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Digital transformation in manufacturing ecosystems: A case of supply and knowledge network decoupling

Relatore
prof. Marco Cantamessa

Candidato
Stefano Negrini

Correlatore
Prof. Paolo Aversa

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Abstract

Recently, the ecosystem perspective has offered a novel way to analyze technological diffusion and competition, which has been extensively leveraged to understand born-digital firms. These, however, represent only a part of the competitive landscape. Non-born-digital industries, like those focusing on manufacturing, have traditionally been arranged in a network composed by peripheral and core firms, with the latter characterized by holding superior knowledge and the control over the network. Yet, the "digital transformation" of non-born-digital firms is scarcely investigated, and we have limited understanding on how this process may shift the firms' position in the knowledge and supply network, thus affecting the entire ecosystem. Through a longitudinal qualitative study of Dallara, an Italian motorsport firm that underwent a radical process of digital transformation, our research identifies the implications for the introduction of digital processes in a manufacturing company. We highlight how digital processes increased the firm's technological modularity, relational orchestration, and knowledge assets, thus allowing the firm to increase its centrality in the knowledge network, while maintaining a peripheral position in the supply network. This corresponded to defocusing from its traditional manufacturing activities, but nonetheless led to increasing performance and sustained firm growth. Implications for theory and practice are discussed.

Keywords: ecosystems, digital transformation, networks, strategy, knowledge, *automotive, motorsport.*

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1. Introduction

In recent years, ecosystems emergence and their dynamics have gained increasing scholarly attention as they represent a novel way to illustrate, investigate, and understand the competitive environment (Adner, 2017; Adner & Kapoor, 2010; Jacobides, Cennamo, & Gawer, 2018; Wareham, Fox, & Cano Giner, 2014). To date, most studies on ecosystems have focused on digital and internet-based firms (Ansari, Garud, & Kumaraswamy, 2016; Cennamo & Santalo, 2013; McIntyre & Srinivasan, 2017; Wareham et al., 2014). The digital sector is indeed highly relevant for management theory and practice, and several works have recently enhanced our understanding about ecosystems made of born-digital firms (Ceccagnoli, Forman, Huang, & Wu, 2012; Zacharakis, Shepherd, & Coombs, 2003). However, despite being often iconic and highly interesting (Amit & Zott, 2001), born-digital companies represent only a part of the competitive landscape. Most companies are undergoing a so-called "digital transformation" from more traditional manufacturing domains, and the non-digital part of the business is still preponderant in most markets. It is thus interesting to understand what are the processes underpinning traditional (i.e., non-born-digital) firms within ecosystems when these are disrupted by digital transformation. Yet, we still lack a complete understanding on these matters and scholars claimed that more research is needed to better frame and comprehend these timely phenomena (Jacobides et al., 2018).

Originally, the literature concerning non-born-digital industries mostly focuses on relations among firm in manufacturing environments (Brusoni, Prencipe, & Pavitt, 2001; Dyer & Singh, 1998; Jacobides, MacDuffie, & Tae, 2016; Kogut, 2000; Kogut & Zander, 1992; Lorenzoni & Lipparini, 1999). By applying the emerging principles of ecosystems (Adner, 2017; Jacobides et al., 2018) to such network of firms one can inquire and explore how certain companies' digital transformation re-defined the structure of their relationships at the intersection between firms relational boundaries and the related knowledge which is mobilized in the exchange. In these accounts, prior studies highlighted how firms aiming to act as system integrators within manufacturing ecosystems need to maintain superior knowledge on the whole product architecture (without necessarily being vertically integrated), thus ultimately they end up "knowing more than what they make" (Brusoni et al., 2001). Other studies echoed such reflections by arguing that system integrator have a core role and control over the manufacturing network (Lipparini, Lorenzoni, & Ferriani, 2013; Takeishi, 2001); they hold superior knowledge because of the need to understand and effectively integrate components in an efficient and coherent product architecture, which leads to an overlap between the supply network underpinning the product architecture and the knowledge network to successfully orchestrate the integration of the product (Brusoni et al., 2001; Cabigiosu, Zirpoli, & Camuffo, 2013). Considering those elements, the literature on those traditional ecosystems tend to agree that there is roughly an overlap between the supply network underpinning the product architecture and the knowledge network so that to be able to successfully orchestrate the integration of the product, one needs to be specialized in the design and production of a core component and thus being at the center of the supply and the knowledge network. This explains why peripheral firms that want to achieve such roles often need to "move to the core" (Lipparini et al., 2013).

Yet, the redefinition of the knowledge flow triggered by the digital transformation unsettles this structure and calls for a consideration of the aforementioned theoretical principles. Innovations can transform the structure of an industry (Adner, 2017: 46) and digital technologies have massively reshaped the relationship between firms (Ansari et al., 2016). Among others, the Airbnb case recently proved that it is possible, in a non-born-digital industry, to become a central actor in the knowledge architecture while not owning or managing any property, and maintaining a peripheral position (Kavadias, Ladas, & Loch, 2016). Evidence, therefore, seems to point to the emergence of complex ecosystems where actors that may be peripherally dedicated to the production of a minor component or a complementor, thanks to digital technologies, may nonetheless obtain a more central position in the knowledge flow. This overall could support a firm's superior product integration. If this is true, we wonder what are the digital technologies and related processes that allow such actors to remain peripheral in the supply network but achieve core roles in integrating the knowledge architecture. Given such evidence, we highlight a question in a context of non-born-digital organizations and ecosystems, and ask: *How do digital processes affect the centrality and knowledge integration role of specialized manufacturing firms?*

We address the key questions by conducting a longitudinal qualitative study on Dallara Automobili (1972-2018), an Italian automotive company with manufacturing in Italy and the United States which, by undergoing a profound and advanced process of digital transformation, managed to obtain knowledge for architectural integration despite keeping its manufacturing dedicated to more peripheral set of activities (i.e., carbon-fiber part manufacturing). This allowed

Dallara not only to sustain growth and performance against competition, but also to obtain a prime position in the different motorsport segments, up to almost becoming a monopolist in the industry. The emerging evidence provides insightful reflections for our endeavor as it suggests to consider as a central element the interdependencies among the ecosystem main actors (Adner & Kapoor, 2010), and the complementors (Ansari et al., 2016; Jacobides et al., 2018; Wareham et al., 2014).

Our reflections suggest that digital technologies can de-couple the structure of relation between firms. If in traditional ecosystems the network of relation mimics the structure of the supply network across core and peripheral parts (with the core firms having superior knowledge in product integration), the digital technologies allow peripheral firms accessing superior data and understanding on the product integration, thus de-coupling the knowledge role from the manufacturing role. A process underpinning the different roles of digital technologies emerges and sheds lights for the timely theme of digital transformation in traditional ecosystems. Implications for theory and practice are discussed.

2. Theoretical background

2.1 Ecosystems: What they are and how to measure them

Since its first appearance (Moore, 1993) the concept of business ecosystems provided a novel and useful lens to observe and interpret the competitive environment and, in recent years, it has been witnessing a massive increase in the scholarly interest (Adner, 2017; Iansiti & Levien, 2004; Jacobides et al., 2018; Teece, 2007). A wide range of studies concerning business ecosystems directed attention to what ecosystems are and how is it possible to represent them (Adner, 2017; Iansiti & Levien, 2004; Jacobides et al., 2018; Teece, 2007). In 2007, Teece defined an ecosystem as a community of actors (i.e., organizations, institutions, individuals, etc.), that impact the enterprise, its customers, and the suppliers (Teece, 2007: 1325). Within the ecosystem, companies may share the same "fate," as in a sort of community (Iansiti & Levien, 2004: 69), and the performance of each company is to a certain extent linked to the performance of the whole ecosystem.

Ecosystems can be represented by two views: "ecosystem-as-affiliation," that defines ecosystems by their networks and platform affiliations; and "ecosystem-as-structure," which considers ecosystems as configurations of activities defined by a value proposition (Adner, 2017: 40), or the structure of relationships among firms linked by distinct types of complementarities in production or consumption (Jacobides et al., 2018). Our study will align more closely to the latter view thus embracing the definition of ecosystems as alignment structure of the multilateral set of partners, which need to interact in order for a focal value proposition to materialize (Adner, 2017: 42).

But why is it crucial to understand ecosystems and their dynamics? Similarly to its biological counterpart, from where the definition derives (Moore, 1993), it is fundamental to understand that the development of the actors inside an ecosystem depends from the "state of health" of the ecosystem itself, which could be ultimately compromised by the decline of even one minor actor. This condition imposes, among all the actors, a widespread awareness of the ecosystems' dynamics and their implications. Like biological ecosystems vie for survival and dominance among other ecosystems, competition in business can develop between ecosystems, not just individual firms, and such dynamic is indeed largely fueling today's industrial transformation (Moore, 1993).

For these reasons, it is thus crucial to understand, measure, and evaluate ecosystems and some recent studies provided a remarkable contribution to framing the phenomenon and providing solid theoretical anchoring for future investigation (Adner, 2017; Jacobides et al., 2018). Adner (2017) offered a comprehensive understanding on how ecosystem research relates to established views; and more recently, Jacobides et al. (2018) took a step further, elucidating the key mechanisms behind the emergence and dynamics of ecosystems, specifically related to modularity and complementarity (Jacobides et al., 2018: 2). Those two elements are pivotal in the evaluation and measuring process of ecosystems.

2.2 Investigating ecosystems

Ecosystems are made of interrelated agents which often jointly contribute to the development of technologies the parts of which are characterized by diverse levels of integration. Technological modularity enables interdependent components' production and design to be coordinated between interrelated but autonomous organizations (Baldwin & Clark, 2000; Henderson & Clark, 1990; Murmann & Frenken, 2006). This happens in ecosystems when actors are separated by "thin crossing points" (Baldwin, 2007), consenting interdependent components to be produced by different actors, with limited coordination required. The result is that through modularity, organizations obtain a larger degree of autonomy in how they design, price, and operate their respective modules (Jacobides et al., 2018).

Modularity can support increasing complexity (Garud, Kumaraswamy, & Langlois, 2002) and it is a necessary condition for the emergence of ecosystems (Jacobides et al., 2018): it offers the potential for speedier innovation, shorter product development lead times, and customization. In addition, the development of modular solutions can be altered by internal or external conditions (Baldwin, 2007; Baldwin & Clark, 2003) like the existence of open or closed technological interfaces (Schilling, 2000) and the presence of standards and rules (e.g., governance, contractual forms, etc. Jacobides et al., 2018).

As far as modularity may be necessary for the ecosystem to function, it is not sufficient. Studies have already highlighted in the past that modularity has failed to be accepted by the central actors of the supply chains as it was perceived as a loss of their hierarchic control (Jacobides et al., 2016). For ecosystems to be useful, there must be a significant coordination which does not require a central actor's fiat and authority structure—as ecosystems do not necessarily fit into the standard buyer-supplier relationship—, Yet, such coordination enables different types of complementarities (Jacobides et al., 2018). The concept of complementarity helps explaining that the availability of complementary goods affects the success of the ecosystem itself (which in some cases can be a platform, as in Rietveld & Eggers, 2018). Recent ecosystem theories assessed how different types of complementarities can affect the emergence of ecosystems, their structure and the value creation and capture (Jacobides et al., 2018), so it is crucial to classify complementarities in order to measure and discern ecosystems.

The central argument on complementarities revolves around network externalities (Boudreau & Jeppesen, 2015; Kapoor & Agarwal, 2017; Ye, Priem, & Alshwer, 2012). Some studies suggested how an increase in the number of complements supporting a platform results in an increased adoption of the platform (Clements & Ohashi, 2005; Nair, Chintagunta, & Dubé, 2004). More recent studies specified that the complement success is influenced not only by the number but also by the heterogeneity in preferences and behavior among actors (Rietveld & Eggers, 2018) and that differences in platform architectures, matter for the decisions and outcomes of complement providers to port their complements to specific platforms (Cennamo, Ozalp, & Kretschmer, 2018).

Jacobides et al. (2018) deepened the analysis on complements and identified their main characteristics: nature, directionality (unidirectional or bidirectional), and intensity (of linkages). Regarding their nature, complementarities can be generic (no need for alignment among the actors), unique ("A doesn't 'function' without B") and supermodular ("more of A makes B more valuable") (Jacobides et al., 2018). Ecosystems, in particular, deal with either unique or supermodular complementarities that are non-generic and require the creation of a specific structure of relationships to generate value (Jacobides et al., 2018). Focusing on how ecosystem dynamics are driven by different types of complementarity while interacting with modularity, Jacobides et al. (2018) deepened and extended existing work on coordination, collaboration, and value creation/capture, providing the emerging principles of ecosystems. Ultimately, complementarities can be on the production and the consumption side, depending on whether they provide an advantage to the agents who create or adopt/consume the good.

2.3 The role of core and peripheral actors

Ecosystems ultimately involve relationship across firms and organizations which operate with functions with varying degrees of functionality. Scholars have acknowledged the importance of understanding firms' relational capabilities within the environment they operate (Ansari et al., 2016; Dyer & Singh, 1998; Lorenzoni & Lipparini, 1999). The peculiar structure of ecosystems, moreover, requires a particular consideration of relationships between actors. For example, the decision-making processes in ecosystems may be distributed, yet they depend on different actors' activities. Firms must manage the challenge of simultaneously granting stability and evolvability through a combination of variance-increasing and variance-decreasing mechanisms (Wareham et al., 2014). In a relational term, this often means balancing the naturally emerging "coopetitive" tensions over time among actors with a mix of "soft power" and "hard power" (Ansari et al., 2016; Tsai, 2002).

