WILEY | Hindawi

Research Article

Strategies for Managing the Structural and Dynamic Consequences of Project Complexity

Serghei Floricel ⬚,[1] Sorin Piperca,[2] and Richard Tee[3]

[1]*Department of Management and Technology, School of Management (ESG), Université du Québec à Montréal (UQAM), Montreal, QC, Canada*
[2]*Department of Management, Birkbeck, University of London, London, UK*
[3]*Management Department, Libera Università Internazionale degli Studi Sociali Guido Carli (LUISS), Rome, Italy*

Correspondence should be addressed to Serghei Floricel; floricel.serghei@uqam.ca

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

1. Introduction

While we know that complexity affects project effectiveness, it is unclear what strategies can be used to manage different forms of complexity. This paper aims to advance our understanding of these strategies. From infrastructure construction to developing biotechnology or software products, complexity has been blamed for causing unexpected events, late changes, additional costs, and delays and for affecting project performance and value creation [1–4]. One example of how complexity affects projects is the launch-day failure of the luggage handling system at Heathrow Terminal 5. While the immediate source of problems was a software bug, during late execution stages, on-site interference between contractors produced delays that eventually required schedule compression that, in turn, prevented an adequate testing of the system. This example points out to the multiplicity of factors and interactions involved in a project as the source of its complexity and to consequences concerning the form the project will take as well as its evolution in time. However, in spite of this basic understanding of complexity, two key issues remain open. First, what are the most important dimensions of project complexity? Second, what strategies can be used to manage them effectively?

Given its impact, the project management field has made significant efforts to understand the nature and consequences of project complexity and to develop approaches for managing it [5]. One source of inspiration was the fundamental literature on complexity. Concepts such as heterogeneity, emergence, or chaos provided a fresh perspective on the dominant approaches for planning and managing projects [6, 7]. However, while these abstract concepts offered a fertile ground for criticizing the foundations of the discipline, they proved to be less useful as a basis for developing concrete practices that would help address complexity. Therefore, another approach was to investigate managers' perceptions in order to map and measure the concrete factors that appear to increase project complexity [8–11]. Some researchers went even further and attempted to identify the strategies that managers deem appropriate for addressing each factor [12]. However, the large number of identified factors makes it difficult to provide theoretical justifications and empirical evidence that goes beyond managers' opinions on what factors are important and what strategies are effective [13]. There is even

a risk that such approaches only collect "rationalized myths" [14] circulating in the organizational field of the project management discipline.

Our attempt to address these issues relies on two premises. First, the most fruitful conceptual strategy for understanding complexity and how it can be managed consists of bridging abstract theories with problematic situations and practices encountered in projects. We believe that the essential aspects of project complexity can be captured by a few generic dimensions, which can be connected to concrete factors observable in various types of projects. Second, we assume that each form of complexity is best addressed by specific strategies out of the variety of available ones. Some of these strategies create an improved representation of the project and of its environment, helping participants to understand the specific complexity they face and to prevent its effects, while others aim to increase the flexibility of the project in order to address the unexpected consequences of complexity [15, 16].

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

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

2. Theoretical Context

The project management literature and the fundamental contributions that inform it use the term complexity to cover three distinct topics: a series of antecedents, such as the multiplicity of relevant factors; a series of mechanisms, such as emergence or self-organization; and a series of consequences such as unpredictability and lack or control. Figure 1 organizes these aspects of complexity and identifies the key dimensions of each aspect.

In terms of *antecedents*, some researchers see complexity as an intrinsic property of reality, irreducible even if our knowledge were perfect. Others argue that complexity perceptions are a product of the cognitive limitations of human and organizational actors and of their knowledge and informational tools with regard to representing this reality, in

particular its heterogeneity and interactions, and, hence, to predicting and controlling their consequences [17, 18]. The *intrinsic* viewpoint is held by philosophers and scientists who assume a *heterogeneous* world, featuring diverse components with multiple aspects and properties, which, therefore, *interact* in multiple ways to produce unpredictable forms and dynamics [19–21]. For example, research on biological systems highlights the indeterminacy and multiplicity of material properties and of their interactions, while research on artificial systems emphasizes the number and diversity of parts or components and their intricate interoperation [22–24]. Project researchers sharing this view tend to emphasize the number and diversity of relevant factors, such as the number of different stakeholders or disciplines involved in a project, as well as their interrelations [8, 16, 25].

In turn, the *cognitive* viewpoint argues that perceived complexity is an artifact of our imperfect representations. A first reason for such perceptions is the imperfect *correspondence* of representations with reality. Our perceptual abilities, even when they are enhanced by detection, magnification, and measurement capabilities, overlook, regularize, and approximate many aspects of the world [26]. Engineering and other conventions for representing objects increase the distance even more by overlooking additional details [27]. In turn, knowledge representations, such as scientific abstractions or engineering formulas, necessarily simplify the properties of natural and artificial objects [28]. In their quest for ideal parsimony, symmetry, and generality, they forego irregularities in shape, structure, or texture, along with secondary forces and interactions [29]. In turn, computer scientists highlight what they call *computational* complexity [30, 31]. Namely, they point out that increasing the correspondence with reality also raises the computational power required for operating with resulting representations [2, 32, 33]. From this point of view, the complexity of an object corresponds to the difficulty of extracting regularities that can simplify its description, along with the volume of computations required for retrieving its form from this condensed representation [34–36].

A second key theme of complexity is related to what we term *mechanisms,* which, given particular antecedents, produce unpredictable consequences or overwhelm cognitive abilities. Existing research has focused on two aspects: the emergence of systemic properties and their evolution over time. The *emergence* stream investigates how the aggregation of component entities produces systemic properties that cannot be explained, let alone anticipated, by only considering the properties of these components, even when their interaction propensities are taken into account [19]. This irreducible character of higher-level properties becomes apparent at all successive levels of organization, from molecules with respect to atoms and cells with respect to molecules [37] to organizations with respect to the individuals composing them [38]. A first dimension of emergence is the "*upward*" *nonadditivity* of component aggregation [39, 40]. Proposed mechanisms start with the breaking of symmetry with respect to physical laws in aggregate systems such as molecules [41]. For higher levels, the focus is on the nature and pattern of interactions or couplings between components [42, 43]. For example,
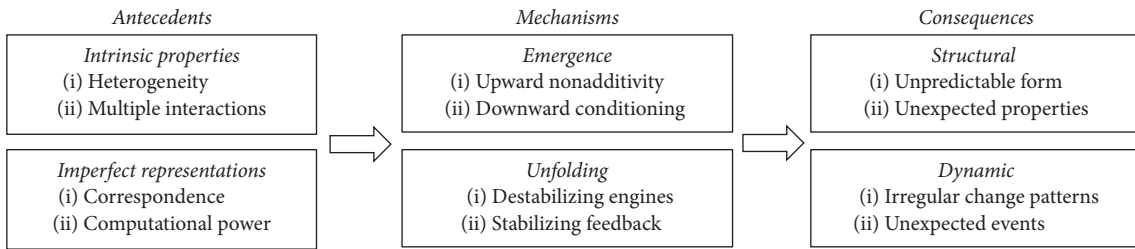
FIGURE 1: Disentangling the literature on project complexity.

research on processes occurring in materials and living organisms turned its attention to the role of supramolecular, noncovalent ties in their complex self-organizing or adaptive properties [44]. Research on artificial objects stresses the role of secondary interactions between components in shaping their form [45]. Sociomateriality researchers suggest that emergent properties of materials and artifacts influence the agency, practices, and relations between human actors [46, 47]. In turn, the properties of social networks and organizations, including projects, emerge from this tissue of practices and relations and the objects with which they are intertwined, by means of constant translation and maintenance efforts as well as unintended routinization [48, 49]. A second dimension of emergence mechanisms includes the *downward conditioning* of collectives of components by higher-level systems [50, 51], or mutual influences between levels [52]. This kind of hierarchical interlevel influences or multilevel nestedness underlies the complexity of biological [53–55], communication [56], and social systems [57]. Research on projects has also turned its attention towards this kind of influences by recognizing that projects, teams, and artifacts are nested in broader technical systems, organizations, interorganizational networks, and institutional frameworks [58–62].

In turn, *unfolding* mechanisms address processes through which, in time, complexity drives the systems of interest along multiple pathways in unpredictable ways. This theme has also been addressed from two perspectives. The first focuses on *destabilizing engines* that bring about sudden, radical transformations or unpredictable, chaotic change patterns [63]. Researchers seek to characterize the causal mechanisms, such as nonlinear interactions or path-dependent processes that amplify small variations in initial conditions [64, 65], and attempt to understand the conditions, such as number of interacting factors [66], that activate these mechanisms. Their insights inspired project management researchers in addressing various dynamics from catastrophic artifact failures to the conflictual unraveling of teams and interorganizational networks [16, 67, 68]. A second perspective focuses on *stabilizing feedback* that tames destabilizing tendencies but still produces unpredictable evolution [69–71]. Fundamental research in self-organization uses simulations to show how order emerges out of chaos [72]. In turn, organization scholars study mechanisms such as structuring from repeated interactions between actors [73, 74] or lifecycles in which stabilization follows turbulent periods [75–77]. Others pay attention to processes that maintain highly dynamic patterns, such as high velocity and exponential growth [78–80].

In terms of *consequences*, the literature also sets apart a structural and a dynamic aspect [81]. The *structural* kind of consequences refers to the *unpredictable form* of the project: organizational and contractual structure, technical or architectural solutions, and as-built artifacts. For example, during development, project concepts go through several iterations, which push the end result far away from the initial vision [82, 83]. Some of this unpredictability stems from underlying material connections between entities [49] and the "rich indeterminacy and magic of matter" ([84]: 91), but also from a range of multilevel influences on projects, the interplay of their "human side" [85] with the formalizing, political and economic forces in organizations [86], industrial sectors, and broader institutional and social systems.

