Complexity, uncertainty-reduction strategies, and project performance

Serghei Floricel
University of Quebec, Montreal
floricel.serghei@uqam.ca

John L. Michela
University of Waterloo, Ontario, Canada
jmichela@uwaterloo.ca

Sorin Piperca
University of Quebec, Montreal
piperca.sorin_eugen@courrier.uqam.ca

Acknowledgements: Research reported in this paper was supported by an Ordinary Research Grant from the Social Sciences and Humanities Research Council of Canada (Project title: "Increasing the response capacity of complex projects: Preparing for the unknown in the planning stage.") and by a an academic research grant from the Project Management Institute (Project title: "Increasing project flexibility: Preparing for the unknown in the concept stage.")

Complexity, uncertainty-reduction strategies, and project performance

ABSTRACT

This paper investigates how complexity influences projects and their performance. We develop a classification of project complexity by relying on fundamental insights about complexity and then use results from practice-oriented literature to assign concrete project complexity factors to the resulting categories. We also identify specific strategies for knowledge production and for organizing that project planners use to address complexity-related uncertainties. We theorize about the way these strategies interact with various types of complexity to increase project performance. Anticipated influences are mostly corroborated using survey data on 81 complex projects from five continents and a diversity of sectors. **Keywords**: complexity; uncertainty; planning; knowledge; organization.

1. Introduction

This paper aims to advance our understanding of project complexity and how planning-stage strategies can address it. Complexity is a major source of uncertainty and risk in projects, which produces additional costs and affects project performance if participants fail to address it from the planning stage (Shenhar 2001; Williams 1999). While project management scholars have made inroads in understanding complexity, efforts to understand its concrete manifestations, the difficulties it creates, and how these could be managed are hindered by the inability to connect two relevant streams of research (Geraldi, Maylor & Williams 2011). One stream builds on fundamental advances, such as highly abstract complexity studies at the Santa Fe Institute, to critically reassess project management prescriptions (Cooke-Davies et al. 2007). While this stream addresses the practices for managing project complexity, its abstract roots hamper a move from criticism to concrete, empirically validated and actionable recommendations. A second, practice-oriented stream focuses on mapping a vast diversity of concrete factors that increase project complexity (Maylor, Vigden & Carver 2008; Bosch-Rekveldt et al. 2011). This identification and prioritization effort relies on surveying managers' opinions, based on the implicit assumption that each factor adds separately to project uncertainty and risk, raising planning and management difficulties, and affecting performance. But the supposed relations between complexity factors and project outcomes lack theoretical base and empirical validation (Geraldi et al. 2011; Xia & Lee 2005). The choice of practices is also left implicit, based on the assumption that factor awareness already takes a big step towards managing complexity.

In this paper, we attempt to provide a theoretical basis for the relation between concrete aspects of project complexity, the efficacy of planning practices and project performance. In this theoretical development, we rely on three premises, each underpinning a distinct contribution of this paper. First, we assume that conceptual issues can be solved by a theoretical framework set midway between generic abstractions and practical classifications of project complexity. With this premise, we rely on the general literature on complexity (Anderson 1999), and on efforts to grasp its specifics in domains such as large systems and infrastructure, biotechnology, software, and sociology, to derive a small set of dimensions that characterize complexity and its effects. Then, based on the practical literature on project complexity (Bosch-Rekveldt et al. 2011) we relate these dimensions to concrete project aspects, such as technology and organization, as well as market and regulatory environments. Our second assumption is that the efficacy of planning-stage strategies in addressing complexity is rooted in the extent to which they enable project organizations to, broadly speaking, *represent* the specific complexities of a project, of its environment and of relevant processes. With this basis, we build on innovation and organization literatures to characterize the representational ability of project organizations and to theorize how it translates into a capacity to develop and apply preventive measures and corrective actions that minimize risks and keep projects on track for success. In particular, we suggest how concrete planning-stage strategies that put in place knowledge production processes and contractual-organizational forms relate to these capacities (Floricel & Miller 2001; Sommer & Loch 2004). Our third assumption is that strategies adopted in a project help improve performance only if they match the particular complexity affecting that project. This premise and the emerging theoretical framework enable us to derive hypotheses about mutual influences between project complexity, planning-stage strategies, and project performance, and then to corroborate these hypotheses empirically on a sample of complex projects from various domains.

Results indicate that the direct influence of complexity on performance is not as straightforward as the literature suggests. Moreover, some planning-stage strategies interact with certain complexity factors and these interactions have a beneficial effect on completion, innovation and operation performance in projects. These results help untangle the nexus of influences between complexity and performance, and have practical implications, by suggesting that strategies adapted to the type and level of complexity mitigate risk with respect to various performance indicators. The paper proceeds as follows. In section 2, we review the literature on complexity, its representation and ensuing challenges in order to establish a basis for our theoretical framework. In section 3, we characterize planning-stage strategies and derive hypotheses about their effect on project performance. Section 4 describes empirical methods, whereas section 5 outlines results. Section 6 discusses results and draws conclusions from them.

2. Complexity in theory and project management practice

The nature and consequences of complexity have become prominent topics in fields such as philosophy and mathematics (Bunge 1979; Thom 1974); physics, chemistry and biology (Prigogine 1997; Mayr 2000); to computer science (Ashby 1958; Simon 1962); technology and engineering (Kim & Wilemon 2003; Lu & Suh, 2009); and social sciences, including economics and management (Luhmann 1995; Levinthal 1997). The generic literature on complexity still debates its definition and nature (Whitty & Maylor 2009). A fundamental issue is whether complexity is an intrinsic property of an objective reality, of the 'world out there', or stems from limitations of, broadly speaking, the cognitive systems that represent the world. But most contributions on both sides of the debate see the origin of complexity in particular relations or interactions between the elements composing systemic entities, which produce unpredictable properties and evolutions in these systems, or preclude their adequate representation. Research focusing on complexity as an intrinsic property of the reality can be, in turn, divided in two strands, one static, or structural, and the other dynamic (Benbya & McKelvey 2006).

Structural complexity. The static stream focuses on interactions between component entities that produce unexpected forms and properties in higher-level systems, which cannot be explained, reduced to, or deduced from the properties of component entities, including their propensities for interaction. For example, properties of cells, organs and living beings cannot all be reduced to the properties of component molecules, including genes and proteins (Sauer et al. 2007). Likewise, some properties of project organizations cannot be reduced to properties of the individuals composing them (Crossley 2011). System philosophers call this possibility 'emergence' and argue that it gives higher-level entities a distinct ontological status; emergent entities exist in their own right, apart from their components (Bunge 1979; Simon 1981). Complexity in this structural sense increases with the 'non-additive' character of component aggregation. While fundamental researchers still debate the nature of emergence and non-additivity (Sawyer 2001; Wimsatt 2006), studies of concrete relations, couplings or interactions between lower level entities have produced conclusions that help us grasp project complexity. These studies trace the complexity of artificial systems, including project artifacts, to functional or secondary interactions between components or their properties (Alexander 1964; Simondon 1989), and track aggregate properties of project networks and organizations, such as flexibility and creativity, to patterns of interactions between actors (Burt 1992).

On top of 'upward' emergence, scholars have traced structural complexity to 'downward conditioning' of components by higher level systems, or to mutual influences between levels (Kontopoulos 1993). Such 'vertical' interactions boost unpredictability and reduce control in projects dealing, for instance, with biological entities, featuring up to nine emergent organization levels (Kohl & Noble 2009), or information and communication systems, having as many as seven distinct architectural layers (Hanseth et al. 1996). In the social realm, several aggregation levels, from individuals, teams and organizations to sectors, nations and global systems, interact to shape phenomena (Meyer & Rowan, 1977; Giddens, 1984; Lundvall, 1993; Malerba, 2002).

Dynamic complexity**.** In its turn, research in the dynamic stream addresses temporal emergence, particularly processes that bring about sudden, radical and unpredictable change in systems. Some researchers focus on structural conditions, such as the number of relevant variables and of interactions between them, to suggest how they produce cyclical, path-dependent, chaotic or random change patterns (Dooley & Van de Ven 1999). Others seek generic causal mechanisms or 'change engines', such as evolutionary variation-selection-retention sequences, or dialectic processes relying on conflict and paradoxes (Campbell, 1960; Smith & Lewis 2011; Van de Ven & Poole 1995), whose outcomes are more difficult to predict and master than those, let's say, of teleological (goal-directed) or life-cycle engines. Mastering dynamic complexity helps projects involving unpredictable material processes—from ground instability and materials fatigue, to flows of gases, fluids and energy, and to biological pathways—achieve useful functions, predict dangerous events and avoid catastrophic failure. But particular attention to dynamic complexity has come from social scientists, who study dynamic engines and temporal patterns (Hernes 2008), from cycles and lifecycles (Klepper 1997; Vohora et al. 2004; Helfat & Peteraf 2003); unpredictable yet path-dependent structuring from repeated interactions between actors (Barley 1986; Coleman 1966; Feldman & Pentland 2003); sudden or radical restructuring (Gersick 1991); to nonlinear, self-reinforcing dynamics that amplify minor events into sweeping changes (Arthur 1989). Some writers even see organizing as an ongoing process in a world of intersecting event strands, and entities as mere cognitive artifacts or a fragile result of recurring processes (Tsoukas & Chia 2002; Hernes & Weik 2007).

Representational complexity. Both static and dynamic views discussed so far implicitly assume that complexity is an intrinsic property of reality. But others see complexity as resulting from the inability of actors and organizations to represent the reality and its dynamics, what we call the correspondence problem. Even those assuming that the world is knowable agree that our most advanced representations are not perfect. For example, research on innovation has found that abstract scientific knowledge and even more specific engineering formulas cannot capture the properties (irregular form, composition, texture, flows, reactions) and multiple interactions that characterize natural and artificial objects (Kline 1987; Nightingale 1998). Biochemistry and biology can hardly represent biochemical pathways in cells and organs, to hope to influence their workings, or to define the functional organization of the human brain, to try and reproduce its performance (Noble 2002; Schwartz 2015). Artificial intelligence researchers point out that even assuming that relevant objects could somehow be mirrored, say, by a string of bits, using some of these representations is beyond actors' conceptual and computational abilities (Biggiero 2001; Tergaden et al. 1995; Katina et al. 2014). Hence they define and measure complexity as the difficulty of identifying object regularities and capturing these in a simplified representation, and as the computational effort required for retrieving the initial object form with some degree of precision (Kolmogorov 1965; Goertzel 1992; Gell-Mann & Lloyd 1996). Such hardships explain why iterative trial and error still dominates the design of complex technical objects (Vincenti 1990), and why, despite scientific advances, pharma and biotech projects have such low success rates and still rely on massive trial and error instead of rational design (Nightingale & Martin 2004; Mandal et al. 2009). Partial, implicit or practical representations obtained through empirical or experimental approaches may reduce the 'distance' between complex reality and its depiction. But the frequent experiment replication failures (Begley & Ellis 2012), the fragility of statistical inference (Taleb 2007), and snags in high-reliability technical systems (Perrow 1984; Leveson et al. 2009; Saunders 2015) all show that they hardly solve the correspondence problem.

The origin of this 'distance' becomes even more evident when the entities that produce representations are no longer seen as abstract knowers but as concrete systems. Perception and cognition studies in psychology and neuroscience (Rosch 1978; Weick et al. 2005; Hodgkinson & Healey 2011), and theories of social construction of reality (Berger & Luckmann 1966; Bourdieu 1977) reveal that representations are not mirroring the external reality but result from constructive processes such as selecting, amplifying, attributing causes, legitimizing, habituating and forgetting. Even scientific and technological knowledge, including that supporting societal perceptions of risk in projects, is seen as a product of similar cognitive and social construction processes (Latour & Woolgar 1979; Douglas & Wildavsky 1982; Bijker et al. 1987; Beck 1992). Organizational fields promote and institutionalize a wide range of doubtful representations, from scientific, technological, economic and moral assumptions and beliefs (Hughes 1983; Haveman

& Rao 1997) to models of organizing (Meyer & Rowan 1977; Abrahamson 1991). Such beliefs and assumptions shape project rationales and forms, while models such as Build-Operate-Transfer, Public-Private Partnerships or Scrum influence their organizing. Some theorists go even further, by arguing that mirroring reality is not even the purpose of representations, which is, in fact, enabling the survival of entities producing them. Entities from microorganisms and individuals to organizations, organizational fields, and entire societies are self-organizing and self-referential communication systems, which set boundaries and differentiate internally, as well as detect, interpret and react to external signals only in reference to their own reproduction goal (Maturana & Varela 1980; Luhmann 1995). This perspective plays a key role in our framework.

Classifying project complexity in practice. The structural-dynamic and representational-intrinsic distinctions identified in our review of complexity can be seen as reflecting fundamental aspects of the world in which we live. For this reason, we adopted them as basic dimensions of a framework used to understand project complexity and its effects. But, research on self-referential communication systems suggests that the 'objective' properties of the 'reality out there' are not necessarily what an 'internal' system formed by project planners (as we focus on planning-stage strategies) would distinguish and address. The sensitivity to complexity aspects of a representing system formed by the emerging project organization (Koskinen 2012) is conditioned instead by the goal of ensuring its own survival, namely acquiring resources and growing to develop and execute the project. Representing the relevant complexity can be seen as the starting point in the self-reproduction of this communication system. This nature of this representation is shaped by two influences. First, objective conditions, and ensuing problems, if these are disregarded, push the system to reduce the 'distance' between its internal complexity and the complexity of the represented system—the project with its environments and processes (Ashby 1958). Second, the representation feeds on planners' understanding of complexity, which builds on their subjective interpretation of past experience, but also on a socially constructed world of distinctions about project complexity and practices for addressing it. This second influence suggests that our two dimensions of complexity should be considered not only in light of truth-seeking debates about the world, its intelligibility and its dynamics, but mainly from a phenomenological perspective, to understand whether and how planners make similar distinctions in the course of their normal activities, what project factors they associate more frequently with which categories, and what practices they adopt to ensure the survival of the project system. Concretely, for our theorizing, this meant adopting practitioners' perspective and imagining how planners perceive and interpret relevant complexity aspects but also using practice-oriented project management literature and research-oriented contributions that respond to practical problems or study everyday practice to identify concepts and models that practitioners would use to make sense of, and legitimate their interpretations. This helped us reinterpret the two dimensions derived from fundamental theory into similar distinctions that reflect the planners' perspective, as explained below.

First, we assumed the intrinsic-representational distinction to imply that planners see complexity aspects either as intrinsic in the 'world out there' or as resulting from imperfections in their own representations. Reliability and systems safety engineers make just this distinction when they set apart stochastic from epistemic uncertainty (Helton & Oberkampf 2004). From this vantage point, a project aspect is intrinsically complex if confusion with respect to factors, interactions levels and engines appears to deny planners any possibility of internal representation that would enable an adequate anticipation or control of that aspect in practice (Biggiero 2001). In light of system survival goals, an added marker of intrinsic complexity is planners' preference for representations in the form of basic frameworks that help them make sense of forms and evolutions in relevant systems but also provide a terminology that legitimates decisions while limiting accountability for eventual failures. On the other hand, representational complexity relates to aspects for which prediction- and control-enabling internal representations appear possible in practice, but raise modeling and computation challenges, often leading to anticipation and control failures. Planners would, in this case, attempt to supplement anticipatory models with experimental, empirical and practical approaches to gradually improve internal representations.