While studying the relations between firms, scholars warn the importance of focusing on the structure of arrangements, the interdependencies among organizations, and their position (Adner & Kapoor, 2010). Most studies agreed on the presence and importance of a central actor in the relational and architectural network (Adner, 2017; Brusoni et al., 2001; Iansiti & Levien, 2004; Williamson & De Meyer, 2012). This actor has been usually termed keystone firm (Iansiti & Levien, 2004), system integrator (Brusoni et al., 2001), core company (Lipparini, Lorenzoni, & Ferriani, 2014), hub firm (Dhanaraj & Parkhe, 2006), focal firm (Adner, 2017), or lead firm (Williamson & De Meyer, 2012). Even if the presence of this actor is not limited to ecosystems (Brusoni et al., 2001; Lipparini et al., 2014) and the literature is not aligned on the way to define it, there is a general consensus in the literature on the position of this actor with respect to the knowledge and to the product architecture. This core company orchestrates (and simplifies) the complex tasks of participants in the network, and connects the more peripheral agents one another, thus becoming vital to the entire ecosystem (e.g., Microsoft, Walmart Iansiti & Levien, 2004: 6). In addition, the core firm needs to act as an architect and a guide, identifying the value for the end customers and attracting partners that can deliver this value (e.g., SAP, IBM Williamson & De Meyer, 2012: 44)[1]. Especially in ecosystems, the relationship is often not just dyadic but also multilateral and intertemporal (Ansari et al., 2016), and complexities related to location and

[1] The interest in the customer engagement and envelopment has emerged particularly important within the "demand-side" view Priem, R. L. 2007. A consumer perspective on value creation. ***Academy of Management Review***, 32(1): 219-235, Priem, R. L., & Swink, M. 2012. A demand-side perspective on supply chain management. ***Journal of Supply Chain Management***, 48(2): 7-13.

uncertainty can be mitigated by the core organization's orchestrating role (Adner & Kapoor, 2010; Giudici, Reinmoeller, & Ravasi, 2017).

Narrowing down our reflections to the manufacturing domains, scholars affirmed that the general structure of the industry is composed by peripheral firms and by core firms, with the latter usually keeping the most of the knowledge and the control over the network (Gottfredson, Puryear, & Phillips, 2005; Lipparini et al., 2014: 579). Peripheral actors can be skilled, but their competencies are often limited to the parts and do not extend to the whole architecture (Lorenzoni & Lipparini, 1999; MacDuffie, 2013). The core companies' knowledge boundaries thus can and have to stretch beyond their production boundaries as they have to maintain the knowledge of the whole system to effectively coordinate the ecosystem and integrate (loosely coupled) sub-systems (Brusoni et al., 2001: 598-599). As a result, core companies (often original equipment manufacturers, "OEM") cited inadequate supplier capabilities as a pretext for maintaining control, despite the intent of peripheral suppliers to obtain responsibility (Jacobides et al., 2016). When modular innovations are introduced, in fact, the overall level of vertical integration of an industry decreases (Cabigiosu & Camuffo, 2012). In the past, empirical studies have shown how, through modularity arrangements, suppliers have tried to "escape" from their peripheral position, obtaining results that however ended in a return to the previous situation, reprioritizing the central role of system integrators (Jacobides et al., 2016). Those empirical examples confirm that the choice of inter-firm coordination mechanisms is not the mere result of product architectural choices but it is driven by the core and the supplier's capabilities, the knowledge scope and the strategic focus (Cabigiosu et al., 2013).

All the aforementioned elements indicate, in practical terms, that firms usually need to be specialized on the design and production of a core component to be able to successfully orchestrate the integration of the product. This moreover explains why peripheral firms who want to achieve such roles need to "go back to the core" network (Gottfredson et al., 2005; Lipparini et al., 2014).

2.4 Digital technologies and the decoupling between supply and knowledge networks in manufacturing ecosystems

Considering all the elements acquired from the existing literature, literature seems to suggest that—at least in traditional manufacturing networks—there is roughly an overlap between product architecture and the underlying distribution of knowledge across the relational architecture of the firms within the ecosystem. At first glance, regardless of the industry, system integrators seem to retain more knowledge as they engage with delivering the final product or the components which are core to the product architecture. This is why these actors are usually dedicated to the product integration (see for example aircraft engine makers or engine manufacturers in automotive Brusoni et al., 2001; or in Jacobides et al., 2016, respectively). As Jacobides et al. (2018) affirm, however, the ecosystem perspectives are mostly investigating internet, high-tech and ICT sectors, or simply put born-digital firms (MacGregor & Madsen, 2013; Pitelis, 2012; Zacharakis et al., 2003; Zahra & Nambisan, 2012).

The theory on ecosystems underlines the importance of firms' networks and complementors (Jacobides et al., 2018). The empirical investigation is at the beginning and almost only limited to the born-digital cases as we have previously witnessed. This is a limitation, especially in this period of digital transformation in non-born-digital sectors. Like other innovations, in fact, the digital transformation should be followed by a change in the configuration of the structure of the industry and its underlying relationships (Adner, 2017). Modularity is a key aspect of ecosystems (Jacobides et al., 2018) and digital technologies (due to the adaptability of bit strings) exhibit relatively high modularity (Ulrich, 1994). During the last decade, the business infrastructure has become more and more digital with increased interconnections and data exchanges among products, processes, and services (Bharadwaj, El Sawy, Pavlou, & Venkatraman, 2013). Digital technologies are remodeling the structure of social relationships in both the consumer and the enterprise space through social networking (e.g., Susarla, Oh, & Tan, 2012) and they are enabling cross-boundary industry disruptions, and thus inducing new forms of business strategies (e.g., Burgelman & Grove, 2007).

The presence of digital technologies is essentially reshaping traditional business strategy as distributed, modular, cross-functional, and global, enabling business processes that allow work conditions across boundaries of time, distance, and function (George, Haas, & Pentland, 2014; Sambamurthy, Bharadwaj, & Grover, 2003), providing different forms of capabilities suitable for turbulent environments (Pavlou & El Sawy, 2006, 2010). In recent years digital technologies have faced exponential advancements in the price/performance of computing, storage, bandwidth, and software applications, and this is moreover driving the next generation of digital technologies to be delivered through cloud computing (Bharadwaj et al., 2013). These elements suggest that digital technologies are redefining the knowledge flow and the effect of those are greater in non-born-digital firms like the manufacturing one, but they have not yet been fully addressed by the literature.

These observations motivate our inquiry into the effect that the digital transformation has had on the structure of ecosystems like the manufacturing one. We will observe if and under which boundary conditions the classic core-periphery firm alignment has been unsettled by the new circumstances and if the overlap between product architecture and knowledge architecture is still into place. We will moreover study the structure of this digitally driven processes and the steps that companies could adopt to develop them.

3. Method

This study is based on a longitudinal, qualitative case study (Eisenhardt, 1989; Yin, 2008) on the digitization of a non-born-digital firm in the automotive and motorsport industry. Prior research have extensively leveraged the automotive industry as a viable setting to explore the relation between technology and firm performance (e.g., Cabigiosu et al., 2013; Dyer & Nobeoka, 2000; Jacobides et al., 2016; Lipparini et al., 2014; MacDuffie, 2013; Schulze, MacDuffie, & Täube, 2015).

The automotive sector—unlike most born-digital sectors like the computer one, which unbundled into independent vertical segments—is historically hierarchical (Jacobides et al., 2016). Past studies have already underlined the rigidity of this sector and the concentration of power and knowledge that was usually associated with system integrators (e.g., Jacobides et al., 2016). In recent years, however, the sector has faced a progressive adoption of (at times disruptive) digital technologies and at the same time an exponential growth of small actors (McGee, 2017). The motorsport industry, which is the part of automotive dedicated to the production and commercialization of high-performance vehicles (usually suitable for amateur or professional racing) tends to pioneer most solutions and therefore represents a viable setting to foresee future changes of the main automotive sector (Aversa & Guillotin, 2018). However, this setting is also small enough to allow combining a rather comprehensive outlook with detailed understanding of micro-dynamics.

Because of such reasons we found the iconic case of the motorsport firm "Dallara" particularly suitable for our inquiry. Dallara is today an established player in the motorsport industry with more than 30 years in the business, with 600 employees, revenues for more than €100 million, and contracts signed with the biggest system integrators in the industry. Yet, in 2007 Dallara was still a family company with 100 employees and €30 million revenues, its growth was still slow, its competences limited, and its position in the supply network rather peripheral. Yet starting with 2007, the company faced remarkable growth rates from all perspectives, being now considered and respected as one of the biggest players in the industry. Evidence suggests that its growth was tightly related to their adoption of digital technologies within their traditional non-digital processes (Aversa, 2014; Nacamulli & Sassoon, 2013).

3.1 Data Sources

Our study combined primary (interviews and observations) and secondary sources or data (from publicly available sources and archives). Table 1 presents all the sources used.

The data collection started in July 2018 and finished in December 2018. We began gathering longitudinal data on Dallara Automobili and the racing industry through keyword searches on publicly available archives, including the website of the company, between the years 2000 (the years when Dallara started introducing digital in its processes) and 2018. We started our online researches through the Google search engine, combining the keyword "Dallara" with other different keywords ("technology", "innovation", "simulator", "digital", "strategy"), both in English and Italian.[2] Apart from publicly available documents we also gained access to two articles and two business cases[3] regarding the automotive ecosystem and Dallara, with these publications dealing with the evolution of the company, its new business proposition, and its expansion. This process resulted in a total of 31 retrieved documents, 4 audio-video documentaries and 3 audio-video interviews and conferences of Giampaolo Dallara, the founder of the company. After a first screening, we consolidated redundancies and divided the documents in "useful" or "not useful". With the term "useful" we identified documents that were providing relevant and reliable information about the company and its processes. This led to the record of 22 "useful" documents (104 pages) and 7 audio-video files.

From the first search, all we could notice how all publications underlined the contribution of the new CEO, Andrea Pontremoli. We then proceeded with a second research, which was followed the same protocol but also added the keyword "Pontremoli" combined with further keywords ("interview", "Dallara", "innovation", "conference", "digital"). We identified 10 documents and 21 audio-video files regarding interviews and speeches at conferences between 2007 (few months before becoming the new CEO of Dallara) and 2018. Adopting the "useful" and "not useful" categorization process after a first qualitative review, we retained 9 documents (54 pages) and 19 audio-video interviews, for a total (with the previous research) of 31 documents (158 pages) and 23 audio-video files. A second review was conducted on the selected relevant material in order to

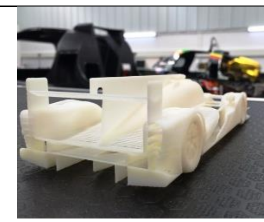
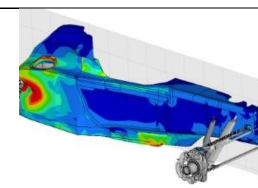
[2] Dallara, as already mentioned, is an Italian company so the majority of the documents were in Italian.
[3] The two articles are from *Il Sole 24 Ore* and *Herald-Tribune*; the two business cases from the *International Institute for Management Development* and the *Financial Times*.

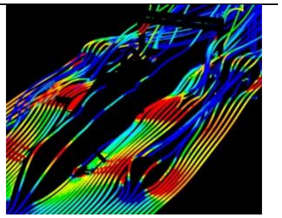
identify and classify the significant quotes and information. Besides, we retrieved and analyzed all Dallara's patents, and paid particular attention to those related to digital technologies. Specific descriptions of characteristics and major advantages of the digital technologies adopted at Dallara are available in Table 2.