A second kind of structural consequence focuses on *unexpected properties*. While such properties may appear to be minor deviations, because they are discovered quite late in the project, when prior decisions and actions are more difficult to reverse, they are even more likely to cause major crises or conflicts around the required corrective changes [87]. For example, advances in execution uncover unexpected interferences between project subsystems or between the project and soil conditions, adjacent structures, natural habitats, neighboring communities, and various regulations [88, 89]. These may, in turn, interfere with the access on site of contractors for subsequent activities, accentuate conflicts of interests between participants, and amplify personal animosities [90].

Other researchers emphasize *dynamic* consequences for the project and its environment. A first dynamic effect is *irregular change*. Management scholars have paid special attention to dynamics in organizations and their environments, as well as the challenges they pose [79, 91–95]. Some researchers even argue that organizing is an ongoing activity, struggling to reconnect a world of intersecting event strands, in which stability is just a cognitive artifact or a fragile result of recurring processes [96–98]. Project scholars also pay attention to the dynamics of projects and their environments, in particular to chaotic change and the special kind of uncertainties it creates [99, 100]. They single out the consequences of unpredictable evolution in user needs and markets, as well as in technological and regulatory environments [82].

A second type of dynamic outcomes consists of *unexpected events*. These are emphasized by scholars who argue that social systems having an inward, self-referential orientation, such as projects attuned to their goals and operating plans, are subject to perceptual discontinuities when dealing with environments whose complexity is higher than their

internal communicational complexity [101, 102]. The management literature highlights the challenges caused by unexpected events [103], for example, jolts [104], attributes their emergence to a complex "causal texture" of the environment, and suggests that they lead to a sudden "increase the area of relevant uncertainty" [105]. Project research also singles out unexpected events occurring inside and outside the project as a key source of trouble [106, 107]. Similar to unexpected interactions, their surprising and late occurrence amplifies their impact on projects [108].

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

3. Theoretical Framework and Propositions

Our theoretical framework uses the same dimensions of complexity proposed in Figure 1, by transforming them into variables and types of complexity. We then use them to develop a more selective model about the influences between these complexity variables. Our approach can be termed mechanismic [109, 110], because we suppose that antecedent factors will trigger alternative mechanisms, namely, bits of processes that are potentially present in the relevant systems, but are activated only in certain conditions and not in others. This enables us to tie structural and dynamic consequences to a given set of antecedents. The overall model relating these aspects is represented in Figure 2.

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

The second pathway, ending in dynamic consequences, also begins with a direct influence from antecedents, which in this case refer exclusively to intrinsic properties and in a more specific way. Namely, we argue that particular combinations of relevant factor diversity and interaction number and nonlinearity increase the chances to trigger either destabilizing or stabilizing unfolding mechanisms. A second influence from antecedents proceeds indirectly, through emergence mechanisms, in particular whether the prevailing processes involve upward nonadditivity or downward conditioning. Depending on whether antecedents trigger stabilizing or destabilizing mechanisms and interlevel emergence is primarily upward

or downward, we propose four types of unfolding processes, with specific dynamic consequences for projects. Because all of these consequences have unexpected or surprising aspects, participants will have to respond after the fact rather than anticipating specific dynamic paths. Therefore, we assume that effective strategies for addressing dynamic consequences rely on cultivating project flexibility and propose, for each of the four types of unfolding, a specific type of appropriate flexibility.

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

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

The first dimension is suggested by researchers who view complexity as an intrinsic property of reality. We interpret this to mean that project participants, given the knowledge that they deem available to them, do not see any chance of completely understanding and mastering the relevant phenomena. Consequently, at some residual level, complexity is an inseparable property of the perceived world. With regard to the antecedents related to this dimension we distinguish heterogeneity, namely, the infinite variety of elements and aspects present in the word, from the multiplicity of interactions between these factors. In other words, the context of some projects may be dominated by the multiplicity of relevant factors while others by the multiple interactions between the various factors. We further assume that the heterogeneity end of this dimension is more likely to give prominence, from the participants' perspective, to upward nonadditivity mechanisms, namely, to conjunction processes that will converge towards overall configurations with unpredictable properties (project form). The interactions end of this dimension is more likely to give prominence to downward conditioning mechanisms, because participants will perceive the mostly hidden interactions as inexorably driving the aggregate towards some stable state, which, in turn, starts to subsume and condition the behavior of converging
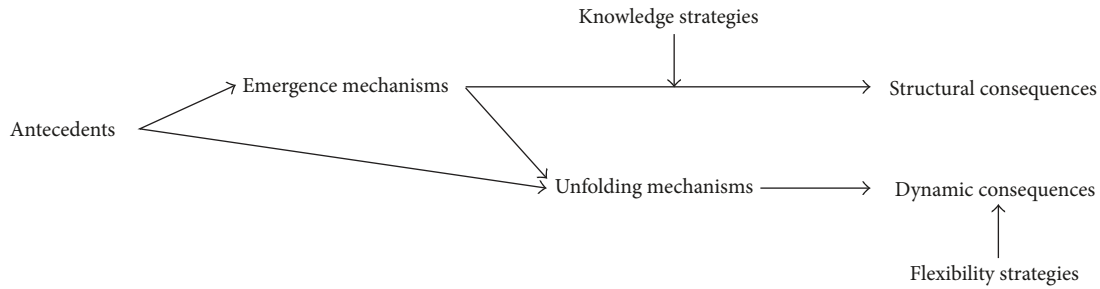
FIGURE 2: Integrative model of complexity influences and strategies for diminishing them.

elements. However, the multiplicity of interactions and "vertical" influences, downward as well as interlevel, means that the aggregate system will have many unexpected properties.

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

Based on these two dimensions, we identify four types of complexity contexts and propose a corresponding emergence processes for each of them. Table 1 presents the four types, suggests the projects and project aspects in which they are most likely to be observed, their most likely structural consequences, and suggests the most appropriate representation-producing strategies that help project participants to increase their anticipation and influence over aggregates, such as the project system. Inspired by organization theory, project management, and engineering design literature, we believe that these strategies reduce the distance and computation difficulties, given the specific combination of heterogeneity, interactions, and representation shortcomings affecting the project [111–113].

Endless Complication. This first type of structural complexity results in a context of high intrinsic heterogeneity and low representation correspondence. The aggregate project form is unstable and its final configuration cannot be predicted because of the constant discovery of new relevant factors. We consider that this situation is typical of innovation projects, in which knowledge derived from previous projects is not entirely pertinent and may induce participants to overlook some key factors or to underestimate their role. This is also

typical of market aspects, in which additional customer needs, market segments, competitors, products, and strategic moves, as well as a host of other factors, are likely to emerge as significant in most projects.

Because such a context continuously reveals new relevant aspects, it is important to detect and bring them to bear on project shaping activities as early and as minutely as possible. Therefore, we believe that distributed learning about various aspects involved in the project [114, 115] through role differentiation as well as background and external network diversity [116] and by bottom-up decision making [117] is likely to be more effective than attempts to centralize learning and decision making. Closeness to the "field" and specialization in detecting the given aspect are likely to reduce the distance between representation and reality for participants, while bottom-up decentralized selection will speed up and make more effective the emergence of the final form. Concrete examples include the approaches used by companies such as 3M and Google. For example, Google encourages individual learning by employees and uses employee panels to predict market demand and democratic voting procedures to decide on innovation projects [118]. Information systems that support a "complex, distributed, and evolving knowledge-base" and an "unstructurable, dynamically changing process of deliberations and tradeoffs" are likely to enable such representation strategies ([119]: 206). This translates into the following proposition.

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

Magic Field. This second type of structural complexity context is prominent in settings with multiple interactions that are inadequately captured by existing knowledge. These interactions drive the project to converge into an overall configuration, but interactions that are unaccounted or misrepresented, such as previously negligible secondary interactions that become a problem in physical artifacts designed for larger scales or performance levels [45, 120], are likely to manifest themselves through aggregate properties that participants cannot control adequately. As a result, project artifacts cannot sustain the required constancy of operation, and corrective interventions do not have the intended effect. This kind of context is likely to be observed in infrastructure

TABLE 1: Types of emergence processes and structural consequences as a function of antecedents, together with the most effective strategies for dealing with them.

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

construction projects, such as airports or power plants, or in projects that develop "complex products and systems" (CoPS) such as aircraft or military systems [58, 62]. As larger scale, higher performance, or additional constraints, such as building new structures in a crammed site surrounded by continuously operating systems, are imposed upon such projects, previously unknown or negligible interactions, including those with the foundations of adjacent buildings or with nearby ecosystems, start to have significant consequences. Because of multiple interactions, these consequences are likely to propagate in unpredictable ways to other parts of the project and to subsequent activities. The organizational aspects of projects are also likely to face a similar complexity context, because the multifaceted relations between participating actors, subunits, and corporate entities, as well as with the broader environments, are likely to bring new interactions to prominence in various projects.

The obvious strategy is mapping all interactions in the project and using pathway analysis to identify and address the systemic risks that they may cause [121, 122]. However, these methods suppose that interactions are known or can be imagined, while the real danger in this context is that project participants "cannot anticipate all the possible interaction of the inevitable failures" ([123]: 11). Even when they encounter unexpected interactions, it is likely that these will be revealed indirectly and to participants that, organizationally, may be responsible only for some of the interacting factors. Therefore, an adequate reaction of project participants depends on their ability to detect these signs [124] and update their routine communicational ties in ways that account for the newly discovered interactions [125]. Building alertness, mindfulness, and heedfulness to make sense of new interactions and restructure communicative ties accordingly is likely to be the most effective strategy [68, 126, 127]. Organizationally, it relies on building strong communication ties [128] and routines for rearranging these ties [129] as well as strong sensemaking and integration capabilities [130, 131]. These arguments are synthesized in the following proposition.