A similar approach was used for the structural-dynamic distinction. If complexity to be mastered is structural, the representation 'distance' comes from the inability to capture all levels, factors and interactions that shape the relevant project aspect. This translates in system properties that differ from planners' anticipation. Survival is advanced by stressing cognitive and structural differentiation that increases the sensitivity and selectivity of the planning team to various levels and factors, communicative ties that help detect and convey interactions, and integrative abilities that detect patterns and translate them as operational routines (Henderson & Clark 1990). When complexity is dynamic, the 'distance' comes from differences between internal anticipations and velocities and patterns of change in external systems. Its' indicators are event unexpectedness, perceptual discontinuity and self-referential confusion (Luhmann 1993). Its reduction hinges on the ability to update internal representations, by maintaining alertness and sensitivity to incoming signals, rapidly making sense of novel conditions and engines, and restructuring communicative ties and routines accordingly (Weick & Roberts 1993; Lampel et al. 2009, Teece 2007).

These reinterpreted distinctions and markers enable us to classify concrete manifestations of project complexity into four quadrants. Since we adopted the planners' perspective, we sought expressions of complexity in the project management field. As mentioned in the introduction, the practical stream attempts to map a vast diversity of complexity factors, and distinguish them by project domains or aspects (Tegarden et al. 1995). Its reliance on eliciting managers' opinions suits our goals because results are close to planners' situated understanding. In one of the most exhaustive efforts of this stream, Bosch-Rekveldt's et al. (2011) inventoried 50 factors and classified them in three categories: technological, organizational, and environmental, creating what they call the TOE framework. We relied on this framework but instead of analyzing each of these factors, we tried, as a first step, to position their categories relative to our four quadrants. We only subdivided their 'environment' category, into 'institutional' and 'market', because, in our view presented later, institutional factors point to dynamic complexity, while market factors, to structural complexity. For each category, we also derive direct consequences for planning and an overall impact on performance. The resulting complexity framework is presented in Table 1.

The markers for *intrinsic structural complexity* revealed by our review are the presence of non-additive aggregation or interactions and of multiple emergent levels influencing each other.

In practice, planners have no hope to design or control the respective project aspect but leave its shaping to mutual interactions between relevant elements and levels, including their own inputs. Among the four factor categories, we believe that institutional complexity is best placed in this quadrant. The complexity of this factor stems from interactions with the management systems of parent organizations, stakeholders and broader networks of interested organizations, and political and regulatory bodies. While planners try actively to influence this area (Pfeffer & Salancik 1978; Oliver 1991; Aaltonen 2011), institutional actors seek to retain their autonomy; planners may even ignore who these actors are or represent, what they want, and how they interact among themselves (Jepsen & Eskerod 2009). Interaction complexity increases because, on top of their own interests, some legitimate and others not, actors bring to the negotiation arena a variety of pragmatic, moral and cognitive logics to legitimate their arguments (Suchman 1995): budget limits, efficiency, development, job creation, urban planning, aesthetics, equal access, equitable treatment, environment protection etc. Actors also change positions in response to other actors' arguments. All this diminishes planners' control over the negotiation process and its outcome predictability, and makes planning for institutionally complex projects a long process, forcing project concepts through several restructurings before an acceptable arrangement is found (Miller & Lessard 2001). Planners attempt represent this environment by using frameworks such as stakeholder analysis, but this do not necessarily increase success rates (Jepsen & Eskerod 2009). Excessive use of analytical representations sometimes even leads to negotiation paralysis (Denis, Lamothe & Langley 2001), which supports our assignment of institutional complexity to the intrinsic end. Project research also supports this indirectly, because the impact of broader organizations and networks of interested and institutional actors is among the few topics studied with multilevel, mostly structurationist perspectives (Engwall 2003; Manning 2008). Complex products and systems (CoPS) research adopts a similar perspective to study how networks of institutional actors interact to shape technical systems (Miller et al. 1995; Brusoni et al. 2001).

In turn, *structural representational* complexity is marked by abstraction and computation challenges and the use of trial and error to surmount them. Among the four categories of factors, we believe *technical complexity* best fits these markers. Technology and innovation literature suggests that managers address technical complexity by representing interactions at three levels: between project functions that interoperate, between solution elements that concur in achieving functions, and from interactions inside parts and materials (Simondon 1989, Ulrich 1995). While some interactions may be intrinsically and dynamically complex, the availability of such design- and control-oriented representations makes all these interactions appear as structural problems. Because some of them are too costly to capture systematically and exhaustively, planners use low-correspondence representations first, to identify approximate solutions, and then rely on trial and error to reduce the 'distance' (Fleming & Sorenson 2004). Even failure to achieve perfect control over artifact functioning is not attributed to uncontrollable dynamics but to unforeseen structural problems, to be solved through better design and further trials (Bohn 1994).

For *intrinsic and dynamic* complexity, markers include special combinations of variables and interdependencies causing nonlinear or chaotic dynamics, and the presence of evolutionary or dialectic engines. In our view, the factor that best fits these markers is *project organization*, defined as the socio-economic system formed by project participants. For a long time and still today, such systems have been implicitly depicted as hierarchical structures, using, for example, authority charts or contract networks. Such structures were deemed to result from rational design processes responsive to functional and normative pressures (Thompson 1967; DiMaggio & Powell 1983; Mintzberg & Lampel 1999). Some representations have also been dynamic, such as PERT or Gantt charts and a variety of life cycles or development processes (Boehm 1988). These aimed to order project activities in a goal-driven temporal sequence, assuming that some implicit teleological or lifecycle engine would push the project along the desired path. Both functional hierarchies and temporal sequences assume that a representation is somehow able to constrain actors' behavior, and all that's left is to maximize the efficiency of its structure and sequence, in light of number and diversity of participants, tasks and resources, precedence relations, and effort or duration uncertainties (Brucker et al. 1999; Chapman & Ward 1994). The focus on solving efficiency problems would hint that, for planners, organizational complexity is representational.

However, even those who agree argue that such representations do not offer sufficient guidance for action, and the problems are much deeper, perhaps intractable (Ballard & Tommelein 2012). This view also fails to take into account that projects are not carried out by perfectly rational and malleable human actors, interacting in predictable ways based on orderly interests. Anecdotal and qualitative evidence suggests that relations between actors are ripe with conflicts of interest, opportunism, misunderstandings, cheating, interpersonal conflicts, excessive emotion, and other forms of non-rational or even criminal behaviors. Failure to explain the difficulties in following the goal-driven path led the field to focus on the human side of projects (House 1988), and to rethink projects as temporary organizations whose essence consists of social interactions (Lundin & Söderholm 1995). More recently researchers asserted that the material substrate of objects and even of actors intertwines with these social relations in many poorly understood ways (Callon 1986; Barad 2003; Orlikowski 2007; Doolin & McLeod, 2012). The new perspectives addressed in priority the issue, worsened by a focus on representational efficiency, of project adaptation to continuous change and unexpected events (MacCormack, Iansiti & Verganti 2001; Soderholm 2008; Piperca & Floricel 2012). Suggested solutions call for enhancing problem detection, agility and response capacity (Schwaber 1997; Highsmith 2001; Kappelman, McKeeman & Zhang 2006; Floricel, Piperca & Banik 2011; Browning & Ramasesh 2015), and even keeping projects on the edge of chaos (Brown & Eisenhardt 1997). Most solutions propose frameworks that stress dialectic or evolutionary engines (Sommer & Loch 2004), which, in our view, are markers of intrinsic dynamics. But applying such new frameworks pushes organizational complexity to the extreme rather than solve the problems it causes, because such abstract representations interact in unexpected ways with existing interests, practices and culture, causing unpredictable dynamics (Floricel, Piperca & Banik 2011; Conforto et al. 2014). Then again, process ontology trends inspired project researchers to see change as the normal state of project organizations, a state of continuing organizing or becoming (Weick & Quinn 1999; Tsoukas & Chia 2002; Hernes & Weik 2007; Pellegrinelli 2011). Those who made the ‘practice turn’ (Blomquist et al. 2010) add that organizing is a continuous effort to reweave the project using a variety of institutionalized and improvisational practices (Floricel et al. 2014; Leybourne 2009). As continuous organizing, becoming and reweaving replace structural depictions, some even researchers began to question whether a real entity exists beyond the variety of metaphors, arguing that a project organization is no more than a conceptual reification (Hernes 2008; Vignehsa 2015). For us, the inability to predict, control and even represent this dynamic reality is a mark of intrinsic complexity.

Finally, the marker for *dynamic representational* complexity is the repeated advent of surprising events. We argue that the *market environment* factor best matches this marker. For this factor, representations also shifted from predictable life-cycle views (Abernathy & Utterback 1978; Klepper 1996) to those focusing on the conditions and engines that produce turbulence and velocity (Eisenhardt 1989; Emery & Trist 1965; Bogner & Barr 2000; MacCormack, Verganti & Iansiti 2001). But planners still believe evolutions can be predicted with anticipatory frameworks (Moore 1991; Rogers 1995) and a host of sales estimation models (Cooper 2001; Bass 1969, Urban, Huser & Roberts 1990), some claiming forecast precisions as high as ten percent (Bass et al. 2001; Mas-Machuca et al. 2014). Contrary to organization dynamics, the effects of actions and interactions in a market may average out because of the larger number of actors and of their relative isolation from each other. Of course, hidden interdependences, due to interactions between novel project elements and ill-defined social aggregates, for example in innovation projects (Aldrich & Fiol 1994), or even to planners' own interests (Flyvbjerg, Skamris Holm & Buhl 2005) often set off evolutionary engines and result in path-dependent patterns (Arthur 1989), which cause surprises and prompt forecast reevaluation. But planners trust they can elude surprises by refining representations, preparing for contingencies, using market tests or limited product launches, as well as discovery-oriented processes (Lynn et al. 1996, Kahn 2014).

The next section discusses how planning-stage strategies that shape the cognitive and organizational representation of complexity help participants address its various forms. But the preceding discussion enables us conclude this section by arguing that all complexity factors have a direct negative impact on project performance, because they overcome the project planners' representational capacities and go on create unpredictable forms, surprising properties, temporal evolutions or unexpected events. This is expressed in the following hypothesis:

H1 Complexity overall and its various concrete factors have a negative influence on performance

3. Planning stage strategies and complexity representations

As we argued in the introduction, we assume that complexity management efficacy, and eventual performance, depends on the capacity of a project organization to represent the complexity of its project. From the communication systems perspective, this means that project planners are able to translate their interpretation of project complexity into a project organization that can continue to grasp key interactions and engines, limit uncertainties and surprises caused by emergence and dynamics, and address consequences in cognizant, proactive, coordinated and flexible ways. We treat the required representational capacities broadly, by distinguishing two aspects. The first, *cognitive aspect* was inspired by psychological, engineering and applied science perspectives. It includes actors' mental representations, shared or not (Weick & Roberts 1991), as well as representations on external supports, such as plans, organization charts and engineering drawings (Floricel, Michela & George 2011). The second, *organizational aspect* was inspired by communication systems research. It refers to representations embedded in work routines and communication patterns in project organizations and networks (Luhmann 1995).

We further assume that planning-stage strategies adopted in projects have a key impact on this representational capacity, not only through their influence on representations produced by the planning activities but also through the conditions they create for producing and updating representations in subsequent stages. Based on the project and innovation management literature we argue that two kinds of strategies have the strongest impact on this capacity. First, strategies that put in place *project development processes* impact mainly the subsequent ability to produce cognitive representations, because the essence of these processes is knowledge production and use (Shenhar 2001). In turn, strategies based on *organizational and contractual structures* create the kernel of the future project organization. In particular, they shape the channels and incentives for communication, which are the key sources of the coordination and integration capabilities that lay at the core of organizational representation capacities (Floricel, Piperca and Banik 2011).

Another argument we advance concerns the fit between the specific complexity faced by a project and the representational capacities of the latter, as well as the impact of this contingent fit upon project performance. We expect that some strategies are more appropriate in creating the capacity to represent a specific complexity factor affecting the project, because they meet the challenges raised by this factor in light of its characteristics along the two dimensions presented in Table 1. As explained when we introduced them, every end of each dimension is better addressed with specific representation capacities. For example, intrinsic complexity favors generic frameworks that help participants make sense of properties and evolutions, while representational complexity favors more specific, prediction- and control-enabling depictions. Equally, structural complexity demands the capacity to comprehend and integrate all aspects and interactions, while dynamic complexity, favors fast change-seizing, sensemaking and tie-restructuring capabilities (Teece 2007). As we will explain below, these representation capacities are more likely to grow from concrete choices on the two types of planning-stage strategies mentioned above. However, not every planning group will adopt the right strategies. They usually adopt organizing models legitimated by the institutional field, for example, development processes such as Scrum, and contractual frameworks such as public-private partnerships. Such models of organizing, “however flawed, unstable and biased they may be, form the means by which actors navigate and connect entities in a fluid and complex world” (Hernes 2008: 49). It is out of such models, through some sort of bricolage, rather than through omniscient, original design, that planners create the kernel of the representational capability of a project: an assemblage of knowledge production activities and communication ties. But, in certain cases, planners have a better understanding of complexity and pick up models that are more appropriate, while in other cases, they adopt models by imitating others, out of insecurity and confusion, without considering their appropriateness for the specific project complexity context

(DiMaggio & Powell 1983; Strang & Macy 2001). This creates variance on the complexity-strategy match, enabling us to hypothesize that strategies are interacting with complexity to influence performance. More precisely, we believe that the project performance will decrease (linearly) to a lesser extent in relation to each complexity factor when planners adopt strategies that match to a greater extent the characteristics of that factor.

We now turn to developing this proposition into testable hypotheses, by identifying concrete planning-stage strategies that allow planners to match the challenges posed by the four complexity factors listed in Table 1. Resulting relations are presented in Figure 1. We distinguish the first type of strategies mentioned above, namely development processes, by the nature of the knowledge they use and by their knowledge production sequence. Both elements condition their ability to match intrinsic versus representational complexity. Based on strategy and innovation research (March 1991; Katila & Ahuja 2002), these characteristics set apart two categories of development processes: more linear sequences relying on preexisting, rather abstract knowledge versus more iterative sequences that favor the production of new project-specific knowledge.

