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Complexity, uncertainty and mental models: From a paradigm of regulation to a paradigm of emergence in project management

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Abstract

In project management research, it is acknowledged that two perspectives on project performance must be considered: *project efficiency* (delivering efficient outputs) and *project success* (delivering beneficial outcomes). The first perspective is embedded in a deterministic paradigm of project management, while the second appears more naturally connected to the emerging non-deterministic paradigm. Complexity and uncertainty are key constructs frequently associated with the non-deterministic paradigm. This conceptual paper suggests that these two concepts could very well explain and define particularities of both paradigms, and seeks to articulate both perspectives in a contingent model.

First, the constructs of complexity and uncertainty are clarified. Second, the role of project managers' mental models in managerial decision-making is considered. In the third part of this article, we propose a theoretical model suggesting that project managers should consider contingent variables to differentiate managerial conditions of regulation from managerial conditions of emergence.

Keywords: Complexity; Uncertainty; Mental models; Systems; Project Management; Performance

1. Executive summary

It is generally understood that the world is becoming more and more complex. Project managers are experiencing this in their daily activities, being faced with a growing number of complex situations. The project management literature – particularly in the non-deterministic paradigm – has focused on this issue of complexity. However, two perspectives – project management and the management of projects – co-exist in the project management research community, as do two paradigms: deterministic and non-deterministic. This lack of unified theory – as well as the difficulty of agreeing on a definition of complexity – does not help project managers understand how to maximize performance in complex projects.

The research presented here attempts to propose richer lenses for looking at project management. We suggest that a better understanding of the construct of complexity, its associated construct of uncertainty, and the way human beings predict these through mental models are possible groundings for a contingent and comprehensive approach.

In this conceptual work, we first investigate the literature on complexity, highlighting three levels that can be found in different research works. We then investigate the literature on uncertainty, which also converges towards three levels of uncertainty. Finally, we add the notion of mental models as a means for project managers to understand the situations in which they find themselves, and gather all the findings in a conceptual model of project management.

Our study adds to the literature on complexity and uncertainty in project management by gathering many existing research works from different sciences. Tables summarizing these literatures shed light on the possibility of identifying three different levels of complexity and of uncertainty, which form the pillars of a contingent project management model.

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Overall, our conceptual paper suggests that it is possible to bridge the existing gap between the two project management paradigms. One reason for the difficulty of managing complex project situations lies in the limitations of classic project management methods. Complex and uncertain projects require newer methodologies based on understanding: the modelling approaches. By understanding the levels of complexity and of uncertainty in a situation, project managers can adapt their decision-making approach in order to maximize performance.

2. Introduction

Ten years ago, researchers in project management started to acknowledge the lack of a unified theory of the management of projects, whether defined in its narrow ('project management': PM) or broad ('management of projects': MoP) sense (Smyth and Morris, 2007). This concern is still raised by the project management research community, especially in the area of project performance, where the streams of research on success and failure do not converge (Padalkar and Gopinath, 2016b). The growing complexity of projects led to the emergence of a non-deterministic paradigm (Padalkar and Gopinath, 2016b), which raised the question of how to generate performance in complex projects; one major issue was agreeing on a definition of complexity itself.

The co-existence of the PM and MoP perspectives is a source of confusion for project managers, who are faced with a wide variety of project management conditions, and who cannot really know which project management approach is better adapted to the complexity of their project. Is there a way to reconcile these two perspectives? How can project managers understand which management principles they should adopt, depending on the managerial decision-making conditions under which they are working?

The PM perspective is supported by the execution-based model of the Project Management Institute (PMI), while the MoP perspective – founded on Peter Morris's research – is more comprehensive and open to a new definition of project success (Pinto and Winch, 2016). In his definition of the nature of project management, Turner makes a real distinction between the 'operational' project perspective (which is focused on the result of the project implementation: the output) and the 'strategic' project perspective (focused on the outcome resulting from the project implementation phase). This distinction is also found in the project management literature on success and failure, which differentiates between 'project efficiency' (project implementation performance), and 'project success' (project benefits performance) (Cooke-Davies, 2002; Serrador and Turner, 2015a; Turner and Zolin, 2012).

Beyond the two perspectives of PM and MoP, two paradigms have emerged from surveys on decades of project management research. The first is the deterministic paradigm, which is well established (Pinto and Winch, 2016) and is strongly dominated by operations research. It contributed significantly to the increase in project management performance with phase-project-planning methodologies in the 1960s (Morris, 2010). The second is the non-deterministic paradigm, which emerged in the mid-2000s (Padalkar and Gopinath, 2016b), putting a particular emphasis on complexity in projects (Crawford et al., 2006; Geraldi et al., 2011a; Whitty and Maylor, 2009). Non-deterministic research employs not only complexity but also uncertainty (following Turner's broader definition of project management) as its main lenses, but both concepts remain ambiguous, preventing this paradigm from moving forward (Padalkar and Gopinath, 2016a). For instance the PMI's view on complexity is far removed from that of complexity theory (Bakhshi et al., 2016).

Although the first paradigm is well established and the second is attracting much research interest, there is no clear way for project managers to understand how to position themselves in relation to these two paradigms. Complexity can sometimes be associated with both the deterministic paradigm (the PMI's view) and the non-deterministic paradigm (the complexity-theory view), and sometimes it is linked only to the non-deterministic paradigm. Complexity in projects is regularly associated with uncertainty, but these two constructs are not clearly differentiated in order to understand their specific role in project management theory.

The first contribution of this conceptual paper is to synthesize various research literatures (systems theory, decision theory and planning theory) in two tables, which reveal the contingency nature of complexity and uncertainty. We reveal not only that both constructs can be categorized in three levels, but also that each of these three levels suggests a specific managerial way of addressing situations: algorithmic, stochastic or non-deterministic. General systems theory revealed that managers interact with projects through decision models (mental models) to make their managerial decisions. The second contribution reveals that the prediction capacity of these decision models defines the level of uncertainty that project managers have to address, and impacts the level of complexity of the project as a whole. The third contribution is a contingent framework of project management, which positions management paradigms of regulation and of emergence according to the level of complexity and uncertainty that project managers must face. As a consequence, this comprehensive framework provides new lenses for project managers in order to select the appropriate management approach.

In Sections 3 and 4 of this paper, the constructs of complexity and uncertainty will be explored, and the link between the two will be developed. In these two sections, three main approaches are revealed: algorithmic, stochastic and non-deterministic, which can be linked with the constructs of both complexity and uncertainty, and which are ingrained in decision theory.

Section 5 sheds light on the fact that mental models are key in managerial decision theory. Mental models – and, more specifically, decision models – are characterized by their role in managerial capacity to predict. Predictability is also a key concept characterizing complexity and uncertainty.