TABLE 1
Data sources

Sources	Type of data	Nr. of docs	Pages/ Mins	Use in the Analysis
Secondary sources	**Internal Dallara documentation.**	2	5	Triangulating observations and facts with quantitative data from the company.
	Public Dallara documentation Descriptions of activities, reports and historical records available on Dallara's website.	5	10	Supporting, integrating, and crosschecking interviews information; clarifying event timelines.
	Press coverage Articles from Il Sole 24 Ore, Herald-Tribune, USA Today, Harvard Business Review, la Repubblica, regional media and automotive press.	24	137	Enhancing validity of insights; better understanding of the company's behavior and of the industry evolution.
	Case studies Two cases study from the International Institute for Management Development and the Financial Times.	2	21	Triangulating observations and facts to overcome the limitation of Dallara's corporate rhetoric; enriching the database of evidence with third-party data.
	Total	**33**	**173**	
Videos	**Pontremoli and Dallara Conferences and Interviews** 2 TEDx events, 4 University events, 8 Industrial Conferences, 8 interviews on regional media.	22	705	Supporting, integrating, and crosschecking interview-based accounts.
	Documentaries Documentaries by automotive press or regional media.	4	53	Enhancing validity of insights; defining the boundaries of Dallara's corporate rhetoric.
	Total	**23**	758	
Interviews	**Dallara's Executives**	12	945	Gathering data regarding the origins and evolution of Dallara and its role in the automotive ecosystem.
	Dallara's Clients	1	92	Expanding the sample to verify Dallara's information from the clients' perspective.
	Dallara's Suppliers	2	80	Expanding the sample to verify Dallara's information from the suppliers' perspective.
	Total	**14**	**1,117**	

TABLE 2
Digital technologies descriptions and features

Technologies	Description	Features	Digital component	Picture [i]
Wind Tunnel	The wind tunnel is an aerodynamic research tool developed to study the effects of air on moving objects. This tool inverts the real-life situation: the studied object is stationary inside a tubular container where the air is blown usually thanks to a powerful fan system. The wind tunnel hosts a test model that reproduces the external surfaces of the studied object, usually in a reduced scale. The wind tunnel model is fitted with digital sensors that measure aerodynamic-related characteristics like drag, pressure distribution, lift, and other aerodynamic forces.	(1) *Empirical validation* (2) *Cheaper and faster than track test* (3) *Allows the testing of third-party products* (4) *Standardized and analytical process*	*(a) Output is a digital information*	
3D Printing	The 3D printing process consists in joining or solidifying material (powder grains being fused together or liquid molecules) added layer by layer under computer control, allowing to create three-dimensional objects of almost any shape or geometry. The process requires a computer-aided design (CAD) digital model that will be the base to produce the object, without the need for molds and previous or further manufacturing steps.	(5) *Single step manufacturing system* (6) *Rapid prototyping* (7) *Manufacturing flexibility*	*(b) Based on CAD models* *(c) Allows the creation of a knowledge database*	
FEM	The finite element method (FEM) is a numerical method that supports the solving process of complex engineering problems like structural analyses. Starting from a CAD digital model (dimensions, materials, etc.), the FEM supports engineers with a wide range of digital simulation options that allows to obtain physical characteristics of objects or assemblies like stiffness, strength, bend, indicating the distribution of stresses and displacements, etc. This tool moreover allows visual representations of those characteristics.	(8) *Cheaper and faster design cycle* (9) *Enhances the design knowledge*	*(d) Based on CAD models* *(e) Digital modeling of a physical test*	

CFD	The computational fluid dynamics (CFD) is a numerical method that analyses and solves problems that involve fluid flows. Computational power is used to simulate a free-stream flow of fluid or gases (for example air) and their interaction with surfaces. The process requires a precise CAD digital model (dimensions, surfaces roughness, moving parts, etc.) of the studied object and the atmospheric conditions of the wanted simulation. Results include a wide range of aerodynamic data (drag, pressures, etc.) and visual 3D representations of vortices (mimicking the physical structures in turbulence) and of all the digital data resulting from the simulation.	(10) *Allows showing complete and transparent results without disclosing the process* (11) *Requires CAD data from clients* (13) *Augments the level of awareness of results* (12) *Enhances wind tunnel performance*	*(f) Allows the creation of a knowledge database* *(g) Based on CAD models* *(h) Digital modeling of a physical test*	
Driving Simulator	The driving simulator is a structure composed of a formula car monocoque actuated by pistons that allow the driver to simulate a track test and the engineers to virtually test and develop the whole car. The replication of real car behavior is obtained thanks to the combination of an advanced system of complete track simulation and a sophisticated multi-body model; the driver, as a consequence, experiences a realistic driving experience while driving the simulator. This tool allows engineers to analyze the same data channels of a real car, but with greater precision, given the absence of noise in the signal and of errors during tool calibration. This tool requires the mathematical model of all the major assemblies of a vehicle and it works as a collector of those. The simulator, as a result, allows to test non-existing cars, so combinations of mathematical models that exist only virtually.	(14) *Allows information modularity* (15) *Allows testing of non-existing car combinations* (16) *Allows humans into the virtual simulation loop* (17) *Facilitates clear and shared project targets*	*(i) Allows technological modularity* *(j) Digital modeling of a real situation* *(k) Works as the collector of all digital aspects of the vehicle* *(l) Enables co-simulation*	

[i] Source: Dallara

In addition to these archival sources, we conducted twelve extensive semi-structured interviews with executives of Dallara (including the company CEO) and visited Dallara's headquarters and plants in Italy seven times. In addition, during data collection, we had regular contact with some of those executives and we spent numerous lunch breaks and informal meetings with them, allowing us to gain additional insights.

We started from interviews with higher level executives (CEO, VP Human Resources), to gain a holistic perspective, and subsequently we interviewed technical executives. All the executives we interviewed had been deeply involved in the key phases of the company evolution (such as technology development and strategic decisions) and had, for the most, at least 11 years of experience inside Dallara (so they were in the company before the arrival of the new CEO, and fully experienced the transition period). We prepared a protocol that followed Corbetta (2003) recommendations and served as a guide to the semi-structured interviews leaving open answers and freedom to the interviewees while covering all the crucial themes. We started our interviews (ranging from 35 to 90 minutes each) by requesting informants to describe their work processes internally and externally, before and after the introduction of technology, with a focus on the changes of relationships with other actors in the Dallara's ecosystem.[4]

To triangulate our interviewees' statements, conduct a more complete analysis, and gather external views on the evolution of the company, we identified three key external actors (clients and suppliers) which were involved in the Dallara's ecosystem and we obtained interviews three interviews 35 to 90 minutes each. We based our interviews on the same themes and structure as the ones approached with Dallara's executives, but we prepared a second research protocol that suited the suppliers' and clients' perspective.

To complete and confirm our intuitions, we re-interviewed higher-level executives that corroborated our understandings and gave us access to longitudinal quantitative data about the company. The complete picture of the interviews we gathered is presented in Table 3. Finally, two scholars discussed the different interpretations and discarded information, which seemed unreliable or not supported by empirical evidence.

[4] The complete set of questions is available from the authors upon request.

TABLE 3
Semi-structured interviews

Name	Role	Duration (min)
Andrea Pontremoli	CEO at Dallara	150
Filippo Di Gregorio	Human Resources and Legal Director at Dallara	220
Alessandro Moroni	Testing Manager at Dallara	40
Mireno Rossi	Head of Electronics and Software Development at Dallara	100
Andrea Vecchi	Plant Manager & former Wind Tunnel Manager at Dallara	37
Maria Vittoria Manfredini	Logistics Manager at Dallara	73
Andrea Bernardi	Project Manager at Dallara	33
Simona Invernizzi	CFD-R&D Manager at Dallara	61
Luca Vescovi	R&D Composites Manager at Dallara	45
Fabrizio Arbucci	Chief Information Officer at Dallara	80
Alessandro Berzolla	Chief Operations Officer at Dallara	60
Enrico Giuliani	Program Management Officer at Dallara	46
Stephen Mahon	Deputy Head of Aerodynamics at Haas F1 Team	92
Dario Marrafuschi	Head of R&D Motorsport at Pirelli	35
Nicola Bedin	Technical Account Manager at Sinthera	45
	Total	**1117**

3.2 Data Analysis and Coding

The collected data allowed us to create a robust chronology of events related to Dallara, thus reconstructing the history and the timeline (see Table 4 below), especially since the year 2000. Moreover, we analyzed our data through an “inductive” process that supported us in bringing “qualitative rigor” to the analysis (Gioia, Corley, & Hamilton, 2013: 20-21). This required to examine explanations in light of empirical evidence, while inferring theoretically relevant constructs.

Starting from our semi-structured interviews as the main source, as suggested by Gioia et al. (2013), we engaged in a fine-grained and intensive reading of the data (Strauss & Corbin, 1990) that resulted in a large dataset of terms and codes. We then iteratively consolidated redundancies and, following the steps of the aforementioned methodology, we collapsed our codes into first-order categories (Gioia et al., 2013). Throughout the entire process, we frequently shifted back to our archival data and notes from our observations to make sure that no information had been omitted or misinterpreted.

In our second step, we compared our first-order categories with the classified data from prior research and we started structuring them into second-order themes, and higher-level aggregate dimensions (Gioia et al., 2013). During this process, we progressed through a more theory-driven explanation of the first-order codes. To obtain a relevant interpretation of our data we iterated this step several times making extensive use of notes and personal observations, going back-and-forth between emergent data, themes and concepts. Subsequently, we built our data structure that represents how we progressed from raw data to terms and themes, providing a visual representation of this process and a testable theoretical model of relation between digital transformation, decoupling and higher order elements (aggregate dimensions).

4. From carbon-fiber to fiber-optics: the digitization of Dallara

4.1 First period: pre-digital transformation

In 1972, after an 11 years' career across all the major car racing manufacturers, Giampaolo Dallara (born in Milan in 1936) took the decision to establish his own company, Dallara Automobili SpA, near Parma, Italy. Giampaolo Dallara had graduated in aeronautical engineering at the Milan's Polytechnic University and had worked for the some of the world's most renowned and glamorous car racing manufacturers (Ferrari, Maserati, Lamborghini, De Tomaso) where he had designed iconic vehicles like the Lamborghini "Miura" and the first F1 chassis for the Williams F1 Racing Team. In short time he had emerged as one best Italian designers for car aerodynamics, handling, and race chassis engineering. Dallara founded his company with the sole objective of focusing on the (prototype) racing cars (i.e., originally excluding road cars of any sort). Giampaolo Dallara leveraged his engineering skills and focused on becoming a third part supplier and partner for high-performance car companies or racing teams. Specifically, he limited his activity to a set of processes and services such as concept design, aerodynamics, vehicle dynamics, prototype manufacturing, product manufacturing, and track testing. Dallara never produced engines, and back at the time did not supplied mechanical or electric parts. He had not originally envisioned, nor planned, to become an OEM and build cars with his own brand, to avoid direct competition with his own customers.

Dallara started moving the first steps in the racing industry (which at the time was very manufacturing-focused) by developing prototypes and components for third parties (mostly racing teams and OEMs involved in motorsport)—the first prototype, the SP1000, was released in 1972.

> *"I had already got the [racing] virus, Lamborghini, Maserati, and De Tomaso could not race […] so I decided to start racing on my own, with the first 1972 prototype." (Online conference of Giampaolo Dallara, Dallara Automobili Founder).*

This prototype was rapidly followed by few other projects (Dallara x1/9, Wolf Dallara CAN AM) that opened the door to the 1978 Dallara debut in Formula 3. The Dallara F378, the first F3 car designed by Dallara brought important innovations to the existing architecture such as the first manufactured structural carbon fiber frame in racing cars. This solution established the company among the top innovators in the industry and a point of reference for carbon-fiber manufacturing. The advantages of cars made out of this material (which is lighter, stiffer, and safer for the driver) were directly translated in the first victory in the F3 Italian championship in 1980. Since the 1980s the company developed at a steady pace: it introduced the first wind tunnel in Italy with a moving belt for 25% scale models in 1984, it participated to Formula 1 (F1) with the "Scuderia Italia" team between 1988 and 1992, and it started expanding its geographic reach outside of Italy, competing in international championships such as the UK Formula 3 (F3) series or the IndyCar Series in the US.

> *"It has been a continuously growing path, […] then we passed through the Formula 1 experience with Scuderia Italia, the collaboration with Ferrari with the Ferrari 333 allowed us to be more and more known in the sector and then the Indianapolis activity enabled us to be recognized globally." (Online interview of Giampaolo Dallara, Dallara Automobili Founder).*

By 2000 the company was globally at the top of car racing. Racing teams using Dallara cars and components had won every major title in F3, as well as races in GP2, IndyCar, and GT Series; but at the same time, Dallara kept pursuing growth and innovation (new headquarters in 1991 and new and improved wind tunnel in 1995). During the first years of the new century, the company advanced its competitive position, becoming the sole chassis supplier for GP2 in 2005, and for the IndyCar and GP3 series soon after.

Since the last years of the 1990s, Dallara started, in parallel to its racing activity, to provide specialized engineering services to road car manufacturers focusing on high-performance vehicles. From the Ferrari F50 GTI in 1996 and the Audi TT DTM in 2000, the company started leveraging its competencies into specific car manufacturers' niche projects. This led to the participation in some road car projects for high-performance vehicles such as the 2001 Bugatti Veyron, the 2004 Maserati MC12, and (by 2007) the KTM X-Bow, and the Alfa Romeo 8C.

By 2007 Dallara employed 107 people, held no debts, recorded revenues in excess of €25 million, net profit margins of 12-15%, and it was globally dominating the racing market as third part supplier (F3, GP2, and IndyCar). From a strategic standpoint, the focus had always been on racing, leveraging its know-how only to participate in the aforementioned specific projects with and for OEMs and racing teams. In addition, it had avoided competing with Giugiaro, Bertone, or Pininfarina in the "design" segment, or with Lotus, McLaren, and Ferrari in producing their own luxury sports cars.

Despite Dallara's primary market position was remarkable, it also presented increasingly worrying issues. As it had almost become monopolist for third-party manufacturing in all motorsport series (having saturated all racing categories but F1), therefore had started facing the actual risk of losing market share. The company presented positive market and financial performance, but the current business model had started showing its future growth limits, especially considering the structure of the industry (fast-paced technological cycles driven by innovations and changes in racing regulations) that was causing unbalanced revenue streams with steep peaks and troughs (Leleux, Jelassi, Ravano, & Seletti, 2016: 7).

