REPRESENTATION AND FLEXIBILITY STRATEGIES FOR MANAGING THE DYNAMIC AND STRUCTURAL CONSEQUENCES OF PROJECT COMPLEXITY

Serghei Floricel
Department of Management and Technology
School of Management, Université du Québec à Montréal (ESG UQAM), Canada
floricel.serghei@uqam.ca

Sorin E. Piperca
Department of Management
Birkbeck, University of London, UK
s.piperca@bbk.ac.uk

Richard Tee
Management Department
LUISS – Libera Università Internazionale degli Studi Sociali Guido Carli, Rome, Italy
rtee@luiss.it

ABSTRACT

In this paper we propose a theoretical framework that highlights the most important consequences of complexity for the form and evolution of projects, and use it to develop a typology of project complexity. This framework also enables us to deepen the understanding of how knowledge production and flexibility strategies enable project participants to address complexity. Based on this understanding, we advance a number of propositions regarding the strategies that can be most effective for different categories of complexity. These results contribute to integrate various strands in the research on project complexity, and provide a roadmap for further research on the strategies for addressing it.

1. Introduction

While we know that complexity affects project effectiveness, it is unclear what strategies can be used to manage different forms of complexity. This paper aims to advance our understanding of different strategies that can be used to address project complexity. From infrastructure construction to developing biotechnology or software products, complexity has been blamed for causing unexpected events, late changes, additional costs and delays, and for affecting project performance and value creation (Shenhar 2001; Tegarden et al. 1995; Williams 1999, Katsila et al. 2016). One example of how complexity affects projects is the launch-day failure of the luggage handling system at Heathrow Terminal 5. While the immediate source of problems was a software bug, during late execution stages, on-site interference between contractors produced delays that eventually required schedule compression that, in turn, prevented an adequate testing of the system. This example points out to the multiplicity of factors and interactions involved in a project as the source of its complexity, and to consequences that concern the form the project will take as well as its evolution in time. But, in spite of this basic understanding of complexity, two key issues remain open. First, what are the most important dimensions of project complexity? Second, what strategies can be used to manage them effectively?

Given its impact, the project management field has made significant efforts to understand the nature and consequences of project complexity, and to develop approaches for managing it (Geraldi et al. 2011). One source of inspiration was the fundamental literature on complexity. Concepts such as heterogeneity, emergence or chaos provided a fresh perspective on the dominant approaches for planning and managing projects (Bakhshi et al. 2016; Cooke-Davies et al. 2007). But, while these abstract concepts offered a fertile ground for criticizing the foundations of the discipline, they proved to be less useful as a basis for developing concrete practices that would help address complexity. Therefore, another approach was to investigate managers' perceptions in order to map and measure the concrete factors that appear to increase project complexity (Bosch-Rekveldt et al. 2011; Chapman 2016; Nguyen et al. 2015; Vidal et al., 2011). Some researchers went even further and attempted to identify the strategies that managers deem appropriate for addressing each factor (Dao et al. 2016). But the large number of identified factors make it difficult to provide theoretical justifications and empirical evidence that goes beyond managers' opinions on what factors are important and what strategies are effective (Xia & Lee 2005). There is even a risk that such approaches only collect "rationalized myths" (Meyer & Rowan 1977) circulating in the organizational field of the project management discipline.

Our attempt to address these issues relies on two premises. First, the most fruitful conceptual strategy for understanding complexity and how it can be managed consists of bridging abstract theories with problematic situations and practices encountered in projects. We believe that the essential aspects of project complexity can be captured by a few generic dimensions, which can be connected to concrete factors observable in various types of projects. Second, we assume that each form of complexity is best addressed by specific strategies out of the variety of available ones. Some of these strategies create an improved representation of the project and of its environment, helping participants to understand the specific complexity they face and to prevent its effects, while others aim to increase the flexibility of the project in order to address the unexpected consequences of complexity (Floricel, Michela & Piperca 2016; Maylor & Turner 2017).

Based on these premises, this paper makes three contributions. First, we integrate various strands in the research on project complexity into a model that highlights its most consequential dimensions for projects and use these to develop a typology of complexity. Second, we use this framework to develop a parsimonious categorization of knowledge production and flexibility strategies for addressing project complexity. Third, we derive a number of propositions regarding the strategies that are most effective with respect to various forms of complexity. In our view, these contributions provide a roadmap for subsequent empirical research on project complexity and the strategies for addressing it. By increasing the feasibility of empirical corroboration, our results also open new perspectives for creating more effective project management practices.

The paper proceeds as follows. In the following section, Section 2, we disentangle the literature on project complexity in three themes: antecedents, mechanisms and consequences. In Section 3, we detail our theoretical framework with respect to complexity and the strategies for addressing it, and propose a series of propositions that connect these elements. A discussion and conclusion section summarizes the argument and suggests ways to carry this research further.

2. Theoretical context

The project management literature and the fundamental contributions that inform it use the term complexity to cover three distinct topics: a series of antecedents, such as the multiplicity of relevant factors; a series of mechanisms, such as emergence or self-organization; and a series of consequences such as unpredictability and lack or control. The following figure organizes these aspects of complexity and identifies the key dimensions of each aspect.

Insert Figure 1 about here

In terms of ***antecedents***, some researchers see complexity as an intrinsic property of reality, irreducible even if our knowledge were perfect. Others argue that complexity perceptions are a product of the cognitive limitations of human and organizational actors and of their knowledge and informational tools with regard to representing this reality, in particular its heterogeneity and interactions, and, hence, to predicting and controlling their consequences (Rheinberger 1997; Whitty & Maylor 2009). The ***intrinsic*** viewpoint is held by philosophers and scientists who assume a *heterogeneous* world, featuring diverse components with multiple aspects and properties, which, therefore, *interact* in multiple ways to produce unpredictable forms and dynamics (Bunge 1979; Rind 1999; Mayr 2000). For example, research on biological systems highlights the indeterminacy and multiplicity of material properties and of their interactions, while research on artificial systems emphasizes the number and diversity of parts or components and their intricate interoperation (DeLanda 2005; Weng et al. 1999; Menges 2012). Project researchers sharing this view tend to emphasize the number and diversity of relevant factors, such as the number of different stakeholders or disciplines involved in a project, as well as their interrelations (Van Marrewijk et al. 2008; Maylor & Turner, 2017; Bosch-Rekveldt et al. 2011).

In turn, the ***cognitive*** viewpoint argues that perceived complexity is an artifact of our imperfect representations. A first reason for such perceptions is the imperfect *correspondence* of representations with reality. Our perceptual abilities, even when they are enhanced by detection, magnification and measurement capabilities, overlook, regularize and approximate many aspects of the world (Floricel, Michela and George, 2011). Engineering and other conventions for representing objects increase the distance even more by overlooking additional details (Henderson 1995). In turn, knowledge representations, such as scientific abstractions or engineering formulas, necessarily simplify the properties of natural and artificial objects (Kline 1987). In their quest for ideal parsimony, symmetry and generality, they forego irregularities in shape, structure or texture, along with secondary forces and interactions (Nightingale 1998). In turn, computer scientists highlight what they call *computational* complexity (Blum 1967; Turing

1937). Namely, they point out that increasing the correspondence with reality also raises the computational power required for operating with resulting representations (Biggiero 2001; Tergaden et al. 1995; Katina et al. 2014). From this point of view, the complexity of an object corresponds to the difficulty of extracting regularities that can simplify its description, along with the volume of computations required for retrieving its form from this condensed representation (Kolmogorov 1965; Goertzel 1992; Gell-Mann & Lloyd 1996).