Proposition 2. *In a context with numerous interactions and low representation correspondence, strategies that build a capability for mindful integration and restructuring of*

communications are most likely to be effective in preventing the "magic field" kind of structural consequences of complexity.

Irreducible Variety. This third type of structural complexity context becomes prominent when the number of relevant factors is important but existing representations cannot reduce them to a more parsimonious set of essential properties with which participants can operate. As a result, participants are likely to concentrate selectively on some of these factors at some moments and on others at another time. This precludes them from converging on a stable project form. This kind of context is likely to be observed in software projects in which the high number of concrete factors cannot be adequately captured with most architectural modeling methods, leading to an endless succession of beta prototypes before the release of a still imperfectly stable product. A particular case could be ICT solutions developed for various implementation conditions, such as countries, sectors, or types of organizations, all of which impose different needs and constraints, which are difficult to compress into a unique parsimonious set of requirements. More generally, this is also the case for the technical aspects of projects, in which taking into account the impact of so many factors (dimensions and other properties) makes designing them a highly iterative endeavor [132, 133].

In this context, the problem is accounting for the variety of factors in a way that is not affected by the low computational power. We believe that the early virtual representation and simulation of the project and its behavior constitute the most effective strategy. Representations may range from pencil and paper sketches to multidimensional digital prototyping using CAD or Building Information Modeling (BIM) tools and to preliminary embodiment of artifact materials and form. Even when powerful software tools are used, the efficacy of this strategy does not come from their added computational power, but from the way representational outputs boost participants' individual and collective cognitive abilities [134]. Even an imperfect output that simulates the real behavior of project aggregates enables participants to rely on their pattern-recognition abilities to uncover diverse factors and creates a boundary object that enables participants to contribute their varied perspectives in an integrated way [135–138]. All this is likely to speed up the iterative process of convergence towards a relatively stable form. Stigliani and

Ravasi's [139] study of the design firm Continuum provides an example of such strategy, by highlighting the way project participants use sequences of varying sketches and assemblages of material objects to converge towards a client-oriented narrative about the object they will design. These considerations are reflected in the following proposition.

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

Intractable Mess. The fourth and final type of context is more likely to occur when the number of interactions between relevant factors makes it impossible to compute their joint consequences based on existing representations. As a result, participants base their predictions only on a manageable subset, which is likely to cause unexpected properties of the aggregate, as evidenced by the "black swans" problem in statistics [140] and the difficulty of creating high-reliability technical systems [68, 123, 141]. One example is biotech projects, in which the large number of levels and interactions in living beings can hardly be considered at the same time in order to predict the properties of drug candidates [142] or even to replicate successful experiments [143]. This leads to unexpected properties such as a lack of therapeutic effect and undesirable side effects. It is also likely that the institutional aspects of most projects will be characterized by a similar complexity context. The large number of social interactions underlying this aspect, even as they are captured in regulations, makes it difficult to work out their consequences for the project and will likely produce undesirable interference and conflicting interests.

Because in this context interactions are so numerous that no amount of computation will account for all of them, the most effective strategy is to let material reality itself work out the consequences of aggregation and then test this result against required properties. In other words, the most effective strategy is trial and error based on concrete objects [144]. For example, in spite of many scientific advances and scores of new computational methods, pharmaceutical and biotechnology projects rely increasingly on massive trial and error instead of rational design based on representations [145, 146]. The effectiveness of this process can be improved by varying the reliance on preexisting knowledge, radicalness, precision, and number of trials and of iterations [147, 148]. Moreover, strategies could rely on serendipity to increase variation in object forms and to induce accidents in their operation, with the goal of exploring areas outside what is normally expected [149] and seeking a sort of "falsification" [150] for any conclusions. These arguments are synthesized in the following proposition.

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

This set of propositions assumes that one type of context will be present, because of prevailing antecedents, and suggests a single strategy that is likely to be effective in this context. Strategies are also mutually exclusive to some extent. For example, the simulation through representation strategy supposes a rather long sequence of representations that gradually approximate the project form, while the massive trial and error strategy calls for arriving as fast as possible at a material instantiation of project form. However, Table 1 suggests that different antecedents may prevail with respect to different aspects of the project, such as market, technical, organizational, or regulatory; to various subsystems, such as hardware versus software; and even to different stages, such as definition versus design. To the extent that these portions of the project can be treated separately, different strategies could coexist in the same project. This could be perhaps the common situation in major projects and programs, or in megaprojects. One example could be a complex product and system project, such as the F35 military aircraft. An "endless complication" context may prevail during the early definition stage, because of the endless, shifting, and contradictory client requirements, an "irreducible variety" context may prevail during the design phase, and a "magic field" context may prevail during testing and early exploitation stages, when many unexpected properties and interactions emerge to cause accidents and delay the effective use of the artifact. The recommended strategies could be emphasized, in parallel, with respect to various aspects, and in sequence, in various stages of the project.

3.2. Pathway and Strategies for Dynamic Consequences. The endpoint of this pathway is a pattern of change that is unpredictable or unexpected. In this case, the relative timing and sequence of events, rather than the conjunction of properties, are the center of attention. As illustrated in Figure 2, we suggest that these consequences result from the activation of unfolding mechanisms, under the joint influence of antecedent conditions and of prevalent emergence mechanisms. Contributions addressing dynamic processes suggest that particular conditions may favor destabilizing mechanisms while others, stabilizing ones. For example, Dooley and Van De Ven [66] argue that a system deterministically influenced by a small number of variables produces a periodic pattern if variables interact linearly. Yet, nonlinear interactions between a small number of variables produce a dynamic termed "chaos," whose path is unpredictable but which follows a predictable pattern of change. Likewise, a system influenced by many variables produces a pattern termed "white noise," meaning totally random, if variables act independently from each other. If their actions are constrained by interactions, the consequence is "colored noise," such as "pink noise"—a random pattern that tends to reverse its trend with low frequency—or "brown noise"—a random pattern with path-dependent tendencies. This suggests that intrinsic contextual aspects, such as heterogeneity and interactions, are also responsible for generating various types of dynamic patterns, with varying levels of predictability.

Like in the case of structural consequences, we used these contributions as a source of inspiration but adopted again the

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

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

In examining the impact of these two dimensions and the strategies for addressing their consequences, we start with the premise that complex dynamics are problematic because of their unpredictability and unexpectedness; their specific dynamic consequences are of the "unknown unknowns" kind. In contrast to our treatment of structural consequences, we also assume that participants consider the sources of dynamic consequences to be intrinsic, rather than imperfect representations. We account for representation issues only by assuming that participants consider the mid-range system as their task environment [151] and focus their attention on it, leaving out some areas of the higher-level system, examining lower-level components with a coarse resolution, and

overlooking many details among their multiple aspects and interactions. This helps distinguish different kinds of surprises for project participants. A further consequence of the unpredictability and unexpectedness assumption is our assumption that the most effective mitigating strategies revolve around cultivating a particular kind of flexibility that enables participants to respond ex post to dynamic consequences.

In order to understand what kind of flexibility is most effective for the various unfolding processes and dynamic consequences, we use the two dimensions introduced above to set apart four typical dynamics. Figure 3 presents each of them as a function of the emergence direction and, respectively, unfolding mechanisms it involves. Each resulting quadrant includes, on the left, a schematic description of how these mechanisms interact; in the center, the name of the dynamic and its most important consequence; and on the right, the strategy most likely to be effective and a depiction of how the strategy addresses the respective dynamic consequence.

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

The consequence of effervescence is a continuous disruption of the system of interest. An example could be an IT project with physical infrastructure components jointly developed by several public transportation authorities operating in the same major urban area. Their numerous demands, many of which arrive quite late in the process, triggered by what other participants have asked or by new understanding of technical possibilities, generate debates among
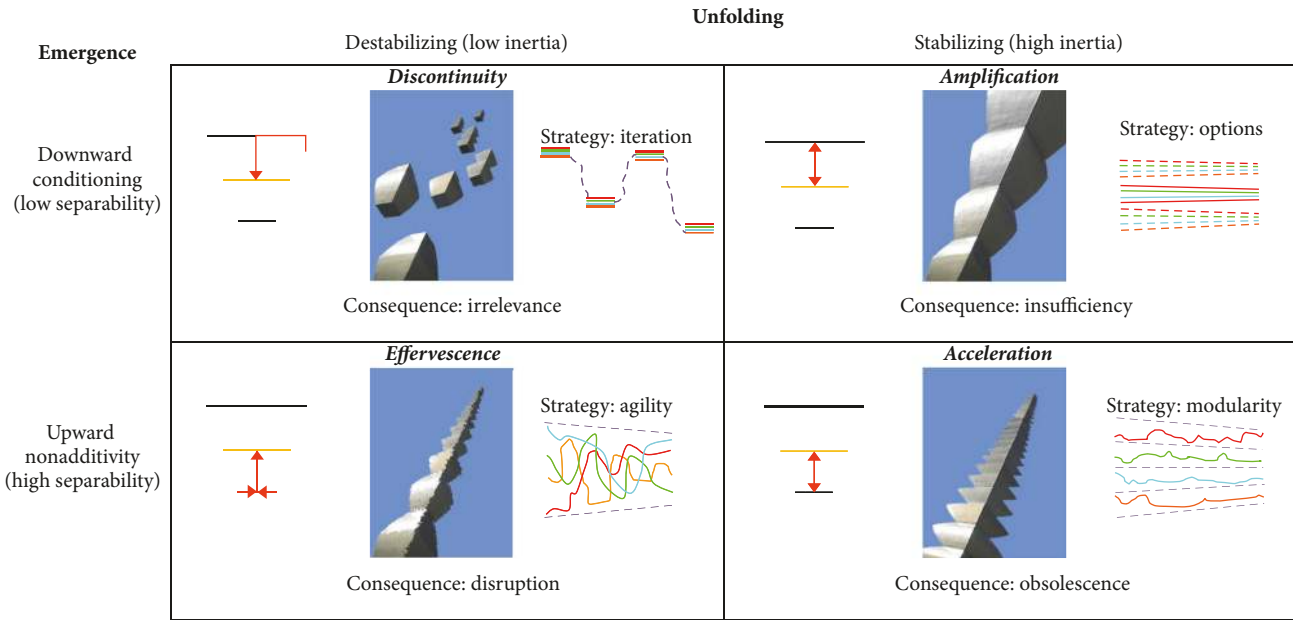
FIGURE 3: Types of dynamic complexity, as a function of prevailing mechanisms, and strategies for dealing with them. *Note.* The three horizontal lines on the left side of each cell in the table represent, respectively, from top to bottom, the macro level, the meso-level (uses orange color to highlight the fact that it represents the context deemed relevant by project participants: task environment, etc.), and the micro level. The red arrows suggest the direction of interlevel influences. The pictures in the middle part of each cell rely on alterations of the Endless Column (or Column of the Infinite) by Constantin Brâncuşi (completed in 1938, Târgu Jiu, Romania) to represent the four patterns of dynamic complexity. Strategies on the right side of each cell suggest ways of organizing project activities, namely, of connecting them simultaneously as well as intertemporally, which are likely to be most effective for dealing with each type of dynamic complexity. Colored lines represent strands of activities and the extent to which these change direction in time.

