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Megaprojects as complex adaptive systems: The Hinkley point C case

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Abstract

Megaprojects are complex projects which impact millions of people, involve public and private stakeholders, and present challenges related to decision making and performance shortfalls. They are relevant cases for studying faulty management thinking as well as performance evolutions and self-organizing dynamics. Our paper builds on the theory of Complex Adaptive Systems (CAS) to understand and model processes of evolution in the Hinkley Point C nuclear power plant megaproject. The results show that CAS properties apply to megaproject changes and provide a theoretical and practical framework for examining and modeling megaproject management dynamics. We designed a research methodology combining *content analysis* and *historical research* for its relevance in conducting organizational research in conditions of complexity and non-linearity. This original research design makes it possible to conduct causal analyses of relations between key megaproject events and thus build models of evolution dynamics in stakeholder success expectations, change mechanisms in the implementation of project outputs, and self-organizing patterns.

Keywords: Complexity theory; Megaprojects; Performance; Complex adaptive systems (CAS); Self-organizing

1. Introduction

A megaproject costs more than 1 billion dollars, involves many private and public stakeholders and impacts millions of people (Flyvbjerg, 2014). Megaproject management is an emerging field of research and the project management literature is still in search of its 'classics' to clearly define the scope of this new field (Flyvbjerg and Turner, 2018; Pollack et al., 2018). Its impact on millions of people, its large quantities of stakeholders and its multi-dimensional ambitions make megaproject interesting object of research for studying inappropriate management thinking and lack of performance (Flyvbjerg, 2014). Megaprojects are complex and evolve in unpredictable political, societal and economic environments involving hundreds of reciprocal ties (Chapman, 2016). Despite the use of advanced planning techniques and risk analysis tools, modeling risk interactions and impacts on the performance of megaprojects remains a major challenge (Boateng et al., 2015), and the causes for massive cost overruns in large projects stem from the limited capacity of humans to estimate, plan or anticipate the impacts of uncertainties (Eden et al., 2005). The megaproject management (MPM) research field has to address challenges related to decision-making risks and performance shortfalls, which emerge when classical project management theories are applied to the management of megaprojects (Li et al., 2018).

In recent decades, classical project management theories, rooted in phase-project-planning methodologies and operations research (Morris, 2010), have been challenged by a new project management paradigm, based on non-deterministic theories

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(Padalkar and Gopinath, 2016b). Recent literature on complexity and uncertainty management in projects calls for the development of a non-deterministic paradigm of Project Management based on principles of *emergence* (Daniel and Daniel, 2018). Project management scholars promoted the idea that project phenomena would benefit from adapting a *complexity theory perspective* (Cooke-Davies et al., 2007; Vidal and Marle, 2008) focusing on the concepts of emergence, change and non-linear feedbacks (Benbya and McKelvey, 2006; Burnes, 2005; Whitty and Maylor, 2009), based on systems thinking (Sheffield et al., 2012) and self-organization (Saynisch, 2010). However, the new paradigm based on emergence still requires more definitional clarity to move forward (Padalkar and Gopinath, 2016a). Mechanisms of adaptive self-organizations in projects are defined in theory but we know very little about how they operate because most of the research on this topic remains theoretical.

The aim of this research is to analyze and model dynamics of emergence in megaprojects, focusing on non-deterministic mechanisms of decision and implementation in megaprojects. We build on the seminal article of Anderson about complex adaptive systems (CAS) theory and its potential for understanding complexity in management and organization science (Anderson, 1999), and we apply it to a megaproject case in order to verify the theoretical and practical applicability of its properties.

The research is focused on the Hinkley Point C (HPC) nuclear power plant megaproject. The project was launched in 2012 with the ambition to build a Franco-British power station, which was to be commissioned in 2018 at an estimated cost of £15 billion at the end of the front-end phase in 2016. It is a very high-profile case with organizational complexity and it has undergone performance changes during the front-end phase. The research method combines a *content analysis* of the key stakeholders' narratives and a *historical analysis* of the key events in the megaproject. We applied a historical case study method because it is a relevant research method for studying causal mechanisms of strategic processes of decision (Vaara and Lamberg, 2016), and because it is particularly well adapted to conducting organizational research within non-linear conditions (Meyer et al., 2005).

In the section 2 of the paper, the literature review first clarifies the two paradigms of project management that coexist, showing that each paradigm focuses on a specific definition of project performance (*efficiency* versus *success*) and a specific project management theory (*planning and controlling* versus *modeling and adapting*). We make it clear that our research perspective examines the second project management paradigm. Then, we address the concept of dynamic complexity in project management and its impact on project managers' limited capacity to control project changes. The megaproject literature on change dynamics opens the debate of self-organizing processes and evolutions. Finally, we introduce the complex adaptive systems (CAS) theory, considered as a promising research perspective in organizations science (Anderson, 1999), and we establish a link with the emerging literature on the self-organization of megaprojects. Our research assumes that CAS theory is a relevant conceptual framework for the analysis of decision-making dynamics in megaprojects. In section 3, we present the content analysis method and the historical research method that were applied to the case of the HPC megaproject. We present the HPC megaproject case in section 4. Section 5 discusses and 6 draws conclusions about the potential of CAS theory applied to megaprojects.

2. Literature review

2.1. Two paradigms of performance in project management

The literature on project management distinguishes two perspectives on performance: a *'project efficiency'* perspective and a *'project success'* perspective (Cooke-Davies, 2002; Serrador and Turner, 2015; Turner and Zolin, 2012). The 'project efficiency' perspective is *short-term oriented* (Brady and Davies, 2014) with considerations of cost and time (Bosch-Rekveldt et al., 2011), focusing on the contribution of the project to the final output during the project implementation phase. The 'project success' perspective is *long-term oriented*, dealing with the project's contribution to the organization's outcomes and the benefits for the environment (Locatelli et al., 2016; Shenhar et al., 2001), with emphasis on strategic value (Eweje et al., 2012; Klakegg, 2009), and long-term benefits (Eduardo Yamasaki Sato and de Freitas Chagas, 2014). Long-term performance in megaprojects is a common topic in the literature through research on corruption (Locatelli et al., 2016), project life cycle (Eduardo Yamasaki Sato and de Freitas Chagas, 2014), governance (Klakegg, 2009), or decisions made by project managers (Eweje et al., 2012).

