Modularity Archetypes and Their Coexistence in Technological Development: The Case of a Telecoms Company from Analogue Voice to 5G

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Abstract

Modularity is a key concept in the research and practice of information systems. Yet, it has been variously interpreted. Synthesizing the literature, we inductively develop a two-by-two matrix encapsulating two dualities of modularity: architectural vs. governance dimensions, and bottom-up vs. top-down perspectives. This matrix groups the literatures into four archetypical approaches to modularity (Engineering, Ecosystem, Generative and Logical). We next illustrate these archetypes through a qualitative study of a large global telecommunications firm. Drawing upon archival data and interviews, we show how each of these four approaches to modularity become dominant at different times, but also how they overlap and coexist.

Keywords: Modularity, telecommunications, architecture, ecosystems, 5G

1. Introduction

Modularity is a key concept in the research and practice of systems' design (Parnas, 1972; Simon, 1962). IBM's System/360 modular computer was an early and paradigmatic example of its implications on the development of systems, and for industrial economics and innovation (Baldwin & Clark, 2000). More recently, it has been identified as a core aspect of ecosystems (Jacobides et al., 2018).

The span of time and range of disciplines using the term has resulted in ambiguous meanings and often incoherent understandings (Cabigiosu & Camuffo, 2016; Frandsen, 2017). In information systems (IS), authors have highlighted inconsistencies between understanding of modularity when applied to industrial production and the characteristics of a modular layered architecture (Hylving & Schultze, 2020; Yoo et al., 2010), particularly in the generative recombination of digital resources (Henfridsson et al., 2014; Henfridsson et al., 2018; Yoo, 2012) and digital infrastructures (Constantinides et al., 2018).

We answer recent calls to develop a better understanding of modularity (Constantinides et al., 2018; Henfridsson et al., 2018; Hylving & Schultze, 2020). This is important given the determinant role modularity plays in driving digital innovation (Hylving & Schultze, 2020; Teece, 2018; Yoo et al., 2010) and supporting digital ecosystems (Jacobides et al., 2018; Wang, 2021). We address the need to reconcile the interpretations of modularity within the literature and make sense of its ambigous nature through the following research question: *How should we understand the concept of modularity in light of its ambiguous nature and shifting interpretations across studies and contexts?*

Our contribution is three-fold. First, drawing inductively from the literature on modularity, we develop a two-by-two matrix encapsulating two main dualities of modularity: architectural vs. governance dimensions, and bottom-up vs. top-down perspectives. This framework allows us to group the literature into four archetypical approaches to modularity and discuss their implications. Second, our qualitative empirical study of the evolution of a telecoms company across decades shows the usefulness of these four approaches in understanding the way the company interprets its environment. This research discusses how different perspectives towards modularity became embedded in the firm's organizational structure over time as it adjusted its internal structure to changing external conditions. Third, we show that all four interpretations of modularity coexist and are useful depending on the perspective and interpretation adopted by the different actors fulfilling different roles within the firm. Thus, our four approaches to modularity appear relevant to practice, and provide a means of describing actors' perceptions towards the firm and the organizational context. We conclude with implications for the management and IS literature on modularity.

2. Two dualities of modularity

2.1. First-order duality: defining modules

Modularity refers to the decomposition of complex systems into smaller self-contained

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components, so that each component is characterized by a high degree of internal independence, while interdependence between them is minimized (Baldwin & Clark, 2000). Modules can be defined and characterized either as technological entities, or organizational entities (Colfer & Baldwin, 2016). As a result, modularity raises both governance and architectural concerns, which we identify as the first-order duality of modularity (MacCormack et al., 2012; Orlikowski, 1992).

From an **architectural perspective**, modularity traces the boundaries of functionally-independent entities (Henderson & Clark, 1990) and it defines interfaces and design rules to enable the recombination and interoperation of modules (Baldwin & Clark, 2000). Modules are understood as physical components (Ulrich, 1995) or logical layers (Yoo et al., 2010) emerging from the allocation of functionalities to self-contained functional clusters (Mikkola, 2006).