A second key theme of complexity regards what we term ***mechanisms,*** which, given particular antecedents, produce unpredictable consequences or overwhelm cognitive abilities. Existing research has focused on two aspects: the emergence of systemic properties and their evolution over time. The ***emergence*** stream investigates how the aggregation of component entities produces systemic properties that cannot be explained, let alone anticipated, by only considering the properties of these components, even when their interaction propensities are taken into account (Bunge 1979). This irreducible character of higher level properties becomes apparent at all successive levels of organization, from molecules with respect to atoms and cells with respect to molecules (Sauer et al. 2007) to organizations with respect to the individuals composing them (Crossley 2011). A first dimension of emergence is the '*upward' non-additivity* of component aggregation (Sawyer 2001; Wimsatt 2006). Proposed mechanisms start with the breaking of symmetry with respect to physical laws in aggregate systems such as molecules (Anderson 1972). For higher levels, the focus is on the nature and pattern of interactions or couplings between components (Alexander 1964; Anderson 1999). For example, research on processes occurring in materials and living organisms turned its attention to the role of supramolecular, noncovalent ties in their complex self-organizing or adaptive properties (Lehn 2002). Research on artificial objects stresses the role of secondary interactions between components in shaping their form (Simondon 1989). Sociomateriality researchers suggests that emergent properties of materials and artifacts influence the agency, practices and relations between human actors (Barad 2003; Orlikowski 2007). In turn, the properties of social networks and organizations, including projects, emerge from this tissue of practices and relations, and the objects with which they are intertwined, by means of constant translation and maintenance efforts as well as unintended routinization (Callon 1986; Floricel et al. 2014). A second dimension of emergence mechanisms include the *downward conditioning* of collectives of components by higher level systems (Simon 1981; Bar Yam 2004) or mutual influences between levels (Kontopoulos 1993). This kind of hierarchical inter-level influences or multilevel nestedness underlie the complexity of biological (Adami 2002; Kohl & Noble 2009; McShea 2001), communication (Hanseth et al. 1996), and social systems (Klein, Dansereau & Hall 1994). Research on projects has also turned its attention towards this kind of influences by recognizing that projects, teams and artefacts are nested in broader technical systems, organizations, inter-organizational networks, and institutional frameworks (Brusoni et al. 2001; Drazin, Glynn & Kazanjian 1999; Engwall 2003; Gobeli, Koenig, & Bechinger 1998; Miller et al. 1995).

In turn, ***unfolding*** mechanisms address processes through which, in time, complexity drives the systems of interest along multiple pathways in unpredictable ways. This theme has also been addressed from two perspectives. The first focuses on *destabilizing engines* that bring about sudden, radical transformations or unpredictable, chaotic change patterns (Thom 1974). Researchers seek to characterize the causal mechanisms, such as nonlinear interactions or path-dependent processes that amplify small variations in initial conditions (Arthur 1989; Whitesides & Ismagilov 1999), and attempt to understand the conditions, such as number of interacting factors (Dooley & Van de Ven 1999), that activate these mechanisms. Their insights inspired project management researchers in addressing various dynamics from catastrophic artefact failures to the conflictual unraveling of teams and inter-organizational networks (Floricel & Piperca 2016; Maylor & Turner 2017; Saunders 2015). A second perspective focuses on *stabilizing feedbacks* that tame destabilizing tendencies but still produce unpredictable evolutions (Prigogine 1997; Maturana and Varela 1980; Luhmann 1995). Fundamental research in self-organization uses simulations to show how order emerges out of chaos (Wolfram, 1984). In turn, organization scholars study mechanisms such as structuring from repeated interactions between actors (Coleman 1966; Feldman & Pentland 2003), or lifecycles in which stabilization follows turbulent periods (Helfat & Peteraf 2003; Klepper 1997; Weick & Quinn 1999). Others pay attention to processes that maintain highly dynamic patterns, such as high velocity and exponential growth (Bogner & Barr, 2000; Eisenhardt 1989; Floricel & Dougherty 2007).

In terms of ***consequences***, the literature also sets apart a structural and a dynamic aspect (Benbya & McKelvey 2006). The ***structural*** kind of consequences refers to the *unpredictable form* of the project: organizational and contractual structure, technical or architectural solutions, and as-built artifacts. For example, during development, project concepts go through several iterations, which push the end result far away from the initial vision (Miller & Lessard, 2001, Verganti et al. 2001). Some of this unpredictability stems from underlying material connections between entities (Floricel et al. 2014), and the “rich indeterminacy and magic of matter” (Kwinter, 2003: 91), but also from a range of multilevel influences on projects, the interplay of their “human side” (House 1988) with the formalizing, political and economic forces in organizations (Aubry et al., 2010), industrial sectors and broader institutional and social systems.

A second kind of structural consequence focuses on *unexpected properties*. While such properties may appear to be minor deviations, because they are discovered quite late in the project, when prior decisions and actions are more difficult to reverse, they are even more likely to cause major crises or conflicts around the required corrective changes (Davies et al. 2005). For example, advances in execution uncover unexpected interferences between project subsystems or between the project and soil conditions, adjacent structures, natural habitats, neighboring communities and various regulations (Hsieh et al. 2004; Sun & Meng 2009). These may, in turn, interfere with the access on site of contractors for subsequent activities, accentuate conflicts of interests between participants and amplify personal animosities (Floricel et al. 2011).

Other researchers emphasize ***dynamic*** consequences for the project and its environment. A first dynamic effect is *irregular change*. Management scholars have paid special attention to dynamics in organizations and their environments, and the challenges they pose (Eisenhardt 1989; D'Aveni 1994; Meyer et al. 2005; Polley 1997; Sydow et al. 2009; Teece et al.1997). Some researchers even argue that organizing is an ongoing activity, struggling to reconnect a world of intersecting event strands, in which stability is just a cognitive artifact or a fragile result of recurring processes (Tsoukas & Chia 2002; Hernes 2008; Hernes & Weik 2007). Project scholars also pay attention to the dynamics of projects and their environments, in particular to chaotic change and the special kind of uncertainties it creates (Collyer & Warren 2009; Sommer & Loch 2004). They single out the consequences of unpredictable evolutions in user needs and markets, as well as in technological and regulatory environments (MacCormack et al. 2001).

A second type of dynamic outcomes consists of *unexpected events*. These are emphasized by scholars who argue that social systems having an inward, self-referential orientation, such as projects attuned to their goals and operating plans, are subject to perceptual discontinuities when dealing with environments whose complexity is higher than their internal communicational complexity (Ashby 1958; Luhmann 1993). The management literature highlights the challenges caused by unexpected events (Morgeson, Mitchell & Liu, 2015), for example jolts (Meyer 1982), attributes their emergence to a complex "causal texture" of the environment, and suggests that they lead to a sudden "increase the area of relevant uncertainty" (Emery & Trist 1965). Project research also singles out unexpected events occurring inside and outside the project as key a source of trouble (Soderholm 2008; Piperca & Floricel 2012). Similar to unexpected interactions, their surprising and late occurrence amplifies their impact on projects (Floricel & Miller 2001).

In the next section, we use this background to develop a parsimonious set of dimensions and a typology to characterize project complexity, and then use it to understand the strategies that can be used to manage complexity and derive a series of propositions about the most effective strategies for managing each type of complexity.

3. Theoretical framework and propositions

Our theoretical framework uses the same dimensions of complexity proposed in Figure 1, by transforming them into variables and types of complexity. We then use them to develop a more selective model about the influences between these complexity variables. Our approach can be termed mechanismic (Hedström & Swedberg 1996; Davis & Marquis 2005), because we suppose that antecedent factors will trigger alternative mechanisms, namely bits of processes that are potentially present in the relevant systems, but are activated only in certain conditions and not in others. This enables us to tie structural and dynamic consequences to a given set of antecedents. The overall model relating these aspects is represented in Figure 2.