The Benefits Realization Management (BRM) models (BCG-PMi, 2015) and the results-based development, monitoring and evaluation models (Daniel and Turner, 2015; Turner, 2009; Turner et al., 2010; Xue et al., 2013) provide a framework designed to combine these two perspectives: the 'project implementation' performance (project efficiency) consists in delivering efficient outputs, and the 'project strategy' performance (project success) consists in delivering effective outcomes and benefits. In these project management models, project outcomes are 'new capabilities enabling the organization to achieve higher-level goals which lead to higher level performance improvement' (Turner et al., 2010). The Benefit Realization Management approach is a comprehensive model which considers that outputs, outcomes and benefits together influence the "project's success" (Serra and Kunc, 2015).

BRM models take a systems theory perspective on project performance (outputs, outcomes, benefits) at the strategic level (organization and environment) as well as at the operational level (project or program), but they do not really reconcile the project management perspectives presented initially (*project efficiency* versus *project success*). *Project efficiency (1)* and *project success (2)* represent two different paradigms. The former is a well established deterministic paradigm influenced by operations research (Morris, 2010; Pinto and Winch, 2016) strongly related to the PMI's execution-based model, rooted in

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the cybernetic model of '*planning and control*'. The latter is a non-deterministic paradigm (Padalkar and Gopinath, 2016b), based on Complexity Theory in projects (Crawford et al., 2006; Geraldi et al., 2011; Whitty and Maylor, 2009), initiated by the Management of Projects (MoP) perspective, built on Peter Morris' research work (Pinto and Winch, 2016). The rational, deterministic paradigm is the dominant approach in project management, and it historically focuses on the planning and control theories of project management (Winter et al., 2006). The non-deterministic paradigm, conceptually based on Complexity Theory (chaos theory, dissipative structures, complex adaptive systems), call for greater focus on non-linearity, instability, emergence and radical unpredictability (Cooke-Davies et al., 2007; Daniel and Daniel, 2018). Systemic models applied to project management revealed that failures occur in projects because traditional methods based on determinism do not fit the actual dynamic complexity of projects influenced by inter-related causal factors and feedback loops (Cicmil et al., 2006). Some research work applied systems theories in order to understand the relations between project performance and project complexity (Antoniadis et al., 2011), but the focus was mainly on short-term performance and project efficiency. Our research clearly takes a '*project success*' perspective, focusing on the study of complex, emerging and changing relations in the megaproject between the outputs (at the operational level) and the expected megaproject outcomes/benefits (at the strategic level) in the front end-period.

2.2. Structural and dynamic complexity in project and megaproject management

Project Management science has borrowed greatly from systems theory to analyze and describe the functioning of projects, and it has long been accepted by the community that projects operate as complex systems (Baccarini, 1996; Williams, 2002). The project management literature usually refers to structural complexity and dynamic complexity (Maylor et al., 2008; Remington and Pollack, 2007; Ribbers and Schoo, 2002; Xia and Lee, 2005). *Structural complexity* is characterized by the interdependence and diversity of components (Baccarini, 1996). These components are present both at the level of the project processes and at the level of project-related business processes (Gann and Salter, 2000), which deal with the goals, the environment and players involved in the project (Antoniadis et al., 2011; Bosch-Rekveldt et al., 2011; Killen and Kjaer, 2012). This article aims at clarifying the relations between the project outputs (considered as the results of project processes) and the project outcomes (considered as the results of project-related business processes). In the megaproject literature, structural complexity results from technical, organizational and environmental aspects (Chapman, 2016; Lu et al., 2015).

Dynamic complexity in projects highlights the question of changes and evolutions over time, and focuses on the dynamic relations between the internal components of the project and between the project components and the environmental components (Geraldi et al., 2011). All these changes interact and create potential new changes in the project (Maylor et al., 2008; Williams, 2003). The manager's attempt to stabilize the system can actually destabilize it (Sterman, 1992; Sterman, 2000), and the best approach to getting the project back on track is not obvious because the strengths of the feedback loops can change during the project (Lyneis James and Ford David, 2007). This article examines mechanisms of dynamic complexity, and how the changes and evolutions of project outputs and outcomes operate during the project implementation.

Megaproject dynamics reveal the emergence of new events that have impacts on project decisions and outcomes (Hertogh and Westerveld, 2010). Even in the very long-term in megaprojects where each project phase may last years or decades, multiple temporalities are revealed, combining temporary and changing forms of organization (Brookes et al., 2017). The different 'moments' in the megaproject make it possible to consider the megaproject as a set of episodes or short-term events (Ruuska et al., 2011). The changes are related to the position and importance of the players involved (Aaltonen et al., 2016; Miller and Hobbs, 2005) but they are also related to the evolutions in the multiple stakeholders' perspective of success (Eduardo Yamasaki Sato and de Freitas Chagas, 2014; Turner and Zolin, 2012). This article considers the megaproject as a set of events and aims at examining the changes generated by the multiple events which are interconnected. We believe that the study of the interconnected events in the megaproject may help reveal patterns of evolutions initiated by the various stakeholders' decisions. The systems theory perspective that we take in this research emphasizes the need to describe interactions between the stakeholder's decisions and the project outputs, outcomes and benefits.