From a **governance perspective**, modularization involves task partitioning, specialization, and the organization and division of labor (Siggelkow & Levinthal, 2003; Von Hippel, 1990). Modules are socio-organizational entities that emerge from the clustering of interdependent tasks into independent organizational units, which interoperate for the performance of broader jobs or value creation processes (Baldwin & Clark, 2000; Rivkin & Siggelkow, 2003). The modularization of tasks into independent organizational units actively contributes to the creation of organizational boundaries between social entities that can cross the legal spheres of authority such as firms, or be contained within them (Baldwin, 2008; Langlois, 2002).

These dimensions reveal the dual nature of the modularity concept (MacCormack et al., 2012), as modules may represent independent legal and socio-organizational entities, and/or independent logical and functional entities. The former reflects a governance dimension of the modularization process, the latter an architectural one. The architectural and governance dimensions are brought together by the realization that one usually "mirrors" the other (Colfer & Baldwin, 2016) and that they dynamically coevolve over time (Tiwana et al., 2010).

2.2. Second-order duality: tracing boundaries

The second duality characterizes two ways in which such modules can be derived and modularization implemented for each of the two perspectives.

2.2.1. Functional determinism vs. functional agnosticism. The architectural perspective has a dual nature (Cabigiosu & Camuffo, 2016; Schilling, 2000) as it involves the decomposition of a whole (system) into functionally-independent parts (modules), and/or the recombination or re-composition of logically distinct parts into a coherent whole (Wang, 2021). Modularization processes thus follow a top-down or bottom-up logic (Hylving & Schultze, 2020).

The *top-down* logic can be understood as functionally deterministic as modules are purposefully created to optimally achieve a system-level outcome, goal or function (Baldwin & Clark, 2000). Functionalities are defined *ex ante* and allocated to modules. Boundaries emerge *ex-post* to separate functionally independent (yet logically agnostic) modules. The *bottom-up* logic ensures coordination and recombination of logically independent modules that perform unforeseen functionalities only defined *ex post* (Ethiraj & Levinthal, 2004; Henfridsson et al., 2014). Similar considerations are evident in the digital innovation (Yoo, 2012) and IT governance literature (Tiwana & Konsynski, 2010). Here, boundaries separate logically independent (yet functionally agnostic) modules. In both cases modularity defines the architecture of interdependences between logically or functionally independent modules.

2.2.2. Centralized vs. decentralized governance. In the governance perspective modules are independent socio-organizational clusters that belong to, and are operated by, a common legal entity (e.g. firm), or by separate entities that can act as legally independent units, thus brining modularity closer to a theory of the firm (Baldwin, 2008; Siggelkow & Levinthal, 2003) and ecosystems (Jacobides et al., 2018).

Top-down governance logic characterizes a process whereby modular tasks and activities are created and located within the boundaries of the same legal authority (Ethiraj & Levinthal, 2004; Rivkin & Siggelkow, 2003). It is a centralized process under the control of a single decision-making authority.

In the bottom-up governance logic modules span organizational boundaries, across different spheres of authority and control (Langlois, 2002). Clusters of tasks and activities are delegated to independent actors and coordinated by means such as contractual agreements, common standards, or practices (Brusoni et al., 2001).

While the former characterizes a modularization process where legal control and authority precede the creation and operation of modules, the latter characterizes a modularization process where the creation and operation of modules define the legal control and authority over these modules. While the architectural dimension is silent with respect to the extent in which governance is decentralized, the governance dimension is silent with respect to the definition and allocation of modules' functionalities.

3. Four modularity archetypes

Our literature review offers a novel and comprehensive socio-technical perspective on modularity (Orlikowski & Robey, 1991) in light of the interplay between architectural and governance dimensions. Furthermore, the bottom-up/top-down duality for each of the two dimensions captures the rationale according to which this socio-technical process can be interpreted. This generates a two-by-two taxonomy matrix uncovering four archetypes of modularity and their associated modularization processes (Figure 1). Each archetype represents a yardstick to examine empirical cases and research.