The model includes essentially two influence pathways, ending, respectively, with structural and dynamic consequences. We assume that both pathways start with the antecedents discussed above, namely intrinsic properties and representation imperfections. The upper path, ending in structural consequences, starts with the influence of these conditions on the emergence mechanisms present in the project. We argue that, depending on the combination of intrinsic conditions and representation imperfections that prevails in the project, four types of emergence processes will be observed in projects. Moreover, each type of emergence process will result in a particular kind structural consequence. Further, we assume that the strategies for minimizing these structural consequences essentially refer to knowledge production capabilities, which enable project participants to understand and master the respective emergence processes.

The second pathway, ending in dynamic consequences, also begins with a direct influence from antecedents, which in this case refer exclusively to intrinsic properties and in a more specific way. Namely, we argue that particular combinations of relevant factor diversity and interaction number and nonlinearity increase the chances to trigger either destabilizing or stabilizing unfolding mechanisms. A second influence from antecedents proceeds indirectly, through emergence mechanisms, in particular whether the prevailing processes involve upward non-additivity or downward conditioning. Depending on whether antecedents trigger stabilizing or destabilizing mechanisms, and inter-level emergence is primarily upward or downward, we propose four types of unfolding processes, with specific dynamic consequences for projects. Because all of these consequences have unexpected or surprising aspects, participants will have to respond after the fact rather than anticipate specific dynamic paths. Therefore, we assume that effective strategies for addressing dynamic consequences rely on cultivating project flexibility, and propose, for each of the four types of unfolding, a specific type of appropriate flexibility.

This model makes two strong assumptions, namely that each type of consequence stems directly from only one type of mechanism, and, moreover, is mitigated by only one type of strategy. In the following subsections, we detail the model by dividing the discussion along these two key influence pathways, and further explaining these and other assumptions we make.

Insert Figure 2 about here

3.1 Pathway and strategies for structural consequences

The endpoint of this pathway, structural consequences, is concerned with the unexpected aspects of project form, considered as an (end) state, namely a set of properties. While accepting that processes leading to this state occur in time, emergence mechanisms, as discussed in the review section, do not emphasize the temporal aspects of phenomena, but particular conjunctions of antecedent properties that produce emergent properties, namely forms with unexpected aspects. To address these phenomena we sought inspiration in the debate between the intrinsic and representational viewpoints on the nature of complexity. Building on phenomenological views on projects (Cicmil et al. 2006), we could assume that, given a current level of knowledge, both sides of the debate contribute to our understanding of complexity perceptions, as experienced by project participants. From this perspective, the aspects emphasized by each side of the debate imply two dimensions of complexity antecedents.

The first dimension is suggested by researchers who view complexity as an intrinsic property of reality. We interpret this to mean that project participants, given the knowledge that they deem available to them, do not see any chance of completely understanding and mastering the relevant phenomena. Consequently, at some residual level, complexity is an inseparable property of the perceived world. With regard to the antecedents related to this dimension we distinguish heterogeneity, namely the infinite variety of elements and aspects present in the word, from the multiplicity of interactions between these factors. In other words, the context of some projects may be dominated by the multiplicity of relevant factors while others by the multiple interactions between the various factors. We further assume that the heterogeneity end of this dimension is more likely to give prominence, from the participants' perspective, to upward non-additivity mechanisms, namely to conjunction processes that will converge towards overall configurations with unpredictable properties (project form). The interactions end of this dimension is more likely to give prominence to downward conditioning mechanisms, because participants will perceive the mostly hidden interactions as inexorably driving the aggregate towards some stable state, which, in turn, starts to subsume and condition the behavior of converging elements. But the multiplicity of interactions and 'vertical' influences, downward as well as inter-level, means that the aggregate system will have many unexpected properties.

The second dimension, inspired by those who see complexity as a consequence of imperfect representations, focuses on the nature of these imperfections, as perceived by project participants who attempt to use their perceptions, knowledge and modeling capabilities to anticipate and influence the form and properties of aggregates. This dimension sets apart a weak representation correspondence with reality from an insufficient computation power to anticipate consequences. On the low correspondence end, the critical issue is that currently available knowledge does not include all relevant factors or interactions or mistakenly considers some of them negligible. As a result, project participants do not take these aspects into account when shaping the project and are bound to discover them while implementing or operating the project. On the weak computation power end, the key issue is that, even with good correspondence, or perhaps because participants attempt to increase it, they cannot work out all the consequences of contributing factors, in term of aggregate form and properties.

Based on these two dimensions, we identify four types of complexity context and propose a corresponding emergence processes for each of them. Figure 3 presents the four types, suggests the projects and project aspects in which they are most likely to be observed, their most likely structural consequences, and suggests the most appropriate representation-producing strategies that help project participants to increase their anticipation and influence over aggregates, such as the project system. Inspired by organization theory, project management and engineering design literatures, we believe that these strategies reduce the distance and computation difficulties, given the specific combination of heterogeneity, interactions, and representation shortcomings affecting the project (Loch & Terwiesch 1998; Chandrasegaran et al. 2013; Visser 2006).

Insert Figure 3 about here

Endless complication. This first type of structural complexity results in a context of high intrinsic heterogeneity and low representation correspondence. The aggregate project form is unstable and its final configuration cannot be predicted because of the constant discovery of new relevant factors. We consider that this situation is typical of innovation projects, in which knowledge derived from previous projects is not entirely pertinent and may induce participants to overlook some key factors or to underestimate their role. This is also typical of market aspects, in which additional customer needs, market segments, competitors, products and strategic moves, as well as a host of other factors are likely emerge as significant in most projects.

Because such a context continuously reveals new relevant aspects, it is important to detect and bring them to bear on project shaping activities as early and as minutely as possible. Therefore, we believe that distributed learning about various aspects involved in the project (Ahern et al. 2014; Prencipe & Tell 2001) through role differentiation as well as background and external network diversity (Cohen & Levinthal 1990), and by bottom-up decision making (Burgelman 1991) is likely to be more effective than attempts to centralize learning and decision making. Closeness to the "field" and specialization in detecting the given aspect are likely to reduce the distance between representation and reality for participants, while bottom-up decentralized selection will speed up and make more effective the emergence of the final form. Concrete examples include the approaches used by companies such as 3M and Google. For example, Google encourages individual learning by employees, and uses employee panels to predict market demand and democratic voting procedures to decide on innovation projects (Iyer & Davenport 2008). Information systems that support a "complex, distributed, and evolving knowledge-base" and an "unstructurable, dynamically changing process of deliberations and tradeoffs" are likely to enable such representation strategies (Markus, Majchrzak & Gasser 2002: 206). This translates into the following proposition:

Proposition 1 In a high heterogeneity and low correspondence context, strategies that build a distributed learning capability are most likely to be effective in preventing the "endless complication" structural consequences of complexity.

Magic field. This second type of structural complexity context is prominent in settings with multiple interactions that are inadequately captured by existing knowledge. These interactions drive the project to converge into an overall configuration, but interactions that are unaccounted or misrepresented, such as previously negligible secondary interactions that become a problem in physical artifacts designed for larger scales or performance levels (Simondon 1989; Hirsh 1989), are likely to manifest themselves through aggregate properties that participants cannot control adequately. As a result, project artefacts cannot sustain the required constancy of operation, and corrective interventions do not have the intended effect. This kind of context is likely to be observed in infrastructure construction projects, such as airports or power plants, or in projects that develop “complex products and systems” (CoPS) such as aircraft or military systems (Miller et al. 1995; Brusoni et al. 2001). As larger scale, higher performance or additional constraints, such as building new structures in a crammed site surrounded by continuously operating systems, are imposed upon such projects, previously unknown or negligible interactions, including those with the foundations of adjacent buildings or with nearby ecosystems, start to have significant consequences. Because of multiple interactions, these consequences are likely to propagate in unpredictable ways to other parts of the project and to subsequent activities. The organizational aspects of projects are also likely to face a similar complexity context, because the multifaceted relations between participating actors, subunits and corporate entities, as well as with the broader environments, is likely to bring new interactions to prominence in various projects.