2.3. A complex adaptive systems (CAS) perspective on megaproject management

The question of '*how dynamic complexity influences megaproject management*' is critical. Megaprojects appear to be self-organized projects where stakeholders adapt their behavior (Chapman, 2016; Ruuska et al., 2011). They do this on a networks basis, as no single player involved is able to control all the rules of the project, and no external control is possible (Hertogh and Westerveld, 2010). The players' behaviors follow a pattern of adaptation where each individual works with others for his/her own reasons (Aritua et al., 2009). The study of the Olkiluoto 3 and Flamanville 3 nuclear power plant projects (Ruuska et al., 2011) suggested the need to review the conventional principles of governance for large projects, and to take into account the following systems characteristics: (1) megaprojects are complex and networked structures, (2) they should emphasize self-regulation mechanisms, (3) they should be viewed as a series of short-term events embedded in a more comprehensive history and (4) they should be managed as open systems. In their approach, governance should be based on *self-organized mechanisms* where interrelations regulate the project, but no component of the network is able to regulate the whole project.

Ruuska & al. highlighted promising proposals to shift the field of megaproject management towards a better understanding of self-organization and emergence. We suggest elaborating on these findings and taking a Complexity Theory approach to examine megaproject processes as complex dynamical systems under conditions of adaptation and emergence. We believe that our research approach could provide a more operative and systematic perspective on these phenomena, with the aim of describing verifiable causal relations between outputs, outcomes and stakeholders in conditions of uncertainty and complexity. Complexity theory applied to management science is a fragmented field where complex systems theories promote deterministic models (*operational research* and *cybernetics*), stochastic models (*engineering sciences*, *science of systems*) and non-deterministic models (*self-organization*, *second-order cybernetics*) (Daniel and Daniel, 2018). In his seminal article on complexity science and organization theory, Anderson suggested that the complex adaptive system (CAS) theory would be a relevant model in organization science. He presented four characteristics of complex adaptive systems (CAS) applicable to organizations (Anderson, 1999):

(1) *Agents with schemata:* Schemata are agents' cognitive structures that determine behaviors and actions. They are a set of rules that emanate from stakeholders' perception of the environment at a given point in time. Stakeholders can have different schemata and these schemata can evolve over time.
(2) *Self-organizing networks*: Stakeholders are interconnected by feedback loops. No single stakeholder dictates the collective behavior of all stakeholders;
(3) *Coevolution to the edge of Chaos*: Stakeholders coevolve with each other. The equilibrium that results from these co-evolutions is dynamic; small changes in behavior at a given time produce small, medium or large changes in the outcomes at the next point in time t + 1.
(4) *Recombination and system evolution*: The system evolves over time through the entries, exits or transformation of system components. The components or agents of the system are formed by recombining elements that could previously be successful. The link between stakeholders will evolve overtime.

Despite relations that appear between CAS properties and some of the megaproject management proposals, the CAS model was only tested in the portfolio management domain (Aritua et al., 2009). We believe that the four CAS properties presented by Anderson are a promising conceptual framework for examining, describing and modeling the megaproject management dynamics of change and evolution as well as their impact on the emergence of the project's 'success' (Fig. 1). The megaproject case study focuses on each of these four characteristics in order to reveal *operational patterns* that would go beyond the mere analogical use of CAS, and to provide a systematic and repeatable approach to self-organization mechanisms in megaprojects.

3. Research aim and methods

3.1. A historical case analysis

A longitudinal case study provides a theoretically sound way of examining and understanding dynamics in the context of megaprojects (Flyvbjerg, 2006; Van Marrewijk et al., 2016). The megaproject selected in this research has been subject to external and internal modifications that impacted the actual

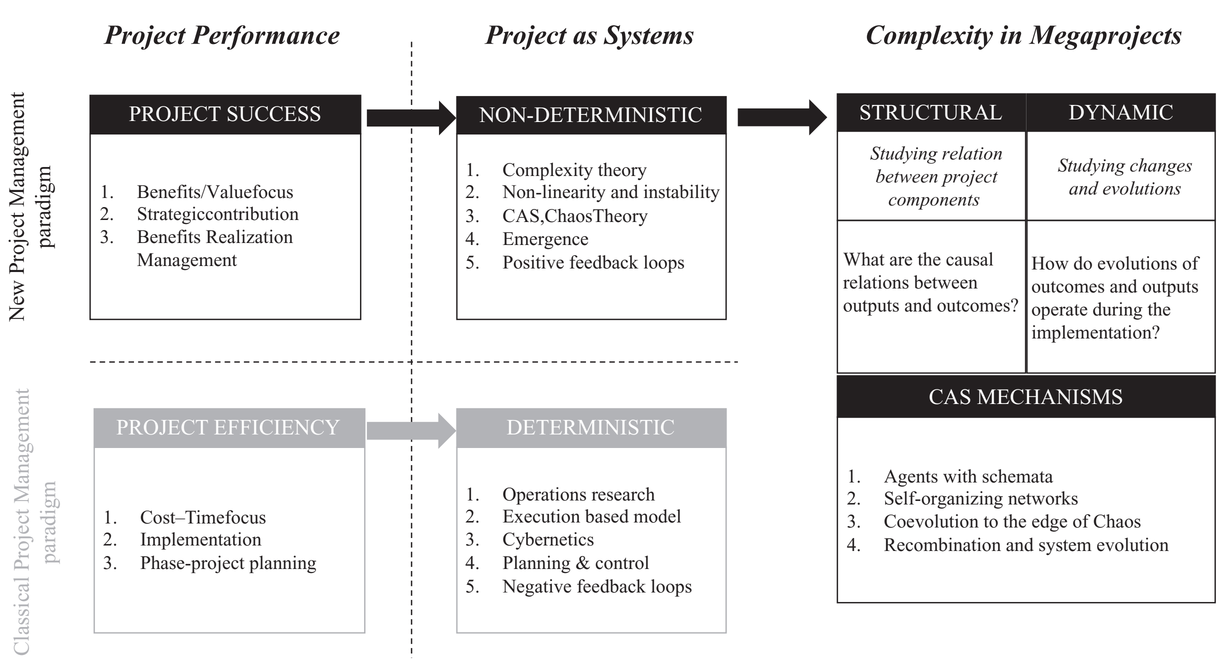

Fig. 1. Literature diagram.