In Section 6, we propose a theoretical framework for project management that helps to distinguish the decision and action conditions of risk versus uncertainty. From a contingency perspective, this conceptual framework reveals systemic characteristics differentiating and comparing project management theories of regulation and of emergence.

3. Towards a clarification of the complexity construct

In the project management community, complexity is not a clear and unified concept (Padalkar and Gopinath, 2016a; Vidal and Marle, 2008); rather, complexity takes a variety of forms (structural complexity, uncertainty, dynamics, pace and socio-political complexity) and frequently signifies complicatedness (Geraldi et al., 2011b). With complicated systems, outcomes are easily *predictable* if the starting conditions (the project's inputs) are known, whereas with complex systems, outcomes are *unpredictable* because of continually changing interactions, even when the starting conditions can be known (Maylor et al., 2008; Sargut and Mcgrath, 2011). Managers involved in complex systems must face events that are difficult to predict or interpret correctly, even retrospectively. These events influence each other, and produce causality relations that are not clear for decision-makers (Kauffman, 1993; Rivkin, 2000; Simon, 1969).

Management sciences have borrowed greatly from systems theory to understand the functioning of projects, and many authors consider that projects operate as complex systems (Baccarini, 1996; Williams, 2002). In 1968, Boulding proposed a 'system of systems' classification to explain how to describe a system and its behaviour (Boulding, 1968). Each new level in the hierarchy reveals specific functions and dynamics of a system, and increases its degree of complexity. Table 1 summarizes this classification.

Boulding's classification of systems uses metaphors at each level of the hierarchy. As an example, the operational (PM) perspective would naturally be positioned at the level of the thermostat, using the metaphor of a cybernetic system, as evidenced by Shewhart's 'quasi-cybernetic loop-of-control' model and Deming's 'plan–do–check–adjust' theory of control. This naturally raises the question: which metaphor is most appropriate for systems from the MoP perspective?

Systems theorists define systems along two dimensions: their structural functions and their dynamic behaviour. This suggests that these two dimensions of projects as complex systems must be taken into account if we are to improve our capacity to model and manage them. Fig. 1 depicts these two dimensions.

Most writings on project complexity highlight the two perspectives of structural complexity and dynamic complexity (Maylor et al., 2008; Remington and Pollack, 2007; Ribbers and Schoo, 2002; Xia and Lee, 2005). Both perspectives establish a natural relationship between project complexity and managerial capacity of prediction: (1) structural complexity focuses on interactions producing unexpected effects that cannot be explained or deduced; and (2) dynamic complexity focuses on processes that generate unpredictable change in systems (Floricel et al., 2016). Scientists and practitioners have highlighted the need to better understand the relationship between complexity and management, and particularly how individuals and organizations should act in situations of complexity (Augustine et al., 2005; Austin et al., 2002; Thomas and Mengel, 2008). Interesting literature reviews based on complexity theory were produced in order to define new directions for research in organization science in general (Anderson, 1999), and more specifically in project management science (Cooke-Davies et al., 2007). In the management and organization science literature, complexity science (the paradigm of complexity) is usually contrasted with Newtonian science (the paradigm of complication), emphasizing the dichotomy and contradictions between the 'old mind set' and 'new thinking' (Sanders, 1998). The philosophy of sciences addresses the question of complexity science in a more nuanced way, revealing its multiple implications for human thinking and rationality, and providing philosophical and anthropological foundations for its opposition to Newtonian science based on reductionism, determinism and objective knowledge (Heylighen et al., 2007). The epistemological perspective taken by Alhadeff-Jones is a good example of such a perspective on complexity. In his article, complexity theory is presented through the perspective of three generations of complexity theories (Alhadeff-Jones, 2008). Considering complexities rather than complexity is a fertile opportunity to try to reconcile the various schools of thought about complexity and project management. This approach to complexities is rooted in the seminal work of Weaver on complexity and science (Weaver, 1948). In his historical perspective on science, Weaver reveals that scientists have addressed complexity in three specific ways, leading to three categories of problems: the *problems of 'simplicity'*, the

Table 1
Boulding's classification of systems.

Level of the system	Name of the system	Structural function of the system	Dynamic behaviour of the system
'Framework'	Static	Static relationships	Static equilibrium
'Clock'	Simple dynamic	Dynamic relationships	Stable equilibrium
'Thermostat'	Cybernetic	Transmission and interpretation of information	Maintaining a given equilibrium within limits
'Cell'	Open	Exchanges with the environment	Self-maintaining equilibrium
'Plant'	Genetic societal	Differentiated and mutually dependent parts	Equifinal growth
'Animal'	Behavioural	Capture of information and transformation of this into a knowledge structure (an image) of the environment	Teleological behaviour
'Individual human'	Human being	Knowledge structure more complex than animal, based on language and symbolism	Teleological behaviour
'Social organization'	Social	Complex knowledge structure, influenced by communication between systems	Teleological behaviour