The obvious strategy is mapping all interactions in the project and using pathway analysis to identify and address the systemic risks that they may cause (Carbone & Tipett 2004; Qazi et al. 2016). However, these methods suppose that interactions are known or can be imagined, while the real danger in this context is that project participants “cannot anticipate all the possible interaction of the inevitable failures” (Perrow 1984: 11). Even when they encounter unexpected interactions, it is likely that these will be revealed indirectly, and to participants that, organizationally, may be responsible only for some of the interacting factors. Therefore, an adequate reaction of project participants depends on their ability to detect these signs (Kappelman, McKeeman & Zhang 2006), and update their routine communicational ties in ways that account for the newly discovered interactions (Henderson & Clark 1990). Building alertness, mindfulness and heedfulness to make sense of new interactions and restructure communicative ties accordingly is likely to be the most effective strategy (Saunders 2015; Weick & Roberts 1993; Weick, Sutcliffe, & Obstfeld 2008). Organizationally, it relies on building strong communication ties (Hansen 1999) and routines for rearranging these ties (Zollo & Winter 2002) as well as strong sensemaking and integration capabilities (O'Sullivan 2006; Weick, Sutcliffe, & Obstfeld 2005). These arguments are synthesized in the following proposition.

Proposition 2 In a context with numerous interactions and low representation correspondence, strategies that build a capability for mindful integration and restructuring of communications are most likely to be effective in preventing the "magic field" kind of structural consequences of complexity.

Irreducible variety. This third type of structural complexity context becomes prominent when the number of relevant factors is important but existing representations cannot reduce them to a more parsimonious set of essential properties with which participants can operate. As a result, participants are likely to concentrate selectively on some of these factors at some moments and on others at another time. This precludes them from converging on a stable project form. This kind of context is likely to be observed in software projects in which the high number of concrete factors cannot be adequately captured with most architectural modeling methods, leading to an endless succession of beta prototypes before the release of a still imperfectly stable product. A particular case could be ICT solutions developed for various implementation conditions, such as countries, sectors or types of organizations, all of which impose different needs and constraints, which are difficult to compress into a unique parsimonious set of requirements. More generally, this is also the case for the technical aspects of projects, in which taking into account the impact of so many factors (dimensions and other properties) makes designing them a highly iterative endeavor (Krishnan et al. 1997; Eppinger et al. 1994).

In this context, the problem is accounting for the variety of factors in a way that is not affected by the low computational power. We believe that the early virtual representation and simulation of the project and its behavior is the most effective strategy. Representations may range from pencil and paper sketches to multidimensional digital prototyping using CAD or Building Information Modelling (BIM) tools, and to preliminary embodiment of artifact materials and form. Even when powerful software tools are used, the efficacy of this strategy does not come from their added computational power, but from the way representational outputs boost participants' individual and collective cognitive abilities (Nicolini, Mengis and Swan, 2012). Even an imperfect output that simulates the real behavior of project aggregates, enables participants to rely on their pattern-recognition abilities to uncover diverse factors, and creates a boundary object that enables participants to contribute their varied perspectives in an integrated way (Thomke & Fujimoto, 2000; Carlile 2002; Ewenstein & Whyte, 2009; Liu et al. 2017). All this is likely to speed up the iterative process of convergence towards a relatively stable form. Stigliani and Ravasi's (2012) study of the design firm Continuum provides an example of such strategy, by highlighting the way project participants use sequences of varying sketches and assemblages of material objects to converge towards a client-oriented narrative about the object they will design. These considerations are reflected in the following proposition.

Proposition 3 In a context with high heterogeneity and low computational power, strategies that build a capability for aggregate representation of form and behavior are most likely to be effective in preventing the "irreducible variety" kind of structural consequences of complexity.

Intractable mess. The fourth and final type of context is more likely to occur when the number of interactions between relevant factors makes it impossible to compute their joint consequences based on existing representations. As a result, participants base their predictions only on a manageable subset, which is likely to cause unexpected properties of the aggregate, as evidenced by the 'black swans' problem in statistics (Taleb 2007) and the difficulty of creating high-reliability technical systems (Perrow 1984; Leveson et al. 2009; Saunders 2015). One example is biotech projects, in which the large number of levels and interactions in living beings can hardly be considered at the same time in order to predict the properties of drug candidates (Sliwoski et al. 2014) or even to replicate successful experiments (Begley & Ellis 2012). This leads to unexpected properties such as a lack of therapeutic effect and undesirable side effects. It is also likely that the institutional aspects of most projects will be characterized by a similar complexity context. The large number of social interactions underlying this aspect, even as they are captured in regulations, makes it difficult to work out their consequences for the project, and will likely produce undesirable interference and conflicting interests.

Because in this context interactions are so numerous that no amount of computation will account for all of them, the most effective strategies is to let material reality itself work out the consequences of aggregation and then test this result against required properties. In other words, the most effective strategy is trial and error based on concrete objects (Vincenti 1990). For example, in spite of many scientific advances and scores of new computational methods, pharmaceutical and biotechnology projects rely increasingly on massive trial and error instead of rational design based on representations (Nightingale & Martin 2004; Mandal et al. 2009). The effectiveness of this process can be improved by varying the reliance on preexisting knowledge, radicalness, precision and number of trials and of iterations (Gavetti & Levinthal, 2000; Fleming & Sorenson 2004). Moreover, strategies could rely on serendipity to increase variation in object forms and to induce accidents in their operation, with the goal of exploring areas outside what is normally expected (Austin, Devin & Sullivan, 2012) and seek a sort of 'falsification' (Popper 1959) for any conclusions. These arguments are synthesized in the following proposition.

Proposition 4. In a context with numerous interactions and low computational power, strategies that build a capability for a testing concrete objects in real conditions are most likely to be effective in preventing the "intractable mess" kind of structural consequences of complexity.

This set of propositions assumes that one type of context will be present, because of prevailing antecedents, and suggests a single strategy that is likely to be effective in this context. Strategies are also mutually exclusive to some extent. For example, the simulation through representation strategy supposes a rather long sequence of representations that gradually approximate the project form, while the massive trial and error strategy calls for arriving as fast as possible at a material instantiation of project form. However, Figure 3 suggests that different antecedents may prevail with respect to different aspects of the project, such as market, technical, organizational or regulatory; to various subsystems, such as hardware versus software; and even to different stages, such as definition versus design. To the extent that these portions of the project can be treated separately, different strategies could coexist in the same project. This could be perhaps the common situation in major projects and programs, or in megaprojects. One example could be a complex product and system project, such as the F35 military aircraft. An 'endless complication' context may prevail during the early definition stage, because of the endless, shifting and contradictory client requirements, an 'irreducible variety' context may prevail during the design phase, and a 'magic field' context may prevail during testing and early exploitation stages, when many unexpected properties and interactions emerge to cause accidents and delay the effective use of the artifact. The recommended strategies could be emphasized, in sequence, in each of these stages of the project.