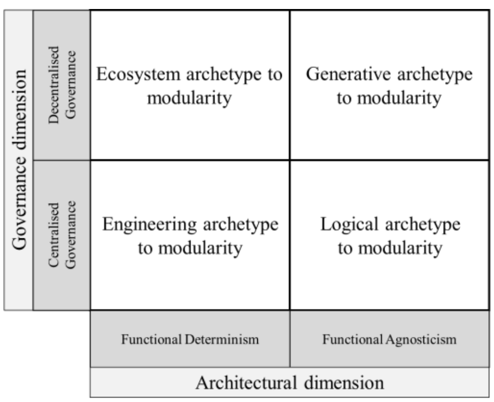

Figure 1. Four modularity archetypes

3.1. Engineering archetype

The first modularity archetype takes a double top-down approach to both the technological and the governance dimension. That is, modules result from a top-down decomposition of a product or project into fundamental functions, under the control and supervision of a single authority that defines system-level goals, parameters, and outcomes. This *engineering archetype* is consistent with classic modularity as applied to physical artifacts (Parnas, 1972) and with the (internal) product platform concept (Gawer & Cusumano, 2014) that characterized the mechanical (Clark, 1985; Ulrich, 1995) or electromechanical (Henderson & Clark, 1990) sectors in the early or mid-20th century. These are typically physical artifacts or analogic services controlled by a vertically integrated firm. The design is proprietary (O'Mahony & Karp, 2020), and the firm is owner and architect (Brusoni et al., 2001). Uses are defined *ex ante* and standards are only compatible with a firm's own products and modules. The modularization goal is production efficiency and optimization of functions set by the product owner (Baldwin & Clark, 2000; Rivkin & Siggelkow, 2003).

3.2. Logical archetype

In the *logical archetype*, modules are functionally agnostic or 'ambivalent' logical entities (Kallinikos et al., 2013) that can be reprogrammed and repurposed across a variety of unforeseen functionalities and uses. Functions follow —rather than drive— the modules' boundaries (Henfridsson et al., 2014). This is typically the case for digital artifacts, where modules are functionally agnostic logical protocols within a layered technology stack (Yoo, 2013; Yoo et al., 2010). Logically, 'higher layers' represent higher levels of semantic abstraction and complexity of functionalities (re-composition of a message), while 'lower layers' implement physical functionalities (signal transmission). Each module can be re-programmed, and repurposed according to the specific application and contingent requirements (Yoo, 2013).

Modules can be seamlessly redeployed to other uses and may support new functions, so that a system can accommodate unforeseen architectures and functionalities (Henfridsson et al., 2014) and is thus not technologically deterministic (Hylving & Schultze, 2020). The process remains centrally controlled and driven by a single legal entity. This process of internal innovation is the typical case of fully proprietary technologies and closed digital platforms (walled gardens) such as the early IBM's vertically integrated computer systems in the 1970s and 1980s (Baldwin & Clark, 2000; Langlois & Robertson, 1992), or the Apple closed ecosystem bundling hardware, operating systems and software/application layers under a centralized control structures (Kapoor & Agarwal, 2017). The goal remains the maximization of a firm's internal agility (Chakravarty et al., 2013) and capacity to innovate (Yoo et al., 2010), rather than the maximization of network effects, and user adoption.

3.3. Ecosystem archetype

In the *ecosystem archetype*, modules emerge as the outcome of a top-down functional decomposition of a product or project; however, modules are implemented and/or provided by independent actors. The various module owners cannot decide what functionality the modules will perform, but exercise control over the performance and delivery of these functionalities. This is where modularity defines legal and governance boundaries between socio-organizational entities (Langlois, 2002). This is the case of modularity generating “modular networks” (Langlois & Robertson, 1992; Sanchez & Mahoney, 1996), as for the case of “industry platforms" (Gawer, 2015; Gawer & Cusumano, 2014) emerging from the delegation of production to third parties producing compatible complements. The ecosystem’s orchestrator, or architect represents a “network hub” (Iansiti & Levien, 2004) as it still exercises top-down control over the way the system is modularized, the architectural design, and the allocation of functions. In this case compatibility between components is key to ensure the correct performance and interoperation of functionalities, as in the case of tyre producers, or peripherals like headphones. This archetype maintains coordination through centralization, while leveraging economies of specialization through functional determinism from the delegation of tasks to specialized third parties (Langlois, 2003).