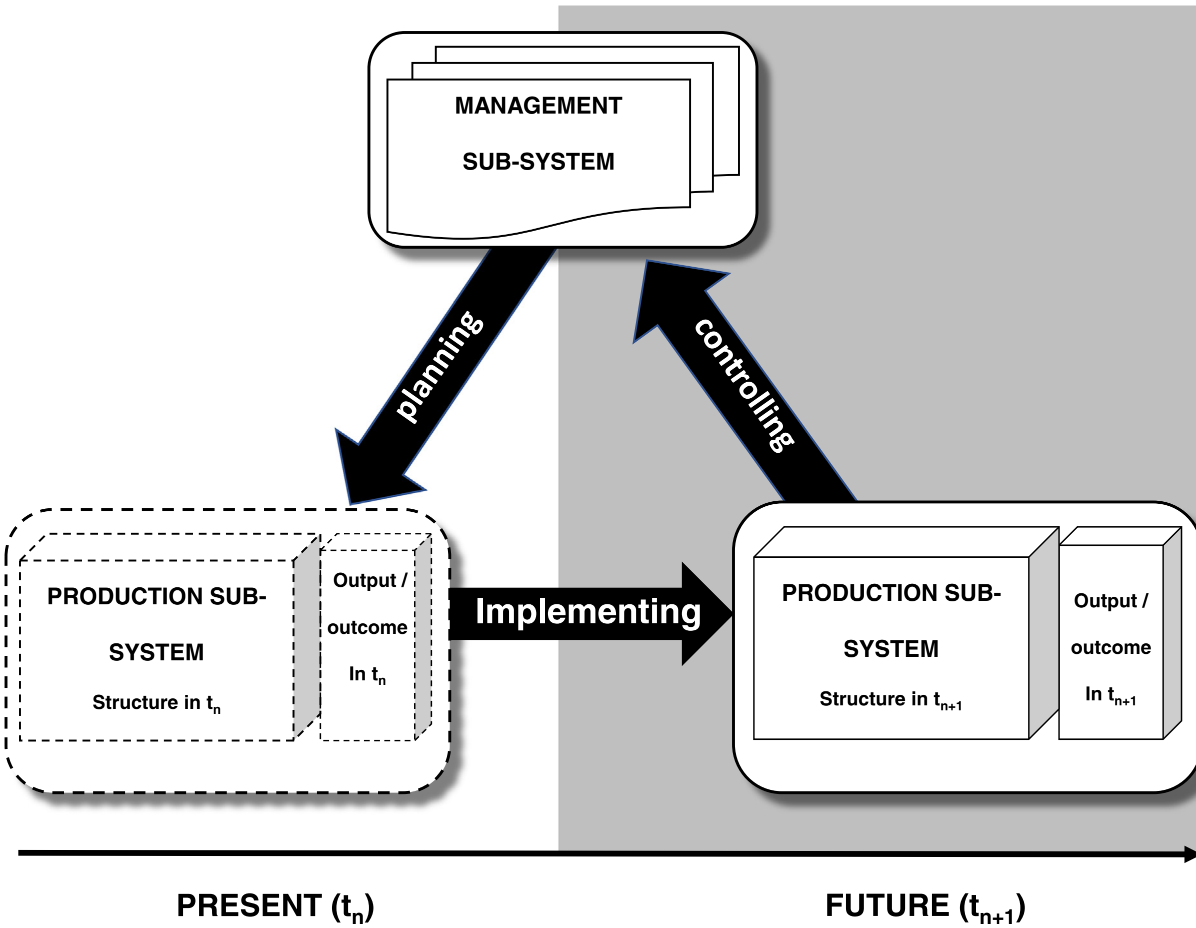

Fig. 1. Structure and dynamic of project management systems.

problems of 'disorganized complexity', and the *problems of 'organized complexity'*. Table 2 shows that complexity theories adapted to management science are not unified but rather reveal that human beings developed three ways of facing complex situations based on three different scientific assumptions and technical perspectives. The first two approaches are fundamentally based on a deterministic paradigm, considering that human beings can simplify the complex reality to control it through regulation. In contrast, the third approach is rooted in a non-deterministic paradigm, considering that: (1) human beings are agents intrinsically subjective and uncertain about their environment and future; and (2) a global organization emerges out of local agents' interactions (Heylighen et al., 2007).

Fig. 2 develops Fig. 1 by emphasizing the three levels of complexity detailed in Table 1 (i.e., three different project dynamics).

4. Towards a clarification of the uncertainty construct

Complexity and uncertainty are frequently associated in the project management literature (Sommer et al., 2009; Turner and Cochrane, 1993; Williams, 1999, 2005) – e.g., in project typologies (Little, 2005; Shenhar and Dvir, 1996), in the definition of project performance (Anderson, 1999; Levinthal, 1997; Levinthal and March, 1993; Rivkin, 2000), and in the selection of managerial tactics for facing uncertainty (Sommer and Loch, 2004). The imbrication of both concepts is so usual in this literature that we could wonder whether complexity and uncertainty are distinct concepts; a theoretical clarification of the relationship between the two constructs is required (Padalkar and Gopinath, 2016a). Analysis of the literature on uncertainty in project management reveals similarities with the analysis of the literature on complexity: both literatures are considered non-unified, and each concept is prone to be confused with the other.

In the previous section, we pointed out that the main issue with the construct of complexity is the confusion between complexity and complicatedness. In this section, we acknowledge the confusion between complexity and uncertainty, but focus our discussion on the confusion between uncertainty and risk, explaining our rationale for this choice.

In the project management literature, there is a tendency to confuse the terms 'uncertainty' and 'risk'; this means that uncertainty is treated in the same way as risk, or is ignored (Perminova et al., 2008). It is dangerous to confuse risk and uncertainty since doing so tends to focus attention on planning and operational control, at the expense of strategic issues (Atkinson et al., 2006). Table 3, building on the work of Daniel (2010) represents an attempt to synthesize previous research work on the different levels of risk/uncertainty on which

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Table 2
Three approaches to complexity in management sciences.

	Algorithmic approach	Stochastic approach	Non-deterministic approach
Weaver (1948)	Problems of **simplicity**: where complex problems can be reduced to simple issues thanks to the paradigm of rational mechanics	Problems of **disorganized complexity**: where disorder is an integral part of the natural phenomena (and can be addressed by statistics and the theory of probability)	Problems of **organized complexity**: where a sizeable number of factors are interrelated into an organic whole (being too complicated for rational mechanics, and not sufficiently disordered for statistics)
Cramer (1993),	**Subcritical complexity**: the amount of information to describe the system is less complex than the system itself	**Fundamental complexity**: the minimum amount of information to describe the system is equal to the complexity of the system itself	**Critical complexity**: emergent simple deterministic structures, with underlying phenomena made of fundamental complexity
Mckelvey (2004)	**Newtonian complexity**	**Stochastic complexity**	**Emergent complexity**
Heylighen et al. (2007)	Phenomena characterized by **order**: like those studied in Newtonian mechanics and systems science	Phenomena characterized by **disorder**: like those investigated by statistical mechanics and postmodern social science	**Neither order nor disorder**: situated somewhere in-between, in the zone that is commonly called the edge of chaos
Scientific assumptions	Mathematical models allow optimization of the decision and the management of complex activities composed of very large number of parameters	Heuristic models improve understanding and accompany learning in condition of uncertainty; human decision-making processes require the mediation of modelling instruments to learn from apparent disorder	The 'emergent' nature of unpredictable activities requires a constant adaptation of groups of actors that are sources of order and disorder; emerging processes and experimentations are management dynamics generating opportunities and bifurcations
Classic schools of thought in the sciences of complexity	***Operational research*** is interested in phenomena involving hundreds or thousands of variables, in order to transform them and reduce them to linear mathematical formulas that can be managed by computers (Beer, 1959; Churchman et al., 1957) ***Cybernetics*** contributes to the definition of the concept of 'feedback' to describe the way in which a system can follow a predefined purpose, adapting to its environment (Wiener, 1948/1961)	***Engineering sciences*** strengthen an understanding of complexity based on a quantitative assessment, leading to the concept of computational complexity (Ashby, 1957; Knuth, 1968; Marcus, 1977) ***Science of systems*** – with work on the 'dynamics of systems' (Forrester, 1961), and on 'the system approach' (Churchman, 1968) – favours the emergence of techniques reducing the complexity of a system to the study of its components and their relationships; any organized set should be described and explained through the use of the same categories (Von Bertalanffy, 1951)	***Self-organization*** theories attempt to define complexity as emergences produced not only by the order that constitutes them but also from the disorder that characterizes the relations to their internal components (Ashby, 1957; Atlan, 1972/2006; Von Foerster, 1960, 1974) ***Second-order cybernetics*** favours a definition of complex systems recognizing the constructivist nature inherent in their design (Bateson, 1973; Von Foerster, 1974); the autopoesis proposes the development of new representations around concepts such as adaptation, evolution, self-esteem, autonomy and emergence (Maturana and Varela, 1992)

managers are placed. Researchers in statistics (Littauer, 1967; Littauer and Ehrenfeld, 1964), decision theory (Rubinstein, 1975), strategy (Courtney et al., 1997) and project management (De Meyer et al., 2002; Sanderson, 2012) have identified three or four levels of risk/uncertainty that they link to managerial conditions: 'certainty conditions', 'risk conditions' and 'uncertainty conditions'. Table 3 distinguishes between all four levels, but we have chosen to regroup levels 2 and 3 under one label. We suggest labelling the three main levels 'algorithmic', 'stochastic' and 'non-deterministic'. Each of these situations implies different management modes.