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performance (*project outputs*) and the expected performance (*expected outcomes or benefits*). The highly strategic dimension of the case makes it a perfect opportunity to study the complex nature of the interaction between the key decision makers' expectations (*project success*) and the actual project outputs delivered during the front end (*project efficiency*). The case offers the possibility to analyze and compare decision-making processes from two stakeholders' perspectives to examine how project complexity may impact differently (or not) both strategic processes of decision.

The contentious nature of the case involving sensitive political and commercial issues makes it very difficult to research (Smyth et al., 2017), and it makes it impossible to use conventional case study methodologies (Yin, 2013). In the project management literature (Lenfle, 2011), and in the management literature (Hargadon and Douglas, 2001; Murmann, 2013), there are similar examples of research cases that benefited from applying alternative methods based on historical analysis. Such research methods are especially fruitful for interpreting the result of decisions in past choice opportunities, and for confronting theories of organizational change with historical development (Kieser, 1994).

In this research paper, project 'reality' is grasped through the analysis of real project systems, processes, outputs and changes. These mechanisms are examined using historical research methods (Morgan and Smircich, 1980). We take a 'realistic history' research approach in order to better understand the conditions and causal mechanisms (Vaara and Lamberg, 2016) which drive the key stakeholders' strategic decision-making. Historical research methods are particularly adapted to conduct organizational research in conditions of non-linearity where turbulent periods may usher in new epochs (Meyer et al., 2005), under conditions of complex and fast changing environments (Murmann, 2013).

Our historical research approach follows the Event-Structure Analysis (ESA) method that helps build replicable and generalizable causal interpretations of events, based on an interpretative heuristics for the computer-assisted analysis of qualitative narrative sequences (Griffin, 1993; Pajunen, 2005). We used the ETHNO software that was specifically developed for researchers to implement Event-Structure Analysis (Corsaro and Heise, 1990). First, we coded the stakeholders' facts as they described them in their narratives. Second, we built a chronology of these facts (Table 2). And third, we used the ETHNO software to generate an Event Structure Analysis *graph*. Generating such a graph requires respecting the following steps:

1) we coded all the facts of the chronology to define 'actions';
2) we linked actions by answering Boolean questions proposed by the software such as 'Does B require A or a similar action?'. Answers must be Yes or NO;
3) the ETHNO software automatically tested the chart of actions. If any non-logical links are revealed, the software proposes some corrections to the researcher. This automatic test helps the researchers go deeper into the analysis and coding of the historical events. The researcher can do this by searching for more pieces of information in the data collected or by reconsidering the relations between actions (events), until the software approves the logical causality links;
4) the software validates the chart that represents the causal chain of actions.

Fig. 3 presents the Event Structure Analysis *graph* in the case of the Hinkley Point C megaproject case.

3.2. Data collection

Our empirical data consists of publicly available information. We used two types of sources: *documentation* and *archival records*. All the data collected cover a specific period of time (from 2012 to 2016). Data were collected in their original language, namely French for the French part and English for the British part. Events used to build the project history were first based on press articles which were then cross-checked and deepened against official sources (Table 1). On the French side, the data were drawn from the sources of the main stakeholder studied (namely EDF), supplemented by data from a key partner (namely Areva). We also gathered data from French state sources such as the French government, the National Assembly and the Court of Auditors. On the British side, our data were drawn from the British Government represented by several of the ministries involved in the project. The data were mainly collected before the analysis. When the Event Structure Analysis *graph* was generated, additional data were collected to strengthen the coherence of the Event Structure Analysis. We considered that data collection was saturated when additional data had no effect on the coherence of the Event Structure Analysis *graph*.

Table 1 presents a detailed inventory of the types of data, their sources and the intended recipients of the data.

3.3. Content analysis of decision makers' perceptions

In combination with the historical analysis that we conducted, we analyzed the key stakeholders' narratives by using the qualitative data analysis program ATLAS.ti (version 1.0.50). The narratives were coded into categories compliant with the Result Based Monitoring model (Daniel and Turner, 2015; Xue et al., 2013), and the Benefits Realization Management model (Serra and Kunc, 2015), distinguishing the *expected outcomes* and the *real outputs* of the project. This process facilitated the distinction between the '*project success*' perspective on performance and the '*project efficiency*' perspective on performance. We then considered all pieces of narratives that referred to goals, objectives, future results, challenges and expectations as the '*project outcomes*'. After the coding process was completed, the coded data were further examined focusing on two sets of analyses: (1) the logical "cause-to-effect" relations between the 'project outcomes' category and the 'project outputs'

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Table 1
Inventory of Hinkley Point C public available data analyzed.

Data type	Quantity	Original data source	Original (intended) data audience
Hearings	6 (121 pages)	Assemblée Nationale *(French National Assembly)*: Economic affairs commission Assemblée Nationale *(French National Assembly)*: Inquiry commission on Nuclear industry cost	National Assembly members Ministries General public
Discourses	1	www.vie-publique.fr official website of the direction for legal and administrative information, French Prime Minister department.	General Public
Electronic periodical and newspapers	25	LeFigaro.fr LePoint.fr LeMonde.fr LesEchos.fr Rfi.fr UsineNouvelle.fr Capital.fr Natura-sciences.fr	General public
Press release	13	Areva EDF UK Government: Department of Energy & Climate change UK Government: Environment Agency UK Government: HM Treasury UK Government: Department for Business, Energy & Industrial Strategy	Journalists General Public
Information report	2 (122 pages)	EDF Assemblée Nationale *(French National Assembly)*: Economic affairs commission	Shareholders National Assembly members Ministries General public
Strategic report	4 (803 pages)	Cour des Comptes *(French court of auditors)* UK Government: Secretary State of Investor Agreement	Prime Minister and government CEO of EDF General public
Website	1	EDF Energy	General Public
Letter	4	EDF UK Government: Department for Business, Energy & Industrial Strategy	French court of auditors UK Government EDF CEO

category, (2) all the changes in each of these two categories in the front-end period of the megaproject. The "cause-to-effect" relations generated by the content analysis were considered against the 'Event Structure Analysis' *graph* generated by the historical research approach. The major changes in the project's actual and expected performance were analyzed and graphically presented. If there were any discrepancies about data from newspaper articles, the information from the official authorities or stakeholders involved was considered more reliable than information provided by external parties. Eventually, we found no contradictions between our sources: no stakeholder' narratives in a source showed any contradiction in another source.