The first category, *exploitation of existing knowledge*, relies mainly on past learning captured in databases, models and rules. It features a rather linear sequence, which translates quite abstract premises into more concrete project elements. Evolutionary search literature suggests that abstract representations expedite and enhance the search for an overall concept, by offering some guidance over a broader solution space (Fleming & Sorenson 2004). But the 'distance' between these representations and the reality 'out there' reduces the efficacy of their guidance for shaping, predicting and controlling concrete project elements (Gavetti & Levinthal 2000). We believe this kind of process is most effective when planners deal with factors they perceive as intrinsically complex. Such perceptions occur when planners are either at loss for grasping the given factor, or when prior experience has taught them that creating representations that enable the precise prediction and control of relevant properties or dynamics is beyond their cognitive and computational abilities. Research shows that when faced with seemingly random phenomena actors tend to 'see' illusory patterns (Whitson & Galinsky 2008), which also prepares them to believe and seek guidance in any representation, even one based on superstition or tradition, which restores some order to a seemingly random world (Kay et al. 2009). Actors are even more inclined to adopt such frameworks if these have been socially legitimated by professional and regulatory bodies (Strang and Macy 2004), or by the units charged with knowledge absorption, circulation and codification in parent organizations (Cohen & Levinthal 1990; Brown & Duguid 1991). There rather abstract and generic frameworks enable managers to make sense of incoming signals and avoid decision- and action-stalling insecurity. Thus, indirect evidence for the hypothesized interaction between intrinsic complexity and existing knowledge exploitation strategies is provided by the rise, along with the recognition of institutional environment complexity, of prescribed practices for stakeholder analysis (Jepsen & Eskerod 2009) and of governance frameworks for developing and approving public projects (Klakegg et al. 2008). For the other factor deemed intrinsic, organizational complexity, we see a comparable proliferation of contractual and organizing frameworks (Lindstrom & Jeffries 2004; Cooper 2008; Tang, Shen & Cheng 2010). Besides, for both factors, project-based organizations have adopted practices that capture, diffuse and codify learning from past projects (Prencipe & Tell 2001), as well as project management offices that formalize and promote practices based on this learning (Aubry et al., 2010), to give planners a menu of generic analysis frameworks and procedures. Our case on existing knowledge exploitation strategies results in this hypothesis:

H2: Development processes that exploit existing knowledge will interact with intrinsic complexity factors, namely institutional (H2a) and organizational (H2b) categories, with beneficial effects for project performance.

A second category of development processes stresses the *production of new knowledge*. This type of process features a deliberate sequence of experiments, simulations, and prototyping, along with concurrent engineering or seeking clients' feedback, which are similar to 'trials' with downstream participants. By emphasizing new knowledge production activities, participants aim to reduce the 'distance' between cognitive representations and specific project complexities. But resulting representations have narrower applicability, and participants have to start all over again if results are unacceptable (Lynn, Morone & Paulson, 1996). Thus, such processes often involve an iterative sequence of trials, producing successively closer representations of the concrete form and performance of the system. We argue that new knowledge production processes are more effective in addressing representational complexity, namely technical and market factors. For these categories, representations can be brought close enough to reality to enable prediction and control of relevant project aspects. For example, technical design is often depicted as an iterative process of knowledge production or problem solving that constructs an increasingly concrete and complex representation of artifact form (Visser 2006; Chandrasegaran et al. 2013). The sequence can be optimized by varying relative reliance on preexisting abstract knowledge versus trials that produce new concrete knowledge (Fleming & Sorenson 2004), the radicalness, precision and number of trials (Thomke & Fujimoto 1998; Luehrman 1998), or the degree of parallelism, overlap, and communication between activities (Thomke 1998; Krishnan et al. 1997; Loch & Terwiesch 1998). In turn, market research supplements generic estimation models with methods that rely on lead users, virtual customers, and simulated or test markets to produce more concrete knowledge (von Hippel 1986; Dahan & Hauser 2002). Likewise, market search strategies for radical and disruptive innovation projects, likely to generate the highest market complexity, rely on launching repeated probes to obtain concrete feedback from possible markets and segments (Christensen 1997; Leifer et al 2000). This enables us to propose the following hypothesis:

H3: Development processes that produce new knowledge will interact with representational complexity factors, namely technical (H3a) and market (H3b) categories, with beneficial effects for project performance.

We also divided in two categories the other group of planning-stage strategies, those shaping the project organization and creating its organizational representation capabilities. Modularity and communication literatures research (Simon 1962; Luhmann 1995) inspired us to distinguish strategies aiming to enhance these capabilities by separating participants into more or less autonomous groups from those that do so by integrating as much as possible all participants.

The first category, *separation-allocation* strategies, assume that complexity is best addressed by decomposing relevant objects and tasks into stand-alone blocks and allocating their execution to distinct organizations or teams. This type includes modular project organizations (Söderlund 2002) and approaches, such as BOT, PPP or turnkey, relying on contracts to allocate project tasks between participant organizations. We argue that such strategies are best suited for structural complexity categories, namely technical and institutional. In fact, attempts to tackle technical complexity inspired design methods that reduce undesired interactions and architectural principles that help control emergent properties by separating complex artificial systems into stand-alone modules (Simon 1962; Ulrich 1995; Suh 2005). These methods 'frontload' the development effort, augmenting its system engineering and architecting part, and enable planners to uncover and represent early on the key interactions between project elements. Then, project organizations and networks can also be separated into modules that parallel technical architecture (Sanchez & Mahoney 1996; Schilling 2000). Those working on each module develop detailed representations of their respective parts. Because technical solutions within each module are developed in an integrated manner, modular units maintain strong internal communication ties that help participants grasp interactions (Hansen 1999). Communication across modules is less frequent and occurs through well-defined interfaces, but hidden interactions can still be captured and mastered if planners maintain and cultivate overall integration capabilities (Murmann & Frenken 2006; O'Sullivan 2006). A similar approach tackles institutional factors by partitioning the project environment into uncertainty areas and relying on well-defined contractual interfaces between participants to allocate respective risks to specific actors (Chapman & Ward 1994; Floricel & Miller 2001). High transactional requirements for understanding, negotiating and defining inter-participant interfaces, such as specifications, rights, price calculation, certification and contingencies, increase the development effort and duration (Miller & Lessard 2001). But this effort also creates a systemic representation akin to a modular architecture, which provides a clear overall picture early on and then enables participants to focus on developing detailed representations of their respective sectors. These arguments led us to the following hypothesis:

H4: Organizing strategies relying on separation and allocation will interact with static complexity factors, namely technical (H4a) and institutional (H4b) categories with beneficial effects for project performance.

Strategies in the other organizational category, *integration-collaboration*, aim to increase the density and strength of communication ties throughout a project organization by stimulating collaborative work, as well as responsibility and risk sharing (Lahdenperä 2012). This helps integrate a diversity of perspectives and knowledge and, while it does not uniformly reduce the 'distance' between project complexity and its organizational representations, it eases the ongoing adaptation of representations to change. Therefore we argue that integration strategies are best suited for addressing dynamic factors, such as organizational and market complexity. To address market dynamics, such as unpredictable changes in user needs and market conditions, project management literature suggests practices such as small-step, gradual-commitment (Olsson 2006; Highsmith, 2010), and multiple frequent iterations based on real-time input (Biazzo 2009). But these practices are harder to implement if participants are constrained by preset contractual interfaces that strictly allocate risks and prescribe communications (Floricel, Piperca & Banik 2011). Thus, organizational strategies that foster collaboration, such as partnering and integrated project delivery (Naoum 2003; Cohen 2010), or encourage frequent communication, such as agile methods (Ballard & Tommelein 2012), help projects adjustments to unexpected market developments. For organization complexity, setting interfaces early on also risks routinizing the communication patterns, which precludes adaptation by entrenching old implicit representations and preventing new systemic sensemaking (Henderson & Clark 1990). The alternative is, once more, to foster organizational representation updating through networks with strong communication ties between participants (Dietricht et al. 2013; Verganti 1999), orchestrated by actors with strong integrative abilities (Brusoni et al. 2001), and driven to collaborate by shared responsibilities (Dougherty 2001). These arguments led us to propose the following hypothesis:

H5: Organizing strategies relying on integration-collaboration will interact with dynamic complexity factors, namely market (H5a) and organizational (H5b) categories, with beneficial effects on project performance, particularly completion and innovation.

Together these hypotheses suggest a systematic association between complexity factors and strategy elements in the form of interactions that reverse the negative impact of complexity on different types of performance. All hypothesized relations are depicted in Figure 1. Their empirical corroboration is described in the next section.

4. Methods

We attempt a preliminary examination of the hypotheses using data from a survey of complex projects, which studied the response capacity of complex projects (see Floricel, Piperca & Banik 2011 for details). The initial theoretical framework of that research did not include variables for complexity, but implicitly accounted for it by targeting certain types of projects. Yet, distinct complexity factors emerged as important from the initial qualitative stage of the research, which performed 17 qualitative case studies of complex projects in three sectors: biopharmaceutical, information and communication systems, as well as energy and transportation infrastructure. In that stage, a total of 47 interviews and tens of documents were analyzed based on a semi-grounded approach (Corbin & Strauss 1990), using case narratives to capture contexts, systemic interactions and processes; inductive content analysis to develop constructs; as well as intra- and inter-case comparisons to work out the relations between constructs. This helped to reformulate the theoretical framework, and enabled the quantitative survey that provides data for this article.

Instrument development and data gathering. Based on the theoretical framework and language obtained from interviews, questionnaire items were generated for each variable. Similar psychometric measures, seven-point Likert-type scales, were used throughout the questionnaire (Meyers, Gamst, & Guarino, 2005: 23). The questionnaire was reviewed by three scholars with practical experience in project management, and by one practitioner. Their comments were used to prepare the final version of the questionnaire that was implemented on line. During the fall of 2011, this version was administered to practitioners who participated in projects that were just completed at the time. Analyses presented here rely on a maximum of 81 answers (see Sample). This represents a response rate of just below 10% with respect to the number of emails sent out, reasonably good for email surveys, which often go as low as 2 percent (Tucker, 2010), even when using the best practices proposed by Dillman, Smyth, and Christian (2009) as we sought to do. The pool of respondents was limited by the low number of complex projects that were identified using periodicals and databases specialized in tracking such projects.

Sample. Although the total sample consists of 81 cases, 1 respondent did not complete strategic practices section and 9 did not complete project performance section. This attrition may have occurred because the overall questionnaire was lengthy, including hundreds of items. Even among those who went through the entire questionnaire, some respondents occasionally missed an item or two. Such missing values (< 1 % of responses) were replaced by sample means for the respective items. The number of cases usable in each form of data analysis is stated below or else implied by degrees of freedom reported. This sample size is acceptable for the analyses that we performed, in that we maintained an approximate ratio of 5 cases to each variable. The sample is diversified geographically, and by project type and sector. Locations span 5 continents: North America (39), Europe (26), Latin America (7), Africa (6), and Australia (3). Sectors and types of projects include: energy (power generation including offshore and nonconventional, oil and gas including offshore, biofuel including demonstration); transportation infrastructure (highways, underpasses, tunnels, bridges, railroads, urban transit, airport terminals, ports), water infrastructure (water and sewer, flood protection); information systems and telecommunication infrastructure; mining and manufacturing facilities; sports, cultural, urban and tourism facilities.

Measures. Because all scales were new and, especially for complexity, emerged from a semi-grounded procedure, we used for validation a combination of exploratory and confirmatory analyses. Survey items for project complexity were entered into a common factor analysis. Non-orthogonal (promax) rotation was used to reduce—but not artificially eliminate—correlations among factor scores saved from the factor procedure. After initial analyses, items that violated simple structure, namely those with factor loadings above 0.40 on a secondary factor were removed and the analysis was repeated until arriving at the structure shown in Appendix Table A1. Aspects of planning strategy were analyzed in the same manner (Appendix Table A2). Items measuring performance were first examined to determine whether aspects of performance should be differentiated by factor analysis or consolidated in one factor. A maximum likelihood factor model with a single factor did not fit the data (Chi-square (54) = 113.37, $p < .001$), so we retained all performance factors with eigenvalues over 1. Scores for performance variables were produced as averages of survey items that appeared together on a factor, so that findings could be expressed in terms of answers on a seven-point scale. Constituent items for the four resulting performance variables, validated via factor analyses, and estimates of measure reliabilities are shown in Appendix Table A3. They correspond to four indicators highlighted in project literature (Wateridge, 1998; Atkinson, 1999). Completion performance measures whether the project met planned resource expenditures and deadlines, and accomplished the entire planned scope and all artifact functions. Innovation measures whether a project produced outstanding or pioneering achievements for artifact uses, functionality and performance. Operation captures the extent to which the project runs uniformly and reliably, with low maintenance and exploitation costs, and few repairs. Value Creation measures the extent to which a project meets expected financial returns, satisfies users' and stakeholders' needs, and enhances promoters' reputation. Most scales have reasonable Cronbach's alpha values; all are above .50, the acceptable value for newer scales (Hair et al. 1999). Correlations within and between the three sets of scores appear in Table 2.

Analyses. Canonical correlation analysis examined, first, the association of complexity factors with performance factors in order to corroborate Hypothesis 1. We also used canonical correlation to analyze the association of complexity factors with planning strategy variables; results helped us interpret results for the remaining hypotheses. In both cases, this multivariate statistical method reduced the 16 pairwise correlations between complexity and performance or strategy variables to the canonical correlations reported. Further, to corroborate Hypotheses 2 to 5, multiple regression (MR) analyses examined associations of performance outcomes with complexity factors, planning factors, and the various two-way interactions each involving a complexity factor and a planning factor. The 16 possible two-way interaction terms were produced by multiplying together each interaction term's complexity and planning linear components. After entering linear terms simultaneously (4 each for complexity and planning) in a first hierarchical MR step, we then entered all 16 interaction terms with stepwise backward elimination analysis. Following Fleiss (1986) and others, we set .10 as a criterion for maintaining interaction terms for further analysis (described with Results). It should be noted that all linear terms were maintained in all four MR analyses (one for each outcome) throughout the analysis. This approach maintained interpretability of the interaction terms as such (Dawson, 2014).

Due to the use of stepwise regression, the MR analysis should be considered exploratory, because the resulting number of statistical tests increases the possibility that some findings at the given error rate have been obtained by chance. However, a further aspect of our further analyses sought to reduce this concern. Specifically, for each of the statistically significant ($p < .05$) or marginal ($p < 10$) two-way interactions, finer-grained analysis of “simple slopes” was conducted based on Preacher, Curran, and Bauer (2006). We describe results only for instances when these analyses pointed to sizable differences in, and statistical significance of (at $p < .05$), one or more regression slopes in connection with each reported interaction.

5. Results

Global Associations of Complexity Factors with Project Performance Factors. As a global test of Hypothesis 1 concerning the general effect of complexity on project performance, canonical correlation analysis was conducted with the measures listed in the first four and last four rows of Table 2. This analysis may be understood to reduce the correlations between all eight variables involved in the analysis to produce the summary results, or ‘global’ results, in Table 3. This summary is accomplished by forming optimal linear composites of the variables involved.

In the findings in Table 3, a single canonical correlation, at .52, is seen to be statistically significant. The pattern of canonical loadings in the table provides a compelling description of the overall association here. Given the generally similar and uniformly positive loadings in the table's top section, the complexity factors turn out to be quite consistent in their apparent effects.