them and opposition from the technical development team, but some generate sufficient impetus to be included among the requirements of the project, which may perhaps prompt a restructuring of the technical architecture, which in turn may induce new demands and so on. However, the same characteristics that enable this surprising dynamic are also likely to enable the flexibility strategy that we term *agility*, namely, dividing the project into small separate strands, each of which traces a relevant aspect through frequent small iterations and a continual restructuring of ties between strands [152–154]. Flexibility results from maintaining the project on the edge of chaos [155], which precludes its coagulation into a stable form that can no longer trace the emerging changes. In practical terms, this strategy favors subdividing the project into a very large number of parts and work packages and minimizing the direct and indirect impact that activities and decisions concerning these subsystems have on adjacent subsystems and subsequent activities. This kind of approach is assumed by agile project management strategies such as Scrum. These arguments are summarized in the following proposition.

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

Discontinuity. The dynamic depicted in the upper left corner of Figure 3 shows a surprising change in the focal system attributable to the downward conditioning by the higher-level system. This kind of change appears when new interactions between the components of the overarching system arise outside the area which is usually considered relevant by project participants. This creates what Emery and Trist [105] call a turbulent field, which generates irregular dynamics in the higher-level system. Because of the significant conditioning impact that these changes have on the focal system, the latter is perceived as sustaining a series of sudden radical changes or jolts. Such change is unpredictable because it originates outside the task environment that project participants normally monitor. In project environments, such as markets and industries, this kind of changes occurs when previously unrelated areas in the global economy interact to impact a given sector. Examples include the recent impact of the subprime crisis in the United States on, say, the economy of Greece (via its debt) or the real estate market in Spain. For project artifacts, this kind of change may arrive when political or economic interests, perhaps hidden, combine to force the client to significantly change project requirements. This occurs frequently in projects, such as movies, videogames, and high performance CoPS, in which external influences vary considerably, but systemic constraints boost the interactions between elements [156].

Because of these interactions, the answer cannot be piecemeal change in the project. In fact, the form the project had prior to a jolt is likely to become irrelevant in its entirety after the jolt. In this case, we argue that the effective strategy is preparing for deep, hierarchically driven iterations [1, 82, 157], essentially getting ready to restart the project several times, keeping only the learning from previous iterations. This strategy calls for reducing intertemporal inertia in the form of irreversible commitments and sunk costs. Thus, projects focus effort on essential elements, whose development provides the shortest path to an integrated solution [158]. This strategy reduces commitment by avoiding the additional effort involved in cultivating flexibility through modular architectures and interfaces. In addition, its swift implementation may signal decisiveness and help to structure the fluid post-discontinuity context of the meso-level system. These arguments are synthesized in the following proposition.

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

Amplification. The dynamic depicted in the upper right corner of Figure 3 occurs in the presence of stabilizing mechanisms involving vertical interactions between the focal system and higher levels systems. These self-organizing or structuring processes produce important and continuous change and impose a strong inertia on this dynamic, but positive feedback between levels also makes it hard to predict the end state of the system; small variations are likely to be amplified into major differences. In the case of project environments, such as markets, this kind of dynamic can be observed when vertical interactions with the societal level produce significant growth. For example, sectors proposing a series of innovative technologies, particularly those providing a new kind of infrastructure, may induce society to redirect resources towards these sectors. In turn, these resources enable further investment in innovation, which increases product functionality, performance, and reliability, which induces new swaths of society to pour resources into the sector. A current example of such processes is the growing "smart" sector of economy, involving smart phones, TVs, home appliances, houses, cities, and governments. Despite the continuity of trends, amplification of small deviations makes it difficult to predict where dynamic processes will bring the sector [159]. In the case of artifacts, similar interactions between the project and its clients may lead to growing demand or, on the contrary, to a downward spiral of mistrust.

The typical consequence of this dynamic for a project is insufficiency, for example, in terms of project scope and capacity, or, in case of a downward trend, overcapacity. In the case of insufficiency, a strategy based on iterations may increase project vulnerability because of their parsimonious nature. The continuity of change and the inertia imposed on the meso-level by the downward conditioning mechanisms maintain the relevance of significant portions of the project, which makes starting all over unneeded. Downward conditioning is also likely to boost interactions and prevent

separate adaptation of various parts of the project. Therefore, we argue that the most effective strategy for this context is preparing real options [160] via small proactive investments that open the possibility of later adding markets or capacities or even open entirely new projects in a relatively short time and with reduced investment [161, 162]. For example, a power plant project may purchase land for a second unit and even complete site preparation activities and be ready for a second unit in case demand grows beyond anticipated level. Likewise, a university may initially only migrate the human resource management system towards the new information platform, but the platform may include from the beginning the option to add other systems. Options to abandon or delay the project or parts of it may help address downward trends. These considerations are summed up in the following proposition.

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

Acceleration. Lastly, the dynamic depicted in the lower right quadrant of Figure 3 is likely to be present in a context of upward nonadditivity and stabilizing unfolding. This dynamic occurs when positive feedback mechanisms involving the meso-level system and its components increase the pace of change in the system while accentuating inertia through path dependency. With respect to project environments, this kind of interaction can be observed between industrial sectors and firms. A notorious example is high velocity sectors [79], which maintain an accelerated pace of change, such as that captured by Moore's Law. Micro level entities, such as firms, perceive and eventually take for granted this pace and synchronize their internal processes, such as new technology and product development, with it. In doing so, they collectively reproduce the pace [78]. If the meso-level system is an artifact, similar self-reinforcing acceleration or pacing may occur between the rhythm of activity or change at the system level and the actions of various participants involved in its development.

The challenge of acceleration is the continuing advancement of relevant knowledge and the constant diversification of required skills, which threatens to make solutions and decisions obsolete. Project participants may cope by pacing activities and capability renewal on the rhythm of meso-level advancements [155, 163]. However, in spite of the relative predictability of trends and pace, acceleration makes it difficult to follow changes. As Bergvall-Kåreborn and Howcroft ([164]: 425) put it, "changes ripple through and accentuate ongoing trends and developments." For project participants, component interactions and nonadditive processes may unfold too rapidly to be understood in a timely manner; the project may escape their control and run away towards an unpredictable outcome [165]. Trying to follow all intersecting strands with an agile strategy is likely to overwhelm the cognitive and adaptive capacities of actors and organizations, even if these are maintained at the edge of chaos.

A strategy with better chances of addressing this complex dynamic would be to separate the project into independent parts, allowing participants to develop and update primarily the specialized knowledge required for the part in which they are involved and to only track and respond to a subset of overall changes. The unfolding inertia created by feedback between the meso-level system and lower-level entities and upward nonadditivity processes enables a relatively continuous dynamic, which provides a chance for durable partitions of this kind. In essence, this strategy cultivates modularity [166], splitting the project into semiautonomous modules interacting through limited and well-defined interfaces that contain most changes locally and regularize the influences between modules [167, 168]. The resulting flexibility is twofold. On the one hand, modularity enables responding to changes that affect each module without affecting the others, and, on the other hand, it simplifies the less frequent replacement or rearrangement of modules [169, 170]. Despite imposing what may appear in the short term as an architectural straightjacket, evidence suggests that modularity enables faster as well as less disruptive change in the long term [171]. With respect to artifacts and their development activities, modularization requires a partition that minimizes the flows of information, energy, and so on between modules, as well as the number of design iterations that would cross interfaces, perhaps isolating the subsystems that appear more likely to be impacted by future change [172–174]. For project organizations or networks, a similar structure enables knowledge specialization and minimizes interactions across unit or firm boundaries, perhaps following the fault lines of technical architectures. However, depending on the nature of artifacts, particularly of the interactions between their parts, modularization also requires an overarching "system integrator" unit or firm [175]. Modularization can be extended into project environments, such as a markets, via the proactive standardization of technical architectures and interfaces [176], and the development of alliances that would impose a particular architecture, platform, or "stack" as a de facto standard [177, 178]. These arguments are summarized in the following proposition.