In order to triangulate our analytical approach, two different researchers coded the various sources on the basis of a conceptual structure derived from the models (outcomes, outputs, stakeholders). Some adjustments were made to ensure that the conceptual structure was generating similar content analysis. The content analysis was facilitated by the tangible project parameters analyzed (outputs, outcomes, stakeholders) and by the application of a clear *systems oriented* model of project management.

Fig. 2 presents the research methods framework that combines the content analysis and the historical analysis.

4. The HPC case study

4.1. Background of the project

4.1.1. The chronology of the project

Areva, a French company, and Siemens, a German company, developed a new nuclear technology in 1992, 6 years after the Chernobyl accident. This technology is the EPR (initially named European Pressurized Reactor, and now named Evolutionary Power Reactor). In 2016, Nuclear Power Plants with EPR were under development in Finland (Olkiluoto OL3), in France (Flamanville FL3) and in China (Taishan 3). Two of these projects, Olkiluoto and Flamanville, have been suffering significant delays (9 years for OL3 and 5 years for FL3) and huge cost overruns (4,5 billions € for OL3 and 7,2 billion € for FL3). Therefore, EDF, a French public company in charge of producing and supplying electricity (the world leader) has taken a leading position in the nuclear industry and has handled the sales and constructions of nuclear power plants on the nuclear market. Areva has become a supplier for EDF nuclear projects.

The Hinkley Point C project went through a first phase from 2008 to 2012, during which the EDF collected the authorizations of the local population to decide on the location of the site. The meeting held on 17 February 2012 between the

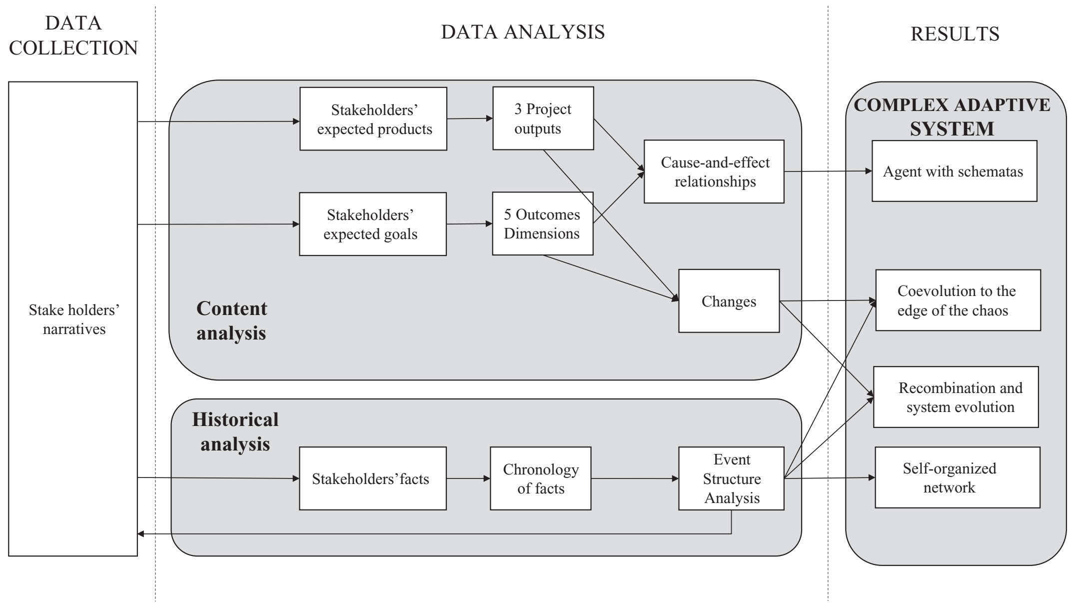

Fig. 2. Research methods framework.

President of the French Republic and the British Prime Minister to sign the agreements on the nuclear program marked the official launch of the project and the start of the phase which is the subject of our study and which ended on September 29, 2016. After this phase, the construction phase of the power plant was supposed to begin. But this is not in the scope of our study. Between February 17, 2012 and September 29, 2016, actions were completed on both the British and French sides. These actions are presented in Table 2.

4.1.2. The outcomes of the project

According to '*project success*', project's outcomes are the results expected by the project's key stakeholders after the end of the project. We analyzed expected outcomes of two of these key stakeholders: EdF and the UK Government. Table 3 presents the expected outcomes of these stakeholders at the beginning and at the end of the front-end period. The outcomes that were analyzed could be classified by stakeholder (EdF and UK Government). The content analysis reveals 5 dimensions of the stakeholders 'expected outcomes':

- *Economic*: expectations related to a market or industry
- *Technological*: expectations related to skills or competences
- *Political*: expectations related to relations between countries and company
- *Financial*: expectations related to financial benefits
- *Ecological*: expectations related to the Environment and the ecology

4.1.3. The outputs of the project

The content analysis of stakeholders' narratives revealed that the stakeholders' decisions and actions contributed to delivering three main *project outputs,* which are:

- *Investment partnerships*: the organization of investors in the project and future operations of the power station
- *Power station*: construction with the EPR technology
- *Contract for difference*: the official contract that sets the price per megawatt/h price when the station is up and running, depending on the electricity market, the date of commissioning for the operation and the level of profitability of the project. This contract describes operating conditions and sets penalties in the event of non-compliance.