This common effect, according to the table's middle section, is to undermine completion performance, as expected given H1, yet enhance innovation performance, contrary to prediction.

Global Associations of Complexity Factors with Planning Strategy Factors. As a preliminary analysis intended to aid interpretation of later findings, the measures of complexity types and planning strategy were also entered into canonical correlation analysis, to bring a large number of correlations (i.e., the first 8 rows of Table 2) to a smaller set of summary findings.

The resulting column in Table 4 for canonical variate 1 shows that a first pair (top and middle sections of first column) of sizably correlated (.56, bottom section) and statistically significant linear composites was obtained in the analysis. In the composite weighting scheme for Complexity factors, Organizational complexity, especially, and Institutional and Market complexity, secondarily, received substantial weight; Technical complexity did not. In the corresponding scheme for Planning factors, New knowledge received high positive weight but Existing knowledge received high *negative* weight. These values give emphasis to the pattern of correlations in Table 2 in which New knowledge has a positive and statistically significant correlation with all of the planning strategy variables, but Existing knowledge's corresponding correlations are mostly negative. There is also a suggestion of greater use overall of Integration and lesser use of Separation with greater amounts of these forms of complexity, again consistent with the correlations in Table 2 upon which this global analysis was based.

Values in the table column for canonical variate 2 were obtained by analysis of residual associations after application of variate 1 to account for the correlations in Table 2. These values and the statistical tests below them indicate that higher Technical complexity (with its loading of .92) is associated with greater use of *both* New knowledge and Existing knowledge. No further residual associations were statistically significant.

These results suggest that project managers have some characteristic ways of responding to particular forms of complexity. When PMs perceive technical complexity they are especially likely to use Existing knowledge and they develop New knowledge. With other forms of complexity, use of Existing knowledge is less evident but New knowledge remains prominent.

Performance prediction from Complexity and Planning Strategies and their interactions. As detailed under Methods, after forming 4 performance outcome scores (according to table A3 in the Appendix), 8 linear predictor terms (see appendix Tables A1 for complexity factors and A2 for strategy variables), and the multiplicative terms for interactions between complexity factors and strategy variables, a multi-step multiple regression (MR) analysis was conducted for each outcome variable. Table 5 provides the unstandardized regression coefficients and the full equation parameters and statistics.

Linear terms' associations with outcomes. The 8 linear terms were entered in the first step of each MR analysis. Results are shown in the columns C1, I1, O1 and V1 of Table 5. Although relatively few tests for direct effects coefficients reached statistical significance, it should be kept in mind that statistical significance concerns the unique variance in the outcomes explained by each predictor, that is, controlled for other complexity and planning variables (unlike in the preceding canonical correlation analyses, which took a different, global approach).

Coefficients reflecting the direct influence of complexity on performance provide additional corroboration for Hypothesis 1. Coefficients were mostly negative for the impact of complexity variables on completion outcome, including one marginally significant coefficient for technical complexity. However, consistent with earlier canonical analysis, coefficients were positive for the impact of complexity on innovation performance. Coefficients for relations between complexity and other performance variables had mixed signs and no significant values.

Regarding the direct impact of planning-stage strategies, existing knowledge exploitation had mostly negative signs, but the other three types of strategies had only positive signs. Of these, Separate organizational strategy has a significant positive influence on all dimensions of performance, except for innovation for which the level of significance is marginal.

Analyses of interactive terms' associations. By entering only the linear terms in the first step and then following with interactions, it was possible to assess the predictive contribution of interactions. While keeping in mind the caveat stated under Methods, concerning the statistical consequences of stepwise MR procedures, we note that these contributions were sizable, ranging from an approximate 50% to a 100% increase (i.e., a doubling) of overall variance explained by regression equations that included interactions. For example, explained variance increased from 0.202 to 0.353 for Completion performance—or from 0.101 to 0.208 in the metric of adjusted R-square. Further, predicting all four outcomes by linear terms alone was of marginal statistical significance, while equations with interactions, except Value creation, were clearly significant.

The specific interaction terms that reached the specified alpha level for further scrutiny ($p < .10$) are shown in the second column under each outcome variable's heading in Table 5 (columns C2, I2, O2 and V2).

Figures 2, 3, and 4 describe the particular forms taken by interactions of complexity with planning strategies. Each sub-figure (e.g., Fig. 2a) corresponds with an interaction coefficient in the table. However, not all coefficients have a corresponding sub-figure, because only interaction terms for which one of the simple slopes reached $p < .05$ are presented in a corresponding graph. In these figures, a simple slope describes the association between a planning strategy and an outcome variable for projects with a level of complexity that is either 1 standard deviation (SD) below the mean for the particular form of complexity, or 1 SD above the mean (Dawson, 2014; Preacher et al., 2006). Significant simple slopes are indicated as such in the figures.

Completion performance. Figure 2a describes an interaction between New Knowledge and Technical Complexity. In projects with high Technical Complexity (structural and representational), a higher use of New Knowledge increases the chances of high Completion performance. This slope is as predicted by our H3a.

Figure 2b shows a prevalence of low Completion performance among projects with low Technical complexity but high use of Existing knowledge. This negative slope was not predicted with respect to this representational type of complexity, but the graphical pattern (unlike the respective coefficient in Table 5) cannot be considered as an indirect disconfirmation of H3a.

Figure 2c shows an interaction between New Knowledge and Organizational Complexity. Namely, for projects with high Organizational complexity (dynamic and intrinsic) projects with higher production of New Knowledge are more often associated with higher completion performance. This negative slope was not expected based on H2b, which predicted a beneficial impact from interactions between Existing Knowledge and Organizational Complexity.

Figure 2d also presents a strong positive association between New Knowledge and Market Complexity. Specifically, in conditions of high Market Complexity, the higher use of New Knowledge production is associated with more prevalence of high Completion performance. This slope corroborates the relation predicted by H3b.

Finally, figure 2e depicts an interaction between Institutional Complexity and New Knowledge. In particular, for *low* Institutional Complexity, a higher production of New Knowledge is associated with higher Completion performance. This slope could be interpreted as providing indirect support for our H2a, which suggested for high Institutional Complexity a positive association of project performance with Existing Knowledge strategies.

Innovation performance. In Figure 3a the interaction between Institutional complexity and Existing knowledge reveals a prevalence of *low* innovation performance among projects with *low* Institutional complexity that make higher use of Existing knowledge. This graphical pattern can be seen as providing indirect support to our hypothesis H2a, which indicated a beneficial effect on project performance from using *high* levels of Existing Knowledge at *high* levels of Institutional Complexity. In fact, the corresponding coefficient in Table 5, with a significance level near .05, would provide just such a confirmation, but we preferred to emphasize the easier to interpret graphical analyses.

Figure 3b indicates that greater use of Separation strategy is associated with greater Innovation performance only with projects of *low* Institutional Complexity. Our hypothesis H4b predicted a similar relation for *high* Institutional Complexity. In Figure 3b, the slope for such high levels is slightly positive but not significant. Together, these two slopes (but not the corresponding coefficient in Table 5) can be seen as providing indirect support for H4a.

Figure 3c shows, again, a striking increase in Innovation performance between projects of *low* rather than high Market complexity when a high use of Separation strategy occurs. This relation can be seen as providing indirect support for our hypothesis H5a because, which classified market complexity as dynamic and hence more suitable for collaboration strategies when its levels are high.

Operation performance. In figure 4a, we observe the increase in Operation performance in conditions of High market complexity (dynamic and representational) when higher levels of Integrate strategies are used. This relation corroborates our hypothesis H5a.

Figure 4b shows a sizable increase of Operation performance in conditions of High Institutional Complexity (structural and intrinsic) when Separate strategies are used to a higher extent. This relation was also expected in light our hypothesis H4b.

Value creation performance interactions are not discussed in detail because the overall regression equation is only marginally significant and no specific interaction term yields significant slopes. The failure to explain the variation in value performance may be caused, by the large number of factors that affect this indicator. Also, this long term factor was assessed soon after completion, perhaps too early for a definitive picture.

6. Discussion and conclusions

Results presented above corroborate our general theoretical arguments as well as most of our detailed theoretical predictions. When some arguments and predictions were not supported, our theoretical framework and additional analyses led us to intriguing new interpretations about the nature of certain complexity types, and about the representational abilities of certain strategic practices. With respect to Hypothesis 1, the canonical analysis indicated that complexity factors were collectively associated with a reduction in completion performance, as we predicted, but surprisingly, they are also associated with an increase in innovation performance. Regression analysis of the direct effects from separate variables to performance reveal a similar pattern of technical complexity affecting completion performance negatively, and market complexity, perhaps, helping to increase innovation performance. A commonsensical interpretation of the surprising finding for innovation performance is provided by the well-known saying that "necessity is the mother of invention." But, more generally, these results suggest a more careful consideration of complexity effects. While project completion, perhaps the closest scrutinized performance indicator, is indeed negatively affected by most complexity factors, the others are not. Besides innovation, for operation and value creation the evidence is mixed at best. Also, from multiple regressions, institutional complexity seems to have a mostly positive impact on performance. This suggests that perceptions of high complexity may generate more intense representation efforts, followed by the implementation of special strategies. Evidence for this suggestion comes from the regression results referring to operation performance that also include interaction terms (column O2 in Table 5). These results show that technical and organizational complexity have a negative effect on this indicator of performance, but this effect may be counterbalanced by some interactions terms (and by a positive effect of institutional performance). The negative impact of higher levels on some complexity factors may be compensated by the selection of more suitable strategies for dealing with them. In general, complexity challenges may lead to more careful planning and better strategy selection, with a positive impact on some aspects of performance.

But which strategies are more suitable for every complexity factor? We have summarized the results with respect to interactions between complexity factors and planning-stage strategies, re-organizing them by complexity factor rather than by performance outcome, and comparing them to hypothesized relations. The summary presented in Table 6 shows that most predictions are corroborated directly or indirectly by these results. Perhaps the clearest corroboration refers to market complexity. In line with hypotheses H3b and H5a development strategies that produce new knowledge iteratively and project organizations that integrate participants' contributions and foster collaboration between them appear to interact with this complexity factor with beneficial effects for performance, the first strategy for completion, and the second one for operation. Indirectly, this also validates our assumption that market complexity is representational and dynamic, and that its critical aspects are predictive model imperfection and resulting surprises.

The other factor for which predictions are well supported is institutional complexity. Its expected beneficial interaction with strategies that separate the tasks and organizational units into modules receives (H4b) one direct and one indirect element of support, from regressions for operation and, respectively, innovation performance. The other hypothesized interaction, namely with strategies that exploit existing generic knowledge (H2a) receives indirect evidence from two equations, for innovation and completion performance. Again, this may provide indirect support for assigning institutional complexity to the static and intrinsic ends. It is also interesting to note that the two complexity factors for which predictions were corroborated are on the opposite ends of our framework, which we interpret as supporting the validity of its dimensions.

Our predictions regarding technical complexity were confirmed only in part. Namely, the expected beneficial interaction with new knowledge production strategies (H3a) obtains direct support with regard to completion performance. However, unexpectedly, strategies that exploit existing knowledge also appear to interact with technical complexity, also with beneficial effects for completion performance. We return below to further analyze this combination, unexpected for what we deemed to be a representational kind of complexity. We should also mention that the expected beneficial interaction between technical complexity and separation strategies (H4a) was not supported, which may be interpreted as suggesting that this factor is not so clearly structural.

Finally, organizational complexity is the only factor for which our hypotheses received no support. In fact, rather than interacting with strategies exploiting existing knowledge, as our assignment of this factor to the intrinsic category would predict (H2b), it appears to interact with new knowledge production to benefit completion performance. This suggests that this factor belongs to the representational end of complexity, an intriguing result, given the care we took to show that organizational complexity is most likely intrinsic. This result may have occurred because some organizational aspects, particularly those referring to the execution stage, which has the most immediate effect on the assessment of completion performance, may display representational characteristics. In other words, the charts used to shape this aspect may in fact have high-enough correspondence to enable prediction and control. Also, our expectation that organizational complexity will interact with integration strategies with a beneficial effect for performance (H5b) did not receive any support, which suggests that this factor may not be on the dynamic end. Perhaps the intertwining of social relations with the material aspects of the artifact being developed as well as with various tools, electronic forms, surveillance systems, roadways and fences, constrains and regularizes these relations to a point when organizational complexity acquires structural traits, inducing project managers to compare it to technical complexity.

In order to understand the lack of support for some hypothesized relations we also probed the association between complexity factors affecting a project and the selected planning-stage strategies. Canonical correlation results in Table 4 suggest the existence of two configurations of complexities in association with planning practices. The first canonical variate implies that, in conditions of high organizational and market complexity, which are both considered dynamic, together with high institutional complexity, which we deemed structural but intrinsic (thus less controllable), planners prefer development processes based on new knowledge production along with integrative organization, and avoid rather strongly development processes based on existing knowledge and separation. As mentioned in the theory section, we do not assume that managers will always select the right strategies and we make no prediction with respect to their choices, only with respect to the effect that an interaction between these choices and complexity factors will have for performance. Yet, an issue that could be explored by further research is whether the association of organizational complexity and market complexity in this configuration accounts for the unexpected interaction of organizational complexity and new knowledge.

The second canonical variate in Table 4 suggests that, when technical complexity is the dominant concern, which we deem representational in nature, planners prefer to use development processes that exploit existing knowledge along with the processes that produce new knowledge. Further research should consider whether this second configuration of planning practices may account for results featuring, simultaneously, the expected interaction of technical complexity with new knowledge production but also, the unexpected one, with strategies that exploit existing knowledge. Possibly, regulation, tradition or management fads induce planners to blend existing knowledge exploitation with knowledge production, and regression analyses attribute some of the beneficial effect on completion performance to the use of existing knowledge.

Irrespective of the less well supported predictions, results are quite encouraging. Notably, for the interactions that produced significant slopes, we obtained no relation that was contrary to what we expected. Overall results also bolster the more general argument that some planning-stage strategies have a better match for some complexity factors, and their interaction has a beneficial effect on performance. The geographic, project and sectoral diversity of our sample ensures that these specific and general conclusions have quite broad applicability. It is also important to mention that these significant results were obtained with a relatively small sample. A number of direct effects and interaction terms, expected or not, may have not reached significance with this sample size. Further research, with larger samples and research instruments revised based on the lessons learned from this research, could perhaps corroborate the observed relations, uncover additional ones, help validate and improve the underlying theoretical assumptions, and increase the confidence in the eventual practical recommendations.