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

Because they may involve different levels, it is possible to observe in the same project a combination of dynamics shown in the same column in Figure 3. For example, ongoing effervescence would be punctuated by relatively less frequent major discontinuities. Likewise a dynamic of acceleration inside a sector may be combined with a dynamic of amplification with respect to a broader society. Also, different aspects of the project may be subject to dynamics pertaining to different columns. For example, the market environment may be subject to a dynamic of amplification, while the institutional environment may face discontinuities caused by accession to power of politicians sharing radically different ideologies.

Likewise, a context of hypercompetition [91] may involve effervescence regarding markets preferences and competitor moves and acceleration with respect to the advancement of technological frontiers. Projects are likely to respond with a combination of strategies. Yet, many requirements of alternative strategies are incompatible; some, such as modularity, require intense front-end preparation, while others, such as iteration, require fast action. Therefore, projects are more likely to be effective if they are able to cultivate a sort of ambidexterity [179], which enables the coexistence of various strategies, within the same organization.

4. Discussion and Conclusions

Complexity has a major impact on projects, through execution failures, changes, delays, additional costs, dissatisfaction, and accidents [180]. The project management literature has depicted this impact as resulting from a variety of factors, which either act independently or interact in unclear ways. Our theorizing suggests that this impact results from a conjunction of antecedents and mechanisms to produce two kinds of consequences. On the one hand, intrinsic properties and representation shortcomings combine to induce deviations of project form and behavior from the expected stable configuration or controllable variation. On the other hand, emergence and unfolding processes combine to induce deviations from the anticipated patterns of activity and change, expected to be regular or predictable. Our theorizing effort resulted in four categories for each of these two kinds of consequences. While relying on abstract notions derived from fundamental research on complexity, this effort creates a conceptual framework with a moderate level of abstraction. To our knowledge, this is one of the few attempts to adopt such a strategy in project management research on project complexity.

This framework contributes to the integration of the two streams of research that addressed project complexity from generic and highly abstract perspectives and, respectively, from a practical viewpoint by relying on managers' opinions. Because of the profusion of concepts advanced by these streams, most attempts at integration had, so far, to rely on a quasi-bibliometric approach to inventory and classify the terms used to discuss project complexity [6, 181]. We believe that our original, theory-driven integration approach and the moderate level of abstraction of the resulting framework provide two benefits. On the one hand, they open the black box of complexity and help ground the understanding of complexity factors in fundamental notions such as emergence. This enabled the creation of categories with a deeper theoretical meaning, tied to essential aspects and relevant consequences of project complexity, rather than to commonsense notions such as technology and organization. On the other hand, the categories we propose remain easy to connect to concrete aspects of projects. Therefore, they can help researchers make sense of the rich set of factors identified by the practical stream of complexity research and guide them towards understanding how each factor becomes a complexity antecedent or mechanism trigger. Of course, any increase in abstraction may result in losing some empirically

derived richness. Therefore, further research should rely on case studies and grounded theorizing to map back concrete complexity factors upon the more general categories included in our framework.

A second important contribution of this paper is theorizing about the strategies that can be used to prevent or to mitigate the impact of complexity. Contributions regarding strategies applied specifically to address project complexity are even less frequent than those discussing the nature and sources of complexity. Our contribution includes, on the one hand, theorizing the knowledge- and representation-producing strategies that are effective in preventing the structural consequences of complexity. On the other hand, we theorized strategies for organizing project activities, namely, by connecting them simultaneously as well as intertemporally, to mitigate the dynamic consequences of complexity. Once again, for each of these two types of strategies, we propose four categories with mid-range of abstraction. This level of abstraction enables the creation of meaningful categories for a host of concrete project management practices observed across a variety of domains. Further research could inventory such practices and connect them to the categories of our framework. The fundamental grounding of this framework would guide researchers towards understanding how these practices block or mitigate detrimental emergence processes or respond to irregular or unexpected dynamics. These results could, in turn, inform research on projects as organizations and networks, in particular in what is related to their flexibility and response capacity [90], along with the research on knowledge production in projects [26], and even on knowledge management and interproject transfer in project-based organizations [115].

A third contribution of this article is using the theoretical framework to develop propositions about the most appropriate strategies for addressing each kind of project complexity. With some notable exceptions [15, 114], past research had produced few theoretical models about the strategies that are effective in addressing various kinds of complexity and even fewer results that have been validated in a variety of empirical settings. Therefore future empirical research could corroborate these propositions both through longitudinal case studies that would investigate how various strategies work, perhaps in different project stages, as well as through cross-sectional studies that could rely on differences suggested by our framework with regard to the nature of complexity in various industries to determine whether the proposed strategies are indeed more effective in addressing various categories of complexity. One particular stream of research could focus on deepening our understanding of the interrelations of the various types of complexity and strategies in a project. In addition to grasping the polyphony of complexity and the mutual exclusivity of strategies in a project, this stream could lead to the development of new research programs on the management of project paradoxes [182] and the ambidexterity of project organizations [179, 183]. In practical terms, these results may suggest what practices or combinations of practices are best suited for addressing the specific forms of complexity that affect a variety of domains, such as software, biotech, and infrastructure construction, and could inspire the development of new complexity management practices.

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

Conflicts of Interest

The authors declare that there are no conflicts of interest related to this paper.

References

[1] A. J. Shenhar, "One size does not fit all projects: exploring classical contingency domains," *Management Science*, vol. 47, no. 3, pp. 394–414, 2001.

[2] D. P. Tegarden, S. D. Sheetz, and D. E. Monarchi, "A software complexity model of object-oriented systems," *Decision Support Systems*, vol. 13, no. 3-4, pp. 241–262, 1995.

[3] T. M. Williams, "The need for new paradigms for complex projects," *International Journal of Project Management*, vol. 17, no. 5, pp. 269–273, 1999.

[4] T. Katsila, G. A. Spyroulias, G. P. Patrinos, and M.-T. Matsoukas, "Computational approaches in target identification and drug discovery," *Computational and Structural Biotechnology Journal*, vol. 14, pp. 177–184, 2016.

[5] J. Geraldi, H. Maylor, and T. Williams, "Now, let's make it really complex (complicated): A systematic review of the complexities of projects," *International Journal of Operations and Production Management*, vol. 31, no. 9, pp. 966–990, 2011.

[6] J. Bakhshi, V. Ireland, and A. Gorod, "Clarifying the project complexity construct: Past, present and future," *International Journal of Project Management*, vol. 34, no. 7, pp. 1199–1213, 2016.

[7] T. Cooke-Davies, S. Cicmil, L. Crawford, and K. Richardson, "We're not in Kansas anymore, Toto: Mapping the strange landscape of complexity theory, and its relationship to project mangement," *IEEE Engineering Management Review*, vol. 36, no. 2, pp. 5–21, 2008.

[8] M. Bosch-Rekveldt, Y. Jongkind, H. Mooi, H. Bakker, and A. Verbraeck, "Grasping project complexity in large engineering projects: The TOE (Technical, Organizational and Environmental) framework," *International Journal of Project Management*, vol. 29, no. 6, pp. 728–739, 2011.

[9] R. J. Chapman, "A framework for examining the dimensions and characteristics of complexity inherent within rail megaprojects," *International Journal of Project Management*, vol. 34, no. 6, pp. 937–956, 2016.

[10] A. T. Nguyen, L. D. Nguyen, L. Le-Hoai, and C. N. Dang, "Quantifying the complexity of transportation projects using the fuzzy analytic hierarchy process," *International Journal of Project Management*, vol. 33, no. 6, pp. 1364–1376, 2015.

[11] L.-A. Vidal, F. Marle, and J.-C. Bocquet, "Measuring project complexity using the Analytic Hierarchy Process," *International Journal of Project Management*, vol. 29, no. 6, pp. 718–727, 2011.

[12] B. Dao, S. Kermanshachi, J. Shane, and S. Anderson, "Project Complexity Assessment and Management Tool," in *Proceedings of the International Conference on Sustainable Design, Engineering and Construction, ICSDEC 2016*, pp. 491–496, usa, May 2016.

[13] W. Xia and G. Lee, "Complexity of information systems development projects: Conceptualization and measurement development," *Journal of Management Information Systems*, vol. 22, no. 1, pp. 45–83, 2005.

[14] J. W. Meyer and B. Rowan, "Institutionalized organizations: formal structure as myth and ceremony," *American Journal of Sociology*, vol. 83, no. 2, pp. 340–363, 1977.

[15] S. Floricel, J. L. Michela, and S. Piperca, "Complexity, uncertainty-reduction strategies, and project performance," *International Journal of Project Management*, vol. 34, no. 7, pp. 1360–1383, 2016.

[16] H. Maylor and N. Turner, "Understand, reduce, respond: project complexity management theory and practice," *International Journal of Operations and Production Management*, vol. 37, no. 8, pp. 1076–1093, 2017.

[17] H.-J. Rheinberger, "Experimental complexity in biology: Some epistemological and historical remarks," *Philosophy of Science*, vol. 64, no. 4, pp. S245–S254, 1997.

[18] S. J. Whitty and H. Maylor, "And then came complex project management (revised)," *International Journal of Project Management*, vol. 27, no. 3, pp. 304–310, 2009.

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

[20] D. Rind, "Complexity and climate," *Science*, vol. 284, no. 5411, pp. 105–107, 1999.

[21] E. Mayr, "Biology in the twenty-first century," *Bioscience*, vol. 50, no. 10, p. 895, 2000.

[22] M. DeLanda, *Digital Tectonics*, N. Leach, D. Turnbull, and C. Williams, Eds., John Wiley & Sons, Chichester, 2004.

[23] G. Weng, U. S. Bhalla, and R. Iyengar, "Complexity in biological signaling systems," *Science*, vol. 284, no. 5411, pp. 92–96, 1999.