The seminal work of Milton Spencer (Spencer, 1962; Spencer and Siegelman, 1959) is very helpful when it comes to pointing out the key question of predictability in this discussion, focusing on distinguishing risk from uncertainty; it also builds bridges between the theory of uncertainty, the theory of decision, and the theory of planning:

Risk may be defined as the quantitative measurement of an outcome, such as a gain or a loss, in a manner such that the probability of the outcome can be predicted ….

Uncertainty, like risk, is also prediction-oriented, but unlike the latter its measurement is not objective and does not assume perfect knowledge. (Spencer, 1962, p. 197).

Knight restricted the notion of risk to two types of situations: probabilities and statistics. In both cases, decision-makers were regarded as able to define objective probabilities within a known range of future events or results (Knight, 1921). Some authors have thought that subjective probabilities could also be a response to ambiguous situations in which leaders found themselves. But subjective probabilities have their limitations, because even when the information is available, it can be of little interest for future results if the conditions of reality change (Rotheim, 1995); this is typically the case in conditions of dynamic complexity.

Uncertainty appears when decision-makers cannot consolidate past observations to form a subjective probability or relative frequencies for the future (Davidson, 1991). This difficult and specific state in which managers cannot know all the important parameters and the possible results is termed 'unawareness' or 'unforeseen contingencies' (Kreps, 1992; Modica and Rustichini, 1994), 'unstable non-determination' (Littauer, 1967), 'wicked problems' as opposed to 'tame problems' (Rittel and Webber, 1973), and 'unknown unknowns' by extension of the Knightian concept of 'known unknowns' (Wideman, 1992). Business developers often do not properly forecast market opportunities or the best way to treat them. They

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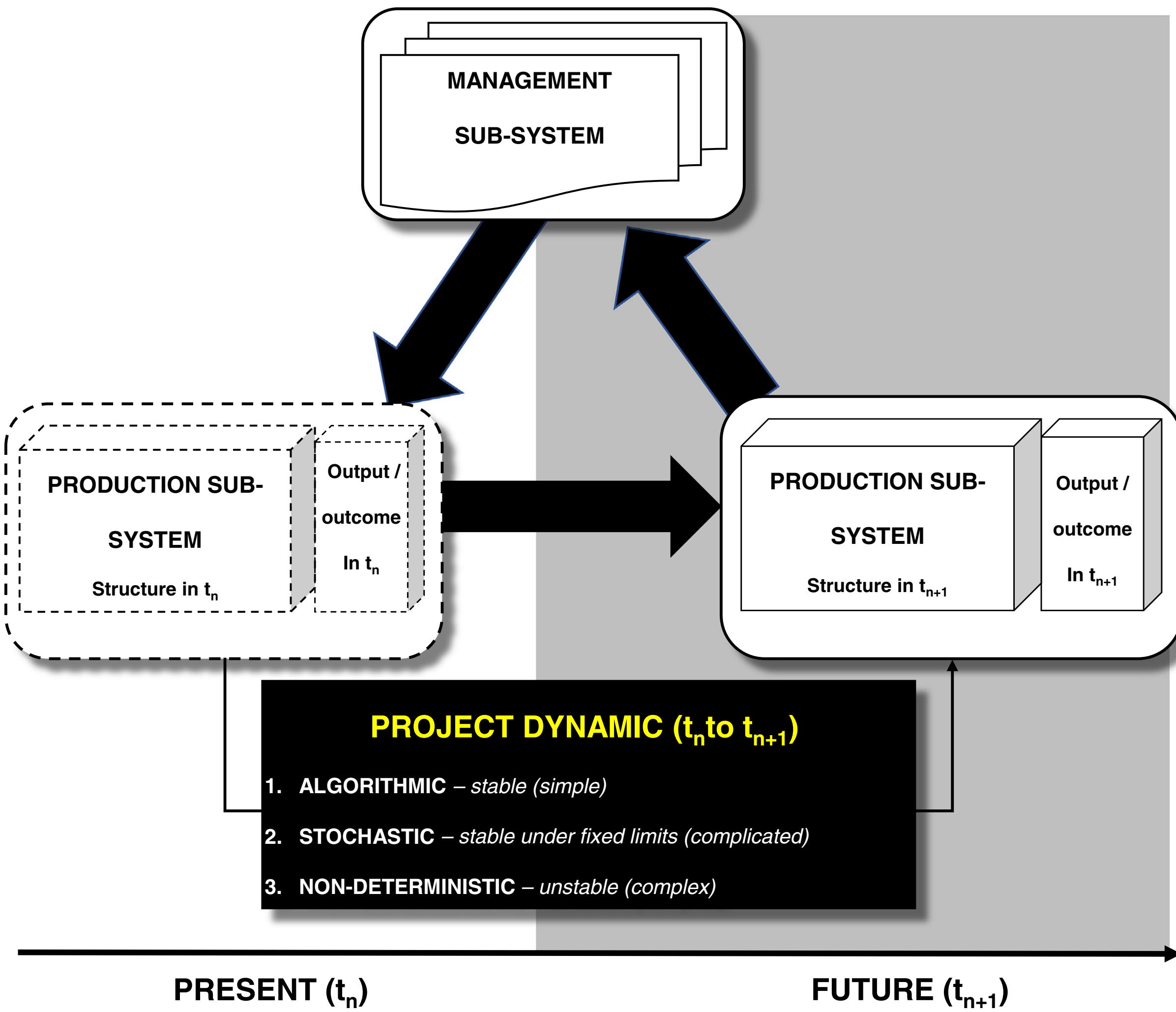

Fig. 2. Three levels of complexity in project management systems.

are therefore forced to adapt and modify their approach over time (Drucker, 1985; Mcgrath and Macmillan, 1995); the information does not exist until the results have produced their effects (Minsky, 1996). When launching a new company, leaders often know very little, and are unable to recognize and articulate the variables and their functional relationships (Schrader et al., 1993); the unpredictable uncertainties are 'rampant' (Bank, 1995).