Our theoretical development and empirical results may also provide other contributions to complexity research in the project management field. On one end, we distilled a vast generic and disciplinary literature, which examined complexity at a fundamental level, into a small set of dimensions and concepts that was then used to make sense of project complexity. On the other end of our effort to connect fundamental thinking about complexity with subjective inventories of practical complexity factors, we employed a quite original method of theoretical analysis which could be, in retrospect, termed a phenomenology of complexity. Moreover, through the second order interpretation we made of the theoretical and practice-oriented literature on project complexity, this method also has elements of what could be called a hermeneutics of complexity. As a proximate outcome, this approach enabled us to assign key complexity factors to our basic categories of complexity and hence, connect the abstract and practical streams of research on complexity. It also advanced our empirical validation goal by providing a rationale for the use of psychometric scales to study complexity. But this approach also opens the door for connecting complexity research to the ‘practice turn’ in project management and organization studies. This perspective, with its emphasis on micro-level, situated, everyday activities and on observational studies enable a more direct observation and interpretation of project managers' perceptions of complexity, and could help us saturate or modify categories such as structural versus dynamic, or intrinsic versus representational. Moreover, such studies could help us grasp how planning stage strategies lead to practices that, day after day, address the challenges raised by complexity.

Our results could also contribute to other fields. Our conceptualization of complexity and empirical results can be used in some technical domains to develop theories and practices that address the more specific forms of complexity affecting those fields. Besides, because our theory refers to cognitive, social and organizational aspects of complexity, including their dynamics, it can help inform more fundamental theories of cognition, team collaboration, and organizational structure and processes that address complexity. These results could improve the effectiveness of scientific and technological development activities, and of managing teams, organizations and networks of firms in many domains. Also, our results may hopefully inspire new insights to help advance abstract conceptualizations of complexity, the same way these nourished our reflection.

In practical terms, these results contribute to a deeper understanding of the rationales for some of the most commonly used planning-stage strategies, particularly of the way they impact the ability of projects to address various types of complexity. The prediction and validation effort that we deployed in this paper with respect to entire categories of factors, could be extended, by relying on the same theoretical framework and methods, to investigate more detailed complexity factors identified by the practical stream of research, such as the 50 factors of the TOE framework. The deeper understanding of these factors and the validation of their interactions with various project management practices can help improve planning practices by eliminating various inessential elements that were included by accident and persist by tradition. It may even lead to new practical approaches, specifically designed to address different project complexity factors. The more nuanced understanding we propose for the key complexity factors can also result in a better mapping of various practices and in criteria for selecting the most appropriate practices for a given project, and in improved guidelines for their concrete application.

REFERENCES

Aaltonen, K. 2011. Project stakeholder analysis as an environmental interpretation process, *International Journal of Project Management*, 29(2): 165-183.

Abernathy, W. J. & Utterback, J. M. 1978. Patterns of industrial innovation. Technology Review, 80(7): 2-29.

Abrahamson, E. 1991. Managerial fads and fashions: The diffusion and rejection of innovations. *Academy of Management Review*, 16(3): 586-612.

Aldrich, H. E. & Fiol, C. M. 1994. Fools rush in? The institutional context of industry creation. *Academy of Management Review*, 19(4): 645-670.

Alexander, C. 1964. *Notes on the Synthesis of Form*. Cambridge, MA: Harvard University Press.

Arthur, W. B. 1989. Competing technologies, increasing returns, and lock-in by historical events. *Economic Journal*, 99: 116-131.

Anderson, P. 1999. Perspective: Complexity theory and organization science. *Organization Science*, 10(3): 216-232.

Ashby, W.R. 1958. Requisite Variety and its implications for the control of complex systems. *Cybernetica* (Namur), 1(2): 83-99.

Atkinson, R. 1999. Project management: cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria. *International Journal of Project Management*, 17(6): 337-342.

Aubry, M., Müller, R., Hobbs, B., & Blomquist, T. 2010. Project management offices in transition. *International Journal of Project Management*, 28(8): 766-778.

Ballard, G. & Tommelein, I. 2012. Lean management methods for complex projects. *Engineering Project Organization Journal*, 2(1-2): 85-96.

Barad, K. 2003. Posthumanist performativity: Toward an understanding of how matter comes to matter. *Signs*, 28(3), 801-831.

Barley, S. R. 1986. Technology as an occasion for structuring: Evidence from observations of ct scanners and the social order of radiology departments. *Administrative Science Quarterly*, 31(1): 78–108.

Bass, F. M. 1969. A new product growth model for consumer durables. *Management Science*, 15(5, Theory Series), 215-227.

Bass, F. M., Gordon, K., Ferguson, T. L., & Githens, M. L. 2001. DIRECTV: Forecasting diffusion of a new technology prior to product launch. *Interfaces*, 31(3_supplement), S82-S93.

Beck, U. 1992. *Risk Society: Towards a New Modernity*. London, UK: SAGE.

Begley, G. C. & Ellis, L. M. 2012. Raise standards for preclinical cancer research. *Nature*, 483(7391): 531-533.

Benbya, H., & McKelvey, B. 2006. Using coevolutionary and complexity theories to improve IS alignment: a multi-level approach. *Journal of Information technology*, 21(4), 284-298.

Berger, P., & Luckmann, T. 1966. *The Social Construction of Reality*. Garden City, NY: Doubleday.

Biazzo, S. 2009. Flexibility, structuration, and simultaneity in new product development. *Journal of Product Innovation Management*, 26(3): 336-353.

Biggiero, L. 2001. Sources of complexity in human systems. *Nonlinear Dynamics, Psychology, and Life Sciences*, 5(1): 3-19.

Bijker, W. E., Hughes, T. P. & Pinch, T. J. (eds.). 1987. *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. Cambridge, MA: MIT Press.

Blomquist, T., Hällgren, M., Nilsson, A & Söderholm, A. 2010. Project-as-practice: In search of project management research that matters. *Project Management Journal*, 41(1), 5-16.

Boehm, B. 1988. A spiral model of software development and enhancement. *IEEE Computer*, 21(5): 61–72.

Bogner, W. C. & Barr, P. S. 2000. Making sense in hypercompetitive environments: A cognitive explanation for the persistence of high velocity competition. *Organization Science*, 11(2): 212-226.

Bohn, R. E. 1994. Measuring and managing technological growth. *Sloan Management Review*, 36(1), 61-73.

Bosch-Rekveldt, M., Jongkind, Y., Mooi, H., Bakker, H., & Verbraeck, A. (2011). Grasping project complexity in large engineering projects: The TOE (Technical, Organizational and Environmental) framework. *International Journal of Project Management*, 29(6), 728-739.

Bourdieu, P. 1977. *Outline of a Theory of Practice*. Cambridge, UK: Cambridge University Press.

Brown, S. L. & Eisenhardt, K. M. 1997. The art of continuous change: Linking complexity theory and time-paced evolution in relentlessly shifting organizations. *Administrative Science Quarterly*, 42(1): 1-34.

Brown, J. S., & Duguid, P. 1991. Organizational learning and communities-of-practice: Toward a unified view of working, learning, and innovation. *Organization science*, 2(1): 40-57.

Browning, T. R. & Ramasesh, R. V. 2015. Reducing unwelcome surprises in project management. *MIT Sloan Management Review*, 56(3): 53-62.

Brucker, P., Drexl, A., Möhring, R., Neumann, K. & Pesch, E. 1999. Resource-constrained project scheduling: Notation, classification, models, and methods. *European Journal of Operational Research*, 112(1), 3-41.

Brusoni, S., Prencipe, A., & Pavitt, K. 2001. Knowledge specialization, organizational coupling, and the boundaries of the firm: Why do firms know more than they make? *Administrative Science Quarterly*, 46(4): 597-621.

Bunge, M. A. 1979. *Treatise on Basic Philosophy: Ontology II: A World of Systems.* Dordrecht, Holland: D. Reidel.

Burt, R. S. 1992. *Structural holes: The social structure of competition.* Cambridge, Mass.: Harvard University Press.

Callon, M. 1986. Some elements of a sociology of translation: Domestication of the scallops and the fishermen of St Brieuc Bay. In J. Law (ed.): *Power, Action and Belief: A New Sociology of Knowledge?* (p. 196-223). London: Routledge.

Campbell, D. T. 1960. Blind variation and selective retention in creative thought as in other knowledge processes. *Psychological Review*, 67(6): 380-400.

Chandrasegaran, S. K., Ramania, K., Sriram, R. D., Horváth, I. Bernard, A., Harik, R. F., & Gao, W. 2013. The evolution, challenges, and future of knowledge representation in product design systems. *Computer-Aided Design,* 45 (2): 204–228.

Chapman, C. B., & Ward, S. C. 1994. The Efficient Allocation of Risk in Contracts. *Omega, International Journal of Management Science*, 22(6): 537-552.

Christensen, C. 1997. The Innovator's Dilemma. New York: Harper Business.

Cohen, J. 2010. *Integrated Project Delivery: Case Studies.* Sacramento, CA: The American Institute of Architects.

Cohen, W. M. & Levinthal, D. A. 1990. Absorptive capacity: A new perspective of learning and innovation. *Administrative Science Quarterly*, 35: 128-152.

Coleman, J. S. 1966. Foundations for a theory of collective decisions. American Journal of Sociology, 71(6): 615-627.

Conforto, E. C, Salum, F., Amaral, D. C., da Silva, S. L. Luís, & Magnanini de Almeida, F. (2014) Can agile project management be adopted by industries other than Software Development? *Project Management Journal*, 45(3): 21–34.

Cooke-Davies, T., Cicmil, S., Crawford, L. and Richardson, K. (2007). We’re not in Kansas anymore, Toto: mapping the strange landscape of complexity theory, and its relationship to project management. *Project Management Journal*, 38(2), 50-61.

Cooper, R. G. 2001. *Winning at New Products* (3rd ed.). Cambridge: Perseus.

Cooper, R. G. 2008. Perspective: The Stage-Gate® idea-to-launch process—Update, what's new, and NexGen systems*. *Journal of Product Innovation Management*, 25(3): 213-232.

Corbin, J. M. & Strauss, A. 1990. Grounded theory research: Procedures, canons, and evaluative criteria. *Qualitative Sociology*, 13(1): 3-21.

Crossley, N.: 2011. *Towards Relational Sociology*. London, UK: Routledge.

Dahan, E. & Hauser, J. R. 2002. The virtual customer. *Journal of Product Innovation Management*, 19(5): 332-353.

Dawson, J. F. 2014. Moderation in management research: What, why, when, and how. *Journal of Business and Psychology*, 29 (1): 1-19.

Denis, J. L., Lamothe, L. & Langley, A. 2001. The dynamics of collective leadership and strategic change in pluralistic organizations. *Academy of Management Journal*, 44(4): 809-837.

Dietrich, P., Kujala, J. & Artto, K. 2013. Inter-team coordination patterns and outcomes in multi-team projects. *Project Management Journal*, 44 (6): 6-19.

Dillman, D. A., Smyth, J. D., & Christian, L. M. 2009. *Internet, Mail and Mixed-mode Surveys: The Tailored Design Method (3rd ed.).* Hoboken, NJ: John Wiley & Sons.

DiMaggio, P, & Powell, W. W. 1983. The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. *American Sociological Review*, 48: 147-160.

Dooley, K. J., & Van de Ven, A. H. 1999. Explaining complex organizational dynamics. *Organization Science*, 10(3): 358-372.

Doolin, B. & McLeod, L. 2012. Sociomateriality and boundary objects in information systems development. *European Journal of Information Systems*, 21(5): 570–586.

Dougherty, D. 2001. Reimagining the differentiation and integration of work for sustained product innovation. *Organization Science*, 12(5): 612–631.

Douglas, M., & Wildavsky, A. 1982. *Risk and Culture: An Essay on the Selection of Technological and Environmental Dangers*. Berkeley, Ca.: University of California Press.

Eisenhardt, K.M. 1989. Making fast strategic decisions in high-velocity environments. *Academy of Management Journal*, 32: 543–576.

Emery, F. E., & Trist, E. L. 1965. The causal texture of organizational environments. *Human Relations*, 18(1): 21-32.

Engwall, M. 2003. No project is an island: Linking projects to history and context. *Research Policy*, 32(5): 789-808.

Feldman, M. S., & Pentland, B. T. 2003. Reconceptualizing organizational routines as a source of flexibility and change. *Administrative Science Quarterly*, 48(1): 94-118.

Fleiss, J.L. 1986. Analysis of data from multiclinic trials. *Controlled Clinical Trials*, 7 (4): 267-275.

Fleming, L. & Sorenson, O. 2004. Science as a map in technological search. *Strategic Management Journal*, 25: 909-925.

Flyvbjerg, B., Skamris Holm, M. K., & Buhl, S. L. 2005. How (in) accurate are demand forecasts in public works projects?: The case of transportation. *Journal of the American Planning Association*, 71(2): 131-146.

Floricel, S., Bonneau, C., Aubry, M. & Sergi, V. 2014. Extending project management research: Insights from social theories. *International Journal of Project Management*. 32(7): 1091–1107.

Floricel, S. & Miller, R. 2001. Strategizing for anticipated risks and turbulence in large-scale engineering projects. *International Journal of Project Management*, 19(8), 445–455.

Floricel, S., Michela, J. L. & George, M., with L. Bonneau. 2011. *Knowledge Representations in Innovation Projects: Refining the Knowledge Production Plan.* Newtown Square, PA, USA: Project Management Institute.

Floricel, S., Piperca, S. & Banik, M. 2011. Increasing Project Flexibility: The Response Capacity of Complex Projects. Newton Square, PA: Project Management Institute.

Gavetti, G., & Levinthal, D. 2000. Looking forward and looking backward: Cognitive and experiential search. *Administrative Science Quarterly*, 45: 113–137.

Gell-Mann, M. & Lloyd, S. Information measures, effective complexity, and total information. *Complexity*, 2(1): 44–52.

Geraldi, J., Maylor, H., & Williams, T. 2011. Now, let's make it really complex (complicated) A systematic review of the complexities of projects. *International Journal of Operations & Production Management*, 31(9), 966-990.

Gersick, C. J. G. 1991. Revolutionary change theories: A multilevel exploration of the punctuated equilibrium paradigm. *Academy of Management Review*, 16(1): 10–36.

Giddens, A. 1984. *The Constitution of Society. Outline of the Theory of Structuration*. Berkeley: University of California Press.

Goertzel, B. 1992. Measuring static complexity. *International Journal of Mathematics and Mathematical Sciences*, 15(1): 161-174.

Hair, J.F., Tatham, R.L., Anderson, R.E. & Black, W. 1999. *Multivariate Data Analysis, 5th ed.* New York: Prentice Hall.

Hansen, M. T. 1999. The search-transfer problem: The role of weak ties in sharing knowledge across organization subunits. *Administrative Science Quarterly*, 44(1): 82-111.

Hanseth, O., Monteiro, E. & Hatling, M. 1996. Developing information infrastructure: The tension between standardization and flexibility. *Science, Technology & Human Values*, 21(4): 407-426.

Haveman, H. A. & Rao, H. 1997. Structuring a theory of moral sentiments: Institutional and organizational coevolution in the early thrift industry. *American Journal of Sociology*, 102(6): 1606-1651.

Helfat, C. E. & Peteraf, M. A. 2003. The dynamic resource-based view: Capability lifecycles. *Strategic Management Journal*, 24(10): 997-1010.