The motor racing sector had always been characterized by the FIA almost yearly changes in regulations aimed to enhance safety and reduce costs, that resulted in frequent modifications to the product architecture or to core components.

> *"In those years the peaks [of revenues] were occurring, so what happened was that it was a yo-yo company, it started, you could invest, but then it was decreasing. It was like that. […] The racing is the one [sector] that gives you the most ups and downs." (Source: interview with Alessandro Berzolla, COO at Dallara).*

Such frequent changes in the conditions of the market were, and are nowadays, the cause of costs and strong uncertainty and dependence for an external and independent actor, such a supplier. Moreover, at the beginning of the years the 2000s, in the automotive sector where Dallara was participating in other projects with car manufacturers, core companies were striving to keep their hierarchical control over peripheral suppliers.[5] Minor actors (third-party part suppliers and carbon-fiber producers) were more and more perceived as suppliers of commodities and were progressively marginalized by core companies, resulting in reduced profit margins caused by tight cost reductions in the supply contracts imposed by powerful manufacturers.

Giampaolo Dallara understood the upcoming threat and inferred from those elements that the company was struggling to fully exploit its innovation potential, and thus failing to maximize market performance. A strategic turnaround was needed, and diversification in complementary markets seemed the most logical path to pursue.

[5] See for example insightful cases in Jacobides, M. G., MacDuffie, J. P., & Tae, C. J. 2016. Agency, structure, and the dominance of OEMs: Change and stability in the automotive sector. ***Strategic Management Journal***, 37(9): 1942-1967.

TABLE 4
Timeline of Dallara Automobili (1972-2018)

Phase	Year	Key Events
Pre-Digital	1972	Dallara Automobili established
	1978	First F3 car
	1980	First F3 Victory (Italian Championship)
	1984	First wind tunnel with moving belt in Italy (25% of real size)
	1988	F1 car Scuderia Italia
	1991	New Dallara headquarters
	1993	F393 and first F3 successes
	1995	New wind tunnel (50% of real size)
	1996	Ferrari F50 GT1 project
	1998	First victory in the Indy car (and first Indy Car)
	1999	First CAD software introduced
	2000	Audi TT DTM
	2001	Bugatti Veyron (chassis and aerodynamics studies and carbon fiber monocoques)
		3D Printing introduction
	2002	Formula Super Nissan
	2004	Maserati MC12 project
	2005	Exclusive supply of GP2 cars
	2006	First CFD and FEM simulations introduced
	2007	KTM X-Bow project
Digital	2007	Pontremoli joined Dallara Automobili as CEO and Investor
		IT Hardware and Software upgrade
		Custom developed enterprise software: BOM Manager
	2008	IT department starts managing all the IS mechanisms of the company
		New Wind Tunnel (60% of real size)
		BOM manager upgrade (managing and tracking all the company processes)
		CFD, FEM, 3D printing become key aspects in the wind tunnel aerodynamic process
		Introduction of knowledge management and internal communication systems
		Exclusive supply of IndyCar series

2009	R&D CFD department creation; Start of driving simulator project
	Exclusive supply of GP3
2010	Creation of the driving simulator
2011	New GP2 cars generation
2012	Dallara IndyCar factory USA (with twin racing simulator)
	Dallara Stradale company
	IT upgrade to grant intercompany IS services as a provider
2013	New Generation of GP3 cars
2014	Dallara Super Formula
	F1 Haas partnership
	IS services provided for external clients
2015	Renault RS01
	Participation in the Cisco's Industry 4.0 Club
2016	IT network and security upgrade
	Construction of a new R&D center (for industrialization of composites)
2017	Introduction of videoconference technology internally and with clients and suppliers
	Motorsport University MUNER created in partnership with other manufacturers
	Dallara Stradale launch
2018	Dallara Academy opening
	Enterprise software iOS App
	Smart tracking project for materials

4.2 Second period: digital transformation

The entrepreneur decided to employ a new, possibly younger CEO to tackle the burgeoning market changes. Andrea Pontremoli, at the time president and CEO of IBM Italy, appeared to Giampaolo Dallara as the ideal person to lead a strategic turnaround and ultimately a potential candidate to become his successors. Giampaolo Dallara and Andrea Pontremoli were sharing both similar passion for motorsport and similar cultural background (as both were from the same geographical area in the Parma province). In October 2007, Andrea Pontremoli resigned from IBM and decided to join the Dallara Automobili as CEO and a minority investor. The new leadership brought more attention to the manufacturing process (introducing "lean design" and "lean manufacturing") but mostly fully embraced digital transformation as a source of competitive advantage when combined with Dallara's technical capabilities.

Pontremoli immediately enhanced the IT infrastructure by introducing supercomputing power that allowed computational fluid dynamics (CFD) simulations and finite element method (FEM) simulations, to become intensively part of the designing process, thus reducing process time and costs. This improvement directly translated in an increase of the 3D printing activity as the more complex shapes that were obtained from the CFD simulations had to be validated in the new wind tunnel, adopting models up to 60% the real size of the vehicles.

In parallel to those improvements, the new CEO gave a central position to the IT department, that until 2007 was considered "no more than an internal help desk."[6] Pontremoli did so also by encouraging the internal development of "BOM Manager," a custom developed enterprise software, that supported the alignment and the standardization of systems and procedures, serving moreover as a knowledge management tool.[7]

> *"Of all the investments aimed at improving computational power, data transmission, infrastructure, and others, I recall only those after the arrival of the new CEO. Before, yes, it was relevant, but not one of the activities considered as the most relevant in the company. Since when he arrived, the IT, the digital, have become a core part of the company." (Source: interview with Luca Vescovi, R&D Composites Manager at Dallara).*

Ditto, infrastructure investments and new organizational plans made processes faster and more competitive on the market thanks to the inclusion of CFD, FEM and 3D printing on the active design process, allowing faster internal design and competitive external consulting services. Results were remarkable since the first year: revenues increased from €30.7 million in 2007 to €57.9 million in 2008, with a significant shift towards external consulting activities, which grew from 5% of the revenues in 2007 to 15% of the revenues in 2008—thus opening the company to a new market. The change was followed by an increase in the personnel, from 107 in 2007 to 139 in 2008, with almost all new units involved in IT related projects.

The innovation trend persisted subsequently to the 2007 FIA F1 new testing restrictions.[8] In

[6] Source: interview with Chief Information Officer at Dallara.
[7] The enterprise software was developed, maintained and evolved through a close partnership with a local software house that assigned developers to the project allowing them to work permanently inside the Dallara headquarters
[8] To force teams to contain costs the FIA imposed its approval upon full scale aerodynamic tests, reducing them to a max of 5 days/year and limited the model scale tests to 15 runs per 8-hour day on 5 days per week with a 60% scale model.

this circumstance, Ferrari, which (as all other F1 teams) was forbidden to run in-season track tests for its cars and drivers, convinced Dallara to partner in building a groundbreaking, professional driving simulator. By leveraging a mix of digital data collected from the real world and simulated mathematics, the simulator would create a virtual reality where pilots could practice, while engineers could test specific components, by using mathematical models before physical prototypes. This tool enabled testing components whether existing or not in a given car setting and to experiment with handling setups for different tracks and weather conditions (Leleux et al., 2016). The simulator, moreover, in order to perform an effective activity, required all the vehicle information do be digitalized and present in the complete mathematical model, thus encouraging digitalization and requiring uniformity in the way information was generated and exchanged.

> *"The simulator is the collector of the sensitive information of a car: it needs to have aerodynamic data, suspension layout, engine data etc. […] Those data give the inputs and are the recipients of the outputs." (Source: interview with Alessandro Moroni, Testing Manager at Dallara).*

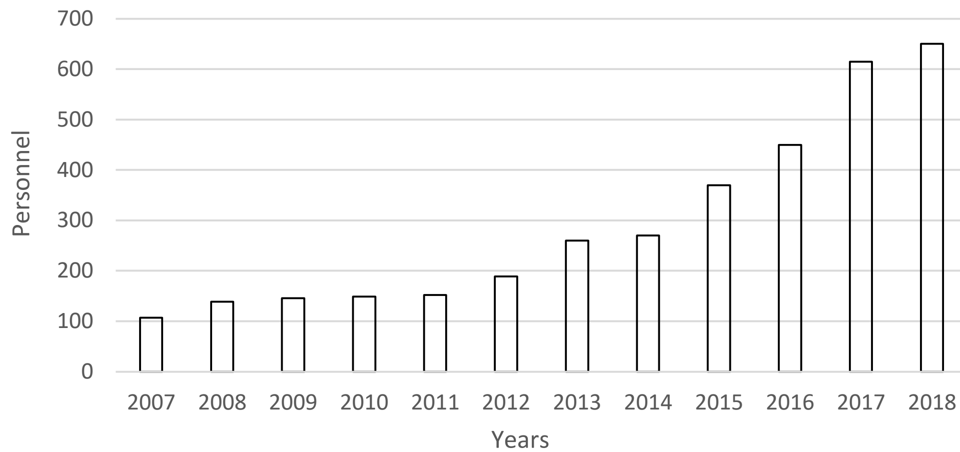
This enhancement of the coordination between departments brought unambiguous benefits to the company. The introduction of the simulator allowed the shrinking of the time-to-market for a new vehicle from three years to nine months, allowing the company to be more competitive and to withstand a higher number of parallel projects, that increased from 10 in 2007 to around 20 in 2011 (when the simulator was completed and completely operative) granting further growth possibilities. Before the simulator was completed, more than 50% of the company's workforce was involved in producing prototypes (65 out of 107 in 2007). This ratio fell dramatically over the following years focusing on vehicle design and (virtual) testing, the personnel reached 152 units in 2011, leaving the production personnel to 65 units.[9] Through the €10 million simulator Dallara started accumulating digital data and mathematical models about cars, components, and tracks that expanded the knowledge of the company; as a result, a new wide set of business opportunities emerged.

> *"With the simulator the basic aim was to offer a service to the client, we have invented, built, set up a hierarchy, a relationship with the client so a number of services also linked to its satisfaction, gathering its feedbacks, being able to improve its loyalty, to accommodate him and its requests, all sort of things that before were*

[9] Along with the digital transformation, Pontremoli contributed to the reinforce the local industrial and social network, inducing investments in educational programs and event sponsorship, to build a stronger "Italian Motor Valley" cluster.

not existing." (Source: interview with Alessandro Moroni, Testing Manager at Dallara).

FIGURE 1 [10]
Dallara's Personnel



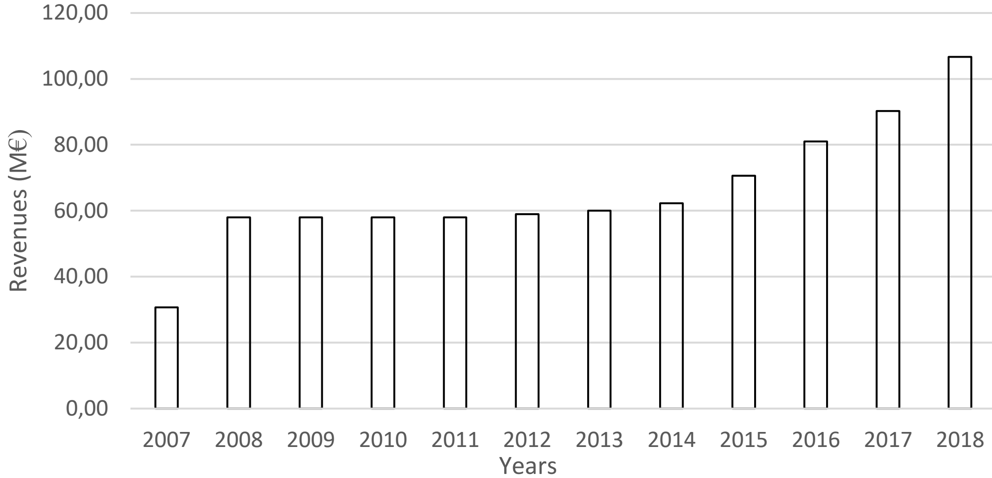
The substantial growth of the company between 2007 and 2008 had shown a slowdown in the three following years, the company needed further investments to unleash its full potential. From 2009 to 2011 the revenues of the company remained constant at €58 million, up until when the simulator was completed and fully operative. With the simulator, the company not only improved substantially its design process, but most importantly increased even further its external consulting offer, making it more complete, more tailored on clients, and more prone to capture commercial opportunities.

> *"We started the consulting activity in the automotive sector with Bugatti, of the Volkswagen group, but we continued with Lamborghini, Ferrari, Audi, and Maserati." (Online interview of Giampaolo Dallara, Dallara Automobili Founder).*

After 2011 Dallara's revenues started growing again after the slowdown, pushed by an increase of the consulting activity that in 2012 counted for 35% of the revenues, they became a crucial part of the business, as displayed in Figure 2.