The uncertainty and complexity constructs appear to be connected by the concept of predictability, which is rooted in decision theory. Two interesting parallels appear to exist between uncertainty theory and the complexity theory: (1) decision-making conditions of risk (as defined by Spencer) are conceptually close to 'problems of disorganized complexity' (as defined by Weaver); and (2) decision-making conditions of uncertainty (as defined by Spencer) are conceptually close to 'problems of organized complexity' (as defined by Weaver). Beyond the parallels revealed in these two sections, a clear distinction can be made between the complexity and uncertainty constructs: complexity defines the *structure* and *dynamics* of the project as a system (system of production, and system of management), and uncertainty defines the *decision-making conditions* of the system of management (the manager as a decision-maker). Fig. 3 adds these decision-making conditions to Fig. 2.

5. Decision theory, mental models and predictability

Classical project management methods/methodologies face limitations when applied to complex projects. In an empirical study of project management practices, respondents identified 'inadequacy for complex projects' (27%) and 'make it difficult to model the real world' (15%) as the first two limitations/drawbacks of such methods (White and Fortune, 2002). While conventional techniques may be well suited to tackling complicated projects (with large numbers of elements), they are unsuited to projects subject to high uncertainty (Cicmil et al., 2006). Complex and uncertain projects require newer methodologies that help the project 'emerge' rather than being fully pre-planned, and that are based on understanding (model-based theories) (Williams, 2005). Recent research works illustrated the relevance of modelling approaches for complex and uncertain projects (Qazi et al., 2016).

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Table 3
Different levels in the conditions of uncertainty of leaders.

	ALGORITHMIC approach	STOCHASTIC approach		NON-DETERMINISTIC approach
Littauer (1967), Littauer and Ehrenfeld (1964)	**Deterministic certainty** In these situations, an action leads to a unique consequence	**Probabilistic certainty** An action leads to a set of consequences with known probabilities of occurrence	**Stable uncertainty** In some situations, there is an even lower degree of knowledge in relation to the action and its consequences	**Unstable uncertainty** The possible consequences of an action are unsure, but in addition we cannot assign probabilities to various consequences
Rubinstein (1975)	**The decision under certainty** Actions lead to a defined result that will definitely occur	**Decision under risk** Each state of nature has a known objective probability		**Decision under uncertainty** An action can have at least two consequences, but the probabilities for the states of nature are unknown
Courtney et al. (1997)	**A clear-enough future** Managers can make an accurate forecast for the development of a strategy	**Alternative future** The analysis cannot identify what the outcome will be, but may establish probabilities there are different scenarios	**A range of future** A range of future potentials can be identified by a limited number of key variables, but the end result can settle anywhere	**The real ambiguity** Multiple dimensions of uncertainty interact to create an environment that is virtually impossible to predict
De Meyer et al. (2002)	**Variation** Cost, duration and performance levels vary randomly, but in a predictable field	**Predictable uncertainty** A small number of known factors will influence the project goal in a predictable way; the foreseeable uncertainties are identifiable; the predictable uncertainty may require several alternative plans	**Unpredictable uncertainty** One or more influencing factors cannot be predicted; the unpredictable uncertainty concerns projects that take place in a partially known market	**Chaos** Unpredictable events invalidate completely the objectives, the planning and the project approach; even the structure of the project plan is uncertain
Sanderson (2012)		**Risk of category 1 (probability a priori)** The decision-maker can define objective probabilities based on mathematical probabilities **Risk of category 2 (statistical probability)** The decision-maker can define objective probabilities on the basis of an empirical sample/statistics from past data	**Uncertainty in category 1 (subjective probability)** The decision-maker lacks data needed to define a probability objective; they then define a subjective probability based on forecasts built on past experiences	**Uncertainty in category 2 (socialized)** The decision-maker faces unknown future situations; the future is fundamentally unpredictable – it is socially constructed and cannot be linked to the past or the present

5.1. Mental models and the question of complexity management

The theory of mental models could be the missing link between complexity and uncertainty in project systems, as predictability is a referential concept in complexity theory and in uncertainty theory. General systems theory applied to management revealed that managers interact with reality through representation models to make their management decisions (Forrester, 1961; Sterman, 2001). The fundamental property of thought is its ability to predict events (Craik, 1943; Jones et al., 2011). Mental models are generalizations (or even images) that influence how we understand – and act in – the world (Senge, 1990). They are constantly adjusted, refined and recreated in dynamic environments subject to constant change, and they play an important role in the construction and interpretation of reality (Chermack, 2003; Ruona and Lynham, 2004). A mental model is a cognitive structure that allows us to describe, explain and predict the purpose, form, function and state of a system (Rouse and Morris, 1986); it establishes causal knowledge about how the system works (Moray, 1998). Mental models guide, draw and provide the basis through which individuals interpret and construct the meaning of life in organizations (Weick, 1990).

Systems modelling is one tool for dealing with decision in conditions of uncertainty, because decisions can be tested out with hypothetical consequences (Morecroft, 1983). If someone has a 'small-scale mental model' of an external reality and of their own possible actions, they are able to define several alternatives, figure out which one is best, respond to future situations before they occur, use knowledge from past events to deal with the present and the future, and react more prudently and skilfully to what emerges (Craik, 1943). Systems-dynamics researchers use constructs of mental models in a pragmatic way, as tools to better understand complex and dynamic systems, and ultimately to improve their design and use (Doyle and Ford, 1998; Moray, 2004).

With complex projects, the learning dynamic arises from the relationship between project leaders and the project systems they manage. Since models are vehicles for learning about the world, studying a model makes it possible to discover the system characteristics that it describes. This cognitive function of models is well known and has given rise to 'model-based reasoning' (Magnani and Nersessian, 2002). Mental models act as inferential frameworks (Gentner and Gentner, 1983) and influence decision-making, which takes place through feedback loops (Forrester, 1961). To learn, we must use the limited and imperfect feedback that is at our disposal to understand the effects of our decisions, to adjust them accordingly, and to align the state of the system with our goals (the simple learning loop). Thus, we can revise our mental models and redesign