Helton, J. C., & Oberkampf, W. L. (2004). Alternative representations of epistemic uncertainty. *Reliability Engineering & System Safety*, 85(1), 1-10.
Henderson, R. M., & Clark, K. B. 1990. Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms. *Administrative Science Quarterly*, 35: 9-30.
Hernes, T. 2008. *Understanding Organization as Process: Theory for a Tangled World.* New York: Routledge.
Hernes, T., & Weik, E. 2007. Organization as process: Drawing a line between endogenous and exogenous views. Scandinavian Journal of Management, 23(3), 251-264.
Highsmith, J. A. 2010. *Agile project management: Creating innovative products (2nd ed.).* Upper Saddle River, NJ: Addison-Wesley.
Hodgkinson, G. P., & Healey, M. P. 2011. Psychological foundations of dynamic capabilities: Reflexion and reflection in strategic management. *Strategic Management Journal*, 32(13): 1500-1516.
House, R.S. 1988. *The Human Side of Project Management*. Reading, MA: Addison-Wesley.
Hughes, T. 1983. *Networks of Power*. Baltimore: John Hopkins Press.
Jepsen, A. L. & Eskerod, P. 2009. Stakeholder analysis in projects: Challenges in using current guidelines in the real world. *International Journal of Project Management*, 27(4): 335-343.
Kappelman, L. A., McKeeman, R., & Zhang, L. (2006). Early warning signs of IT project failure: The dominant dozen. *Information systems management*, 23(4), 31-36.
Kahn, K. B. 2014. Solving the problems of new product forecasting. *Business Horizons*, 57(5): 607-615.
Katila, R. & Ahuja, G. 2002. Something old, something new: A longitudinal study of search behavior and new product introduction. *Academy of Management Journal*, 45(6): 1183-1194.
Katina P. F., Keating, C. B. & Jaradat, R. M. 2014. System requirements engineering in complex situations. *Requirements Engineering*, 19(1): 45–62.
Kay, A. C., Whitson, J. A., Gaucher, D., & Galinsky, A. D. 2009. Compensatory control achieving order through the mind, our institutions, and the heavens. *Current Directions in Psychological Science*, 18(5): 264-268.
Kim, J., & Wilemon, D. 2003. Sources and assessment of complexity in NPD projects. *R&D Management*, 33(1), 15-30.
Klakegg, O. J., Williams, T., Magnussen, O. M., & Glasspool, H. 2008. Governance frameworks for public project development and estimation. *Project Management Journal*, 39(S1) : S27-S42.
Klepper, S. 1997. Industry life cycles. *Industrial and Corporate Change*, 6 (1): 145-182.
Kline, R. 1987. Science and engineering theory in the invention and development of the induction motor, 1880-1900. *Technology and Culture*, 28(2), 283-313.
Kohl, P. & Noble, D. (2009). Systems biology and the virtual physiological human. *Molecular Systems Biology*, 5(1): 1-6.
Kolmogorov, A. N. 1965. Three approaches to the quantitative definition of information. *Problems of Information Transmission*, 1(1), 1-7.
Kontopoulos, K. M. 1993. *The Logics of Social Structure*. Cambridge, UK: Cambridge University Press.

Koskinen, K. U. 2012. Organizational learning in project-based companies: A process thinking approach. *Project Management Journal*, 43(3), 40-49.

Krishnan, V., Eppinger, S.D., & Whitney, D. E. 1997. A model based framework to overlap product development activities. *Management Science*, 43(4): 437-451.

Lahdenperä, P. 2012. Making sense of the multi-party contractual arrangements of project partnering, project alliancing and integrated project delivery. *Construction Management and Economics*, 30(1): 57-79.

Lampel, J., Shamsie, J., & Shapira, Z. 2009. Experiencing the improbable: Rare events and organizational learning. *Organization Science*, 20(5): 835-845.

Latour, B. & Woolgar, S. 1979. *Laboratory Life: The Social Construction of Scientific Facts.* Beverly Hills, CA: Sage.

Leifer, R., McDermott, C. M., Colarelli O'Connor, G., Peters, L. S., Rice, M. & Veryzer, R. W. 2000. *Radical Innovation: How Mature Companies Can Outsmart Upstarts*. Boston: Harvard Business School Press.

Leveson, N., Dulac, N., Marais, K. & Carroll, J. 2009. Moving beyond normal accidents and high reliability organizations: A systems approach to safety in complex systems. *Organization Studies*, 30(2-3): 227-249.

Levinthal, D. A. 1997. Adaptation to rugged landscapes. *Management Science*, 43(7): 934-950.

Leybourne, S. A. 2009. Improvisation and agile project management: a comparative consideration. *International Journal of Managing Projects in Business*, 2(4), 519-535.

Lindstrom, L. & Jeffries, R. 2004. Extreme programming and agile software development methodologies. *Information Systems Management*, 21(3): 41-52.

Loch, C. H. & Terwiesch, C. 1998. Communication and uncertainty in concurrent engineering. *Management Science*, 44(8): 1032-1048.

Lu, S. C.-Y. & Suh, N.-P. 2009. Complexity in design of technical systems. *CIRP Annals - Manufacturing Technology*, 58(1), 157-160.

Luehrman, T. A. 1998. Strategy as a portfolio of real options. *Harvard Business Review*, 76(5): 89-101.

Luhmann, N. 1993. *Risk: A sociological theory*. New York: Aldine De Gruyter.

Luhmann, N. 1995. *Social systems*. Stanford University Press.

Lundvall, B.A. 1993. *National Systems of Innovation*. London, UK: Frances Pinter.

Lundin, R. A., & Söderholm, A. 1995. A theory of the temporary organization. *Scandinavian Journal of Management*, 11(4): 437-455.

Lynn, G., Morone, J. & Paulson, A. 1996. Marketing discontinuous innovation: The probe and learn process. *California Management Review*, 38(3): 8–37

MacCormack, A., Verganti, R. et Iansiti M. 2001. "Developing Products on "Internet Time": The Anatomy of a Flexible Development Process." Management Science, 47(1): 133–150.

Malerba, F. 2002. Sectoral systems of innovation and production. *Research Policy*, 31(2): 247-264.

Mandal, S., Moudgil, M., & Mandal, S. K. 2009. Rational drug design. *European Journal of Pharmacology*, 625(1–3), 90-100.

Manning, S. 2008. Embedding projects in multiple contexts – a structuration perspective. *International Journal of Project Management*, 26(1): 30–37.

March, J. G. 1991. Exploration and exploitation in organizational learning. *Organization Science*, 2: 71-87.

Mas-Machuca, M., Sainz, M. & Martinez-Costa, C. 2014. A review of forecasting models for new products. *Intangible Capital*, 10(1): 1-25.
Maturana, H. R., & Varela, F. 1980. *Autopoiesis and Cognition: the Realization of the Living.* Dordrecht: Reidel.
Maylor, H., Vidgen, R. & Carver, S. 2008. Managerial complexity in project-based operations: A grounded model and its implications for practice. *Project Management Journal*, 39(S1): S15–S26.
Mayr, E. 2000. Biology in the twenty-first century. *BioScience,* 50(10), 895–897.
Meyer, J. W. & Rowan, B. 1977. Institutionalized organizations: Formal structure as myth and ceremony. *American Journal of Sociology*, 83: 340-363.
Meyers, L. S., Gamst, G. & Guarino, A. J. 2005. *Applied Multivariate Research: Design and Interpretation*. Thousand Oaks, CA: Sage.
Miller, R.E., Hobday, M., Leroux-Demers, T., & Olleros, X. 1995. Innovation in complex systems industries: The case of flight simulation. *Industrial and Corporate Change*, 4(2): 363-400.
Miller, R.E. & Lessard, D.; with S. Floricel and the IMEC Research Group. 2001. *The Strategic Management of Large Engineering Projects*. Cambridge, MA: MIT Press.
Mintzberg, H. & Lampel, J. 1999. Reflecting on the strategy process. *Sloan Management Review*, 40(3): 21-30.
Moore, G. 1991. *Crossing the Chasm*. New York: Harper.
Murmann, J. P. & Frenken, K. 2006. Toward a systematic framework for research on dominant designs, technological innovations, and industrial change. *Research Policy*, 35(7): 925-952.
Naoum, S. 2003. An overview into the concept of partnering. *International Journal of Project Management*, 21(1), 71-76.
Nightingale, P. 1998. A cognitive model of innovation. *Research Policy*, 27: 689-709.
Nightingale, P. & Martin, P. 2004. The myth of the biotech revolution. *Trends in Biotechnology*, 22(11): 564-569.
Noble, D. 2002. The rise of computational biology. *Nature Reviews Molecular Cell Biology*, 3(6): 459-463.
Oliver, C. 1991. Strategic responses to institutional processes. *Academy of Management Review*, 16: 145-179.
Olsson, N. 2006. Management of flexibility in projects. *International Journal of Project Management*, 24 (1): 66-74.
Orlikowski, W. J. 2007. Sociomaterial practices: Exploring technology at work. *Organization Studies*, 28(9), 1435-1448.
O'Sullivan, A. 2006. Why tense, unstable, and diverse relations are inherent in co-designing with suppliers: an aerospace case study. *Industrial and Corporate Change*, 15 (2): 221–250.
Pellegrinelli, S. 2011. What's in a name: Project or programme? *International Journal of Project Management*, 29(2): 232-240.
Perrow, C. 1984. *Normal Accidents: Living with High-Risk Technologies*. New York: Basic Books.
Pfeffer, J., & Salancik, G. 1978. *The External Control of Organizations.* New York: Harper and Row.

Preacher, K. J., Curran, P. J., & Bauer, D. J. 2006. Computational tools for probing interaction effects in multiple linear regression, multilevel modeling, and latent curve analysis. *Journal of Educational and Behavioral Statistics*, 31: 437-448.

Prencipe, A. & Tell, F. 2001. Inter-project learning: processes and outcomes of knowledge codification in project-based firms. *Research Policy*, 30(9): 1373–1394.

Prigogine, I. 1997. *The End of Certainty*. New York: Free Press.

Rogers, E. M. 1995. *Diffusion of Innovations* (4th ed.). New York: Free Press.

Rosch, E. 1978. Principles of categorization. In E. Rosch and B. B. Loyd (eds.): *Cognition and Categorization*, 27-48. Hillsdale, NJ: Lawrence Erlbaum.

Sanchez, R. & Mahoney, J. T. 1996. Modularity, flexibility, and knowledge management in product and organization design. Strategic Management Journal, 17(S2): 63-76.

Sauer, U., Heinemann, M. & Zamboni N. 2007. Getting closer to the whole picture. *Science*, 316 (5824), 550-551.

Saunders, F. C. 2015. Toward high reliability project organizing in safety-critical projects. *Project Management Journal*, 46(3): 25–35.

Sawyer, R. K. 2004. The mechanisms of emergence. *Philosophy of the Social Sciences*, 34(2): 260-282.

Schilling, M. A. 2000. Towards a general modular systems theory and its application to interfirm product modularity. *Academy of Management Review*, 25 (2): 312-334.

Schwaber, K. 1997. Scrum development process. In D.J. Sutherland et al. (eds.) *Business Object Design and Implementation* London: Springer, p. 117-134.

Schwartz, A. 2015. The promise of neurotechnology. *Science*, 350(6256): 11-11.

Shenhar, A. J. 2001. One size does not fit all projects: Exploring classical contingency domains. *Management Science*, 47(3), 395–414.

Simon, H. A. 1962. The architecture of complexity. *Proceedings of the American Philosophical Society*, 106(6): 467-482.

Simon, H. A. 1981. *The Sciences of the Artificial (2nd ed.).* Cambridge, MA: MIT Press.

Simondon, G. 1989. *Du mode d'existence des objets techniques*. Paris: Aubier.

Smith, W. K. & Lewis, M. W. 2011. Toward a theory of paradox: A dynamic equilibrium model of organizing. *Academy of Management Review*, 36(2): 381-403.

Soderholm, A. 2008. Project management of unexpected events. *International Journal of Project Management*, 26(1): 80-86.

Söderlund, J. 2002. Managing complex development projects: arenas, knowledge processes and time. *R&D Management*, 32(5): 419-430.

Sommer, S. C., & Loch, C. H. 2004. Selectionism and learning in projects with complexity and unforeseeable uncertainty. *Management science*, 50(10): 1334-1347.

Strang D. & Macy, M. W. 2001. In search of excellence: Fads, success stories, and adaptive emulation. *American Journal of Sociology*, 107(1): 147-182.

Suchman, M. C. 1995. Managing legitimacy: Strategic and institutional approaches. *Academy of Management Review*, 20(3): 571-610.

Suh, N. P. 2005. Complexity in engineering. *CIRP Annals - Manufacturing Technology*, 54(2): 46-63.

Taleb, N. N. 2007. Black swans and the domains of statistics. *American Statistician*, 61(3): 198-200.

Tang, L., Shen, Q. & Cheng, E.W.L. 2010. A review of studies on Public–Private Partnership projects in the construction industry. *International Journal of Project Management*, 28(7): 683-694.

Teece, D. J. 2007. Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance. *Strategic Management Journal*, 28(13): 1319-1350.

Tegarden, D. P., Sheetz, S. D. & Monarchi, D. E. 1995. A software complexity model of object-oriented systems. *Decision Support Systems*, 13(3-4): 241–262.

Thom, R. 1974. Stabilité structurelle et morphogenèse. *Poetics*, 3(2): 7-19.

Thomke, S. H. 1998. Managing experimentation in the design of new products. *Management Science*, 44(6): 743-762.

Thomke, S. & Fujimoto, T. 2000. The Effect of "Front-Loading" Problem-Solving on Product Development Performance. *Journal of Product Innovation Management*, 17(2): 128–142.

Thompson, J. D. 1967. *Organizations in Action*. New York: McGraw-Hill.

Tsoukas, H. & Chia, R. 2002. On organizational becoming: Rethinking organizational change. *Organization Science*, 13(5):567-582.

Tucker, T. 2010. *Supply Chain Orientation: Refining a Nascent Construct* [Unpublished doctoral thesis]. Department of Management Sciences, University of Waterloo, Ontario, Canada.

Ulrich, K.1995. The role of product architecture in the manufacturing firm. *Research Policy*, 24(3): 419-440.

Urban, G. L., Hauser, J. R. & Roberts, J. H. 1990. Prelaunch forecasting of new automobiles. *Management Science,* 36(4): 401-421.

Van de Ven, A. H. & Poole, M. S. 1995. Explaining development and change in organizations. *Academy of Management Review*, 20(3): 510-540.

Verganti, R. 1999. Planned flexibility: linking anticipation and reaction in product development projects. Journal of Product Innovation Management, 16(4), 363-376.

Vignehsa, K. 2015. Genealogical ethnography: Process thinking to study the "inside" of projects. *Project Management Journal*, 46(2), 60-72.

Vincenti, W. G. 1990. *What Engineers Know and How They Know It.* Baltimore: John Hopkins University Press.

Visser, W. 2006. Designing as construction of representations: A dynamic viewpoint of cognitive design research. *Human-Computer Interactions*, 21: 103-152.

Vohora, A., Wright, M. & Lockett, A. 2004. Critical junctures in the development of university high-tech spinout companies. *Research Policy*, 33(1): 147-175.

von Hippel, E. S. 1986. Lead users: A source of novel product concepts. *Management Science*, 32(7), 791-805.