[10] Source: Company's databases

FIGURE 2[11]
Dallara's Revenues



In 2012 a new 9,500 m2 factory was opened in Indiana (USA) as a joint venture between Dallara and the State-funded IndyCar Experience. The plant was dedicated to manufacturing facilities and an "edutainment" center for visitors (Leleux et al., 2016: 9). The new technologies opened opportunities for growing consulting activities for car manufacturers or racing teams outside Italy. Consequently, a twin simulator to the Italian one was installed within the new American factory. From the opening of this new factory, the number of employees in 2012 was more than doubled from 2007 figures and the company faced the need to newly upgrade its information systems architecture. To fulfill the increased dimension and the knowledge management and knowledge sharing needs among the companies, the network infrastructure was strengthened, and the choice was made to maintain a central provider in the Italian headquarter that became the intercompany provider of all the IT services. Providing "external" services obligated to establish security protocols but enabled the possibility to provide IT services to clients and supplier as an additional line of business.[12]

The following years saw Dallara increasing even further its racing presence becoming the supplier of all new generation GP3 cars in 2013, Super Formula cars in 2014, and Formula Electric cars, starting with the first 2014/2015 season of this new series. The company still recognized the importance of innovation, both on the technical side, with the opening of a new R&D center for composites, and on the IS side, participating to multisector initiatives like the Industry 4.0 Club

[11] Source: Company's databases
[12] The FIA for example accessed to Dallara's database to check the authenticity and the regularity of vehicles' parts

with Cisco.

> *"We spent more or less ten million [euros] in R&D every year and seven million [euros] on CAPEX. That is a big number compared to our sales. We have 23, 24 percent of our revenues that is devoted to investments. It is a lot." (Source: online conference of Andrea Pontremoli, CEO at Dallara).*

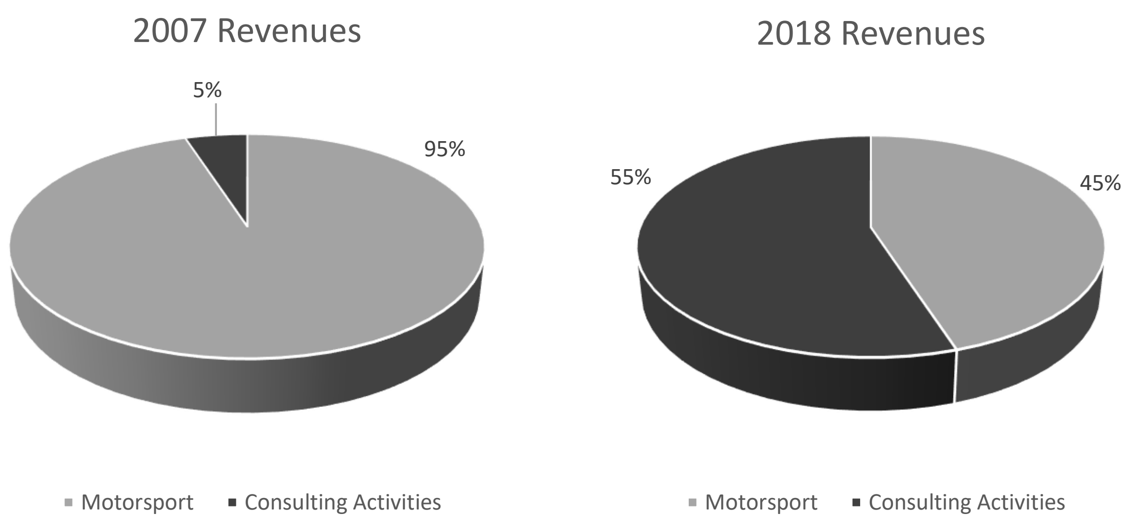
Moreover, in 2016, Dallara became the main supplier of the newborn F1 Haas Racing Team for chassis, carbon fiber manufacturing and IS services, stating its return to the top series of motorsport competitions. By 2016 Dallara Automobili employed over 380 employees and its revenues approached €70 million. The constantly increasing dimension was regularly followed by upgrades of the IT network and by investments that were intended to contain the risks of such growth, like the introduction of videoconference technology between departments, with clients and suppliers. The year 2017 saw the company participating as main actor to a large production car project for Bugatti, regarding its new model "Chiron", a very important milestone for Dallara. However, as the reader should have realized, the path that led to being chosen for such complete and large projects was not a simple one.

> *"We do consultancy for companies that produce racing cars, […] like Porsche […], Audi, and companies that produce supercars. You can see here Alfa Romeo 8C, 4C, we have done Lamborghini Huracan, Aventador, LaFerrari […], Porsche 918. But the most important for us has been the first, Bugatti Veyron. […] And two years ago they [Bugatti] have asked us to develop the new one, […] Bugatti Chiron." (Source: online conference of Andrea Pontremoli, CEO at Dallara).*

The year 2017 also welcomed the launch of Dallara's own road legal production car, the "Dallara Stradale," that will ultimately be produced in a limited series of 600 units. This vehicle is not supposed to be a competitor to any product of Dallara's clients, but it represents an explicit showcase of the company's core competencies: vehicle dynamics, aerodynamics, and carbon fiber manufacturing.

The constant expansion of the external consulting offer and the maintenance of state-of-the-art processes allowed Dallara to expand its businesses (especially increasing its consulting activity) accepting growing numbers of parallel projects that enabled strong growth rates, reaching 30 parallel projects and €90 million revenues in 2017, of which 45% in consulting activities. In 2018 Dallara embraced new innovation challenges, starting to develop an iOS app for their enterprise software and setting up a smart tracking project for materials in collaboration with Cisco. By the end of 2018, the number of employees raised to 650 (less than 20% in production) and the company surpassed €106 million in revenues, half of which comes from its consulting activity; since 2007 it had increased by more than six times the number of employees and more than quadrupled its sales, increasing its consulting activity from 5% to 55% of their revenues, as displayed in Figure 3.

FIGURE 3 [13]
Dallara's revenues structure



[13] Source: Company database

5. The decoupling of supply network and knowledge network: a process view

The empirical evidence was progressively coded into first-order concepts, second-order themes, and ultimately aggregate dimension, by following common protocols of inductive research (Gioia et al., 2013). Table 5 presents the results of our process subsequently to the coding phase, whose results are displayed in Table A1 (that can be found in the annex section).

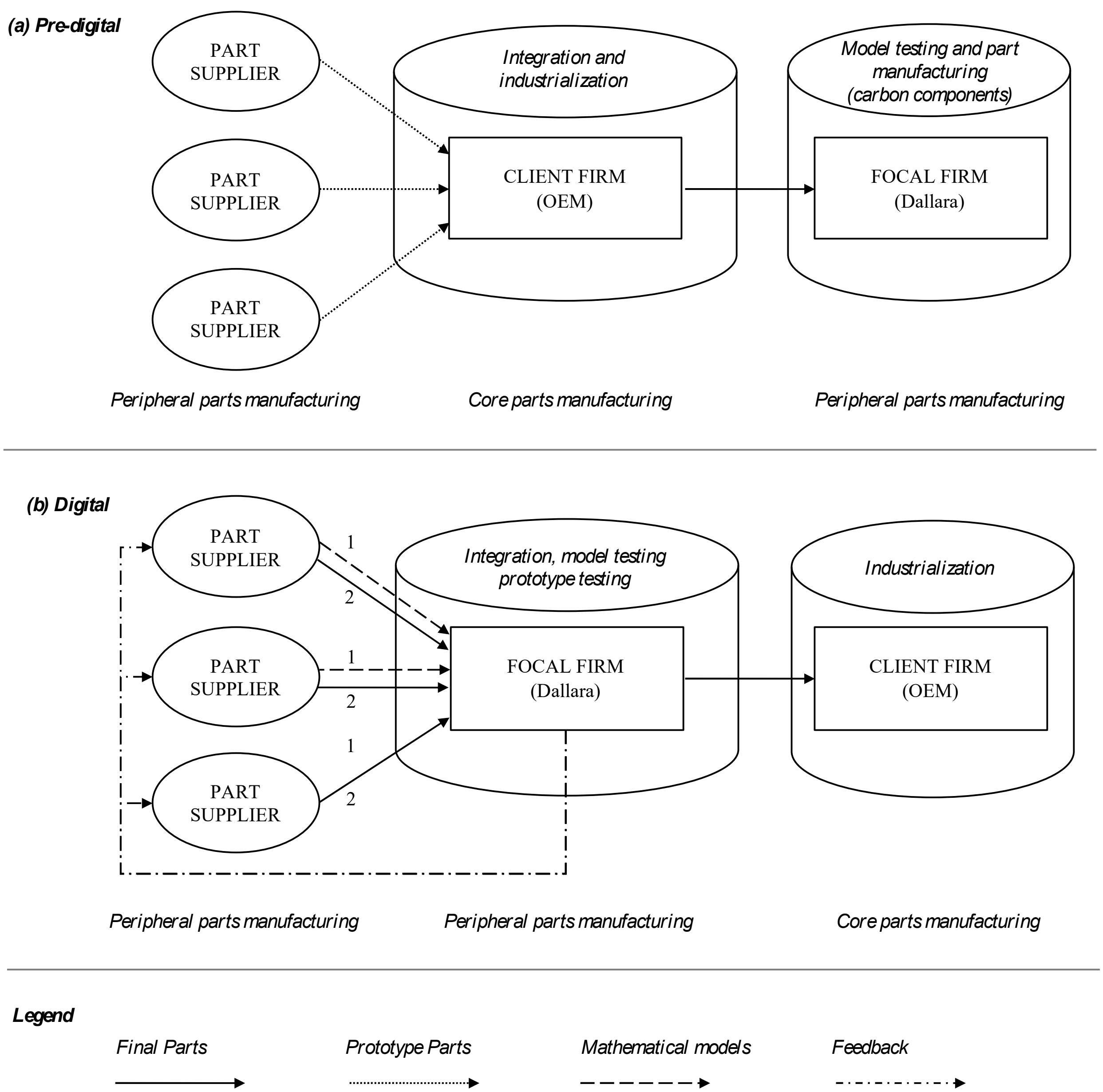
Analyzing the results, we noticed that the obtained second-order themes were closely recalling the established metrics used in the literature to measure ecosystems (Jacobides et al., 2018), specifically the second-order concepts pointed to: (1) technological modularity, (2) information modularity, (3) interfaces, (4) standards and rules, (5) co-specialization, (6) knowledge assets and (7) absorptive capacity. As mentioned by (Jacobides et al., 2018) those metrics are employed to evaluate the complementarity across actors (generic, unique, or supermodular), both in production (i.e., for the manufacturers) and in consumption (i.e., for the users/consumers). In our specific case, dealing with a manufacturing company with no direct contact with final consumers, we decided to exclusively focus on the metrics and mechanisms pointing to complementarities in production. We further noted how those themes and metrics, at a higher aggregate level, identified a set of general capabilities— (1) product modularization, (2) relational orchestration, and (3) technological learning—that act as higher-order mechanisms.

TABLE 5
Digital transformation enhancing mechanisms

First-order concepts	Second-order themes	Aggregate dimensions
(1) **Database enabling service modularity**: database technology enables different services to be provided to different actors internally and externally from the same source.	Technological Modularity	Product Modularization
(2) **Software modularity**: commercial and internally developed software can be combined with flexibility and in a reasonable time, to work together in providing more complex functionalities.		
(3) **Hardware and network modular expansion**: hardware and physical network can be upgraded or extended in different timeframes in a modular way, a new server unit or a new network can be added without the need of changing the existing.		
(4) **Virtualization of physical tests**: the technicians use virtual, digital environments to combine the mathematics of the different components and perform virtual tests of the product.	Information Modularity	
(5) **Internal and external data integration**: all data from different sources (clients, suppliers, internal) can be integrated and jointly processed to obtain further information.		
(6) **Information hiding**: modularity of information allows each actor to share data (e.g. mathematical models) without interfering with industrial secrecy of each party encouraging at the same time transparency.		
(7) **Process generation**: software architects make sure that digital processes are specific enough to suit to their company's needs while taking into account that they should be generic enough to combine with other actors (suppliers, clients, and partners).	Interfaces	
(8) **Common protocols**: new shared protocols are easy to establish and fast to implement between internal or external actors.		
(9) **Full digitalization at every stage of the company**: the digitalization path should be adopted at every stage of the process (from manufacturing to logistics) to allow an efficient combination and a better performance.		
(10) **Process integration**: the digital integration of the processes acts as a catalyst towards the establishment of common and shared standards, supporting the emerging of habits and coding languages.	Standards and Rules	Relational Orchestration
(11) **New communication interaction**: new technologies enable improved ways of interactions that respect common standards and are compatible among them, allowing different actors to interact shortening distances.		
(12) **Market pre-adaptation**: each actor searches constantly the best methodology that allows works or processes to improve.		
(13) **Shared system upgrade**: different actors keep up with industry emergent best practices and systems in a coherent process.	Co-specialization	
(14) **Mutual customization**: actors internally and externally customize and adapt their outputs or their processes to obtain a best-fit.		
(15) **Co-design**: projects are approached as a joint collaboration which lead to the creation of new project-specific solutions.		
(16) **Complementary assets**: different actors deploy their competencies and infrastructures to complement other actors' competencies through long-term, value-driven, transparent collaborations.		
(17) **Information sharing**: knowledge management systems enhance knowledge retention and diffusion; digital tools allowed faster communication, massive exchange of data and more transparent data sharing.	Knowledge assets	Technological Learning
(18) **Reduction of causal ambiguity**: virtual tests allow high replicability of conditions and exponential testing providing increased and superior knowledge on the effect of every innovation on the overall product performance.		
(19) **Selection awareness**: digital simulations enable to understand the reasons behind the discard or the choice of design versions.		
(20) **Increased understanding**: the more the company understands products, the more it is able to develop knowledge on them.	Absorptive Capacity	
(21) **Knowledge application**: the aim of each internal or external collaborative project is to deploy the possessed knowledge in order to develop and obtain further know-how.		