In the stakeholders' narratives, it clearly appeared that these three project outputs were contributed to the achievement of project outcomes categorized in economic, political, ecological, technological and financial dimensions. Table 4 presents stakeholders' decisions/actions related to project outputs and project outcomes.

4.1.4. The event structure of Hinkley point C

From 2012 to 2016, Hinkley Point C involved a chain of actions that were linked by causes-and-effects relations. Fig. 3 presents the causes-and-effect relations of project actions through the Events Structure Analysis (ESA). Actions start with the "UK-France agreement" signed by the President of the French Republic and the British Prime minister; and finish with the "Final Investment Agreement" signed by EdF, CGN and the British Government. Actions like "New UK Prime Minister" and "Other projects" are *external causes* of the HPC megaproject but have *real effects* on the HPC megaproject. Fig. 3 is the Event Structure Analysis *graph* that clarifies the causal relations inside the megaproject.

4.2. Agents with schematas

'Agents' may be individuals, groups or coalitions of groups. Schemata are cognitive structures that determines behaviors

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Table 2
Chronology of facts and actions in the HPC project.

Date	Facts	Actions
17/02/12	Nuclear Program Contract signed between the President of French Republic and the Prime Minister of the United Kingdom	UK-FR agreement
04/04/12	£1.6 m for West Somerset Community College to train young people	Investment
18/05/12	Bridgewater college receives £2 m for local skills development	Investment
16/07/12	HPC temporary Jetty given permission	Permits
06/08/12	European Commission states that HPC proposal fulfils objectives of Euratom treaty	European approval
11/09/12	£100 m package of mitigation measures agreed with Local Authorities	Investment
31/10/12	1000 Somerset firms sign up to compete for HPC contracts	Investment
26/11/12	HPC Nuclear Site License granted	Permits
13/12/12	Regulators approve EPR nuclear reactor design for use in the UK	Permits
04/02/13	Centrica Withdrawal	Replace Centrica
13/03/13	Three main environmental permits granted by the Environment Agency	Permits
19/03/13	Secretary of State approves construction of new nuclear power station at HPC in Somerset	Permits
05/06/13	Ground-breaking industrial relations agreements for HPC project	Investment
16/10/13	Memorandum of understanding UK-China	UK-China agreement
21/10/13	Agreement on commercial terms for HPC Between UK government and EDF	Commercial agreement
05/11/13	Electrical and mechanical Trade Union agreements announced with GMB and Unite	Investment
18/12/13	European Commission announces an opening decision on HPC	European approval
10/12/13	New tensions between Areva and TVO on Finland EPR due to delays	Other projects
06/03/14	"Grand Carenage" Project is decided by the French government and supported by EDF	Other projects
07/04/14	HPC State Aid consultation completed	European approval
08/10/14	European Commission approves HPC agreements	European approval
19/11/14	Areva withdrawal	Replace Areva
23/02/15	Construction skills and Innovation Centre opens in Cannington	Preworks
20/03/15	New National College for Nuclear announced	Preworks
31/07/15	Preferred bidder companies join the team	Preworks
21/09/15	Chancellor announces £2billion Infrastructure UK guarantee	Guarantee approval
24/09/15	Further preferred bidder contracts announced	Investment
09/10/15	European Commission approves UK waste transfer contracts	European approval
21/10/15	EDF and CGN sign the Strategic Investment Agreement of HPC	Investment agreement
17/12/15	Opening of new bypass around nearby village of Cannington	Preworks
07/03/16	EDF Financial Director withdrawal	EDF approval
May 2016	French government decides to waive dividends of EDF equity	EDF approval
04/07/16	Conclusion of consultation with EDF Company Works Council	EDF approval
13/07/16	New Prime Minister appointed	New UK PM
28/07/16	EDF Board of Directors approves final Investment decision	EDF approval
31/07/16	UK new Prime minister decide to postpone her decision on HPC project	Review project
15/09/16	UK Government confirms its agreement for the construction of HPC	Review project
16/09/16	EDF accepts the agreement of the UK government	EDF agreement
29/09/16	Final Agreement signed for Hinkley Point C	Final Investment agreement

and actions. They are a set of rules that emanates from stakeholders' perceptions of the environment at a time t. Stakeholders can have different schemata and these schemata may or may not evolve

Anderson (1999, p.219).

In the project management literature, *project success* is a shared and common perception of project stakeholders (Davis, 2016). Table 5 describes the results of the content analysis based on the narratives of EdF and the UK Government.

Our analysis revealed two conclusions: (1) both stakeholders share the same structure of perception, based on common dimensions, (2) but each stakeholder defines his/her own expected outcomes.

4.2.1. Shared structure of perception

Each stakeholder perceives the project and its long-term performance through three characteristics: (1) *environmental orientations*, (2) *organizational levels* and (1) *individual intentions*:

- *Environmental orientations.* They are domains of the project environment that would be impacted after the end of the project: economic, technological, political, financial and ecological.
- *Organizational levels*. Each stakeholder perceives three organizational levels of the project: micro, *meso* and macro. The micro level is the perception of the project as a range of outputs. The meso level is the perception of the project according to the entire organization. The macro level is the perception of the project as a part of a program or portfolio of projects in a corporate strategy or country policy.
- *Individual intentions*. These intentions are a set of interests that clarifies stakeholders' commitments to the project such as '*business oriented'* for EdF and '*citizens oriented'* for the UK Government.

4.2.2. Distinct meanings of perception

Table 5 reveals that although the stakeholders' structure of perception is shared, their real expected outcomes may be very different:

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Table 3
Outcomes of Hinkley Point C megaproject.