The functional determinism of ecosystems results from three main reasons: (i) exogenous technological constraints derived from physical characteristics or intrinsic properties of functionally specific modules, (ii) consolidation of common industry standards (Hanseth & Lyytinen, 2010); (iii) artificial constraints created by an ecosystem’s architect, or orchestrator, which retains control, as in the case of industry platforms (Gawer & Cusumano, 2014) or centrally managed ecosystems (Iansiti & Levien, 2004). Given the limits to full specialization and autonomy, ownership-based definitions of the boundaries of the firm differ from the authority-based definition of the firm’s boundaries (Brusoni, 2005).

3.4. Generative archetype of modularity

In the *generative archetype* new functionalities and/or modules are added *ex post* and this process emerges in a decentralized manner, with the participation of independent parties. This conflation of open access and delegated control (O'Mahony & Karp, 2020) evokes the notion of generativity as “a system’s capacity to produce unanticipated change through unfiltered contributions from broad and varied audiences” (Zittrain, 2008, p. 70). This archetype is seen within literature on innovation ecosystems (Granstrand & Holgersson, 2020), innovation platforms (Cusumano et al., 2019), and open innovation (Nambisan et al., 2018), and is typical of novel meta-organizational arrangements (Gulati et al., 2012) such as open source systems (Von Krogh & Von Hippel, 2006) and web 2.0 application ecosystems (Carignani et al., 2011; Ransbotham & Kane, 2011).

In some contexts, the combination of fully open access and fully delegated control may generate fundamental inefficiencies and be neither feasible (Brusoni et al., 2001) nor desirable (Zhang et al., 2020). Generally, though, this archetype is adopted whenever overall value creation depends on the novel contributions of a variety of dispersed actors. This is a peculiar feature shared by digital commons (Mindel et al., 2018) where participants’ contributions are spontaneous and unsolicited.

4. Methodology and research design

We conducted an in-depth qualitative case study of ABC (pseudonym), a multinational and multidivisional telecom company that has evolved and adjusted its organizational structure and business strategy facing an evolving technological, market, and regulatory context. ABC is particularly appropriate to examine how different interpretations of modularity emerge and coexist, as the company co-evolved within the industry and adjusted to the changing technological and institutional environments.

We reviewed archival public documents (e.g., annual reports, industry documents and financial statements that are cited as ABCdate but not listed in references) to understand how different archetypes emerged throughout the history of the industry. We conducted semi-structured interviews (n=15, μ=~60min via video conference between 2020 and 2022) with ABC managers and heads of divisions asking about boundaries, technological modules, tasks, information flows, and channels of decision-making, seeking to infer types of modularity involved.

Our analysis is primarily deductive using the case to test our theory on the different approaches to modularity. Following Rivard (2021) we iteratively and incrementally accumulated and analyzed our data to refine our theory construction. The symmetry between the four stages and archetypes is therefore the result of this iterative interplay between a deductive and interpretative approach to the case study (Sarker et al., 2018). This is supported by two types of data our case study relies on: archival and field data.

First, archival documents allowed us to identify four main stages in the evolution of the industry and ABC’s history. In line with interpretative and exploratory approaches, this informed our four main archetypes of modularity. Second, through an incremental and iterative reading of the literature alongside the case material (Rivard, 2021), we uncovered how the four different archetypes may have been internalized and shaped organizational processes through interviews, in line with a more deductive theory-testing approach (Sarker et al., 2018). We then revisited our data to verify observations and develop our theoretical framework (Strauss & Corbin, 1998). Interviews' data were analyzed and coded with NVivo and clustered according to themes and sub-themes capturing discussions about information channels, decision-making processes, organization and of tasks, power and authority relationships.