It can therefore be seen, in a process view of the Dallara case, how these capabilities were instrumental in shifting the structure of the relationship among actors, and how the ecosystem metrics were affected in this process, thus pointing to a series of noteworthy underlying mechanisms. Figure 4 (a and b) presents a simplified representation of the relational shifts in the "pre-digital" and the "digital" phases within the ecosystem.

FIGURE 4
Dallara's ecosystem change: a process view



Process in the pre-digital phase

Figure 4a provides a simplified representation of the supply network prior to Dallara's digital transformation. In this period the sector was centered on the OEMs, that controlled and enacted the product design, its physical integration (from prototyping), and its industrialization. In these circumstances, OEMs held substantial power over part suppliers, which were only required to manufacture physical components, later integrated by the OEM itself. Suppliers were led in at the periphery supply network, which also corresponded to a peripheral position of the knowledge network, focused on the one single task: the specialized manufacturing of the component(s). In this period, Dallara—despite working for most motorsport championships—was relegated to a peripheral and very limited position in both the supply and knowledge network. OEMs would hire Dallara for prototype static testing (i.e., with machines) or dynamic testing (i.e. on track) of car prototypes. As for the manufacturing, Dallara was merely supplying carbon components, one of the firm's key competencies.

> *"What happened was making, for example, torque tests on clients' cassis. […] They ask you to test it, but it was a spot test, you were doing it once for an external client, and it ended there." (Source: interview with Alessandro Moroni, Testing Manager at Dallara).*

As it can be inferred, pre-digital relationships among actors revolved around physical products and components. Each actor exchanged physical artifacts, and prototypes had to be manufactured to test compatibility and characteristics, causing high production costs and considerable time consumption. In addition, exchanging physical products for integration purposes opened parties to the risk of early-stage component revealing, and thus opportunities for opportunistic behaviors in particular through reverse engineering. All those aspects are direct result of limited technological modularity offered by physical objects. The physical constraint, moreover, limited the manufacturing possibilities (especially for component prototyping), leading to tests with minimum viable products, which corresponded to high causal ambiguity between specific design solutions and product performance. As a matter of facts, testing physical prototypes at early stages with insufficiently replicable tests proved to be challenging. The physical component forces executives and technicians to deal with physical interfaces. Further, the increasing complexity of establishing common protocols among parts, limits co-design and inter-firm interaction. Product integration of physical prototyping also requires information sharing, which in the pre-digital phase needed to resolve the delicate tradeoff between information disclosure and strategic hiding. If on the one hand the former improves coordination and integration, on the other hand, the latter increases possibilities of knowledge leakage and opportunistic behaviors. These phenomena resulted into difficulties of an extensive modularization of the prototypes, limited, insufficient testing, and therefore a mediocre final product performance. In the same vein, co-specialization was riskier and more expensive (e.g., production or testing machinery), with difficulty to establish processes and standards within and between firms in the supply network. This inhibited the application of automation and imposed severe versioning constraints that negatively affected the experimentation process, thus generating a more superficial understanding of products, their architecture, and functioning.

> *"From the OEM point of view, you can't tell the supplier how you want to do the vehicle, […] you can't tell everything you know. […] There was a lack of communication because in addition, you were testing with an early stage prototype that was far from the final target one, so testing on something that is not the final product means you are not taking the optimal developing path." (Source: interview with Dario Marrafuschi, Head of R&D Motorsport at Pirelli).*

Overall it emerges how the separation of testing (performed by Dallara) and technological integration (which together with the original product design was developed by the OEMs), not only negatively affected Dallara position and knowledge absorption, but provided an inferior outcome for the entire supply network. In addition, the lack of tools that enabled an established knowledge management system was causing data to reside in organizational memories and in few individuals, with frequent loss and inefficiencies in case of key individuals moving to a different company or industry, or retiring.

Process in the digital phase

Figure 4b provides a simplified representation of the process in the digital phase, corresponding to the arrival of the new CEO Andrea Pontremoli. Here Dallara increased its performance by engaging with a process of digital transformation and became more central in the knowledge network thanks to product modularization, relational orchestration, and technological learning. Still, this did not modify its position within the supply network, as its manufacturing activity remained focused on peripheral parts (i.e., manufacturing of carbon components), and less core within Dallara's overall activity portfolio and key competencies. As displayed in Figure 4b, the company engages with OEMs for final product specifications, but then it coordinates the suppliers, undertaking an integration role that was previously in the OEMs' hands.

> *"The clients [OEMs] give us a project target, they tell us where they want to realize, in how much time, etc. […] We lead the development, we manage it and we say –now we arrived here, we do this or that- and they are updated on the various steps of the development we are doing." (Source: interview with Simona Invernizzi, CFD-R&D Manager at Dallara).*

During this process, the OEM, which remains as the client firm, is kept in the loop for higher-level decisions and is informed of developments, but is distant from the suppliers and its interaction is mediated through Dallara.

> *"The aim of the simulator […] is that of having, way before the physical car, a virtual car that can be driven to test. […] It is the collector of the sensitive information of the car: it requires the aerodynamic data, the project, the suspension layout etc." (Source: interview with Alessandro Moroni, Testing Manager at Dallara).*

The differences from the pre-digital case start at the exchange between Dallara and part suppliers: the parties exchange physical products only at a very late stage of the process, whereas the majority of it occurs digitally through digital tests, simulations, and prototyping. In this system, Dallara acts as the "funnel" and prime repository of all the digital data related to the product, has a virtual integration role, provides testing, designs and provides feedback and guidance to the ecosystem towards the subsequent digital iterations. By doing so, the company becomes more central in the knowledge network, while keeping its peripheral position in the manufacturing network and leaving the industrialization process to OEMs. As already stated, only the last phase sees Dallara receiving physical prototypes from suppliers, but this is adopted exclusively as final empirical confirmation of virtual tests, which are done before the delivery of a final prototype to OEMs that subsequently proceeds with the product industrialization.

> *"We confine ourselves in the physical realization of only a few prototypes of our vehicles, the mass production is outsourced to external suppliers, otherwise Dallara would need at least 700 workers more than it has now. […] Strategically the company decided to pursue this direction, we don't want to become mass producers." (Source: interview with Filippo di Gregorio, Human Resources and Legal Director at Dallara).*

The digital transformation brought by the adoption and efficient integration of digital tools into the process brought unambiguous benefits to the modularity of technology and information. The factual results were a cost-effective development, ditching expensive and time consuming physical prototypes for fast and flexible digital prototyping, supported by technologies such as 3D printing. Dallara and suppliers started exchanging digital models and end-project target data, allowing virtual tests with complete products, lower causal ambiguity, granted by the high replicability of conditions enabled by virtual testing, and potential for restricted data revealing and information hiding. The encryption characteristics of digital data leave fewer risks of reverse engineering from potential competitors, thus expanding information modularity. Similar effects were obtained from co-simulation arrangements that allowed all parties to put at stake their entire knowledge, thus encouraging integration without interfering with industrial secrecy.

The pursuing of the digital transformation path brought improvements and gains at every level of the interaction between different actors: protocols and standards became easier to establish and digital co-specialization became less expensive and safer, as a result of the unusual neutral positioning of Dallara in the eyes of the other stakeholders in the network. Automation, moreover, supported all the digital processes, leaving less space for errors and more time for high added value activities such as experimentation of new product versions.

> *"If 20 years ago it was all done by hand, now it is all automated. [..] Well, we programmed, us, in house, a number of Python programs that automatically rework software outputs and already layout PDFs rather than reports, rather than even sending emails so that you can already see the results, and you can know remotely how the case went." (Source: interview with Simona Invernizzi, CFD-R&D Manager at Dallara).*

From the knowledge standpoint, management systems supported the inter-firm processes, to lower the risks of knowledge loss, and absorptive capacity improved as a result of the different network arrangements of that granted improved learning economies to Dallara. During this change, interfaces gained in importance, thus becoming the focal point between the parties, especially considering the knowledge funnel position of Dallara, whose digital integration processes rely on effective and efficient interfaces.

All in all, we have explored how, by engaging with a radical digital transformation process, Dallara moved its position in the supply network, occupying a previously non-existent role in the sector. This allowed the firm to be able to become central in the knowledge network, still, while maintaining a peripheral position in the manufacturing network—as a matter of fact Dallara executives underlined at multiple stages their firm's defocusing from mere carbon fiber part production. Dallara, in fact, made its manufacturing abilities less core in its activities and in its competence portfolio, while shifting to become a true knowledge company.

> *"We are not anymore only a racing car producer, but […] half of our business is consultancy. […] We moved from a manufacturing company to an engineering company, and now we are a knowledge company. […] Now we sell the mathematical models of our cars, and then the manufacturing of the car could be done by anybody else." (Source: online conference of Andrea Pontremoli, CEO at Dallara).*

Ultimately Table 6 spells out a comparison of the underlying mechanisms of complementarity in production in Dallara's ecosystem within the pre-digital and digital phase.

TABLE 6
Mechanisms: Complementarity in production in Dallara's ecosystem

Metrics	Pre-digital	Digital
Technological modularity	**Efficiency**: - **High production costs** (molds production, raw materials, prototypes, integration of physical components). - **Time consumption** (production, shipping, and integration). - **Component revealing** (physical disclosure of components).	**Efficiency**: - **Cost-effective development** (cheaper programming, development, and use of digital tools, compared to physical). - **Time reduction** (development of digital tools is faster than the physical one). - **Digital data revealing and component hiding** (digital files could be encrypted and be virtually integrated without revealing their overall structure).
	Efficacy: - **Manufacturing technical limitations** (lower precision of results and physical replicability of components). - **Inferior or no computational power**. - **Physical test with minimum viable products** (due to early prototyping stages or strategic decisions). - **High causal ambiguity** (limited replicability of physical tests).	**Efficacy**: - **Manufacturing flexibility** (CAD models' manufacturing grants higher flexibility and precisions). - **Superior computational power.** - **Virtual tests with complete products** (virtual tests based on shared end projects targets). - **Lower causal ambiguity** (virtual tests allow exponential tests and high replicability of conditions).

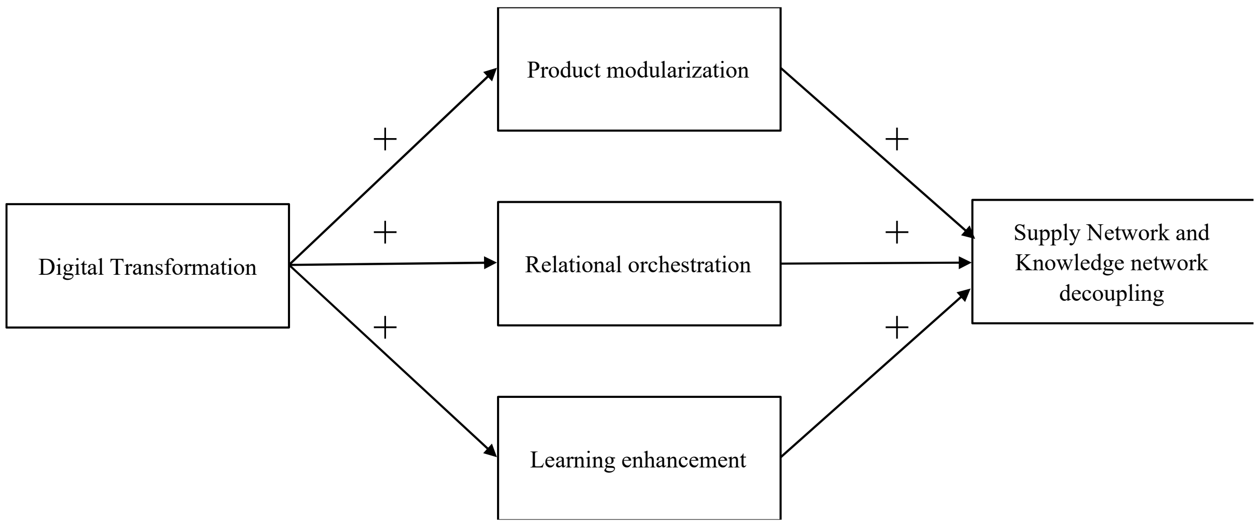
Information modularity	- **Product information revealing** (parties must disclose certain information about their products or components). - **Inferior interaction** (lower strategic information exchange results in poor interaction results).	- **Information hiding** (grants modularity of information encouraging parties' transparency without interfering with industrial secrecy). - **Superior interaction** (all the parties put at stake all their knowledge).
Interfaces	- **Importance on physical interfaces** (are a constraint to component interaction). - **Hard to establish common protocols** (require a broad amount of data and control).	- **Importance on digital interfaces** (without the component, the interaction is based only on the digital interface). - **Easier establishment of common protocols** (digital protocols need less information to be chosen and respected).
Standards and rules	- **Hard to establish standards**. - **Inferior versioning**. - **Limited automation**.	- **Easier to establish standards**. - **Versioning flexibility**. - **Extensive automation**.
Co-specialization	- **Expensive co-specialization** (need to invest in machines or to physically share spaces or personnel). - **Riskier co-specialization** (higher risk that one agent would benefit and subsequently vertically integrate).	- **Less expensive co-specialization** (digital co-specialization is faster and cheaper). - **Safer co-specialization** (the neutrality granted by the knowledge integrator enables safer partnerships).
Knowledge assets	- **Less experimentation** (less experimentation generates inferior knowledge production). - **Lack of an information database:** data reside in organizational memories and individuals.	- **More experimentation** (more experimentation results in increasing knowledge acquisition). - **Knowledge management systems** (enabled by digital technologies).
Absorptive Capacity	- **Integration separated from testing** (separating the two phases results in learning diseconomies).	- **Higher knowledge assets improve absorptive capacity** (the company improves learning economies).