Outcomes			
Dimensions	Stakeholders	Start - IN 2012	End - IN 2016
Economic	UK Government	To create jobs	UK companies could be entrusted with up to 60% of the work 26,000 jobs created during construction and 900 permanent jobs
	EdF	To go through market price fluctuations	To create thousands of jobs To create 64% of benefit for UK industries To become a leader on the low carbon market
Technological	UK Government	To improve nuclear safety	Power supplied to nearly 6 million homes
	EdF	To recognize its industrial expertise and key milestones in the implementation of its new nuclear strategy	To supply safe power for 7% of future needs in the UK in 2025
Political	UK Government	To reinforce industrial partnerships	To ensure that the full implications of foreign ownership are duly examined for the purposes of national security
	EdF	To reinforce partnerships with UK	To consolidate the presence of EdF in the UK To not reduce EdF shares under 50% without the UK government's consent
Financial	UK Government	To reduce consumers' bills over long-term	To provide financial security for the next generation Not pay a consumers' penny until the plant is up and running
	EdF	To build 4 power stations in the UK	To develop new stations in Suffolk and Essex
Ecological	UK Government	To produce low carbon energy	A clean, home-grown source of electricity which will avoid by 9 million tons of CO2 per year
	EdF	To provide low carbon power	To provide low carbon power To fight global warming

- For *'Environmental orientations'*, stakeholders share the same 5 dimensions, but their expectations have different meanings as far as economic, technological, political and financial orientations are concerned.
- For '*Organizational levels*', stakeholders share a '3-levels' structure of organization but the meaning of perception is different for the macro level.
- For '*Individual intentions*', stakeholders share the fact that they have an interest in the project, but their interests are different.

Table 4
Outputs of Hinkley point C.

Project outputs	Outcomes dimensions	Stakeholders' actions
Investment partnership	Economic Technological Political	UK-FR agreement Replace Centrica UK-China agreement European approval Replace Areva Guarantee approval Investment agreement EDF approval Review project EDF agreement Final Investment agreement
Power station	Economic Technological Political Financial Ecological	Investment Permits European approval Preworks
Contract for difference	Economic Financial Ecological	Commercial agreement Investment agreement Review project Final investment agreement

4.3. Self-organizing networks

> *Stakeholders are interconnected by feedback loops. No single stakeholder dictates the collective behavior of all stakeholders.*
>
> (Anderson, 1999, p.219–220).

A self-organizing network is characterized by stakeholders that have a supplier role in the network and not by a hierarchical structure with principal and agent roles (Ruuska et al., 2011). Based on the Event Structure Analysis of the Historical research (Fig. 3), we analyzed actions where a stakeholder has an impact on the behavior of the other stakeholder.

Fig. 4 presents the roles played and actions that one stakeholder in influencing the behavior of the other stakeholder:

- In the '*Replace Centrica*' action, EdF plays the role of the finder of investors. It selects Areva and CGN a Chinese company. Its decision influences the UK Government that signs a UK-China agreement on Nuclear activities.
- In the '*Guarantee approval*' action, the UK Government plays the role of market regulator by financially guaranteeing £2 billion in infrastructures for the first tranche of the project. Its decision influences EdF that signs the Investment agreement with CGN.
- In the '*EdF approval*' action, the board of EdF plays the role of future operator by approving the future operating conditions. Its decision influences the UK Government and the new Prime minister, who decides to review all the conditions of national safety decided by the former Prime minister.
- In the '*Review project*' action, the new UK Prime minister plays the role of safety regulator by changing the investment

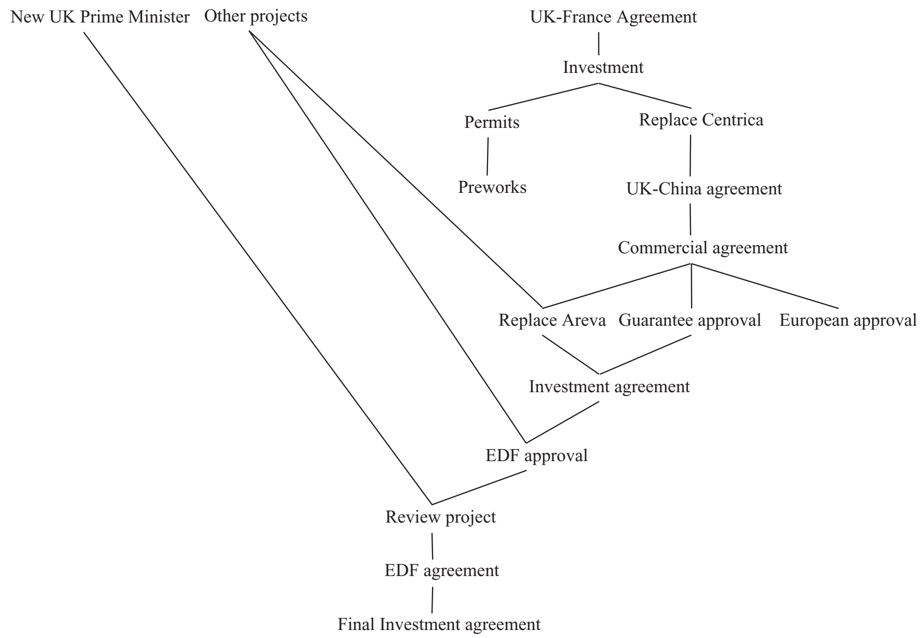

Fig. 3. Event structure analysis graph of Hinkley Point C megaproject.

conditions for foreign investors to ensure the national safety. Her decision influences EdF, which agrees to not having less than 50% of shares without the consent of the UK Government.

Our findings reveal that influences are mutual: they go from one stakeholder to the other. No stakeholder has total control over the behavior of the other. It is not clear which one is the "principal", and which one is the "Agent". This two-way relation represents the feedback loops described by Anderson.