[24] A. Menges, "Material computation: Higher integration in morphogenetic design," *Architectural Design*, vol. 82, no. 2, pp. 14–21, 2012.

[25] A. van Marrewijk, S. R. Clegg, T. S. Pitsis, and M. Veenswijk, "Managing public-private megaprojects: Paradoxes, complexity, and project design," *International Journal of Project Management*, vol. 26, no. 6, pp. 591–600, 2008.

[26] S. Floricel, J. L. Michela, M. George, and L. with Bonneau, *Refining the Knowledge Production Plan: Knowledge Representations In Innovation Projects*, Project Management Institute, Newton Square, PA, 2011.

[27] K. Henderson, "The Political Career of a Prototype: Visual Representation in Design Engineering," *Social Problems*, vol. 42, no. 2, pp. 274–299, 1995.

[28] R. Kline, "Science and engineering theory in the invention and development of the induction motor," *Technology and Culture*, vol. 28, no. 2, pp. 283–313, 1987.

[29] P. Nightingale, "A cognitive model of innovation," *Research Policy*, vol. 27, no. 7, pp. 689–709, 1998.

[30] M. Blum, "A machine-independent theory of the complexity of recursive functions," *Journal of the ACM*, vol. 14, pp. 322–336, 1967.

[31] A. M. Turing, "On Computable Numbers, with an Application to the Entscheidungsproblem," *Proceedings of the London Mathematical Society. Second Series*, vol. 42, no. 3, pp. 230–265, 1936.

[32] L. Biggiero, "Sources of complexity in human systems," *Nonlinear Dynamics, Psychology, and Life Sciences*, vol. 5, no. 1, p. 19, 2001.

[33] P. F. Katina, C. B. Keating, and R. M. Jaradat, "System requirements engineering in complex situations," *Requirements Engineering*, vol. 19, no. 1, pp. 45–62, 2014.

[34] A. N. Kolmogorov, "Three approaches to the quantitative definition of information," *International Journal of Computer Mathematics. Section A. Programming Theory and Methods. Section B. Computational Methods*, vol. 2, pp. 157–168, 1968.

[35] B. Goertzel, "Measuring static complexity," *International Journal of Mathematics and Mathematical Sciences*, vol. 15, no. 1, pp. 161–174, 1992.

[36] M. Gell-Mann and S. Lloyd, "Information measures, effective complexity, and total information," *Complexity*, vol. 2, no. 1, pp. 44–52, 1996.

[37] U. Sauer, M. Heinemann, and N. Zamboni, "Getting closer to the whole picture," *Science*, vol. 316, no. 5824, pp. 550-551, 2007.

[38] N. Crossley, *Towards Relational Sociology*, Routledge, London, UK, 2011.

[39] R. K. Sawyer, "The mechanisms of emergence," *Philosophy of the Social Sciences*, vol. 34, no. 2, pp. 260–282, 2004.

[40] W. C. Wimsatt, "Aggregate, composed, and evolved systems: Reductionistic heuristics as means to more holistic theories," *Biology and Philosophy*, vol. 21, no. 5, pp. 667–702, 2006.

[41] P. W. Andersen, "More is different," *Science*, vol. 177, no. 4047, pp. 393–396, 1972.

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

[43] P. Anderson, "Complexity theory and organization science," *Organization Science*, vol. 10, no. 3, pp. 216–232, 1999.

[44] J. M. Lehn, "Toward self-organization and complex matter," *Science*, vol. 295, no. 5564, pp. 2400–2403, 2002.

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

[46] K. Barad, "Posthumanist performativity: Toward an understanding of how matter comes to matter," *Signs*, vol. 28, no. 3, pp. 801–831, 2003.

[47] W. J. Orlikowski, "Sociomaterial practices: Exploring technology at work," *Organization Studies*, vol. 28, no. 9, pp. 1435–1448, 2007.

[48] M. Callon, "Some elements of a sociology of translation: Domestication of the scallops and the fishermen of St Brieuc Bay," *The Sociological Review*, vol. 32, no. 1, pp. 196–233, 1984.

[49] S. Floricel, C. Bonneau, M. Aubry, and V. Sergi, "Extending project management research: Insights from social theories," *International Journal of Project Management*, vol. 32, no. 7, pp. 1091–1107, 2014.

[50] H. A. Simon, *The Sciences of the Artificial*, MIT Press, Cambridge, MA, 2nd edition, 1981.

[51] Y. Bar-Yam, "A mathematical theory of strong emergence using multiscale variety," *Complexity*, vol. 9, no. 6, pp. 15–24, 2004.

[52] K. M. Kontopoulos, *The logics of social structure*, Cambridge University Press, Cambridge, UK, 1993.

[53] C. Adami, "What is complexity?" *BioEssays*, vol. 24, no. 12, pp. 1085–1094, 2002.

[54] P. Kohl and D. Noble, "Systems biology and the virtual physiological human," *Molecular Systems Biology*, vol. 5, no. 1, pp. 1–6, 2009.

[55] D. W. McShea, "The hierarchical structure of organisms: A scale and documentation of a trend in the maximum," *Paleobiology*, vol. 27, no. 2, pp. 405–423, 2001.

[56] O. Hanseth, E. Monteiro, and M. Hatling, "Developing information infrastructure: The tension between standardization and flexibility," *Science, Technology & Human Values*, vol. 21, no. 4, pp. 407–426, 1996.

[57] K. J. Klein, F. Dansereau, and R. J. Hall, "Levels issues in theory development, data collection, and analysis," *Academy of Management Review (AMR)*, vol. 19, no. 2, pp. 195–229, 1994.

[58] S. Brusoni, A. Prencipe, and K. Pavitt, "Knowledge specialization, organizational coupling, and the boundaries of the firm: Why do firms know more than they make?" *Administrative Science Quarterly*, vol. 46, no. 4, pp. 597–621, 2001.

[59] R. Drazin, M. A. Glynn, and R. K. Kazanjian, "Multilevel theorizing about creativity in organizations: A sensemaking perspective," *Academy of Management Review (AMR)*, vol. 24, no. 2, pp. 286–307, 1999.

[60] M. Engwall, "No project is an island: Linking projects to history and context," *Research Policy*, vol. 32, no. 5, pp. 789–808, 2003.

[61] D. H. Gobeli, H. F. Koenig, and I. Bechinger, "Managing Conflict in Software Development Teams: A Multilevel Analysis," *Journal of Product Innovation Management*, vol. 15, no. 5, pp. 423–435, 1998.

[62] R. Miller, M. Hobday, T. Leroux-demers, and X. Olleros, "Innovation in complex systems industries: The case of flight simulation," *Industrial and Corporate Change*, vol. 4, no. 2, pp. 363–400, 1995.

[63] R. Thom, "Stabilité structurelle et morphogenèse," *Poetics*, vol. 10, no. C, pp. 7–19, 1974.

[64] W. B. Arthur, "Competing technologies, increasing returns, and lock-in by historical events," *The Economic Journal*, vol. 99, no. 394, p. 116, 1989.

[65] G. M. Whitesides and R. F. Ismagilov, "Complexity in chemistry," *Science*, vol. 284, no. 5411, pp. 89–92, 1999.

[66] K. J. Dooley and A. H. Van De Ven, "Explaining Complex Organizational Dynamics," *Organization Science*, vol. 10, no. 3, pp. 358–372, 1999.

[67] S. Floricel and S. Piperca, "Project management between will and representation," *Project Management Journal*, vol. 47, no. 3, pp. 124–138, 2016.

[68] F. C. Saunders, "Toward high reliability project organizing in safety-critical projects," *Project Management Journal*, vol. 46, no. 3, pp. 25–35, 2015.

[69] I. Prigogine, *The End of Certainty*, Free Press, New York, NY, USA, 1997.

[70] H. R. Maturana and F. Varela, *Autopoiesis and Cognition: the Realization of the Living*, Reidel, Dordrecht, 1980.

[71] N. Luhmann, *Social systems*, Stanford University Press, 1995.

[72] S. Wolfram, "Cellular automata as models of complexity," *Nature*, vol. 311, no. 5985, pp. 419–424, 1984.

[73] J. S. Coleman, "Foundations for a theory of collective decisions.," *American Journal of Sociology*, vol. 71, no. 6, pp. 615–627, 1966.

[74] M. S. Feldman and B. T. Pentland, "Reconceptualizing organizational routines as a source of flexibility and change," *Administrative Science Quarterly*, vol. 48, no. 1, pp. 94–118, 2003.

[75] C. E. Helfat and M. A. Peteraf, "The dynamic resource-based view: Capability lifecycles," *Strategic Management Journal*, vol. 24, no. 10, pp. 997–1010, 2003.

[76] S. Klepper, "Industry life cycles," *Industrial and Corporate Change*, vol. 6, no. 1, pp. 145–181, 1997.

[77] R. M. Kramer, "Trust and distrust in organizations: emerging perspectives, enduring questions," *Annual Review of Psychology*, vol. 50, pp. 569–598, 1999.

[78] W. C. Bogner and P. S. Barr, "Making Sense in Hypercompetitive Environments: A Cognitive Explanation for the Persistence of High Velocity Competition," *Organization Science*, vol. 11, no. 2, pp. 212–226, 2000.

[79] K. M. Eisenhardt, "Making fast strategic decisions in high-velocity environments," *Academy of Management Journal (AMJ)*, vol. 32, no. 3, pp. 543–576, 1989.

[80] S. Floricel and D. Dougherty, "Where do games of innovation come from? Explaining the persistence of dynamic innovation patterns," *International Journal of Innovation Management*, vol. 11, no. 1, pp. 65–92, 2007.

[81] H. Benbya and B. McKelvey, "Using coevolutionary and complexity theories to improve IS alignment: A multi-level approach," *Journal of Information Technology*, vol. 21, no. 4, pp. 284–298, 2006.