3.2 Pathway and strategies for dynamic consequences

The endpoint of this pathway is a pattern of change that is unpredictable or unexpected. In this case, the relative timing and sequence of events, rather than the conjunction of properties, are the center of attention. As illustrated in Figure 2, we suggest that these consequences result from the activation of unfolding mechanisms, under the joint influence of antecedent conditions and of prevalent emergence mechanisms. Contributions addressing dynamic processes suggest that particular conditions may favor destabilizing mechanisms, while others, stabilizing ones. For example, Dooley and Van de Ven (1999) argue that a system deterministically influenced by a small number of variables produces a periodic pattern if variables interact linearly. Yet, nonlinear interactions between a small number of variables produce a dynamic termed 'chaos', whose path is unpredictable but which follows a predictable pattern of change. Likewise, a system influenced by many variables produces a pattern termed 'white noise', meaning totally random, if variables act independently from each other. If their actions are constrained by interactions, the consequence is 'colored noise', such as 'pink noise'—a random pattern that tends to reverse its trend with low frequency, or 'brown noise' a random pattern with path dependent tendencies. This suggests that intrinsic contextual aspects, such as heterogeneity and interactions are also responsible for generating various types of dynamic patterns, with varying levels of predictability.

Like in the case of structural consequences, we used these contributions as a source of inspiration, but adopted again the point of view of participants' lived experience. We assume that dynamic patterns are considered from the point of view of a system at some mid-range level of aggregation, which is of interest to project participants. Moreover, the evolution of this system is influenced by the aggregation of lower level elements as well as by constraints from a higher level system. For example, if participants are interested in the dynamics of the environment of their project, the market or industry is the system of interest, organizations such as firms and projects are the elements, and the broader societal system is the higher-level constraining system. If the system of interest is the project artifact (building, infrastructure, product etc.), elements are the needs, technologies, components, materials and activities that converge to shape it, and the overarching system is formed by the broader technical, organizational and natural environments (technical networks, built surroundings, landscape and soil, firms, communities etc.) that incorporate the artifact. In terms of antecedents, we consider only intrinsic properties.

We further assume that the dynamics of the focal system, as perceived by project participants, will be influenced by two dimensions. The first dimension regards the nature of unfolding mechanisms that are activated through a direct influence from intrinsic complexity antecedents. In particular, we distinguish mechanisms that are primarily destabilizing from those that are primarily stabilizing. As explained above, certain intrinsic antecedents, namely combinations of factor heterogeneity and interactions, may favor destabilizing unfolding mechanisms, while other combinations may favor stabilizing mechanisms. As a corollary, we assume that contexts in which destabilizing mechanisms are prevailing imply that the focal system has a relatively low inertia, while contexts dominated by stabilizing mechanisms involve systems with high inertia. The second dimension concerns the indirect influence of the intrinsic context, occurring through emergence mechanisms, in particular through the prevailing 'vertical' interactions involving the focal system and the other two relevant systems. Hence, we distinguish situations in which emergence processes involve upward non-additivity influences from the lower level system from situations involving downward conditioning from higher level systems. As a corollary, we assume that systems in contexts dominated by upward non-additivity are more easily decomposable, while systems in contexts characterized by downward conditioning are not easily decomposable, because of the constraints that the higher level system imposes upon them.

In examining the impact of these two dimensions and the strategies for addressing their consequences, we start with the premise that complex dynamics are problematic because of their unpredictability and unexpectedness; their specific dynamic consequences are of the 'unknown unknowns' kind. In contrast to our treatment of structural consequences, we also assume that participants consider the sources of dynamic consequences to be intrinsic, rather than imperfect representations. We account for representation issues only by assuming that participants consider the mid-range system as their task environment (Dess & Beard 1984) and focus their attention on it, leaving out some areas of the higher-level system, and examining lower-level components with a coarse resolution, overlooking many details among their multiple aspects and interactions. This helps distinguish different kinds of surprises for project participants. A further consequence of the unpredictability and unexpectedness assumption is our assumption that the most effective mitigating strategies revolve around cultivating a particular kind of flexibility that enables participants to respond ex post to dynamic consequences.

In order to understand what kind of flexibility is most effective for the various unfolding processes and dynamic consequences, we use the two dimensions introduced above to set apart four typical dynamics. The following figure presents each of them as a function of the emergence direction and, respectively, unfolding mechanisms it involves. Each resulting quadrant includes, on the left, a schematic description of how these mechanisms interact; in the center, the name of the dynamic and its most important consequence; and on the right, the strategy most likely to be effective and a depiction of how the strategy addresses the respective dynamic consequence.

Insert Figure 4 about here

Effervescence. The dynamic depicted in the lower left box designates an irregular evolution of the focal system (yellow line) which results from non-additive interactions between lower level entities. We assume that heterogeneous lower level entities autonomously initiate changes, but these changes interact in multiple ways with those initiated by other entities. The situation becomes problematic when several actions concur to create a local trend that, due to interactions, becomes a path dependent tendency strong enough to erupt into and destabilize the next level of aggregation, which is the focal system. This kind of intrusion from what can be seen as insignificant lower-level details, will be perceived by project participants as coming out of nowhere. Required unfolding conditions are similar to Brownian motion of lower level entities, which produce, dynamic patterns that can be termed brown noise or random walk. But, what transforms occasional spikes into important changes are upward non-additivity mechanisms, for example non-linear interactions between the elements involved in the spike. This kind of phenomena can be observed in project environments such as markets, where several independent competitive actions, which in themselves may have insignificant consequences, create, through nonlinear interactions a major trend that unexpectedly transforms the competitive context. With regards to project artefacts, this kind of situation, and the continual disruption it induces, can happen in the development stage of a material project, and throughout the lifecycle of software projects. In both cases, elements are characterized by low inertia and high subsystem separability, which enables the required frequency and autonomy of changes.

The consequence of effervescence is a continuous disruption of the system of interest. An example could be an IT project with physical infrastructure components jointly developed by several public transportation authorities operating in the same major urban area. Their numerous demands, many of which arrive quite late in the process, triggered by what other participants have asked or by a new understanding of technical possibilities, generate debates among them and opposition from the technical development team, but some generate sufficient impetus to be included among the requirements of the project, which may perhaps prompt a restructuring of the technical architecture, which in turn may induce new demands and so on. But the same characteristics that enable this surprising dynamic are also likely to enable the flexibility strategy that we term *agility*, namely dividing the project in small separate strands, each of whom traces a relevant aspect through frequent small iterations, and a continual restructuring of ties between strands (Conforto et al. 2016; Highsmith, 2010; Serrador & Pinto 2015). Flexibility results from maintaining the project on the edge of chaos (Brown & Eisenhardt 1997), which precludes its coagulation into a stable form that can no longer trace the emerging changes. In practical terms, this strategy favors subdividing the project into a very large number of parts and work packages, and minimizing the direct and indirect impact that activities and decisions concerning these subsystems have on adjacent subsystems and subsequent activities. This kind of approach is assumed by agile project management strategies such as Scrum. These arguments are summarized in the following proposition.

Proposition 5 The presence of destabilizing unfolding and upward non-additivity produces a dynamic of effervescence, whose consequence of disruption is most likely to be effectively addressed by strategies that increase the agility of the project.

Discontinuity. The dynamic depicted in the upper left corner of Figure 4 shows a surprising change in the focal system attributable to the downward conditioning by the higher level system. This kind of change appears when new interactions between the components of the overarching system arise outside the area which is usually considered relevant by project participants. This creates what Emery and Trist (1965) call a turbulent field, which generates irregular dynamics in the higher-level system. Because of the significant conditioning impact that these changes have on the focal system, the latter is perceived as sustaining a series of sudden radical changes or jolts. Such change is unpredictable because it originates outside the task environment that project participants normally monitor. In project environments, such as markets and industries, this kind of changes occur when previously unrelated areas in the global economy interact to impact a given sector. Examples include the recent impact of the subprime crisis in the United States on, say, the economy of Greece (via its debt) or the real estate market in Spain. For project artifact, this kind of change may arrive when political or economic interests, perhaps hidden, combine to force the client to significantly change project requirements. This occurs frequently in projects, such as movies, videogames and high performance CoPS, in which external influences vary considerably, but systemic constraints boost the interactions between elements (Levinthal 1997).