5. Analysis

We identify four main stages in the evolution of ABC, each characterized by a different technological and regulatory regime. First, in the "legacy" stage ABC operated as a monopolist and public infrastructure provider. A second stage shifted the focus on the unbundling and open access to ABC's infrastructure following the emergence of broadband services. The third stage saw the emergence of wifi and mobile communications ecosystems, along with the arrival of the 4G spectrum. The fourth stage is characterized by big data, smart devices, and artificial intelligence, and corresponds with the arrival of 5G.

Each stage reflects innovations in technology and changes in the legal and institutional context. We observe that each stage was dominated by one of the modularity archetypes, which appear to coexist and overlap, building on each other. We show how ABC's organizational boundaries, internal structures and logics historically reflect the way in which ABC reinterprets its evolving role within the industry.

5.1. The engineering interpretation of modularity: efficient and compliant interconnection between functional elements

Like many European countries, the country's telecommunication industry had originally been a vertically integrated network, controlled and operated by a monopolist telecommunication carrier offering telephony services, such as local, long distance, and international telecommunication services and supplying telecoms equipment for customers' premises (Hunt & Lynk, 1991). After privatization, and given this former monopolist status, ABC was simultaneously regarded as a service and infrastructure provider. Its focus was on connection availability, and it faced regulatory duties, such as minimum service quality and coverage. This role carried into the wholesale market as ABC had to offer mandatory access rights to emerging competitors.

In the early 1990s the company was privatized and open to the market. The company accounts for that time reveal the main sources of revenues and the new organizational structure (ABC, 1991). In these accounts, the various lines of business corresponded to the various elements (or segments) of the infrastructure for ensuring interconnection and service delivery – *"telephone calls", "telephone exchange line rental", "international telephone calls", "customer premises equipment supply", "other"*. In this sense, the organization and operation of the business were functionally deterministic and closely reflected an engineering modularization of the infrastructure. Modular boundaries centered on optimal access, availability, and interconnection to ABC's infrastructural elements.

These themes still at times emerge today as: (i) regulatory constraints from the original public service role persist; (ii) old legacy equipment and systems still influence decisions; (iii) retail customers still have priority over business customers. As one interviewee said, the long history of the organization and its regulatory responsibility leads to technical debt:

"… it was part of the government for many years with the incumbent operator … That leaves the big legacy base, a very long tail of things that we're supporting…we've still got customers out there who've got rotary dial phones… we need to account for them in anything we do as well."

The inherited importance of retail consumers is evidenced by KPIs including market penetration and sales volumes in the retail market, given the regulatory framework shaping ABC's decisions. As discussed by a different interviewee: *"the consumer budget… [and] the consumer market would be larger and… they probably have a bit more power in the organization."*

In sum, this first stage is mainly concerned with issues such as the availability of the interconnection understood as an undifferentiated and functionally deterministic telecommunication service subject to regulatory constraints shaping the quality of the communication, and the scope of customers served. These issues are consistent with an engineering approach to modularity (both functionally deterministic and internal to the firm) that was reflected in the way in which ABC thinks of itself and organizes (traces boundaries between) its businesses.

5.2. The logical interpretation of modularity: unbundling layers of converged infrastructure

At the turn of the millennium, personal computers and digital communications shifted the focus of the competition, as well as of the regulatory environment, towards a layered understanding of the industry. The physical infrastructural layer was separated from the "over-the-top" services operated by internet service providers (ISP). The public regulator changed names from "tel" for telephone to "com" for communications, and encompassed new digital services such as TV, radio, telecoms, broadcasting, mobile spectrum (Doyle & Vick, 2005). This marked the shift from functionally deterministic and service-specific infrastructure-based approaches to one more attuned to a converged (and functionally agnostic) digital economy (GovRegulatorCom, 2012).

This new perspective became widespread across the company as ABC appeared to regard its network as a layered infrastructure arranged according to a variety of horizontal logical layers. The company accounts of this period evidence this layered approach by including a distinction between *"retail"* and *"wholesale"* business divisions: the former focused on final customers at the service or device layer, the latter focused on other ISPs at the infrastructure layer (or network layer: Yoo et al., 2010).