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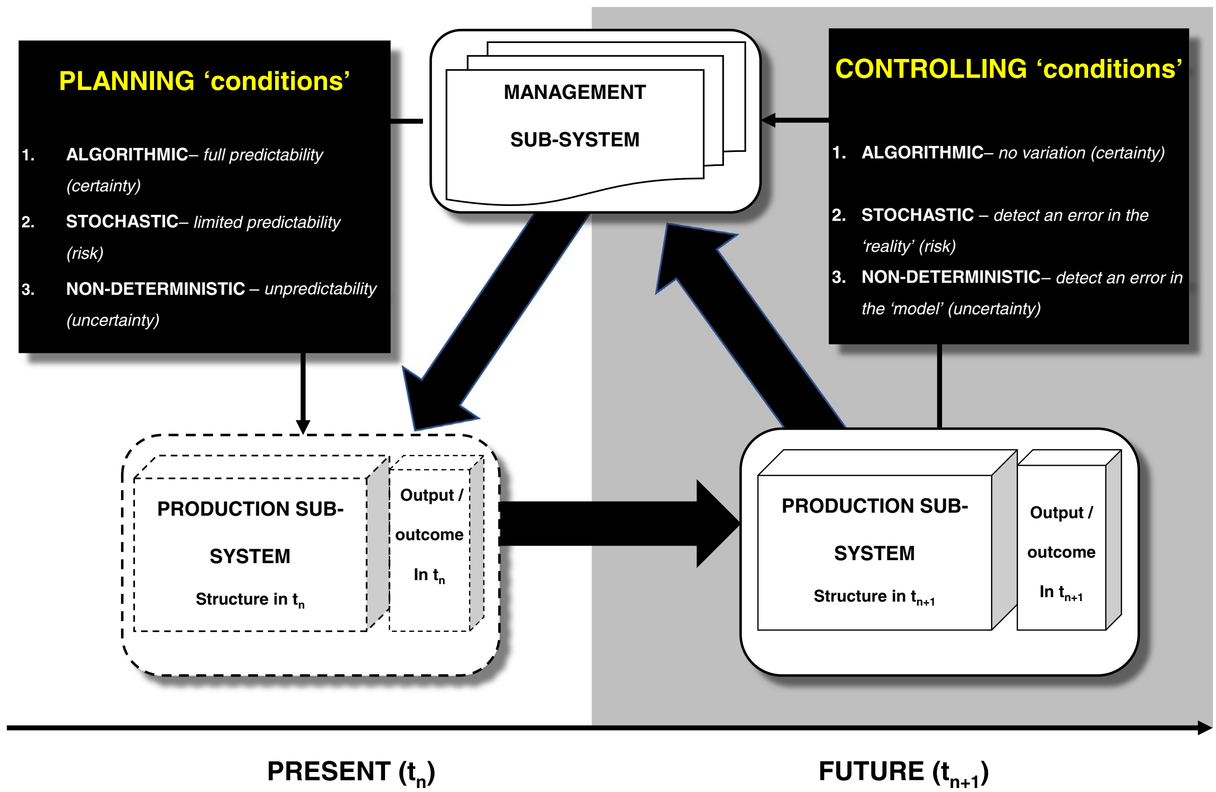

Fig. 3. Three levels of uncertainty in project management systems.

the system itself (the double learning loop) (Argyris, 1985; Sterman, 2000).

5.2. The challenges, uncertainty and complexity of mental models

Having stressed the key role of mental models in complex and uncertain projects, it is important to consider two main difficulties that can disturb the prediction mechanism: cognitive limitations and socio-organizational issues.

Results from experimental research in the psychology of decision-making identify significant limitations in the cognitive abilities of human beings (Gilovich et al., 2002; Kahneman et al., 1982). Indeed, mental models integrate individuals' biases, such as beliefs, experiences and values (Ford and Sterman, 1998). The limitations inherent to human cognition have an impact on how decision-makers face risk and uncertainty; for instance, decisions and judgements under conditions of uncertainty are subject to numerous biases that preclude prediction (Kahneman et al., 1982) and generate an 'illusion of control' (Langer, 1975). Self-regulation theory explains that since individuals are driven by their internal goals concerning control over their environment, they try to reassert their control under conditions of chaos, uncertainty and stress. One way they can deal with their lack of control is to incorrectly assume control over the situation (Fenton-O'creevy et al., 2003). Confirmation-bias theory suggests that individuals look for information that corresponds to their understanding of the world at a given moment. New information may strengthen existing mental models or be rejected categorically (Klayman and Ha, 1989).

In complex systems, actions and decisions can amplify counter performance, notably by the effect of mental representation, which are counter-intuitive. Effective management is difficult in a world of high dynamic complexity. Decisions can create unanticipated adverse effects and lagged consequences over time. Attempts to stabilize the system can in fact destabilize it (Sterman, 2000); this phenomenon is known as 'counter-intuitive behaviour of social systems' (Forrester, 1971). Learning in situations of dynamic complexity is often very poor (Paich and Sterman, 1993).

Beyond cognitive challenges, mental models must face social/organizational challenges. The decisions and actions taken by managers result from many interactions between various stakeholders. Both at the individual and at the collective levels, facing complexity requires the ability to filter strategically a vast amount of available information, and to integrate this into an implicit or explicit prediction model (Beratan, 2007). The effective functioning of teams requires the existence of a mental model shared by team members (Langan-Fox et al., 2000). A shared mental model is the mental model built within a team, and shared by its members. It represents the cognition shared among groups of individuals (Langan-Fox et al., 2001). A team model is the collective knowledge that team members bring to a specific situation – i.e., the collective understanding that team members share about a specific situation, also termed the 'team situation model' (Cooke et al., 2000). More recently, research work on shared mental models (SMMs) proved that higher SMMs in project teams improved team learning and performance (Yang et al., 2008), and more specifically improved performance in project requirement analysis (Xiang et al., 2016).

6. Reconciling deterministic and non-deterministic paradigms in a new contingent theoretical framework

In this section, we propose a systemic model in an attempt to integrate the complexity and uncertainty constructs discussed in Sections 3 and 4, together with the modelling function discussed in Section 5. We bring these together in a theoretical framework presenting the three resulting contingent approaches of project managers' decisions and actions: algorithmic, stochastic and non-deterministic.

6.1. Theoretical model for an integrative perspective of complexity and uncertainty in project management

The theoretical model of project management presented in Fig. 4 is an attempt to unify the various approaches of complexity and uncertainty that were presented in Sections 3 and 4.

In this model, the construct of complexity is depicted in the project system's dynamic (the black box at the bottom of Fig. 1), which can be simple (simplified by algorithmic models), complicated (patterned by stochastic models) or complex (experimented with through non-deterministic approaches). This is consistent with the usual categories of systems presented in the business literature (Sargut and Mcgrath, 2011).

The construct of uncertainty is depicted in the two key characteristics of the management model: prediction and detection. For instance, when the project system is simple, the management system can design a model able to predict the project dynamic with certainty (model prediction) and reveal no gap between the prediction of the model and the output delivered by the production system (model detection).

Through a single systemic model, we differentiate two paradigms of project management: regulation (deterministic), based on a planning–implementing–controlling cycle (number 1 in the triangle of arrows in Fig. 4); and emergence (non-deterministic), based on a modelling–experimenting–learning cycle (number 2 in the triangle of arrows).