Because of these interactions, the answer cannot be piecemeal change in the project. In fact, the form the project had prior to a jolt is likely to become irrelevant in its entirety after the jolt. In this case, we argue that the effective strategy is preparing for deep, hierarchically driven iterations (MacCormack et al. 2001; Shenhar 2001; Whyte et al. 2016), essentially getting ready to restart the project several times, keeping only the learning from previous iterations. This strategy calls for reducing intertemporal inertia in the form of irreversible commitments and sunk costs. Thus, projects focus effort on essential elements, whose development provides the shortest path to an integrated solution (Olsson 2006). This strategy reduces commitment by avoiding the additional effort involved in cultivating flexibility through modular architectures and interfaces. In addition, its swift implementation may signal decisiveness and contribute to structure the fluid post-discontinuity context of the meso-level system. These arguments are synthesized in the following proposition:

Proposition 6. The presence of destabilizing unfolding and downward conditioning produces a dynamic of discontinuity, whose consequence of irrelevance is most likely to be effectively addressed by strategies that prepare the project for deep iterations.

Amplification. The dynamic depicted in the upper right corner of Figure 4 occurs in the presence of stabilizing mechanisms involving vertical interactions between the focal system and higher levels systems. These self-organizing or structuring processes produce important and continuous change and impose a strong inertia on this dynamic, but positive feedbacks between levels also make it hard to predict the end state of the system; small variations are likely to be amplified into major differences. In the case of project environments, such as markets, this kind of dynamic can be observed when vertical interactions with the societal level produce significant growth. For example, sectors proposing a series of innovative technologies, particularly those providing a new kind of infrastructure, may induce society to redirect resources toward these sectors. In turn, these resources enable further investment in innovation, which increases product functionality, performance and reliability, which induces new swaths of society to pour resources into the sector. A current example of such processes is the growing 'smart' sector of economy, involving smart phones, TVs, home appliances, houses, cities and governments. Despite the continuity of trends, amplification of small deviations makes it difficult to predict where dynamic processes will bring the sector (Lord, Dinh & Hoffman, 2015). In the case of artifacts, similar interactions between the project and its clients may lead to growing demand, or, on the contrary to a downward spiral of mistrust.

The typical consequence of this dynamic for a project is insufficiency, for example in terms of project scope and capacity, or, in case of a downward trend, overcapacity. In the case of insufficiency, a strategy based on iterations may increase project vulnerability because of their parsimonious nature. The continuity of change and the inertia imposed on the meso-level by the downward conditioning mechanisms, maintain the relevance of significant portions of the project, which makes starting all over unneeded. Downward conditioning is also likely to boost interactions and prevent separate adaptation of various parts of the project. Therefore, we argue that the most effective strategy for this context is preparing real options (Trigeorgis 1996) via small proactive investments that open the possibility to later add markets or capacities, or even open entirely new projects in a relatively short time and with reduced investment (Garvin & Ford

2012; Fichman et al. 2005). For example, a power plant project may purchase land for a second unit, and even complete site preparation activities, and be ready for a second unit in case demand grows beyond anticipated level. Likewise, a university may initially only migrate the human resource management system towards the new information platform, but the platform may include from the beginning the option to add other systems. Options to abandon or delay the project or parts of it may help address downward trends. These considerations are summed up in the following proposition.

Proposition 7 The presence of stabilizing unfolding and downward conditioning produces a dynamic of amplification, whose consequence of insufficiency is most likely to be effectively addressed by strategies that prepare options for the project.

Acceleration. Lastly, the dynamic depicted in the lower right quadrant of Figure 4, is likely to be present in a context of upward non-additivity and stabilizing unfolding. This dynamic occurs when positive feedback mechanisms involving the meso-level system and its components, increase the pace of change in the system while accentuating inertia through path dependency. With respect to project environments this kind of interaction can be observed between industrial sectors and firms. A notorious example are high velocity sectors (Eisenhardt 1989), which maintain an accelerated pace of change, such as that captured by Moore's Law. Micro level entities, such as firms, perceive and eventually take for granted this pace, and synchronize their internal processes, such as new technology and product development, with it. In doing so, they collectively reproduce the pace (Bogner & Barr 2000). If the meso-level system is an artefact, similar self-reinforcing acceleration or pacing may occur between the rhythm of activity or change at the system level, and the actions of various participants involved in its development.

The challenge of acceleration is the continuing advancement of relevant knowledge and the constant diversification of required skills, which threatens to make solutions and decisions obsolete. Project participants may cope by pacing activities and capability renewal on the rhythm of meso level advancements (Brown & Eisenhardt 1997; Klarner & Raisch, 2013). But, in spite of the relative predictability of trends and pace, acceleration makes it difficult to follow changes. As Bergvall-Kåreborn & Howcroft (2014: 425) put it, "changes ripple through and accentuate ongoing trends and developments." For project participants, component interactions and non-additive processes may unfold too rapidly to be understood in a timely manner; the project may escape their control and run away towards an unpredictable outcome (Perrow 2008). Trying to follow all intersecting strands with an agile strategy is likely to overwhelm the cognitive and adaptive capacities of actors and organizations, even if these are maintained at the edge of chaos.

A strategy with better chances of addressing this complex dynamic would be to separate the project into independent parts, allowing participants to develop and update primarily the specialized knowledge required for the part in which they are involved, and to only track and respond to a subset of overall changes. The unfolding inertia created by feedbacks between the meso-level system and lower level entities and upward non-additivity processes enables a relatively continuous dynamic, which provides a chance for durable partitions of this kind. In essence, this strategy cultivates modularity (Simon 1962), splitting the project into semi-autonomous modules interacting through limited and well-defined interfaces that contain most changes locally and regularize the influences between modules (Sanchez & Mahoney 1996; Suh 2005). The resulting flexibility is twofold. On the one hand, modularity enables responding to changes that affect each module without affecting the others, and, on the other hand, it simplifies the less frequent replacement or rearrangement of modules (Ulrich 1995; Schilling, 2000). Despite imposing what may appear in the short term as an architectural straightjacket, evidence suggests that modularity enables faster as well as less disruptive change in the long term (Langlois & Robertson, 1992). With respect to artefacts and their development activities, modularization requires a partition that minimizes the flows of information, energy etc. between modules, as well as the number of design iterations that would cross interfaces, and perhaps isolating the subsystems that appear more likely to be impacted by future change (Dahmus, Gonzalez-Zugasti & Otto 2001; Hölttä-Otto et al. 2014; Magnusson & Pasche 2014). For project organizations or networks, a similar structure enables knowledge specialization and minimizes interactions across unit or firm boundaries, perhaps following the fault lines of technical architectures. But depending on the nature of artifacts, particularly of the interactions between their parts, modularization also requires an overarching 'system integrator' unit or firm (Brusoni & Prencipe 2001). Modularization can be extended into project environments, such as a markets, via the proactive standardization of technical architectures and interfaces (Wodczak et al. 2016), and the development of alliances that would impose a particular architecture, platform or 'stack' as a de facto standard (Kenney & Pon 2011; Gawer & Cusumano, 2014.). These arguments are summarized in the following proposition:

Proposition 8 The presence of stabilizing unfolding and upward non-additivity produces a dynamic of acceleration, whose consequence of obsolescence is most likely to be effectively addressed by strategies that increase the modularity of the project.