Such separation (unbundling) of lower layers from upper ones was further operationalized with the creation (in part due to legislative requirements) of a separate business we are calling LastMeters to provide the final customer connections to the entire industry. By 2007, ABC's internal organization was therefore the result (and reflection) of a logical or layered interpretation of modularity, where its three divisions (LastMeters, wholesale, retail) corresponded to businesses operated at the three layers of the unbundled infrastructure. This shift from a functionally deterministic understanding of the socio-technical context to a converged layered (and functionally agnostic) understanding of the socio-technical context was also evidenced by a rebranding for *"better reflect[ing] the range of activities that we encompass."* (ABC, 2003: 8) since the old logo had *"become associated with some outdated perceptions of ABC as simply a fixed-line telephone company."*

The relevance of the layered stack is still evident today as ABC changes in a variety of other ways, namely the decomposition of the network units into a set of converged "service platforms" operating over ABC's network (formalized in the following organizational restructuring – see section 5.3), including TV, broadband, mobile, and so forth. A recent annual report makes clear that one of its four missions has been *"building the foundations of our new IT architecture, based on modern, modularized software components deployed on industry standard platforms."* (ABC, 20xx: 23). In this case, the term modularized can mean different things, but it hints at a logical layered interpretation of the term.

This interpretation of modularity understood as a separation between logical layers providing a variety of (functionally agnostic) services emerges in a variety of ways from the interviews, mainly with reference to: (i) layers, or layered modularity, (ii) common platforms and shared services, (iii) minimum viable products (MVP), (iv) network neutrality or convergence, (v) compatibility and conflicts between services and the underlying network. As the network becomes modularized along logical layers, the focus shifts from the performance of the underlying network layer to the higher "service enablement" layers:

"the network development is a layer… we're not looking to just operate as a network developer anymore. We need to build on that a layer of IT, whether that be edge, clouds, cloud computing or on-premise edge… And then on top of that, there's a service creation layer as well."

The slicing of the network into functionally agnostic layers generates new problems, as those operating at one layer cannot have a coherent vision of what happens across the whole stack, thus creating coordination and visibility problems (Henfridsson et al., 2014): *"instead of being vertically integrated, your operations need to be horizontal…and if something goes wrong [with a service], [the service person] needs to go to a team who are managing all of the platforms across [multiple services] … and that team [will] have no concept of what's running on it…"*

In sum, boundaries in this novel perspective are traced between agnostic logical layers, not between physical functionally determined components. Since the early 2000s, ABC classifications and categorization of business services as well as their organizational structure have reflected that.

5.3. The ecosystem interpretation of modularity: Common standards to ensure ecosystems' interoperability and coordination

Mobile phones and 4G mobile networks mark a further shift in the industry. This generated problems and opportunities for legacy telecommunication carriers deriving from the technological interoperation and the strategic coopetition between fixed and mobile ISP. Existing fixed broadband lines could now be fully complemented (or threatened) by mobile broadband.

In the decade after 2010, ABC and the industry further shifted towards consolidation of the digital and converged ecosystem. An annual report midway through this decade stated: *"We are developing converged fixed-mobile offerings that build on our strengths in fixed services and will use our 4G spectrum"* (ABC 201x). The need to ensure seamless interoperation between fixed and mobile connections as the mobile market exploded, led to the acquisition, by ABC, of a mobile focused carrier XYZ and to a major restructuring of ABC around three brands and six lines of business. This new context required the interoperation, compatibility, and integration of two previously separated ecosystems (XYZ's 4G, ABC's broadband), each composed of their own components, protocols, vendors and legal requirements. This was noted by ABC after the acquisition:

"XYZ uses technologies from a number of vendors and incurs significant capital expenditure deploying these technologies. There can be no assurance that common standards and specifications will be achieved, that there will be interoperability across networks, that technologies will be developed according to anticipated schedules, that they'll perform according to expectations or that they will achieve commercial acceptance." (ABC, 2016: 55).