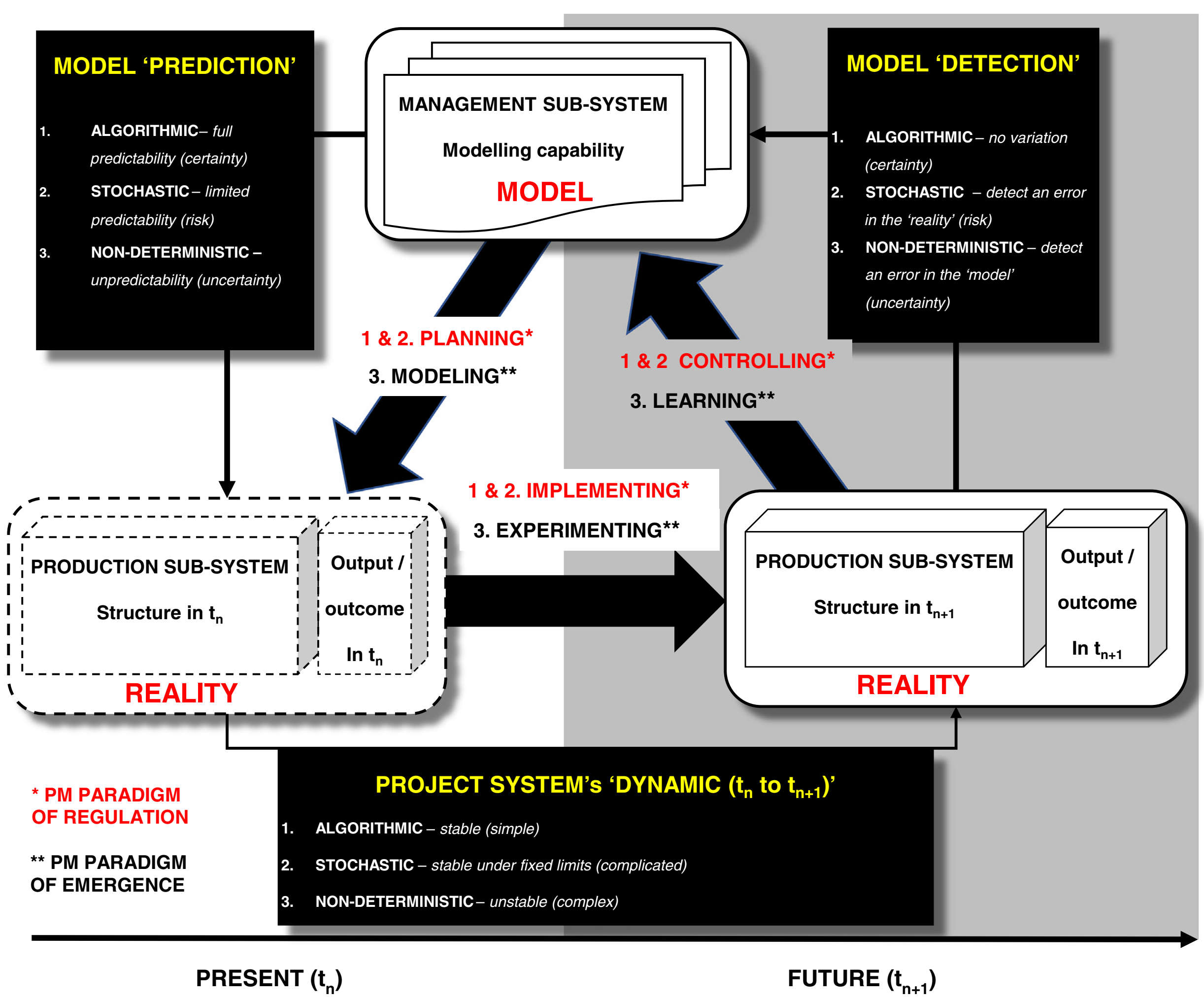

Fig. 4. The theoretical model of project management.

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In Fig. 4, white boxes represent the project system, composed of two sub-systems interacting together, both contributing to generating project complexity:

(1) A *production sub-system* represents the project-implementation function, delivering project outputs and outcomes. It is defined by its structure, outcomes and dynamics (revealing the potential changes in the project structure and outcomes over time, the dynamic from tn to tn + 1).
(2) A *management sub-system* represents the project-management function focused on achieving project performance. It interacts with the production sub-system over time through a modelling function based on a capability to predict the production sub-system behaviours, as well as a capability to detect a gap between the reality produced by the production sub-system and the prediction of the model.

The interactions between the *production sub-system* and the *management sub-system* constitute a dynamic process comprising feedback loops, the management system that impacts the dynamic of the production system, and the production system that impacts the modelling capability of the management system (Sterman, 2001).

In our model, the uncertainty construct is a characteristic of the management sub-system; it defines the decision-making conditions of project managers interacting with the production sub-system. It is a fundamental characteristic of the *modelling capability* of the management sub-system.

In contrast, the complexity construct is a characteristic of the project system, including the management sub-system, the production sub-system and their interactions. Complexity is a characteristic of the production sub-system (multiple interactions with the environment, and changing conditions from the environment), amplified by the interactions between the production sub-system and the management sub-system through positive feedback loops, and by the cognitive limitations of mental models.

6.2. The deterministic paradigm of regulation

The project management literature has clearly presented the difference between a classical project management paradigm and a model-based theory paradigm (Williams, 2005). The latter challenges three characteristics of the former: (1) a heavy emphasis on planning; (2) the influence of the cybernetic-control model; and (3) a low sensitivity to environmental influences. The classic planning-and-control paradigm is fully influenced by cybernetics, a systemic theory of regulation based on: (1) the capacity of the agents in the management system to predict the behaviour of the production system; and (2) the deterministic or statistical stability of the production system (Littauer, 1967). Cybernetics deals with all forms of behaviour insofar as they are regular, determinate or reproducible (Ashby, 1957). The real strength of cybernetics is in its scientific application by Shewhart (through the quasi-cybernetic loop-of-control model) in management science, and more specifically in operations research (Shewhart, 1931). The famous ‘plan–do–check–adjust’ theory of operational control, popularized as the Deming wheel, is a perfect example of the planning-and-control paradigm proposed by cybernetics (Deming, 1986).

‘A phenomenon will be said to be in control when, through the use of past experience, we can predict, at least within limits, how the phenomenon may be expected to vary in the future’ (Shewhart, 1931). Consequently, in the planning-and-control paradigm, the behaviour of the *production sub-system* (identified as a phenomenon) is characterized by stability (subject only to variation), and the *management sub-system* can predict the behaviour of the production sub-system through its repetition (past experiences). Thus the management sub-system plays the role of a regulator that must model what it regulates, modelling being a necessary part of regulation (Conant and Ashby, 1970). Finally, following the words of Ashby, ‘Cybernetics offers the hope of providing effective methods for the study, and control, of systems that are intrinsically extremely complex’ (Ashby, 1957).