Wateridge, J. 1998. How can IS/IT projects be measured for success. *International Journal of Project Management*, 16(1): 59-63.

Weick K. E. & Quinn, R. E. 1999. Organizational change and development. *Annual Review of Psychology*, 50(1): 361-386.

Weick, K. E., & Roberts, K. H. 1993. Collective mind: Heedful interrelations on flight decks. *Adminstrative Science Quarterly*, 38: 357-381.

Weick, K. E., Sutcliffe, K. M., & Obstfeld, D. 2005. Organizing and the process of sensemaking. *Organization science*, 16(4): 409-421.

Whitson, J. A. & Galinsky, A. D. 2008. Lacking control increases illusory pattern perception. *Science*, 322(5898): 115-117.

Whitty, S. J., & Maylor, H. 2009. And then came complex project management (revised). *International Journal of Project Management*, 27(3), 304-310.

Wimsatt, W. C. 2006. Aggregate, composed, and evolved systems: Reductionistic heuristics as means to more holistic theories. *Biology & Philosophy*, 21(5), 667–702.

Williams, T. M. (1999). The need for new paradigms for complex projects. *International Journal of Project Management*, 17(5): 269-273.

Xia, W. & Lee, G. 2005. Complexity of information systems development projects: Conceptualization and measurement development. *Journal of Management Information Systems*, 22(1): 45-83.

Table 1. Types of project complexity, their markers and effects on planners, corresponding categories of practical factors and their influence on performance

	Structural	***Dynamic***
Intrinsic	Non-additive aggregation or interactions Multilevel frameworks *Effect*: unpredictable form *Typical factor*: ***institutional complexity***	Number and interdependence of variables Evolutionary and dialectic frameworks *Effect*: path-dependent or chaotic change *Typical factor*: ***organizational complexity***
Represen-tational	Abstraction and computation difficulties Systematic trial and error *Effect*: unintended properties *Typical factor*: ***technical complexity***	Hidden interdependencies Contingency planning and early tests *Effect*: repeated significant surprises *Typical factor*: ***market complexity***

Table 2. Inter-correlations of scores for complexity, planning strategy, and performance variables.

	Complexity Factors				Planning Strategy Factors				Performance Factors			
	Technical	Organiza-tional	Institutional	Market	New Knowledge	Existing Knowledge	Integrate	Separate	Completion	Innovation	Operation	Value Creation
Technical												
Organizational	-0.10											
Institutional	0.17	0.57**										
Market	0.22†	0.04	0.13									
New Knowledge	0.38**	0.30**	0.27*	0.24*								
Existing Knowledge	0.15	-0.42**	-0.23*	-0.24*	-0.31**							
Integrate	0.21†	0.10	0.09	0.20†	0.33**	-0.02						
Separate	0.03	-0.15	-0.12	-0.26*	-0.20†	0.41**	-0.05					
Completion	-0.18	-0.07	-0.11	-0.15	-0.10	0.14	0.13	0.35**				
Innovation	0.22†	0.22†	0.26*	0.25*	0.27*	-0.12	0.17	0.09	0.22†			
Operation	-0.02	-0.14	0.01	-0.02	-0.07	0.18	0.14	0.36**	0.56**	0.10		
Value Creation	0.03	0.13	0.03	-0.10	0.05	0.10	0.19	0.31**	0.43**	0.29*	0.37**	

**p < .01, *p < .05, †p < .10

Table 3. Results of canonical correlation analysis relating complexity factors to performance factors.

	Canonical Variate 1
Canonical loadings	
Complexity Factors	
Technical	.66
Organizational	.41
Institutional	.63
Market	.71
Performance Factors	
Completion	-.44
Innovation	.75
Operation	-.09
Value Creation	-.01
Canonical correlation	0.52
Chi-square	49.01
df	16
p-level	.026

Note. Values entered in the first 8 rows describe correlations of measured variables with the single obtained canonical variate that was statistically significant.

Table 4. Results of canonical correlation analysis relating complexity factors to planning strategy factors.

	Canonical Variate 1	Canonical Variate 2
Canonical loadings		
Complexity Factors		
Technical	0.38	0.92
Organizational	0.76	-0.34
Institutional	0.54	-0.01
Market	0.59	-0.12
Planning Strategies		
New Knowledge	0.86	0.48
Existing Knowledge	-0.71	0.68
Integrate	0.44	0.24
Separate	-0.42	0.32
Canonical correlations	0.56	0.47
Chi-square	49.01	21.30
df	16	9
p-level	< .001	0.011

Note. Values entered in the first 8 rows describe correlations of measured variables with the two obtained canonical variates that were statistically significant.

Table 5. Unstandardized regression coefficients and equation statistics from multiple regression analyses

Complexity and Planning Strategy Predictor Variables	**Performance outcome variables**							
	Completion		Innovation		Operation		Value creation	
	C1	C2	I1	I2	O1	O2	V1	V2
Constant	4.912	4.675	4.814	4.674	4.217	4.077	5.068	4.989
Technical complexity	***-0.309***	***-0.296***	0.132	0.260	-0.185	**-0.382**	-0.005	-0.067
Organizational complexity	-0.081	-0.231	0.160	-0.009	-0.279	***-0.330***	0.216	0.102
Market complexity	-0.069	-0.231	0.350	0.219	0.068	0.074	-0.071	-0.223
Institutional complexity	0.023	0.212	0.296	**0.441**	0.256	**0.391**	-0.039	0.085
Existing knowledge exploitation strategy	-0.028	-0.149	-0.157	-0.316	-0.009	0.049	-0.001	-0.062
New knowledge production strategy	0.072	0.196	0.226	0.157	0.036	0.190	0.042	0.108
Separate organization strategy	**0.484**	**0.575**	***0.441***	**0.528**	**0.518**	**0.516**	**0.423**	**0.469**
Collaborate organization strategy	0.239	0.197	0.102	0.080	0.233	0.213	0.216	0.204
Technical complexity x Existing knowledge		**0.407**				***0.280***		
Technical complexity x New knowledge		***0.368***						
Organization complexity x Existing knowledge						**-0.363**		
Organizational complexity x New knowledge		***0.368***						***0.365***
Market complexity x New knowledge		**0.425**						**0.369**
Market complexity x Separate organization				**-0.815**				
Market complexity x Integrate organization						**0.438**		
Institutional complexity x Existing knowledge				***0.421***				
Institutional complexity x New knowledge		***-0.425***						-0.293
Institutional complexity x Separate organization				**-0.454**		**0.367**		
R-square	***0.202***	**0.353**	***0.205***	**0.395**	***0.191***	**0.368**	0.169	***0.257***
Adjusted R-square	***0.101***	**0.208**	***0.104***	**0.284**	***0.088***	**0.240**	0.062	***0.118***
F-ratio	2.00	2.44	2.03	3.56	1.86	2.87	1.57	1.85
df numerator, denominator	8, 63	13, 58	8, 63	11, 60	8, 63	12, 59	8, 62	11, 59
p-level	0.051	0.010	0.057	0.001	0.082	0.004	0.151	0.065

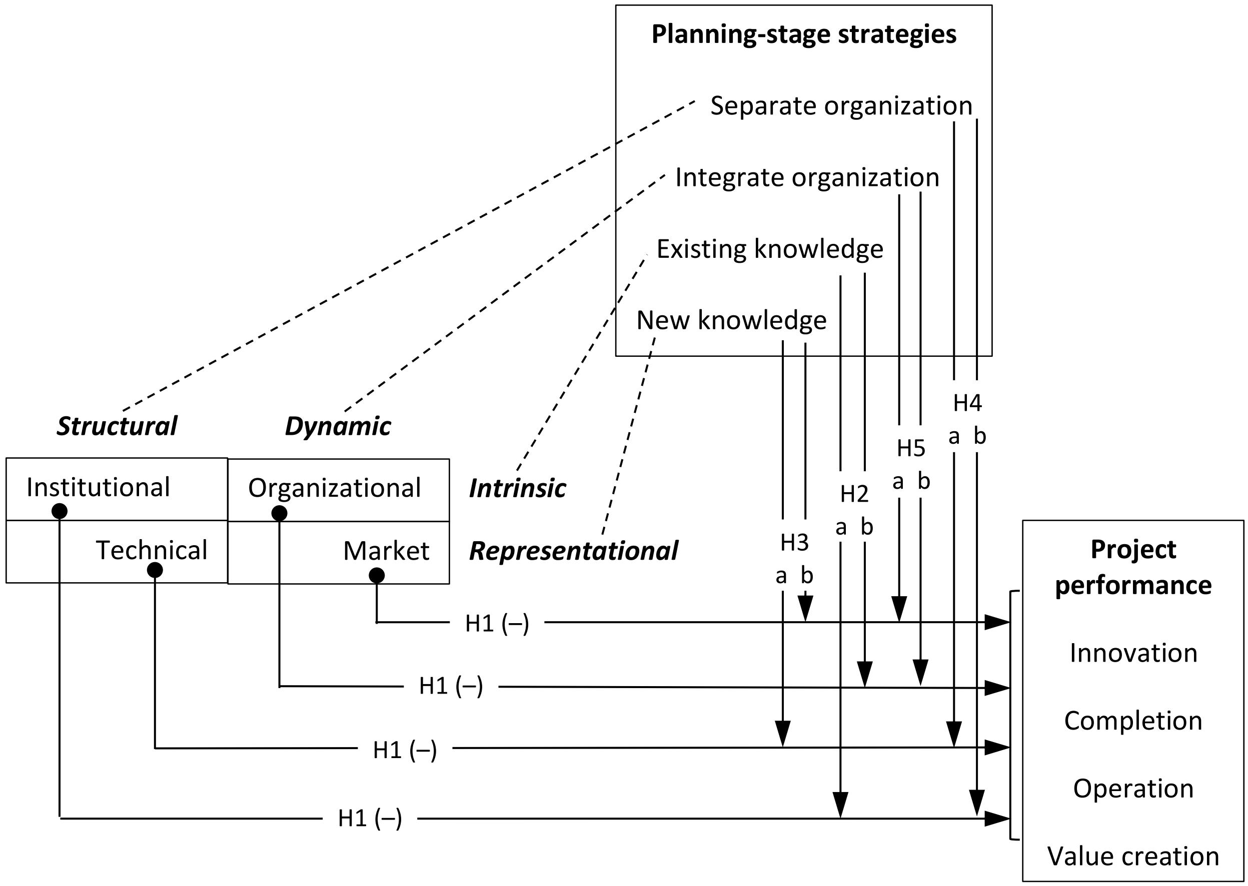
Note: Regression coefficients are all unstandardized and are in **boldface** when statistically significant ($p < .05$) or in ***italicized boldface*** when marginally significant ($p < .10$). Underscored coefficients are very close to the next best level of significance

Table 6. Summary of results compared to initial hypotheses, grouped by complexity factor

Hypothesized complexity by strategy interaction effects with beneficial impact on project performance (organized by complexity factor)		Observed results **Boldface = direct confirmation** ***Boldface italics = indirect confirmation*** Regular font = result involving different strategy	
Complexity	Strategy	Observed interactions	Outcome
Market	New knowledge (H3b)	**Market x New knowledge**	**Completion**
	Integrate organization (H5a)	**Market x Integrate**	**Operation**
		(–) ***Market complexity x Separate***	***Innovation***
Organization	Existing knowledge (H2b)	Organizational x New knowledge	Completion
	Integrate organization (H5b)		
Technical	New knowledge (H3a)	**Technical x New knowledge**	**Completion**
		Technical x Existing knowledge	Completion
	Separate organization (H4a)		
Institutional	Existing knowledge (H2a)	***Institutional x Existing knowledge*** *(high use of existing knowledge reduces performance at low levels of institutional complexity)*	***Innovation***
		(–) ***Institutional x New knowledge***	***Completion***
	Separate organization (H4b)	**Institutional x Separate**	**Operation**
		Institutional x Separate *(stronger for low complexity)*	***Innovation***

Note: When no sign is indicated the interaction has a beneficial effect on the performance indicated on the rightmost column; when the sign is negative the effect is detrimental.

Figure 1: Summary of hypotheses regarding influences and interactions

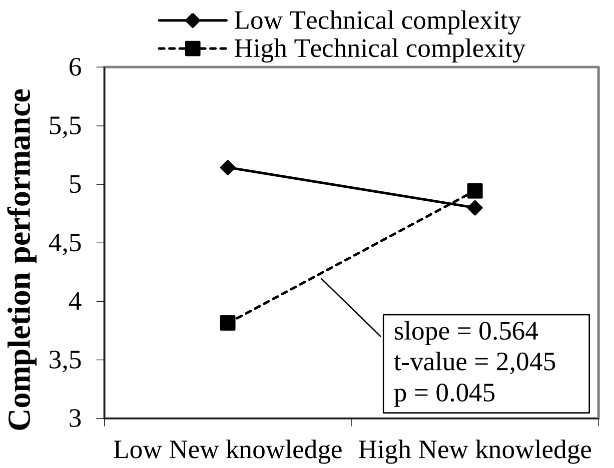


Note 1: The predicted form of all interactions is an increase in performance in the presence of high levels of the particular type of complexity if high levels of the respective planning variable are present

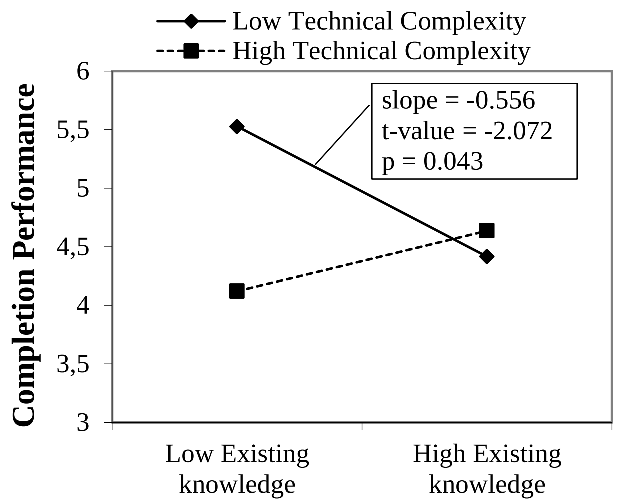
Note 2: Dotted lines highlight the theoretical basis of interaction predictions, namely that the interaction effect stems from the correspondence between a given planning stage strategy and the nature of complexity as expressed by the respective rows or columns

