There are four layers in Fig. 3 from the top: network partner relationships, TCDC processes, focal firm's technological co-development competence, and time.

The first layer presented in Fig. 3 is the network partner relationships. They range from a few at the beginning of the Alpha spinout to many relationships at the end of our data collection period (the spinout had more than 100 business relationship at the end of our data collection period). The importance of these relationships are not in doubt and feature in many studies (Benneworth et al., 2017; Prokop, 2021) albeit with fewer empirical studies focusing primarily on developing competence in a spinout's network of customer relationships. To help the reader understand how the process unfolds, the figure presents the initial key relationships that allowed the spinout to develop. Starting with Actor 1, the figure describes the growth of business relationships through the development of TCDC. TCDC enables creating and managing multiple relationships over time to develop and commercialize new technology. Accordingly, the Figure shows the number of network partners growing over time (see the upward curve of the network partner relationships) as TCDC unfolds. The growth of business relationships is also supported by network partners' willingness to involve other actors in their network. The actors aim to contribute to developing the new technology manifested through their role in engaging other actors who are able to contribute to AlphaCost's technological development.

The second layer presented in Fig. 3 is the technological co-development processes. The study proposed that TCDC evolves over time through four processes. The processes show one way of exploiting commercial value from relationships external to the university spinout that it has been identified as poor at doing (Lubik et al., 2013). The figure presents the four processes of TCDC. The four processes identified complement existing studies on technical and market capabilities needed for spinouts (Buratti et al., 2021; Leone et al., 2022; Scaringella et al., 2017; Scousa-Ginel et al., 2017) by showing how the underpinning competence is developed. Fig. 3 aims to present these processes as concurrent, overlapping (see, blue lines in Fig. 3 to represent both of these features of the processes), and with the possibility of moving backward as well as forward that is a forward moving linear process is not assumed given the length of time it took our spinout to develop TCDC. Fig. 3 also shows that TCDC's processes do not have the same size and shape over time that is they vary in their impact and intensity at different stages. However, all the processes are present continually in the data.

Coming back to the four processes of TCDC derived from our data as shown in Table 2. Technological frictions and tensions management process entails addressing three thematic abilities. The first two are managing the spinout's roadmap priorities and users' expectations (Lockett et al., 2003). The third ability lies in not disappointing initial users by making them feel neglected (Baraldi, 2008). The network-level relationship development process unfolds through four thematic abilities and skills as shown in Table 2. The first skill is to leverage the previous academic background of the founders to develop new business relationships for the spinout (Mathisen and Rasmussen, 2019; Mu and Di, 2012). These newly formed relationships allow the spinout to develop the ability to address users' needs. By accumulating relationships over time, the spinout can develop the skill to leverage them to begin new ones, and the ability to protect itself from adverse relational dynamics (La Rocca et al., 2019). Product features development process was derived from three thematic skills. The first is the skill of the spinout to demonstrate how the new technology works to help it commercialize



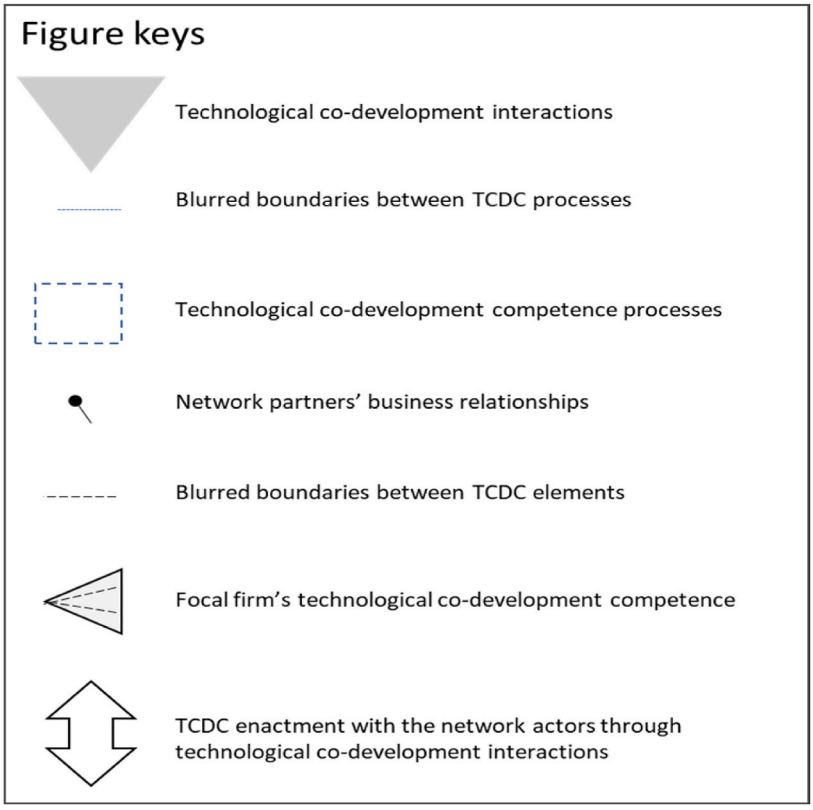




**Fig. 3.** Technological co-development competence evolution in interaction with the network over time. Source: Authors.