[82] A. MacCormack, R. Verganti, and M. Iansiti, "Developing products on "Internet time": The anatomy of a flexible development process," *Management Science*, vol. 47, no. 1, pp. 133–150, 2001.

[83] R. Miller and D. R. Lessard, "The Strategic Management of Large Engineering Projects: Shaping Institutions, Risks, and Governance," Cambridge, MA: MIT Press.

[84] S. Kwinter, "The computational fallacy," *Thresholds*, vol. 26, pp. 90–92, 2003.

[85] R. House, *The Human Side of Project Management*, Addison-Wesley, Reading, Mass, 1988.

[86] M. Aubry, R. Müller, B. Hobbs, and T. Blomquist, "Project management offices in transition," *International Journal of Project Management*, vol. 28, no. 8, pp. 766–778, 2010.

[87] A. Davies, D. Gann, and T. Douglas, "Innovation in megaprojects: Systems integration at London Heathrow terminal 5," *California Management Review*, vol. 51, no. 2, pp. 101–125, 2009.

[88] T. Y. Hsieh, S. T. Lu, and C. H. Wu, "Statistical analysis of causes for change orders in metropolitan public works," *International Journal of Project Management*, vol. 22, no. 8, pp. 679–686.

[89] M. Sun and X. Meng, "Taxonomy for change causes and effects in construction projects," *International Journal of Project Management*, vol. 27, no. 6, pp. 560–572, 2009.

[90] S. Floricel, S. Piperca, and M. Banik, *Increasing Project Flexibility: The Response Capacity of Complex Projects*, Project Management Institute, Newton Square, PA, 2011.

[91] R. A. D'Aveni, *Hypercompetition: Managing the Dynamics of Strategic Maneuvering*, Free Press, New York, NY, USA, 1994.

[92] A. D. Meyer, V. Gaba, and K. A. Colwell, "Organizing far from equilibrium: Nonlinear change in organizational fields," *Organization Science*, vol. 16, no. 5, pp. 456–473, 2005.

[93] D. Polley, "Turbulence in Organizations: New Metaphors for Organizational Research," *Organization Science*, vol. 8, no. 5, pp. 445–457, 1997.

[94] J. Sydow, G. Schreyögg, and J. Koch, "Organizational path dependence: Opening the black box," *Academy of Management Review (AMR)*, vol. 34, no. 4, pp. 689–709, 2009.

[95] D. J. Teece, G. Pisano, and A. Shuen, "Dynamic capabilities and strategic management," *Strategic Management Journal*, vol. 18, no. 7, pp. 509–533, 1997.

[96] H. Tsoukas and R. Chia, "On organizational becoming: rethinking organizational change," *Organization Science*, vol. 13, no. 5, pp. 567–582, 2002.

[97] T. Hernes, *Understanding Organization as Process: Theory for a Tangled World*, Routledge, New York, NY, USA, 2008.

[98] T. Hernes and E. Weik, "Organization as process: Drawing a line between endogenous and exogenous views," *Scandinavian Journal of Management*, vol. 23, no. 3, pp. 251–264, 2007.

[99] S. Collyer and C. M. J. Warren, "Project management approaches for dynamic environments," *International Journal of Project Management*, vol. 27, no. 4, pp. 355–364, 2009.

[100] S. C. Sommer and C. H. Loch, "Selectionism and learning in projects with complexity and unforeseeable uncertainty," *Management Science*, vol. 50, no. 10, pp. 1334–1347, 2004.

[101] W. R. Ashby, "Requisite Variety and its implications for the control of complex systems," *Cybernetica (Namur)*, vol. 1, no. 2, pp. 83–99, 1958.

[102] N. Luhmann, *Risk: A sociological theory*, Aldine De Gruyter, New York, NY, USA, 1993.

[103] F. P. Morgeson, T. R. Mitchell, and D. Liu, "Event system theory: An event-oriented approach to the organizational sciences," *Academy of Management Review (AMR)*, vol. 40, no. 4, pp. 515–537, 2015.

[104] A. D. Meyer, "Adapting to environmental jolts.," *Administrative Science Quarterly*, vol. 27, no. 4, pp. 515–537, 1982.

[105] F. E. Emery and E. L. Trist, "The causal texture of organizational environments," *Human Relations*, vol. 18, no. 1, pp. 21–32, 1965.

[106] A. Soderholm, "Project management of unexpected events," *International Journal of Project Management*, vol. 26, no. 1, pp. 80–86, 2008.

[107] S. Piperca and S. Floricel, "A typology of unexpected events in complex projects," *International Journal of Managing Projects in Business*, vol. 5, no. 2, pp. 248–265, 2012.

[108] S. Floricel and R. Miller, "Strategizing for anticipated risks and turbulence in large-scale engineering projects," *International Journal of Project Management*, vol. 19, no. 8, pp. 445–455, 2001.

[109] P. Hedström and R. Swedberg, "Social Mechanisms," *Acta Stereologica*, vol. 39, no. 3, pp. 281–308, 1996.

[110] G. F. Davis and C. Marquis, "Prospects for organization theory in the early twenty-first century: Institutional fields and mechanisms," *Organization Science*, vol. 16, no. 4, pp. 332–343, 2005.

[111] C. H. Loch and C. Terwiesch, "Communication and uncertainty in concurrent engineering," *Management Science*, vol. 44, no. 8, pp. 1032–1048, 1998.

[112] S. K. Chandrasegaran, K. Ramani, R. D. Sriram et al., "The evolution, challenges, and future of knowledge representation in product design systems," *Computer-Aided Design*, vol. 45, no. 2, pp. 204–228, 2013.

[113] W. Visser, "Designing as construction of representations: A dynamic viewpoint in cognitive design research," *Human–Computer Interaction*, vol. 21, no. 1, pp. 103–152, 2006.

[114] T. Ahern, B. Leavy, and P. J. Byrne, "Complex project management as complex problem solving: A distributed knowledge management perspective," *International Journal of Project Management*, vol. 32, no. 8, pp. 1371–1381, 2014.

[115] A. Prencipe and F. Tell, "Inter-project learning: Processes and outcomes of knowledge codification in project-based firms," *Research Policy*, vol. 30, no. 9, pp. 1373–1394, 2001.

[116] W. M. Cohen and D. A. Levinthal, "Absorptive capacity: A new perspective of learning and innovation," *Administrative Science Quarterly*, vol. 35, no. 1, pp. 128–152, 1990.

[117] R. A. Burgelman, "Intraorganizational Ecology of Strategy Making and Organizational Adaptation: Theory and Field Research," *Organization Science*, vol. 2, no. 3, pp. 239–262, 1991.

[118] B. Iyer and T. H. Davenport, "Reverse engineering Googles innovation machine," *Harvard Business Review*, vol. 86, no. 4, pp. 58–134, 2008.

[119] M. L. Markus, A. Majchrzak, and L. Gasser, "A design theory for systems that support emergent knowledge processes," *MIS Quarterly: Management Information Systems*, vol. 26, no. 3, pp. 179–212, 2002.

[120] R. F. Hirsh, *Technology and Transformation in the American Electric Utility Industry*, Cambridge University Press, Cambridge, UK, 1989.

[121] T. A. Carbone and D. D. Tippett, "Project risk management using the project risk fmea," *EMJ - Engineering Management Journal*, vol. 16, no. 4, pp. 28–35, 2004.

[122] A. Qazi, J. Quigley, A. Dickson, and K. Kirytopoulos, "Project Complexity and Risk Management (ProCRiM): Towards modelling project complexity driven risk paths in construction projects," *International Journal of Project Management*, vol. 34, no. 7, pp. 1183–1198, 2016.

[123] C. Perrow, *Normal accidents: Living with high risk technologies*, Basic Books, New York, NY, USA, 1984.

[124] L. A. Kappelman, R. McKeeman, and L. Zhang, "Early warning signs of IT project failure: The dominant dozen," *Information Systems Management*, vol. 23, no. 4, pp. 31–36, 2006.

[125] R. M. Henderson and K. B. Clark, "Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms," *Administrative Science Quarterly*, vol. 35, pp. 9–30, 1990.

[126] K. E. Weick and K. H. Roberts, "Collective mind: Heedful interrelations on flight decks," *Adminstrative Science Quarterly*, vol. 38, pp. 357–381, 1993.

[127] K. E. Weick, K. M. Sutcliffe, and D. Obstfeld, "Organizing for high reliability: Processes of collective mindfulness," *Crisis management*, vol. 3, no. 1, pp. 81–123, 2008.

[128] M. T. Hansen, "The search-transfer problem: the role of weak ties in sharing knowledge across organization subunits," *Administrative Science Quarterly*, vol. 44, no. 1, pp. 82–111, 1999.

[129] M. Zollo and S. G. Winter, "Deliberate learning and the evolution of dynamic capabilities," *Organization Science*, vol. 13, no. 3, pp. 339–351, 2002.

[130] A. O'Sullivan, "Why tense, unstable, and diverse relations are inherent in co-designing with suppliers: An aerospace case study," *Industrial and Corporate Change*, vol. 15, no. 2, pp. 221–250, 2006.

[131] K. E. Weick, K. M. Sutcliffe, and D. Obstfeld, "Organizing and the process of sensemaking," *Organization Science*, vol. 16, no. 4, pp. 409–421, 2005.

[132] V. Krishnan, S. D. Eppinger, and D. E. Whitney, "A model-based framework to overlap product development activities," *Management Science*, vol. 43, no. 4, pp. 437–451, 1997.

[133] S. D. Eppinger, D. E. Whitney, R. P. Smith, and D. A. Gebala, "A model-based method for organizing tasks in product development," *Research in Engineering Design*, vol. 6, no. 1, pp. 1–13, 1994.