Figure 2. Graphical depictions of interaction effects for Completion Performance

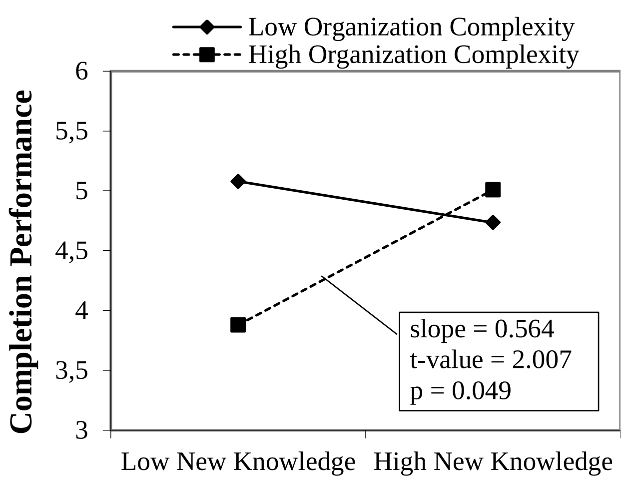
2a. Technical Complexity by New Knowledge



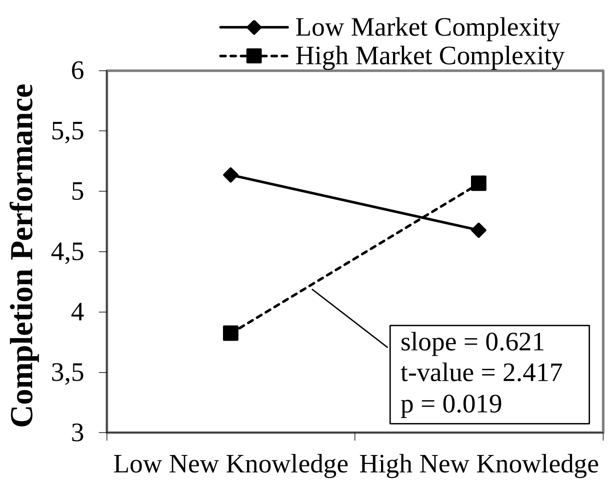
2b. Technical Complexity by Existing Knowledge



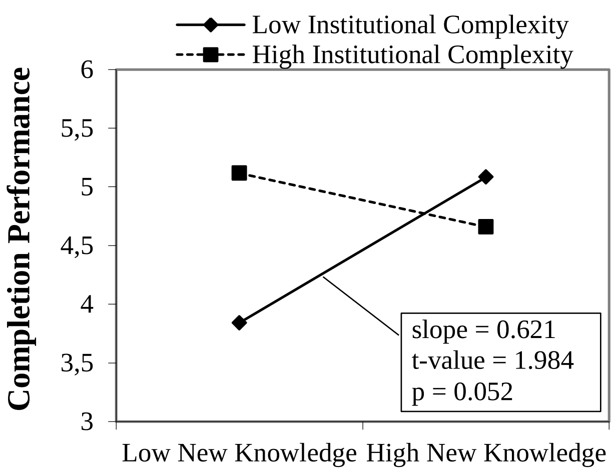
2c. Organizational Complexity by New Knowledge



2d. Market Complexity by New Knowledge



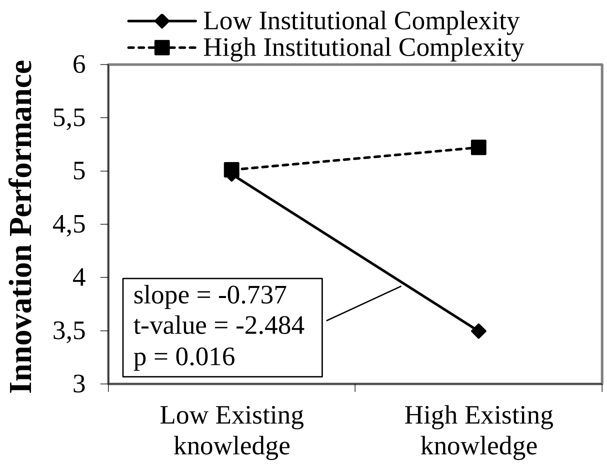
2e. Institutional Complexity by New Knowledge



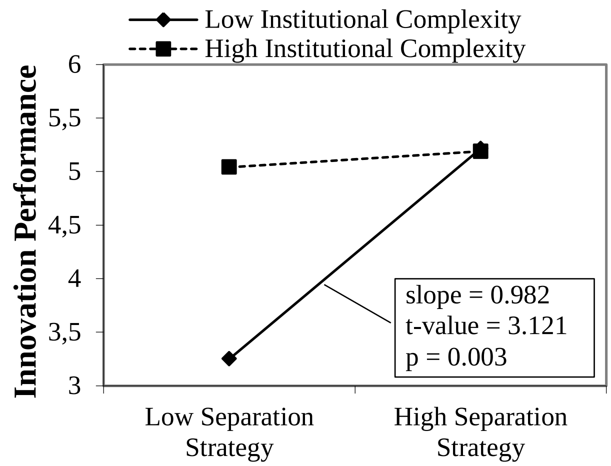
Note. Differential associations of planning strategies with the outcome, at low and high levels of the moderating (interacting) complexity variable, are depicted by showing the regression slopes at +1 Standard Deviation and -1 Standard Deviation on the complexity variable. This slope is provided on the graph whenever it reached statistical significance.

Figure 3. Graphical depictions of interaction effects for Innovation Performance

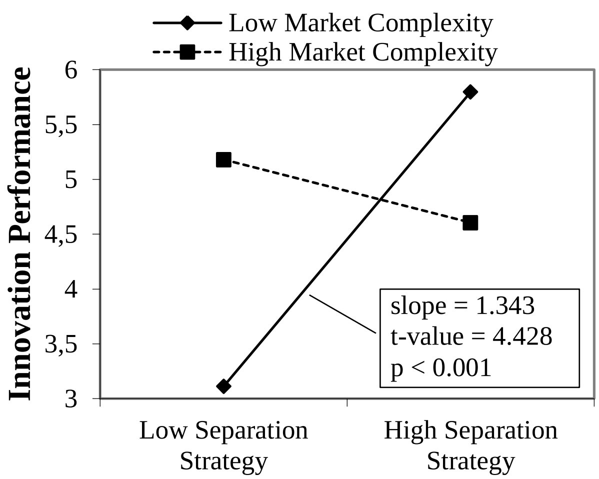
3a Institutional Complexity by Existing Knowledge



3b Institutional Complexity by Separation Strategy



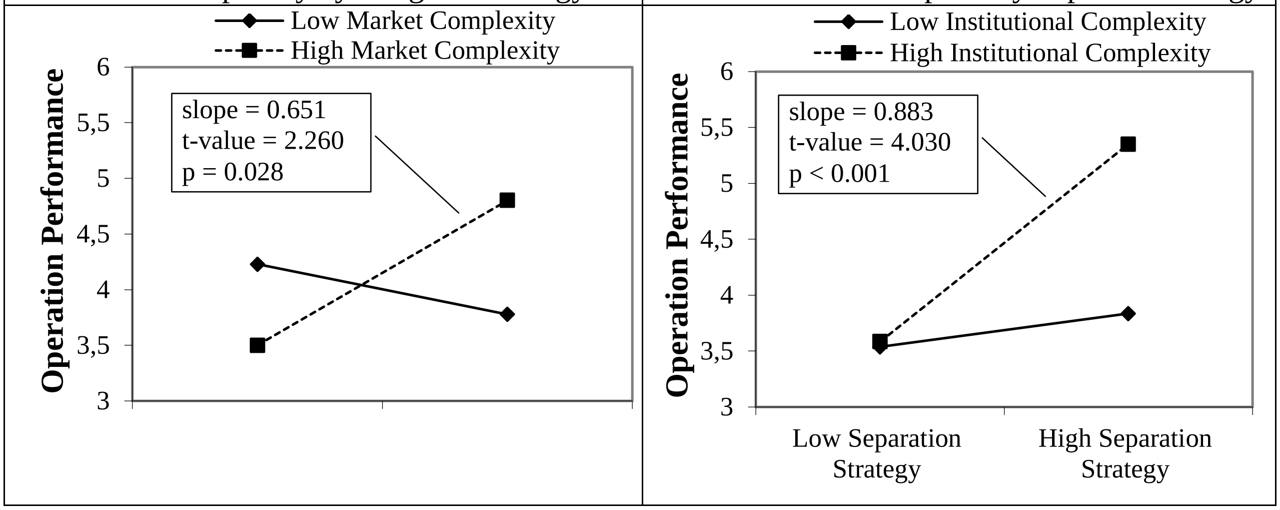
3c. Market Complexity by Separation Strategy



Note. Differential associations of planning strategies with the outcome, at low and high levels of the moderating (interacting) complexity variable, are depicted by showing the regression slopes at +1 Standard Deviation and -1 Standard Deviation on the complexity variable. This slope is provided on the graph whenever it reached statistical significance.

Figure 4. Graphical depictions of interaction effects for Operation Performance

4a. Market Complexity by Integrate Strategy | 4b. Institutional Complex. by Separate Strategy



Note. Differential associations of planning strategies with the outcome, at low and high levels of the moderating (interacting) complexity variable, are depicted by showing the regression slopes at +1 Standard Deviation and -1 Standard Deviation on the complexity variable. This slope is provided on the graph whenever it reached statistical significance.

APPENDIX A. Items and variable statistics

Table A1. Items, descriptive statistics and factor loadings for project complexity variables

Items used to measure project complexity	Mean	Standard Deviation	Factor 1 Technical (α = .82)	Factor 2 Organizational (α = .78)	Factor 3 Institutional (α = .53)	Factor 4 Market (α = .71)
Technical Complexity						
Our challenge was maintaining full control over the behavior of the artifacts we made	4.16	1.87	**0.843**	0.092	-0.187	0.020
We strived to gain influence over natural processes affected by many invisible factors	3.88	1.86	**0.650**	0.004	0.115	-0.066
Our problem was ensuring coherent interoperation between scores of artifact functions	4.47	1.75	**0.855**	-0.023	0.043	0.044
Organizational Complexity						
The project was much larger than all other projects the owner had ever managed	4.17	2.22	0.087	**0.566**	0.180	-0.261
The project was the first to implement new project management processes and norms	4.05	2.14	-0.129	**0.935**	-0.034	0.088
During this project, the owner organization embarked on a major restructuring	3.86	2.07	0.067	**0.498**	0.288	0.145
The project was seen as an occasion for trying new financial or contractual methods	4.30	2.07	0.103	**0.677**	-0.163	-0.013
Market Complexity						
The project output targeted a market whose emergence and growth were still uncertain	2.81	1.94	-0.043	0.057	0.045	**0.776**
The market we intended to serve was known for its severe swings in price and demand	3.27	1.88	0.044	-0.071	-0.024	**0.724**
Institutional Complexity						
Regulatory approval was a critical precondition for initiating or exploiting the project	5.43	1.86	-0.264	0.062	**0.464**	-0.040
The project was likely to become a battleground for political interests and militants	3.62	2.13	0.133	-0.098	**0.927**	0.036

Note. As estimates of reliability, values of Cronbach's alpha (α) are provided.

Table A2. Items, descriptive statistics and factor loadings for planning-stage strategy variables

Items used to measure planning-stage strategies	Mean	Standard Deviation	Factor 1 (New knowledge) (α = .70)	Factor 2 (Existing knowledge) (α = .77)	Factor 3 (Integrate organization) (α = .63)	Factor 4 (Separate organization) (α = .64)
Existing knowledge exploitation						
We fully relied on templates, models and data already existing in our organization	3.84	1.75	0.162	**0.891**	-0.043	-0.105
Past learning captured in rules and information systems was more than enough for us	3.34	1.74	-0.217	**0.604**	0.012	0.227
Planning decisions followed directly from regulatory norms or industry standards	4.20	1.63	-0.084	**0.640**	0.010	-0.025
New knowledge production						
We had to produce lots of new data and models before being able to shape this project	4.78	1.71	**0.408**	-0.002	-0.045	0.186
We used a pilot project or the early stages of this project in order to gain experience	3.55	2.04	**0.565**	0.092	-0.020	0.041
We carefully validated all our decisions based on simulation or external feedback	4.06	1.85	**0.519**	-0.047	0.106	0.260
The planning process went through several iterations that totally redefined the project	4.93	1.72	**0.499**	-0.108	-0.121	-0.086
The planning was full of twists and turns as a result of our learning and discoveries	4.93	1.71	**0.567**	-0.127	0.132	-0.099
We expected to change plans for later phases based on learning from earlier phases	4.58	1.71	**0.634**	0.083	-0.023	-0.136
Separate organization						
The plan strictly delimited the responsibility area for every participant in the project	4.90	1.49	0.044	0.039	0.221	**0.623**
All contracts had to include clear and detailed specifications with substantial penalties	4.61	1.91	0.225	0.152	-0.076	**0.475**
Suppliers and contractors had to provide significant warranties and performance bonds	4.96	1.63	-0.140	-0.175	-0.115	**0.713**
Integrate organization						
Fostering collaboration between participants was seen as the only way to reduce risk	5.23	1.58	0.101	0.034	**0.475**	0.174
Cost plus contracts, alliances or joint ventures were preferred as a way to build trust	3.28	1.79	0.243	0.025	**0.408**	-0.006
The plan entrusted the parties to major contracts with jointly defining specifications	4.26	1.63	-0.183	0.032	**0.766**	-0.183
Quality and expertise, rather than price, were the main contractor selection criteria	4.36	1.86	-0.025	-0.105	**0.567**	0.062

Note. As estimates of reliability, values of Cronbach's alpha (α) are provided.

Table A3. Items, descriptive statistics and factor loadings for project performance variables

Items used to measure project performance	Mean	Standard Deviation	Factor 1 Completion (α = .66)	Factor 2 Innovation (α = .74)	Factor 3 Operation (α = .64)	Factor 4 Value creation (α = .61)
Completion Performance						
We put into service the entire planned scope of the project and some additional objects	5.61	1.30	**0.680**	0.045	0.063	0.091
The project went on line ahead of the planned launch date set when it was approved	4.18	1.92	**0.686**	0.018	0.032	0.305
The final project cost was below the budget that was approved at the go-ahead date	3.94	1.90	**0.471**	-0.095	0.428	0.269
All specified functional and performance goals were met and some even exceeded	5.82	1.12	**0.677**	0.407	0.400	-0.134
Innovation Performance						
Outstanding technical accomplishments made this project a worldwide reference	5.21	1.59	0.356	**0.796**	0.024	0.205
The project implemented technical innovations that were firsts in worldwide practice	4.42	1.81	-0.151	**0.907**	0.035	0.088
Operational performance						
Even when running at top regime, the project had no malfunctions, bugs or accidents	4.08	1.62	0.446	0.021	**0.563**	-0.071
The operation and maintenance costs of this project are much lower than expected	3.94	1.21	-0.076	0.151	**0.806**	0.191
No major new spending was needed in order to remedy problems with this project	4.56	1.74	0.485	-0.062	**0.624**	0.081
Value creation performance						
Sales and profits from this project are significantly better than expected at go-ahead	4.04	1.60	-0.042	-0.144	0.431	**0.666**
The users and stakeholders of this project are delighted with the value it provides them	5.51	1.20	0.415	0.205	0.118	**0.650**
The project greatly enhanced the reputation and strategic positioning of its owner	5.66	1.42	0.134	0.267	-0.052	**0.767**

Note. As estimates of reliability, values of Cronbach's alpha (α) are provided.