6. Discussion

Our study looks at the digital transformation and at its effects for a firm in a non-born-digital domain, the motorsport industry, by focusing on changes concerning the supply and knowledge network. We complement the rich literature on ecosystems (Adner, 2017; Iansiti & Levien, 2004; Jacobides et al., 2018; Teece, 2007) by advancing an empirical process on how traditional ecosystems can evolve and can be manipulated by engaging with digital solutions. We also present a fine-grained breakdown of the core mechanisms behind the digital transformation, and we deliver insights on the decoupling between the knowledge and the supply network.

By leveraging our empirical evidence, our reflections seem to point to an overarching model, depicted in Figure 5. Digital transformation allows organizations to potentially decouple their position in the supply network from their position in the knowledge network. This means being able to collect, elaborate and retain a greater amount of data and knowledge, without necessarily upgrading the underlying manufacturing activities towards components that are more central in the product architecture. Ultimately, this process is mediated by three mechanisms: superior product modularization, relational orchestration, and knowledge assets. Given this contribution, it is thus important to articulate the theoretical underpinnings of the observations we presented in previous sections, by discussing the transferability of these insights (Lincoln & Guba, 1985) and showing how our observations differ or complement vis-à-vis current research across three key literatures: ecosystems, firm networks, and digital transformation.

FIGURE 5
From Digital Transformation to Supply and Knowledge Network Decoupling: Final model



6.1 Implications for ecosystems

First, this paper extends our understanding of ecosystems, their emergence, and their dynamics. We complement research by studying an empirical non-born-digital company, via-à-vis the focus on born-digital firms of the main literature on ecosystems (Ansari et al., 2016; Cennamo & Santalo, 2013; McIntyre & Srinivasan, 2017; Wareham et al., 2014). Our study contributes to the exploration on how it is possible to evaluate manufacturing ecosystems with generic ecosystem metrics (Jacobides et al., 2018), noticing that for certain manufacturing ecosystems, complementarity in production is one of the key metrics. We find in fact that, in opposition to born-digital products (e.g. platform, apps, operation systems etc.) whom joint consumption is more common and easily distinguishable from separate consumption, in a lot of tradition products (e.g. vehicles) it can hardly be distinguished. Cars, for example, have to be fitted with custom developed tires, making joint consumption a black-box experience. We moreover complement the literature on the challenges that disruptors face in ecosystems (e.g. tensions Ansari et al., 2016), by highlighting how the digital transformation may change ecosystem dynamics. Specifically, we identify how the peculiar characteristics of digital processes enable a neutral positioning by the disruptor (focal firm), that diminishes the usually high level of tensions between actors in the ecosystem.

Our study considers the key role of modularity in ecosystems (Baldwin, 2007; Garud et al., 2002; Jacobides et al., 2018), proposing a further division of the metric into technology modularity and information modularity. This division allowed us to discern the differences between physical and digital modularity and their contrasting effect on the ecosystem structure. While Jacobides et al. (2016) showed the failure of physical modularity initiatives by automotive suppliers, our case reveals that through the digital transformation it is instead possible to manipulate the structure of a manufacturing ecosystem.

6.2 Implications for firm networks

Second, our study contributes to the understanding of the role of firms inside an established manufacturing network, by focusing on how the role of core and peripheral actors can evolve. We focused on the dynamics of an existing ecosystem, while the vast majority of studies analyze firms that shape new ecosystems. We furthermore show how the traditional network arrangement, composed of peripheral and core firms (Brusoni et al., 2001; Dhanaraj & Parkhe, 2006; Lipparini et al., 2014; Williamson & De Meyer, 2012), with the latter usually orchestrating the supply and the knowledge network, has evolved towards a more ecosystem-like arrangement. Our findings support the assertion that "network innovation output will be greater the higher the level of knowledge mobility orchestrated by the hub firm" (Dhanaraj & Parkhe, 2006: 662), as proven by the Dallara's increasing knowledge absorption, innovation output, derived from its more central position in the knowledge network. However, we also explore how the supply network remained unchanged in the process (as displayed in Figure 1).

We find that the focal firm in these circumstances is orchestrating and simplifying complex tasks of participants in the network (Adner & Kapoor, 2010; Giudici, Reinmoeller, & Ravasi, 2018; Iansiti & Levien, 2004), and manages to channel most of the knowledge in the network (Gottfredson et al., 2005; Lipparini et al., 2014); yet, despite it does not manufacture a core component or the final product (Lipparini et al., 2014; Paquin & Howard-Grenville, 2013) and it does not enjoy major innovation appropriability (Dhanaraj & Parkhe, 2006: 663), it can still provide a prime and pivotal innovation output.

Our study also shows that, by embracing the digital transformation, even in an established ecosystem, these "hub" firms can remain peripheral in the supply network (i.e. the manufacturing process), and they are not obligated to be the primary actor in capturing most of the value of the final product's commercialization. Differently from prior reflections (Dhanaraj & Parkhe, 2006: 663), in cases of digital transformation like the one we observe, the focal firm is not appropriating the value of innovation, which is left to the OEMs, but it is mobilizing and appropriating the value of a complex knowledge integration, that becomes the core capability of the firm, and central to the ecosystem's architecture. This facilitates the knowledge centrality of the company, making it a major funnel of digital data (and related knowledge) within the entire network. We complement Brusoni et al. (2001) explaining how their analysis on system integrators, that need to "know more than what they make" (Brusoni et al., 2001), becomes valuable for knowledge integrators, despite this—thanks to the mobilizing of digital technologies—is not related to "moving to the core" (Gottfredson et al., 2005; Lipparini et al., 2014). We contribute to the understanding of new emerging network arrangements where not necessarily the OEM (i.e. system integrator) is the actor that collects more value and will have greater innovation output and knowledge, but a "digital knowledge integrator" (e.g. Dallara) can play a significant innovation role despite not appropriating most the value of innovation through the final product.

Such role recalls the "virtual knowledge broker" (Verona, Prandelli, & Sawhney, 2006): firms that connect, recombine, and transfer knowledge to companies in order to facilitate innovation (Hargadon & Sutton, 2000). This allows the company that operates this role to be perceived as "neutral" by all (often competing) parties, thus reaching a wider customer base (Verona et al., 2006), and avoiding competition with its customers. Dallara orchestrates a very delicate network in ways that its clients cannot perform, involving ,for example, lead users (e.g., pilots) in the orchestration (Von Hippel, 1986). We complement those studies by showing a different but complementary role, where a virtual knowledge broker maintains physical testing activities (usually realized at the end of the process) for empirical confirmation, thus extending the concept's applicability to manufacturing settings.

6.3 Implications for digital transformation

Our final substantive contribution relates to the broader and emerging topic of digital transformation. We argue that at a lower level, the digital transformation is enabled by a series of digital processes that are enabling cross-boundary industry disruptions (Burgelman & Grove, 2007), showing how they permit the decoupling between the knowledge and the supply network that Dallara has obtained. Our analyses on digital processes affirm that digital technologies exhibit relatively higher modularity than physical components (Ulrich, 1994), but they moreover enable superior information hiding, easier to support co-specialization, and higher knowledge absorption and retention. We thus respond to George et al. (2014) and Sambamurthy et al. (2003) by arguing that digital technologies not only allow work conditions across boundaries of time, distance, and function, but they open possibilities to become the funnel of knowledge in an industry, while remaining peripheral in the manufacturing process.

We contribute to Dhanaraj and Parkhe (2006) specifying that not always the stability of the innovation network positively impacts the strength of the innovation appropriability. While considering digital complementors in a manufacturing sector (e.g. software houses, technology manufacturers etc.), technological disruption (i.e. the introduction of a new groundbreaking digital technology) could positively affect the innovation output of the focal firm enabling new or improved processes. The digital transformation entails a deep uncertainty aspect (Dattée et al., 2018), Dallara maneuvers this uncertainty, but in its favor, capturing the advantages that the digital transformation allows, being an incumbent that gained advantage from the emergence of new technologies. In saying so we furthermore show that innovation in complements is not always reducing the leader's competitive advantage (Adner & Kapoor, 2010: 327). In the case of digital complementarities, in fact, it can lead to an increased technological advantage for the aforementioned reasons.

Finally, our research contributes to identifying how digital processes can favor and catalyze the emergence of ecosystems in non-born-digital sectors, enabling the decoupling of the supply and knowledge network, allowing firms that pursued the digital transformation to become virtual knowledge brokers in their sector.

7. Conclusions

Our research question asked what are the digitally-driven processes by which a firm can obtain superior knowledge about core components and system integration, while manufacturing peripheral components and subsystems. Specifically, we aimed to explain how non-digital firms embraced digital transformation, and by doing so decoupled their position in the knowledge network from their (manufacturing) role in the supply network—that is keeping a central position in the knowledge network while remaining peripheral in the manufacturing. We chose to investigate the automotive industry in the motorsport segment as an established non-digital domain to research on. Moreover, the company Dallara Automobili was chosen as a relatively small and peripheral (compared to entrenched OEMs), but fast-growing actor in the industry.

We identified ecosystem metrics and we tracked them longitudinally on Dallara's history, focusing on how they changed after the arrival of Andrea Pontremoli, the new CEO perceived as the catalyst of the digital transformation of the company. We then evaluated how processes had changed between the two periods, linking how that change has influenced the network of relations and the related knowledge flow. As already mentioned, the automotive sector has been organized for a long time around the centrality of system integrators, even resisting change attempts by peripheral actors (Jacobides et al., 2016). Dallara's strategy allowed the company to slowly but increasingly gain the trust of OEMs without incurring in conflictual situations, thus acquiring major sources of data (which in this case we can call "big data"), superior system integration capabilities, and ultimately increasing in parallel its centrality in the knowledge network.

Our case displays how it is possible to reach this situation in an established ecosystem, by pursuing a digital transformation. Previous studies showed that it was possible to obtain this position by manufacturing a core subsystem or component, but the Dallara case overcomes those assumptions by moving the focus from the product to the integration. Thanks to the digital transformation adoption, producing less central parts is no longer a constraint to access superior knowledge; instead, it means obtaining lower competition from part suppliers and OEM, becoming a virtual knowledge broker. Verona et al. (2006) presented examples (e.g. Innocentive, Homestore, Edmunds etc.) proving how this role is being developed in numerous sectors and show that our example can span beyond the niches and idiosyncrasies or motorsport and automotive.

The knowledge advantage that Dallara has reached cannot be easily copied or easily reappropriated by third parties. From the technological point of view, the majority of the tools are tailored for the company and would not make sense in another company, moreover, other tools (e.g., the simulator) are not commercially available, have to be custom-made, require unavoidable developing times, and a wide range of partnerships before granting an empirical value. In addition, the key advantage resides in the processes expertise of relational orchestration (Giudici et al., 2017), rather than the mere possession of the digital resources.

Among others, the primary implication for practice is that digital transformation allows promising development trajectories in several industries, even those that—being anchored to physical products—seem peripherally related to the digital phenomenon. However, companies that are willing to pursue this path should focus on remaining in achieving a "neutral position" vis-à-vis their clients in order not to be perceived as a potential competitor, or a mean for other players in the same market to access valuable knowledge in opportunistic fashion. Regarding this aspect, companies that embrace the digital transformation should always be ready to maintain their digital competitive advantage, constantly updating and improving systems and digital tools through customizations and best practices research, just like Dallara does.

Our study presents some limitations that depend on the width of our research and that are imposed by the characteristics of our case. We focused on the dynamics of an existing ecosystem, while the vast majority of studies analyze firms that shape new ecosystems, however this creates a limitation because we analyze a special type of ecosystems and our findings may not apply to emerging ecosystems. Moreover, oOur qualitative research design provides nuanced understanding of underlying processes, but most certainly does not allow us to test causality or fully rule out endogeneity. Dallara, for example, was an already established company that was well performing in its niche and that was able to allocate the necessary considerable investments needed to pursue the digital transformation.

In addition, being Dallara a technology company working in the automotive (motorsport) sector, our results might better fit similar types of technology companies, which underwent a strategic digital transformation, rather than firms in service or creative industries.

It is moreover difficult to find a clear counterfactual as there is a wide set of peripheral actors that have not embraced the digital transformation, continuing their historical activities and remaining peripheral in their respective sector, but this does not prove that this has occurred because of their lack of digital processes. Despite acknowledging the unavoidable limitations of our study, we believe our study might provide an initial contribution to an important, timely, and rather underexplored phenomenon at the intersection of manufacturing) ecosystems, networks, and digital transformation. We hope future studies will further unpick and resolve the issues this paper has left open, and uses our reflections as a stepping stone to drive new insights for this intriguing and relevant conversation.