[134] D. Nicolini, J. Mengis, and J. Swan, "Understanding the role of objects in cross-disciplinary collaboration," *Organization Science*, vol. 23, no. 3, pp. 612–629, 2012.

[135] S. Thomke and T. Fujimoto, "Effect of 'front-loading' problem-solving on product development performance," *Journal of Product Innovation Management*, vol. 17, no. 2, pp. 128–142, 2000.

[136] P. R. Carlile, "A pragmatic view of knowledge and boundaries: Boundary objects in new product development," *Organization Science*, vol. 13, no. 4, pp. 442–456, 2002.

[137] B. Ewenstein and J. Whyte, "Knowledge practices in design: The role of visual representations as 'Epistemic objects'," *Organization Studies*, vol. 30, no. 1, pp. 7–30, 2009.

[138] Y. Liu, S. van Nederveen, and M. Hertogh, "Understanding effects of BIM on collaborative design and constructionAn empirical study in China," *International Journal of Project Management*, vol. 35, no. 4, pp. 686–698, 2017.

[139] I. Stigliani and D. Ravasi, "Organizing thoughts and connecting brains: Material practices and the transition from individual to group-level prospective sensemaking," *Academy of Management Journal (AMJ)*, vol. 55, no. 5, pp. 1232–1259, 2012.

[140] N. N. Taleb, "Black swans and the domains of statistics," *The American Statistician*, vol. 61, no. 3, pp. 198–200, 2007.

[141] N. Leveson, N. Dulac, K. Marais, and J. Carroll, "Moving beyond Normal Accidents and High Reliability Organizations: A Systems Approach to Safety in Complex Systems," *Organization Studies*, vol. 30, no. 2-3, pp. 227–249, 2009.

[142] G. Sliwoski, S. Kothiwale, J. Meiler, and E. W. Lowe Jr., "Computational methods in drug discovery," *Pharmacological Reviews*, vol. 66, no. 1, pp. 334–395, 2014.

[143] C. G. Begley and L. M. Ellis, "Drug development: Raise standards for preclinical cancer research," *Nature*, vol. 483, no. 7391, pp. 531–533, 2012.

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

[145] P. Nightingale and P. Martin, "The myth of the biotech revolution," *Trends in Biotechnology*, vol. 22, no. 11, pp. 564–569, 2004.

[146] S. Mandal, M. Moudgil, and S. K. Mandal, "Rational drug design," *European Journal of Pharmacology*, vol. 625, no. 1-3, pp. 90–100, 2009.

[147] G. Gavetti and D. Levinthal, "Looking forward and looking backward: cognitive and experiential search," *Administrative Science Quarterly*, vol. 45, no. 1, pp. 113–137, 2000.

[148] L. Fleming and O. Sorenson, "Science as a map in technological search," *Strategic Management Journal*, vol. 25, pp. 909–925, 2004.

[149] R. D. Austin, L. Devin, and E. E. Sullivan, "Accidental innovation: Supporting valuable unpredictability in the creative process," *Organization Science*, vol. 23, no. 5, pp. 1505–1522, 2012.

[150] K. R. Popper, *The logic of scientific discovery*, Hutchinson and Co., Ltd., London, 1959.

[151] G. G. Dess and D. W. Beard, "Dimensions of organizational task environments," *Administrative Science Quarterly*, vol. 29, no. 1, pp. 52–73, 1984.

[152] E. C. Conforto, D. C. Amaral, S. L. da Silva, A. Di Felippo, and D. S. L. Kamikawachi, "The agility construct on project management theory," *International Journal of Project Management*, vol. 34, no. 4, pp. 660–674, 2016.

[153] J. A. Highsmith, *Agile project management: Creating innovative products*, Addison-Wesley, Upper Saddle River, NJ, 2nd edition, 2010.

[154] P. Serrador and J. K. Pinto, "Does Agile work? - A quantitative analysis of agile project success," *International Journal of Project Management*, vol. 33, no. 5, pp. 1040–1051, 2015.

[155] S. L. Brown and K. M. Eisenhardt, "The art of continuous change: linking complexity theory and time-paced evolution in relentlessly shifting organizations," *Administrative Science Quarterly*, vol. 42, no. 1, pp. 1–34, 1997.

[156] D. A. Levinthal, "Adaptation on rugged landscapes," *Management Science*, vol. 43, no. 7, pp. 934–950, 1997.

[157] J. Whyte, A. Stasis, and C. Lindkvist, "Managing change in the delivery of complex projects: Configuration management, asset information and 'big data'," *International Journal of Project Management*, vol. 34, no. 2, pp. 339–351, 2016.

[158] N. O. E. Olsson, "Management of flexibility in projects," *International Journal of Project Management*, vol. 24, no. 1, pp. 66–74, 2006.

[159] R. G. Lord, J. E. Dinh, and E. L. Hoffman, "A quantum approach to time and organizational change," *Academy of Management Review (AMR)*, vol. 40, no. 2, pp. 263–290, 2015.

[160] L. Trigeorgis, *Real options: Managerial flexibility and strategy in resource allocation*, MIT press, Boston, MA, 1996.

[161] M. J. Garvin and D. N. Ford, "Real options in infrastructure projects: Theory, practice and prospects," *Engineering Project Organization Journal*, vol. 2, no. 1-2, pp. 97–108, 2012.

[162] R. G. Fichman, M. Keil, and A. Tiwana, ""Options thinking" in IT project management," *California Management Review*, vol. 47, no. 2, pp. 74–96, 2005.

[163] P. Klarner and S. Raisch, "Move to the beat-rhythms of change and firm performance," *Academy of Management Journal (AMJ)*, vol. 56, no. 1, pp. 160–184, 2013.

[164] B. Bergvall-Kåreborn and D. Howcroft, "Persistent problems and practices in information systems development: A study of mobile applications development and distribution," *Information Systems Journal*, vol. 24, no. 5, pp. 425–444, 2014.

[165] C. B. Perrow, "Complexity, catastrophe, and modularity," *Sociological Inquiry*, vol. 78, no. 2, pp. 162–173, 2008.

[166] H. A. Simon, "The architecture of complexity," *Proceedings of the American Philosophical Society*, vol. 106, no. 6, pp. 467–482.

[167] R. Sanchez and J. T. Mahoney, "Modularity, flexibility, and knowledge management in product and organization design," *Strategic Management Journal*, vol. 17, no. 2, pp. 63–76, 1996.

[168] N. P. Suh, "Complexity in Engineering," *CIRP Annals - Manufacturing Technology*, vol. 54, no. 2, pp. 46–63, 2005.

[169] K. Ulrich, "The role of product architecture in the manufacturing firm," *Research Policy*, vol. 24, no. 3, pp. 419–440, 1995.

[170] M. A. Schilling, "Toward a general modular systems theory and its application to interfirm product modularity," *Academy of Management Review (AMR)*, vol. 25, no. 2, pp. 312–334, 2000.

[171] R. N. Langlois and P. L. Robertson, "Networks and innovation in a modular system: lessons from the microcomputer and stereo component industries," *Research Policy*, vol. 21, no. 4, pp. 297–313, 1992.

[172] J. B. Dahmus, J. P. Gonzalez-Zugasti, and K. N. Otto, "Modular product architecture," *Design Studies*, vol. 22, no. 5, pp. 409–424, 2001.

[173] K. Hölttä-Otto, N. Chiriac, D. Lysy, and E. S. Suh, "Architectural decomposition: The role of granularity and decomposition viewpoint," *Advances in Product Family and Product Platform Design: Methods and Applications*, pp. 221–243, 2014.

[174] M. Magnusson and M. Pasche, "A contingency-based approach to the use of product platforms and modules in new product development," *Journal of Product Innovation Management*, vol. 31, no. 3, pp. 434–450, 2014.

[175] S. Brusoni and A. Prencipe, "Unpacking the black box of modularity: technologies, products and organizations," *Industrial and Corporate Change*, vol. 10, no. 1, pp. 179–205, 2001.

[176] M. Wadczak, T. B. Meriem, B. Radier et al., "Standardizing a reference model and autonomic network architectures for the self-managing future internet," *IEEE Network*, vol. 25, no. 6, pp. 50–56, 2011.

[177] M. Kenney and B. Pon, "Structuring the smartphone industry: Is the mobile Internet OS platform the key?" *Journal of Industry, Competition and Trade*, vol. 11, no. 3, pp. 239–261, 2011.

[178] A. Gawer and M. A. Cusumano, "Industry platforms and ecosystem innovation," *Journal of Product Innovation Management*, vol. 31, no. 3, pp. 417–433, 2014.

[179] C. A. O'Reilly and M. L. Tushman, "Ambidexterity as a dynamic capability: resolving the innovator's dilemma," *Research in Organizational Behavior*, vol. 28, pp. 185–206, 2008.

[180] B. Flyvbjerg, M. Garbuio, and D. Lovallo, "Deception in large infrastructure projects: Two models for explaining and preventing executive disaster," *California Management Review*, vol. 51, no. 2, pp. 3–193, 2009.

[181] M. Padalkar and S. Gopinath, "Are complexity and uncertainty distinct concepts in project management? A taxonomical examination from literature," *International Journal of Project Management*, vol. 34, no. 4, pp. 688–700, 2016.

[182] W. Smith and M. Lewis, "Toward a theory of paradox: A dynamic equilibrium model of organizing," *Academy of Management Review (AMR)*, vol. 36, no. 2, pp. 381–403, 2011.

[183] P. Boumgarden, J. Nickerson, and T. R. Zenger, "Sailing into the wind: Exploring the relationships among ambidexterity, vacillation, and organizational performance," *Strategic Management Journal*, vol. 33, no. 6, pp. 587–610, 2012.