Because they may involve different levels, it is possible to observe in the same project a combination of dynamics shown in the same column in Figure 4. For example, ongoing effervescence would be punctuated by relatively less frequent major discontinuities. Likewise a dynamic of acceleration inside a sector may be combined with a dynamic of amplification with respect to a broader society. Also, different aspects of the project may be subject to dynamics pertaining to different columns. For example, the market environment may be subject to a dynamic of amplification, while the institutional environment may face discontinuities caused by accession to power of politicians sharing radically different ideologies. Likewise, a context of hypercompetition (D'Aveni 1994) may involve effervescence regarding markets preferences and competitor moves and acceleration with respect to the advancement of technological frontiers. Projects are likely to respond to with a combination of strategies. Yet, many requirements of alternative strategies are incompatible; some, such as modularity, require intense front-end preparation, while others, such as iteration, require fast action. Therefore, projects are more likely to be effective if they are able to cultivate a sort of ambidexterity (O'Reilly & Tushman, 2008), which enables the coexistence of various strategies, within the same organization.

4. Discussion and conclusions

Complexity has a major impact on projects, through execution failures, changes, delays, additional costs, dissatisfaction and accidents (Flyvbjerg et al. 2009). The project management literature has depicted this impact as resulting from a variety of factors, which either act independently or interact in unclear ways. Our theorizing suggests that this impact results from a conjunction of antecedents and mechanisms to produce two kinds of consequences. On the one hand, intrinsic properties and representation shortcomings combine to induce deviations of project form and behavior from the expected stable configuration or controllable variation. On the other hand, emergence and unfolding processes combine to induce deviations from the anticipated patterns of activity and change, expected to be regular or predictable. Our theorizing effort resulted in four categories for each of these two kinds of consequences. While relying on abstract notions derived from fundamental research on complexity, this effort creates a conceptual framework with a moderate level of abstraction. To our knowledge, this is one of the few attempts to adopt such a strategy in project management research on project complexity.

This framework contributes to integrate the two streams of research that addressed project complexity from generic and highly abstract perspectives, and, respectively, from a practical viewpoint by relying on managers' opinions. Because of the profusion of concepts advanced by these streams, most attempts at integration had, so far, to rely on a quasi-bibliometric approach to inventory and classify the terms used to discuss project complexity (Padalkar & Gopinath 2016; Bakhshi, Ireland & Gorod 2016). We believe that our original, theory-driven integration approach and the moderate level of abstraction of the resulting framework provide two benefits. On the one hand, they open the black box of complexity and help ground the understanding of complexity factors in fundamental notions such as emergence. This enabled the creation of categories with a deeper theoretical meaning, tied to essential aspects and relevant consequences of project complexity, rather than to commonsense notions such as technology and organization. On the other hand, the categories we propose remain easy to connect to concrete aspects of projects. Therefore, they can help researchers make sense of the rich set of factors identified by the practical stream of complexity research, and guide them towards understanding how each factor becomes a complexity antecedent or mechanism trigger. Of course, any increase in abstraction may result in losing some empirically-derived richness. Therefore, further research should rely on case studies and grounded theorizing to map back concrete complexity factors upon the more general categories included in our framework.

A second important contribution of this paper is theorizing about the strategies that can be used to prevent or to mitigate the impact of complexity. Contributions regarding strategies applied specifically to address project complexity are even less frequent than those discussing the nature and sources of complexity. Our contribution includes, on the one hand, theorizing the knowledge- and representation-producing strategies that are effective in preventing the structural consequences of complexity. On the other hand, we theorized strategies for organizing project activities, namely by connecting them simultaneously as well as inter-temporally, to mitigate the dynamic consequences of complexity. Once again, for each of these two types of strategies, we propose four categories with mid-range of abstraction. This level of abstraction enables the creation of meaningful categories for a host of concrete project management practices observed across a variety of domains. Further research could inventory such practices and connect them to the categories of our framework. The fundamental grounding of this framework would guide researchers towards understanding how these practices block or mitigate detrimental emergence processes, or respond to irregular or unexpected dynamics. These results could, in turn, inform research on projects as organizations and networks, in particular in what concerns their flexibility and response capacity (Floricel, Piperca & Banik 2011), along with the research on knowledge production in projects (Floricel, Michela & George 2011), and even on knowledge management and inter-project transfer in project-based organizations (Prencipe & Tell 2001).

A third contribution of this article is using the theoretical framework to develop propositions about the most appropriate strategies for addressing each kind of project complexity. With some notable exceptions (Ahern et al. 2014; Floricel et al. 2016), past research had produced few theoretical models about the strategies that are effective in addressing various kinds of complexity, and even fewer results that have been validated in a variety of empirical settings. Therefore future empirical research could corroborate these propositions both through longitudinal case studies that would investigate how various strategies work, perhaps in different project stages, as well as through cross sectional studies that could rely on differences suggested by our framework with regard to the nature of complexity in various industries to determine whether the proposed strategies are indeed more effective in addressing various categories of complexity. One particular stream of research could focus on deepening our understanding of the interrelations of the various types of complexity and strategies in a project. In addition to grasping the polyphony of complexity and the mutual exclusivity of strategies in a project, this stream could lead to the development of new research programs on the management of project paradoxes (Smith & Lewis, 2011) and the ambidexterity of project organizations (Boumgarden, Nickerson & Zenger, 2012; O'Reilly & Tushman, 2008). In practical terms, these results may suggest what practices or combinations of practices are best suited for addressing the specific forms of complexity that affect a variety of domains, such as software, biotech and infrastructure construction, and could inspire the development of new complexity management practices.

Our results also provide insights that may contribute to other fields of research. First of all, they could help advance the more abstract conceptualizations of complexity, in particular by helping identify commonalities and connections between concepts used by various researchers. Also, taken together, the results of our theorizing effort portray the becoming of complex projects as an unpredictable and uncontrollable emergence taking place in a context of surprising events and irregular unfolding. This could contribute to the emerging research on organizing as a process or an event system. Besides, results on representational and organizational strategies for addressing complexity can inform other fundamental theories of collaboration and organization.

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Figure 1 Disentangling the literature on project complexity

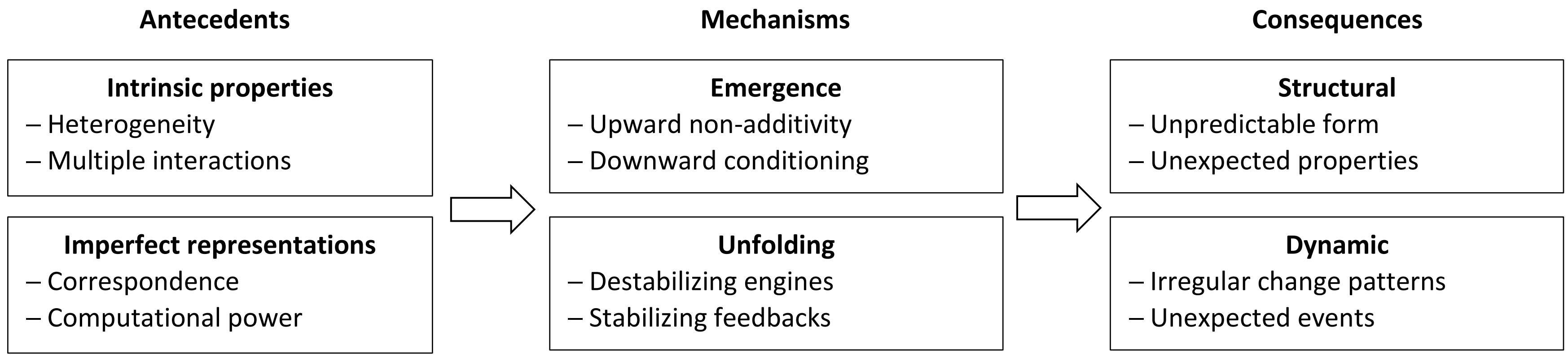


Figure 2 Integrative model of complexity influences and strategies for diminishing them