The acquisition of XYZ, and the need to integrate two formerly separated ecosystems, led to the third major organizational restructuring of the company which highlighted the consolidation of three main trends, consistent with the rapid evolution of the industry: the emergence of a technology unit managing a new "service platform" division, the adoption of a multi-brand strategy based on the nature of the infrastructure operated (fixed or mobile), and the creation of a new business unit (for XYZ).

This further reorganization appears associated with novel concerns over boundaries and interdependences, thus with novel interpretations of modularity, mainly focused on the compatibility of standards and devices, the rationalization of vendors and providers, and the coordination of the various actors participating within the ecosystem that goes beyond the mere coordination between the fixed broadband provider (ABC) and the mobile provider (XYZ). This change expands the focus of analysis beyond the boundaries of ABC and mainly frames interactions, communication channels and power dependences in interorganizational terms; that is, across the boundaries of the single legal entities participating in the ecosystem, in line with our ecosystem interpretation of modularity.

The provision of a service over multiple platforms and multiple infrastructures originally belonging to different firms raised new problems of duplication of infrastructural components, of rationalization and investments in legacy systems:

"we have legacy services. We also have legacy systems, and those are an issue. So, one particular issue we have is that [ABC] is [ABC] and also [XYZ] following a merger or acquisition around six years ago and both of those have their own systems. And the result is if we need to do anything… I need to do it on the [ABC] stack and I need to do it on the [XYZ] stack, and that is very painful."

This generates novel problems of integrating different systems that could become interoperable according to identical standards. In this ecosystem perspective integration goes beyond the technological considerations guiding the interconnection between infrastructural components, and beyond the considerations on the relationship and the compatibility between different logical layers. This ecosystem integration depends on a variety of ambiguous considerations that extend the technological and financial dimensions, and reflects political or cultural considerations. As stated by an interviewee:

"When [two older mobile networks which merged to form XYZ] came together, ... there's definitely a clash of cultures and preferred vendors."

In sum, the deployment of 4G technology and ABC's entry in the new industry in the mid-2010s reveals two things: (i) When ecosystems are involved, interoperability is not a mere issue of infrastructural interconnection or logical compatibility between logical layers, but more generally about defining common dominant standards between autonomous actors such as vendors, device manufacturers and equipment providers; this may be the outcome of political decisions. (ii) Modules mainly emerge as compatible components between interoperable ecosystems whose functionalities are mainly defined *ex ante* in agreement with the ecosystem's partners. The acquisition and rationalization of the partners thus becomes an important (yet problematic) objective.

5.4. The generative interpretation of modularity: agility and seamless innovation

The latest turn of the industry represents the emergence of generally pervasive interconnection among autonomous elements in computing developments (such as 'smart' -cities, -homes and -factories, IoT, gaming and VR, shared platforms, AI, and big data) supported by the development of 5G technology. 5G raises new issues as boundaries can be traced according to agency and legal responsibilities, not just technical standards or logical layers.

5G's deployment led to a further organizational restructuring. Logical boundaries between retail and wholesale layers (from stage 2) were dropped. New support divisions (Digital and Networks) emerged to coordinate novel services and value propositions inside and outside the company, and foster new opportunities. In this way, technological support functions acquire increasing strategic relevance, even if political relevance still appeared to reside within the home consumer part of the business. A cloud-based gaming service provides an example of how ABC's strategy adjusted to new markets and opportunities.

As a result, the emergence of these new divisions (Digital and Networks) alongside Consumer, Enterprise and Global can be read as a generative approach to modularity whereby the role of ABC is not merely to centrally coordinate the tasks and activities of ecosystem's partners (or to support connectivity), but rather to provide a common terrain to a dispersed and generative ecosystem of companies in support of their developing novel business propositions and unforeseen services and functionalities in Digital and Networks. The perception of ABC as a fully digital organization requires novel perspectives on problems and the adoption of novel organizational structures, while innovation and agility required new holistic perspectives bringing all aspects of a system together.

In sum, the agility characterizing a generative modularity goes beyond the horizontal layered architecture, and rather acts as a coherent coordinating entity that senses the environment and reacts and adjusts to its evolution. Indeed, ABC created a "digital" function to lead innovative digital efforts, and ensure strategic coherence, across the company.