In our model, the deterministic paradigm of regulation corresponds to this classic project-management paradigm of planning and control – i.e., to the deterministic paradigm of risk.

6.3. The non-deterministic paradigm of emergence

When it comes to unique events (changes that have never happened before) or so-called discontinuities (e.g., technological innovations, price increases, evolution of consumers' attitudes, and legislative decisions), forecasts become virtually impossible (Makridakis and Hibon, 1979). In these contexts, the retrospective approach often fails (Pant and Starbuck, 1990). The understanding of unique events is delicate, as their modelling is often impossible to build (Makridakis and Wheelwright, 1981). System-dynamics theory reveals that sometimes the project behaviour is non-intuitive, leading to non-linear behaviour, being difficult for the human brain to predict and understand intuitively (Sterman, 1989). Project-management researchers have used the systems theories characterized by unpredictability and instability (such as chaos theory, dissipative structures, and complex adaptive systems) to identify the theoretical aspects that should be analysed in project-management science: non-linearity, emergence, instability and radical unpredictability (Cooke-Davies et al., 2007).

While the epistemology of cybernetics is very influential in the paradigm of regulation, the epistemology of second-order cybernetics is key to understanding the paradigm of emergence. The main thesis of second-order cybernetics is that human beings, as observers, are also cybernetic systems (Von Foerster, 1974). Their knowledge is a subjective construction, not an objective reflection of reality, which means that the emphasis should shift from the apparently objective systems around us to the cognitive and social processes by which we construct our subjective models of those systems (Heylighen et al., 2007).

The concept of emergence has never been analysed clearly in the project management literature, yet it is central to the concept of the *non-deterministic paradigm*, just as the concept of regulation is central to the *deterministic paradigm*. In the deterministic paradigm, regulation is based on the modelling capacity of the management sub-system to produce a good model of the production sub-system (named the 'isomorphic' or 'homomorphic' model) (Conant and Ashby, 1970). This high-quality model enables us to regulate the production sub-system, which means maintaining its stability. In the non-deterministic paradigm, emergence is the result of the incapacity of the management sub-system to produce a good model of the production sub-system, as the production sub-system itself is unstable over time. Therefore, the project management 'model' is not a 'plan' able to create stability; it is a model able to generate both stability and instability in the production sub-system. The result of such an unstable interaction is the emergence of unexpected outputs and outcomes in the project. In the non-deterministic paradigm of emergence, as in model-based theories, the imperfect model is a management artefact enabling decision-makers to learn from reality through feedback loops; by so doing, they improve the quality of their model, and consequently the quality of their management decisions.

7. Discussion and conclusion

The systemic model presented in this paper shows the contingency nature of project management systems where degrees of uncertainty and of complexity are embedded, uncertainty being a characteristic of the management sub-system, and complexity being a characteristic of the project-management system, combining the management and production sub-systems. In this theoretical model of project management, the paradigm of regulation is clearly related to the deterministic paradigm of project management (Padalkar and Gopinath, 2016b) that one can associate with the operational-project perspective (Turner et al., 2010). Consequently, project managers applying the PMI's execution-based model should verify the conditions of *stability* of the project's production systems (inputs, outputs and outcomes). Without such requirements, the planning–implementing–controlling paradigm of regulation is inappropriate, because of management models that are unable to predict – or unable to detect – an error in the production systems. In the theoretical model, the paradigm of emergence is related to the non-deterministic paradigm of project management. It emphasizes a project management theory based on modelling–experimenting–learning processes, built on imperfect management models. We believe that the paradigm of emergence would be fruitful to improve the strategic project perspective (Turner et al., 2010).

Recently, Serrador and Turner asked an interesting question about the 'quantity' of planning that is required in a project (Serrador and Turner, 2015b). The legitimacy of planning projects is questioned in dynamic environments if activities cannot be foreseen, or if planning leads to false expectations (Andersen, 1996; Collyer et al., 2010; Collyer and Warren, 2009). The theoretical model presented in this paper suggests that this question could be interestingly supplemented by another: what is the nature of the planning that is required? The rationale of the *paradigm of regulation* is questioned in the sense that in the uncertainty paradigm, there is no further reference to a 'good' model or plan. While the project plan (or schedule) is a *good model* of project reality in the risk paradigm, it is an *imperfect model* in the uncertainty paradigm.

O*rganizational improvisation theory* is an example of management practices that are faced with imperfect plans, even in structured contexts such as projects (Moorman and Miner, 1998, 2001). Improvisation in organizations is a managerial capacity to explore unexpected opportunities and to neutralize unpredicted threats (Cunha et al., 1999, 2003). The perspective of complex responsive processes of relating is another attempt to transfer elements of complex adaptive systems theory to organizations and complexity management, through an emphasis on the interactions among people, based on acts of communication, power relations, and interplay between people's choices (Stacey, 2007). Systems-modelling approaches, such as systems dynamics, are based on building better models of the complexity of the project (the production sub-system) to improve the learning process of decision-making (the management sub-system) (Diehl and Sterman, 1995; Sterman, 1992, 2001). However, no attention has been paid to how project *decision models* (project plans, work breakdown structures, product breakdown structures etc.) are built, adapted and applied in the project-management loop. One of the basic assumptions of the paradigm of emergence is that imperfect decision models impact the production sub-system and create emergent outcomes. But we know very little about how this emergent dynamic of production systems interacts with management systems. Management under 'unforeseeable-uncertainty' theories promotes management processes based on 'selectionism' and 'trial-and-error learning' (Loch et al., 2001, 2008). A preliminary step consists of breaking down the project into sub-projects under conditions of 'foreseeable uncertainty' and 'unforeseeable uncertainty', in order to contingently adapt the management process (routine execution, or novel strategic project) (Lenfle, 2011; Lenfle and Loch, 2010). But the literature is poor when it comes to present management models able to reveal/analyse the conditions of predictability and control of the management sub-system towards the production sub-system. Project-management tools and techniques mainly focus on descriptions of the production sub-system, whereas project performance is a consequence of the unstable and emergent interactions between the production sub-system and the management sub-system. More than describing the static conditions of predictability and control, project management scholars and professionals need to know more about the evolution of this interaction over time. Studying the dynamic of the emergent interaction between the production sub-system and the management sub-system is central to understanding how process performance and success are created, as it cannot be controlled in conditions of unforeseeable uncertainty. The next challenge of project management science should be to generate a theory of emergence, just as a theory of regulation.

Conflict of interest

The authors declare no conflicts of interest.

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