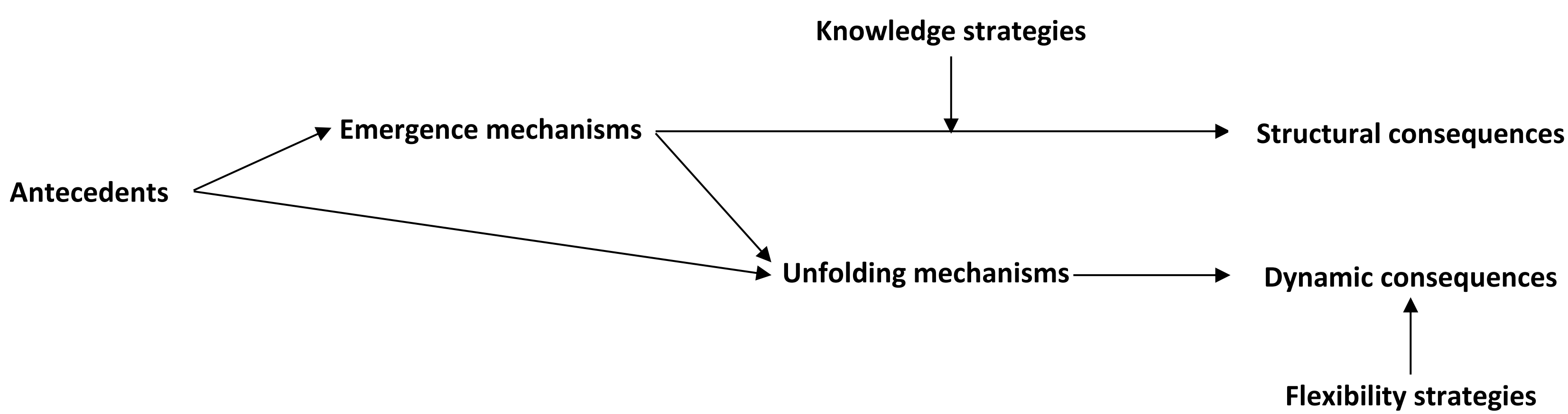
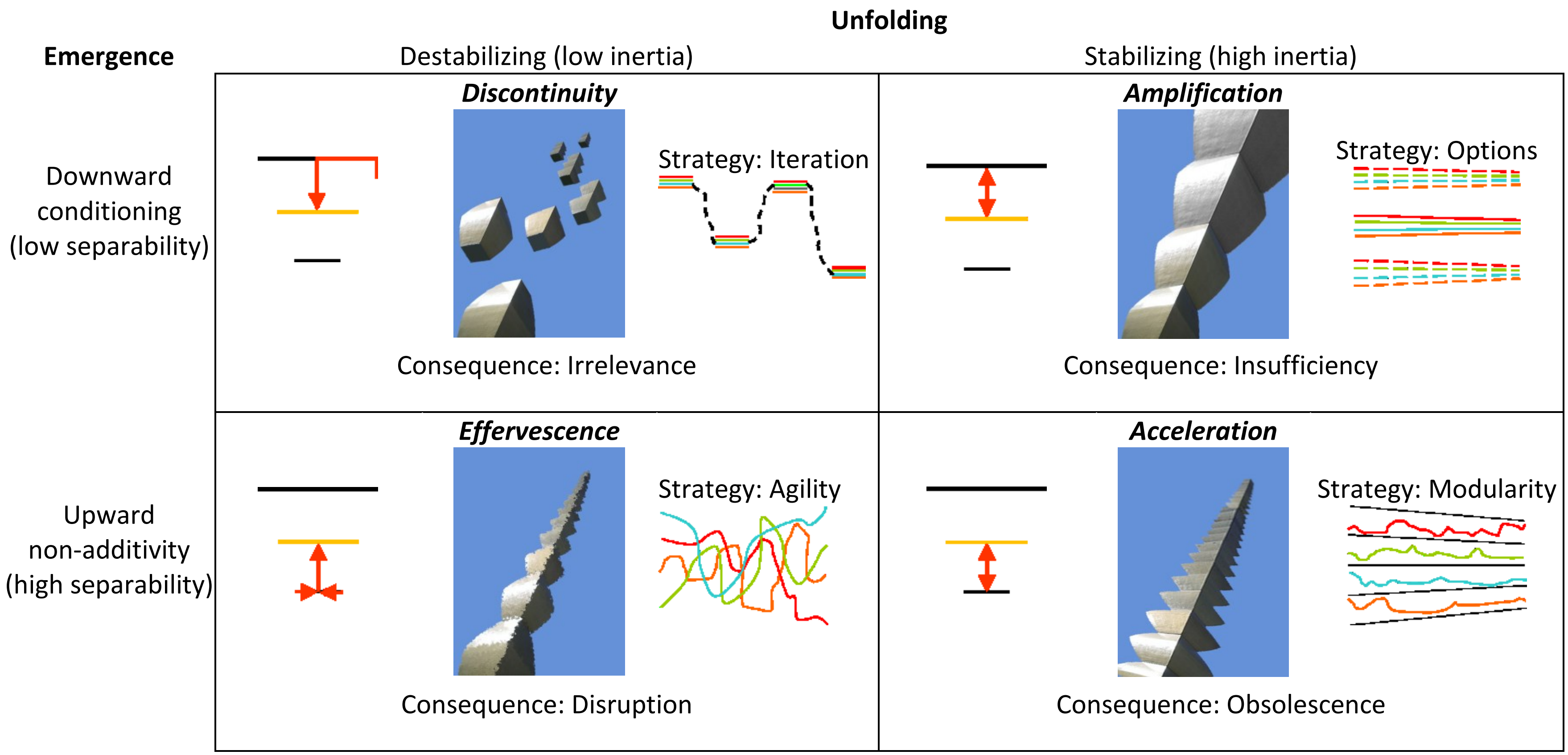


Figure 3 Types of emergence processes and structural consequences as a function of antecedents, together with the most effective strategies for dealing with them

		Intrinsic properties: Heterogeneity	Intrinsic properties: Multiple interactions
Representation	Correspondence	***Endless complication*** Innovation project, market aspects Consequence: unpredictable form Strategy: Distributed learning	***Magic field*** CoPS & infrastructure, organization aspects Consequence: uncontrollable properties Strategy: Heedful connectedness
	Computation	***Irreducible variety*** Software project, technical aspects Consequence: slow-converging form Strategy: Simulation through representation	***Intractable mess*** Biotech project, institutional aspects Consequence: unexpected properties Strategy: Massive trial and error

Figure 4: Types of dynamic complexity as a function of prevailing mechanisms, and strategies for dealing with them



Note: The three horizontal lines on the left side of each cell in the table represent, respectively from top to bottom, the marcro level; the meso level (uses orange color to highlight that it represents the context deemed relevant by project participants: task environment, etc.), and the micro level. The red arrows suggest the direction of inter-level influences. The pictures in the middle part of each cell rely on alterations of the Endless Column (or Column of the Infinite) by Constantin Brâncuşi (completed in 1938, Târgu Jiu, Romania) to represent the four patterns of dynamic complexity. Strategies on the right side of each cell suggest ways of organizing project activities, namely of connecting them simultaneously as well as inter-temporally, which are likely to be most effective for dealing with each type of dynamic complexity. Colored lines represent strands of activities and the extent to which these change direction in time.