6. Discussion and conclusion

Our analysis reveals that the evolution of ABC retraces changing interpretations of modularity. As the external industry, regulatory and technology context evolved, so ABC reacted adjusting its organizational structure and internal processes accordingly. We argue that how boundaries are traced within and across its legal authority in each stage of its development, and how functionalities are defined, reflected a dominant interpretation of a modular system at that time, and yet they coexist within the organization today.

As the organization changed and evolved, these four archetypes coexisted and overlapped. The *engineering archetype* of modularity overlaid the early period of ABC, and yet today emerges as technologists and strategists are concerned with the legacy of ABC as a regulated public provider of connectivity services to the general public. The *logical archetype* emerges with the horizontal modularization of the company's activities and businesses into logical layers (Yoo et al., 2010), thus separating infrastructure from platform services and distinguishing retail from wholesale. The *ecosystem archetype* focused on the coordination and integration of independent vendors, service providers and partners –a foundation for the later restructuring. Lastly, the *generative archetype* focused attention towards ABC's decision to set-up new digital and network units to foster the role of ABC within an open digital ecosystem where unforeseen opportunities are created by a variety of actors outside ABC. In essence, the goal of the new digital strategy of ABC appears to ensure a transition to a new perspective of modularity as functionalities and services are developed by autonomous external actors but coordinated and internalized by ABC.

Three implications can be derived. Firstly, that the nature of the modules making up modular systems should be kept distinct from the process through which modularization occurs as both can be characterized by their own "top-down" or "bottom-up" logics. Both aspects have been highlighted by the literature; however, the literature tends to conflate the two and identifies organizationally centralized systems with functionally deterministic systems and vice versa (Hylving & Schultze, 2020). This is evident when discussing layered modularity in the context of digital innovation (Henfridsson et al., 2018). Our study of ABC shows that this does not need to be the case: The layered modularity adopted by the telecommunication industry in the early 2000s was the first step in separating the underlying stable infrastructure from the service layers. Generative patterns emerged later, as the ecosystem perspective replaced the original vertically integrated perspective.

Secondly, our research reveals that various approaches to modularity can coexist and overlap. This suggests a contingent view of the mirroring hypothesis (Sorkun & Furlan, 2017) that may explain why in some circumstances the concept of modularity confirms the alignment between governance and architectural dimensions (Colfer & Baldwin, 2016), and in others it defies it (Furlan et al., 2014).

Thirdly, our study reveals the importance of legacy systems in shaping and constraining the way in which the organization continues to be modularized – what we term architectural modular inertia. As ABC illustrates, socio-technical systems do not remain fixed but change and coevolve over time through discrete stages (Lyytinen & Newman, 2008), each fostering, and reflecting, a different perspective. This interplay between perspectives can enrich the assessment of situations and reveal novel opportunities. However, our case study also reveals the opposite: some decisions attempt to undermine and unravel previous modular structures as the company tried to align with the wider industry's trend. In a complex, converged and interconnected environment (such as the ICT one), this unveils an interesting management challenge that needs to be further explored: understanding the value that each perspective brings to the overall organization and ensuring that the value from the integration of perspectives is realized whilst managing its tensions.

In conclusion, this research calls for a more comprehensive interpretation of modularity that goes beyond the dichotomy between functionally deterministic artifacts and functionally agnostic logical layers typical of the recent IS literature on digital innovation and digital platforms (Constantinides et al., 2018; Henfridsson et al., 2014; Yoo, 2012). Given the increasing importance of open and polycentric ecosystems (Mindel et al., 2018) and meta-organizational forms fostered by increasing digitalization (Kretschmer et al., 2020), future research in this field should adopt a socio-technical approach to modularity (Sarker et al., 2019) blending both perspectives. This requires a characterization of modularity in duality terms (Farjoun, 2010), and an acknowledgement of the paradoxical nature of socio-technical systems (Putnam et al., 2016) where a multiplicity of blurred and overlapping boundaries (Gawer, 2020) emerge from the coexistence of multiple levels and units of analysis (Wang, 2021).

7. References

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