8. Appendix

TABLE A1
Coding table – from quotes to first-order concepts

(1) " Today the Dallara group is composed by 10 companies. […] we had to manage a world like the intercompany one, […] we have done some technological choices that allowed us to provide all IT services from Varano, here." (CIO at Dallara).

(2) " For example, if an accident happened and some parts of the car were damaged, FIA could say that a certain component could no more being used. […] Yes, FIA in following competitions was going to check if those components were still on any cars, because they could not race with those. […] It was a service we were directly providing to them." (CIO at Dallara).

(3) " Some work had already been made […] to do something compatible with the outside world, just like our tires are mounted on cars, our tire models have to be mounted on the vehicle model of others. […] It has been an attention we had while creating the models, but that Dallara has had in making sure that its software and hardwre architecture of the simulator, was modular so that anone could interface with it." (Head of R&D Motorsport at Pirelli).

(4) " Our internal programs are modular, to dialogue with other softwares, clearly, at a input, but also at an output level." (CFD-R&D Manager at Dallara).

(5) " We were going with one of our laptops, we branched a network cable where we were sending the state information of the vehicle, that were the inputs for tires. […] The computer solved the equation for tyres, returned the forces and all this was looped in real time for all four tires." (Head of R&D Motorsport at Pirelli).

(6) " When the infrastructure could handle it, we have done the investments on the instruments, to unify them, to merge them. Now there is a network of softwares inside here thet are all, how can i say, so super interconnected that they give you a diffent visibility […]." (R&D Composites Manager at Dallara).

(7) " [The first step] is has been starting to invest on the infrastructure, […] Fabrizio acquired an overall view, he started thinking how to do a shared and unique network, how to chose servers, and how to put services on serers." (R&D Composites Manager at Dallara).

(8) " Imagine you are producing a hybrid car. Question: Where do you place the engines? The electric in the front, the combustion in the back? Both back? Both in the front? With our simulator you don't have to build four prototypes to understand which one works best, you just need to change the mathematical models." (Andrea Pontremoli, CEO of Dallara, interview, Linkiesta.it, 11 March, 2017)

(9) " The aim of the simulator […] is that of having, way before the physical car, a virtual car that can be driven to test. […] It is the collector of the sensible information of the car: it requires the aerodynamic data, the project, the suspension layout etc." (Testing Manager at Dallara).

(10) " Or we speak the same language, or we settle on an interface and we both respect an interface protocol between the two models, it is possible, it is called co-simulation" (Testing Manager at Dallara).

(11) " From the OEM point of view, you can't tell the supplier how you want to do the vehicle, […] you can't tell everything you know. […] now instead while finding the final target, your supplier could not be knowing what your weight distribution is, or the type of suspension, because the test is on the simulator. From the OEM side, he can put in place all his knowledge on the vehicle without showing it to the supplier, but the supplier is like if he was testing it on the track" (Head of R&D Motorsport at Pirelli).

(12) " The company networks have been evolved in the direction of hosting hundreds of linked objects, in the direction of managing those objects, and managing them in a safe and unified way, it has all been conceptually structured with layers." (CIO at Dallara).

(1) Database enable service modularity

(2) Software modularity

(3) Hardware and network modular expansion

(4) Virtualization of physical tests

(5) Internal and external integration

(6) Information hiding

(7) Common protocols

(13) " They overlap, but on antother layer, our softwares, our programs used to create a sort of mask and interface between the user and the use of other commercial softwares, so the Python that has been internally developed, takes the Fluent output, reads it, processes it, and instead of seing a monitor with 50 columns and 1500 rows, it simply shoots out a column where it tells you the resistence, the load,, the balance, and so the distribution on the posterior and anterior axle are these ones." (CFD-R&D Manager at Dallara).

(14) " The Ferrari systems are very difficult to integrate with. […] They have their own system they develop fast, around what they want to do, they don't care what we do, so we have to find a way to link into that data. Everything has to be generic at Dallara [because they produce a lot of cars] which is good because then it fits what you need, maybe 40% fit, [but with Ferrari] it would be 0%" (Deputy Head of Aerodynamics at Haas F1 Team).

(15) " The advantage of those systems is thet they work on standard protocols, so if you have a videoconference system on the other side, you use it, if you don't have it, i give you the client and you can connect to this one that is free […]. We are using this one with cients, suppliers, it linked us to universities." (CIO at Dallara).

(16) " Having this virtual model forces to become the collector of all a series of information and cooperation between departments that before, not having this need, it was very likely that this exchange was not happening." (Testing Manager at Dallara).

(17) " You need to have everything in your digital shaker, everything at a technical level and at a management level." (R&D Composites Manager at Dallara).

(18) " The first big step has been having a common factor, everithing managed by the IT, all the softwares of the company, this helped a lot because it allowed all departments to speak the same language." (CIO at Dallara).

(19) " Nowadays knowledge and competencies are more disseminated, […] they are enclosed in controlled systems, with access, with backup, so we are working in a way that if one of us leaves, his knowledge remains inside Dallara" (R&D Composites Manager at Dallara).

(20) [We applied] an adaptive model […] starting from a base that we had already developed, for a software that managed article codes and bills of material, […] we evolved it, we made sure that it took care of all the company processes up until the wharehouse and deliveries. As we developed it internally, we created that software on the model that best represented our work." (CIO at Dallara).

(21) " [Differnt parts of the car] speak through the simulator. They speak the same language. [The simulator] It has been used to standardize the way of exchanging information between departments." (Testing Manager at Dallara).

(22) " We unified the communication inside the company, so the way data and information are exchanged" (CIO at Dallara).

(23) " Today we are in touch much more frequently on videocall than we see in person, because it is a consolidated relationship and consequently the use of this type of instruments shortens distances" (Technical Account Manager at Sinthera).

(24) " The collaboration between users is being developed way beyond the data and information exchange, in order to improve the company's processes and as the base for the profesional growth of all employees, that receive tools that allow them to actively participate in the evolution of the company and of innovation processes." (Fabrizio Arabucci, CIO at Dallara, interview, zerounoweb.it, 12 April, 2016)

(25) " 20 years ago there could have been a mutual recrimination -you have changed the car in the meanwhile, I had not understood where we were going-, then if you don't end with optimal results there could have been some political game, in this case [the change] has benefited also to the seriousness and the sincerity of Pirelli and Dallara, everyone knows clearly where he has to arrive, […] it had been defined virtually" (Head of R&D Motorsport at Pirelli).

(5) Internal and external integration

(6) Information hiding

(7) Processes generality

(8) Common protocols

(9) Full digitalization at every stage of the company

(10) Process integration

(11) New communication interaction

(26) " Some products required some optimizations that before were not required by the market. So, maybe, if before you were able to produce a component even though it weighted a bit more, you know, to be safer, now the market doesn't allow you to do so." (R&D Composites Manager at Dallara).

(27) " The work of the CFD engineer that does research is to find each time a new metodology that has to be either more accurate, from the correlation point of vue, or that, for identical accuracy, it allows to save time." (CFD-R&D Manager at Dallara).

(28) " Research, because speaking of such a recent science and speaking anyway about simulation, that like all simulation tool require correlation, validation and are very linked to hardware innovation and softwre evolution." (CFD-R&D Manager at Dallara).

(29) " Well, we programmed, us, in house, a number of Python programs that automatically rework software outputs and already layout PDFs rather than reports, rather than even sending emails so that you can already see the results, and you can know remotely how the case went." (CFD-R&D Manager at Dallara).

(30) " Every 30 min Bom manager goes in and does an export for us, [..] it takes the data and pushes it out. […] Dallara set that up for us. We told them we wanted to use BOM manager in a certain way, we said we just needed to see the data, they said we could link to BOM manager directly, we said fine, but can you push, and we read that data, and they did it. […] We have been using it for 4 years now and it works and is reliable" (Deputy Head of Aerodynamics at Haas F1 Team).

(31) " It has been some years that the market has gone in the direction of customizing products for cars, even though name and dimension of tires are the same, […] for Lamborghini it is a tire and for Ferrari it's another. Even though they look the same, they are different." (Head of R&D Motorsport at Pirelli).

(32) " Dallara joined forces with Bosch to develop the key safety and engine control systems needed to handle this extreme sports car on the road and race track, pairing peak performance with maximum safety to make it a joy to drive." (Bosch-presse.de, 24 October, 2018)

(33) " There are some less established technologies, maybe with vertical applications, that […] are less in the domain of the supplier, and the applicability and the specific use case, is being developed together, four-handed. […] In those cases an extended team is created [in the smart tracking case] Dallara, Sinthera, Cisco was involved, and also a company especially focused on localization technologies was involved." (Technical Account Manager at Sinthera).

(34) " During these years, material scientists understood that without having people who are conscious of what the final product is, it was very hard to keep going. Us, that we are between material scientists and the production line, so we design, we understood that designing without understanding the production processes is very complex." (R&D Composites Manager at Dallara).

(35) " The power of Dallara has been creating a lot of long-term relationships, […] with Bugatti for example, we work together since 20 years, so we all know each other, everyone knows how we work and we know them. You create such relationships where basically your strength is a bit being what they lack. (R&D Composites Manager at Dallara).

(36) " For each project we make there is always the concept of value […] in two roads: one is the optimization of processes, so creating value by increasing the efficacy of what you are already doing […], on the other side we make it with the idea of adding new services, new products and so creating something new." (CIO at Dallara).

(37) " The group that we had at Ferrari agreed to come to our system, […] but it was quite painful, quite a long process, […] but now we have one source of data with one single template which contains requirements linked to master sheets of data, so all the information comes automatically from BOM manager, we don't add it" (Deputy Head of Aerodynamics at Haas F1 Team).

(12) Shared market anticipation

(13) System augmentation

(14) Customization

(15) Co-design

(16) Complementarity in production

(17) Information Sharing

(38) " We interface also with all the themes of product industrialization, at DARC what we are doing with presses and robots is not something that is been used today but it is something we are developing to give guidance to our clients on what is called product industrialization. We don't want to go there, but we want to control also that part of the process, then if you want to do it at your place, I told you which pros and cons are of using different types of technology and processes" (Human Resources and Legal Director at Dallara)

(39) " [Dallara] they were making parts [for the wind tunnel], we make 1000 parts for 1 week of testing, […] so we are pushing them to be more efficient. When we started, they did customer test for Ferrari GT, now their efficiency for plastic parts […] and the quality of their 60% models is the same of a F1 team, the CAD now is becoming better because they have to make parts lighter, stronger, faster. […] There is not -you can't do that-, but -how can we do that-" (Deputy Head of Aerodynamics at Haas F1 Team).

(40) " It has augmented the level of awareness […], and obviously all this awareness then is being transferred also to clients, and clients grow with you. [Clients] let you do more, they trust you" (CFD-R&D Manager at Dallara).

(41) " Each time that you present the evolution steps of your vehicle development, you present a report where you show numbers and images, and you explain that on his vehicle you have done this variant and that the effect has been this one. You really explain him with pressures and speeds images, […] and it is a greater interaction with him because in the end we play cards on the table […], you make him part of the development and also of the comprehension of the product that he will find himself with" (CFD-R&D Manager at Dallara).

(42) " With CFD you not only decide whether to discard or not the version, but you are also able to understand why that version has been positive or has been negative, and you learn. This is why I say that it has augmented the level of awareness of who does the work" (CFD-R&D Manager at Dallara).

(43) " The simulator, for what it allows you to see, it increases remarkably the understanding, it gives you something that lets you better understand what you have" (Testing Manager at Dallara).

(44) " Now I know exactily wich tests you make, the results you obtain, the advantages you have, where it goes well, were it goes worse, why it goes well, why it goes bad, so it has increased a lot what we are able to see, but also what they can test with our product and what they now about it.." (Testing Manager at Dallara).

(45) " Only through phenomena simulation you can anticipate problems and errors, learning in a faster way." (Automazione-plus.it, 16 October, 2017)

(46) " We need to have the knowledge that reaches the equation level, because a lot of time race cars are not easy to describe, so you need to get in, made customizations and adaptations to the dynamic problem you want to solve." (Testing Manager at Dallara).

(47) " We told [the client] we are at this point, I set up this type of simulation and now I want to try it on a rolling prototype […], would you like if we do it on your car? Would you be willing to? Then we share the know-how and we show you the results of the acoustic simulation on your car" (CFD-R&D Manager at Dallara).

(48) "This simulator not only augments the technological level inside the motorsport industry, but also goes outside that sector to promote the use of those innovative concepts in other technologically intensive sectors." (Andrea Pontremoli, CEO of Dallara, interview, Repubblica.it, 27 May, 2013)

(49) For each project we make there is always the concept of value […] in two roads: one is the optimization of processes, so creating value by increasing the efficacy of what you are already doing […], on the other side we make it with the idea of adding new services, new products and so creating something new. (CIO at Dallara).

(17) Information Sharing

(18) Reduction of causal ambiguity

19) Selection awareness

(20) Increased Understanding

(21) Knowledge enhancement

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