the innovation (Mathisen and Rasmussen, 2019). The second skill is the awareness to avoid dead ends in dealing with a single actor, and the final skill is to develop the technology and exploit relationships to continually develop the product's software features (Lubik et al., 2013; Wright et al., 2004). Technological co-development enablement processes was derived from three thematic abilities found in the data (see, Table 2). The first is spinout's ability to being open for collaboration and customization with the actors of the business network (Atzmon et al., 2022; Johnsen and Ford, 2006; Murovec and Prodan, 2009). Then, it enhances customer involvement to develop and adapt the new technology by having the ability to gather and code information and knowledge. The third thematic skills is to engage actors' product knowledge through the establishment of technological co-development relationships (Aarikka-Stenroos and Sandberg, 2012; Munksgaard et al., 2012).

The third layer presented in Fig. 3 are the three elements that comprise TCDC. A spinout's TCDC grows over time as the three elements of TCDC develop in application and in interaction in the firm's network. The three elements (multi-actor coordination, interface management,

and knowledge and information integration) are concurrent and intertwined (represented by the double arrows connecting all three). Fig. 3 presents the elements of TCDC in an interaction area to depict their progression in developing network partner relationships over time.

The inverted pyramids represent the spinout's engagement with the actors of the business network during the technology development process. The pyramids are inverted to represent how the intensity of technological co-development increases through the four processes and as the number of network partner relationships increases over time. The movement between the spinout and the actors is recursive (back and forth between Alpha and the actors, see the arrows in the pyramids) realised through technological co-development interactions. The inverted pyramids overlap with the four processes to show that TCDC spreads from the spinout and unfolds through the four processes of TCDC.

Finally, Fig. 3 presents the concept of time as the fourth layer in our model. Time is relevant as the study aims to provide a processual and longitudinal perspective of how TCDC evolves. TCDC's development by Alpha was bumpy (non-linear) as it developed and regressed through cycles until it became a critical competence in Alpha's success. The time component to our model highlights the spinout's development process through the two phases identified by Huynh et al. (2017), allowing us to understand how TCDC enables the development of relationships and technology in the creation and growth phase of the firm. The study may also provide an insight into how TCDC enables spinouts to overcome the "death valley" between creation and growth (Ellwood et al., 2022; Huynh et al., 2017; Vohora et al., 2004).

## 6. Implications

### 6.1. Managerial implications

The study clearly has implications for start-ups and spinouts, offering some guidance to founders and managers developing new technologies in interaction with the business network. The study suggests that early interactions with a few or one key actor(s) remain relevant for the initial development and growth of the spinout. However, the development of TCDC helps to avoid lock-ins and dead-end collaboration while enhancing the ability to interact for technological development with an increasing number of new buyers; possessing TCDC allows the simultaneous engagement of several actors for technological co-development interactions. Therefore, it is worth noting that many technological co-development interactions are developed with actors who are potential or future buyers of the solution under development. Hence, TCDC shortcuts the path to commercialising the technology, supporting the spinout to improve commercialization activities and interactions. Finally, recognizing the processual nature of TCDC helps firms to identify and track the technological co-development processes and set future milestones to support the interaction with key actors of the business network. As seen in the case, the spinout firm uses TCDC to identify which actors in the business network have the specific knowledge needed to develop or validate each piece of software.

### 6.2. Policy implications

There is ample opportunity and need to increase the empirical contributions on university spinout policy that relate to increasing a spinout's network especially with customers (Wright and Fu., 2015). Often the focus of policy and practice is on the relationship with the first, or on a large or prestigious customer. The negative side of this policy is also seen in the failure of start-ups to move beyond the initial customer as the technology developed is locked-in and over-customized to this one customer. A focus on TCDC presents one opportunity to avoid this policy and practice problem through the use of networks of relationships with customers and other actors making the product less susceptible to over-customization and thus, dependence on one customer. Policy mechanisms that support a spinout to engage in multiple relationship for technology and market development may take a little longer to see results but may make the spinout more resilient. Lean start-up approaches that focus strongly on a customer pipeline also should have to balance the need for market and technology development that spreads the start-up's influence into the wider network with the benefit of the information and knowledge, and interfaces made with these partners likely to impact the start up's abilities and skills into the long term.

## 7. Conclusion

The study develops the concept of TCDC and provides an empirical perspective on how it evolves interactively in a university spinout's network over time. The study was triggered by the opportunity to provide a contribution to a topic – technological co-development in a university spinout's context - that, according to the extant literature, has many gaps for new empirical contributions (La Rocca et al., 2016; Ritter and Gemünden, 2003; Zahoor and Al-Tabbaa, 2020). In particular, the study contributes to the understanding of how TCDC evolves in the network of a spinout firm over time (Baraldi, 2008; Håkansson and Waluszewski, 2003; Leone et al., 2022; Mishra and Shah, 2009; Möller, 2006; Mu et al., 2017; Thomas et al., 2020). The paper takes the perspective of a university spinout firm that develops new software for design-to-cost manufacture. The study empirically observes TCDC with a processual perspective to understand how it evolves over time. The study outlined how TCDC supports a spinout's technological co-development interactions while creating business relationships with the network. As mentioned, the study develops a novel perspective on technological development competencies by inductively conceptualizing TCDC, identifying its three core elements, and providing a longitudinal perspective of how TCDC interactively evolves at the network level over time through four processes. The four processes of TCDC are developed in interaction in the network.

By answering the research question "How does technological co-development competence evolve in the spinout's network over time?" the study developed a processual model (see, Fig. 3) to comprehensively understand all the processes involved. The study posits that TCDC evolves over time through the increasing number of business relationships engaged in technological development interactions. TCDC's processual nature unfolds in four processes: technology frictions and tensions management, network-level relational processes, product features development, and technological co-development enablement. The study suggests that TCDC develops through these processes which unfold together in a concurrent, interactive, and recursive way. TCDC and its three elements (multi-actor coordination, interface management, information and knowledge integration) grow over time in tandem linked with the increasing number of technological development interactions and the unfolding of the four processes. The study suggests that these three elements of TCDC are concurrent and intertwined. The study also highlights how TCDC is possessed by the spinout company and exchanged over time with the network actors through the technological development interactions occurring during the unfolding of the four processes.

The relevance of TCDC links to the need/opportunity to mitigate the typical problems of the academic spinout's development like, among others, the lack of university support, the uncertainty of the academic career, the over-reliance on a single partner, and the lack of adaptability to fit multiple potential customers' needs. The article pinpoints TCDC as one solution to those problems as it helps spinouts to cope with the interactive nature of technological co-development processes in the business network. The study extends prior understanding of business network's technological co-development interactions over time taking the market-as-network tradition of studies and the spinout literature, where it adds new knowledge on developing a spinout competency in technology co-development.

### 7.1. Limitations and further research

Even though the study provides valuable insights to both the empirical literature and for managers, it is not without its limitations. Although qualitative studies are increasingly adopted to provide insights into interactive empirical processes, the generalizability of the findings described in the manuscript is bounded by a specific context and scope. Our case context is limited to one region in Italy with a strong network to support the case company's growth which was able to happen without the company internationalizing which is not often the case for a software technology start-up. However, the company's product does has wide application in the design-to-cost space which has unlimited application and the product's potential has been shown in a range of industry applications (see, Fig. 2). The scope of our case study focused on a high technology software as a service product is wide and has potential to contribute more broadly to the literature despite our qualitative findings being necessarily limited in generalizability. In addition, how TCDC unfolds in interaction with the network over time may look very different that is take different shapes (see, Fig. 3) when other technologies or business contexts are considered. Also, it is worth noting that the present study provides a case of a successful spinout; this can lead to underestimating potential issues that might emerge in other more problematic cases.

Further studies are needed to investigate the phenomenon of TCDC. Future studies might focus on spinouts that do not develop software, hence providing different empirical contexts where the model developed might be enhanced by further evidence. In addition, multiple and comparative case studies are welcomed to investigate differences and similarities among various settings and contexts. Also, further studies can consider cases that are still not successful but are dealing with growth problems and not yet out of "death valley" (Ellwood et al., 2022) to provide a novel perspective on the same phenomenon. Finally, given the paramount relevance of spinouts to the economic performance of regions and universities' advancement, further studies can be focused on understanding the policymaker's perspective on TCDC and how it can support the spinout's development of TCDC to benefit future academic technology transfer initiatives.

## CRediT authorship contribution statement

**Andrea Sabatini:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Thomas O'Toole:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Formal analysis, Data curation, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The data that has been used is confidential.

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