4.4. Coevolution to the edge of chaos

Stakeholders coevolve with each other. The equilibrium that results from these co-evolutions is dynamic: small changes in behavior at a time t producing small, medium or large changes in the outcomes at time t + 1

(Anderson, 1999, p.220).

The co-evolution process involves at least two agents (industries, populations, stakeholders). The analytical process of co-evolution implies two steps: (1) the first step should show that agents have changed from time t to time t + 1, (2) the

Table 5
Key stakeholders' schemata structures and meanings.

Schemata structures and meanings	Electricité de France (EdF)	UK Government
'Environmental orientations'	*Economic:* International nuclear market	*Economic:* National economy
	Technological: Quality of electricity produced	*Technological:* Quantity of electricity produced
	Political: EdF investments control	*Political*: Foreign investments control
	Financial: Spin-off for EdF Group	*Financial*: Spin-off for UK Consumers
	Ecological: Carbon emission reduction	*Ecological:* Carbon emission reduction
'Organizational level'	*Macro*: Corporate strategy	*Macro*: Country policy
	Meso: HPC project	*Meso*: HPC project
	Micro:	*Micro*:
	Power station	Power station
	Contract for difference	Contract for difference
	Investment partnership	Investment partnership
'Individual intentions'	*Business oriented:*	*Citizens oriented:*
	a) Client satisfaction	a) UK employment
	b) Profit for the Group	b) UK businesses
	c) Optimizing cost	c) Homes receiving electricity
	d) Position on the market	d) UK security for foreign investments
	e) Skills and expertise	e) Next UK generation
	f) Low carbon energy producer	f) UK CO2 production

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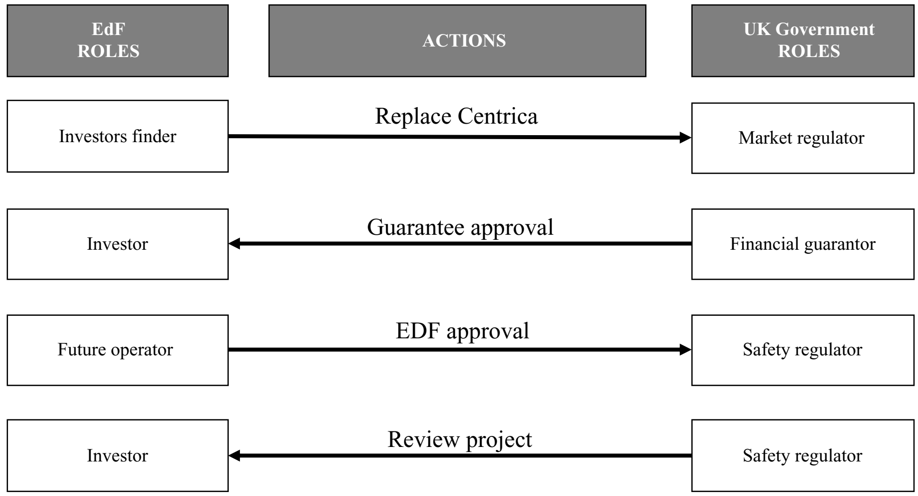

Fig. 4. Mutual influences of stakeholders.

second step is the analysis of a reciprocal causal mechanism that exists between the agents (Murmann, 2013). The cause-to-effect mechanism between two agents is appropriate to analyze a co-evolutionary phenomenon.

Fig. 5 presents actions extracted from the Event Structure Analysis *graph* that contribute to the evolution of EdF's outcome and the UK Government's outcome. Each stakeholder starts with his own outcome: '*to reinforce the partnership with the UK by owning 50% of the shares of the power station*' and '*to reinforce the industrial partnership with France by having a UK company as a shareholder in the project*'. At the end of the evolution process, expected outcomes are '*to consolidate presence in the UK with 66% of shares of the power station*' and '*to ensure that foreign ownership is duly examined for the national security by controlling the shares of the French and Chinese project owners*'.

The evolution of stakeholders' outcomes is the consequence of a "cause-to-effect" chain between the two stakeholders:

1. '*Replace Centrica'* is an EdF action that induces a UK Government action: "UK-China agreement"
2. '*Guarantee Approval'* is a UK Government action that induces an EdF action: "Investment agreement"
3. '*Investment agreement'* is an EdF action that induces a UK Government action: "Review project"
4. '*Review project'* is a UK Government action that induces an EdF action: "EDF approval"

The findings show that one stakeholder's outcome does not depend only on its choice but also on the choice of another stakeholder. The chain of cause-to-effect actions explains how an outcome at time t evolves to another outcome at time t + 1. This chain of cause-and-effect and the evolution of outcomes show how stakeholders adapt to each other: their action influences the outcome of another stakeholder, who in return reacts by implementing an action that influences the initial stakeholder's outcome. Therefore, we can describe a coevolution as a chain of causes-to-effects between stakeholders that generate changes in their outcomes. Fig. 5 graphically represents such a dynamic process.

4.5. Recombination and system evolution

> *The system evolves over time through entries, exits or transformations of system components. The components or agents of the system are formed by recombining elements that could be previously successful. Thus, patterns of interconnections, the strength of each connection and the links between the stakeholders will evolve over time*
> (Anderson, 1999, p.220).

Based on the Event Structure Analysis *graph* (Fig. 3) we applied content analysis on actions as entries and their effects on other actions in the project:

- For entries: "Other projects" and "New UK Prime Minister"
- For effects: "Replace Areva", "Investment agreement", EDF approval", "Review project", "EDF agreement" and "Final Investment agreement"

Table 6 presents changes in output characteristics and stakeholder relations due to entries and transformations in HPC:

- *Entries* are actions that introduce a new stakeholder in the project or new information about external project;
- *Transformations in project outputs* are changes in characteristics such as profit (capital structure), schedule (date of commissioning year) and specifications (investment conditions).

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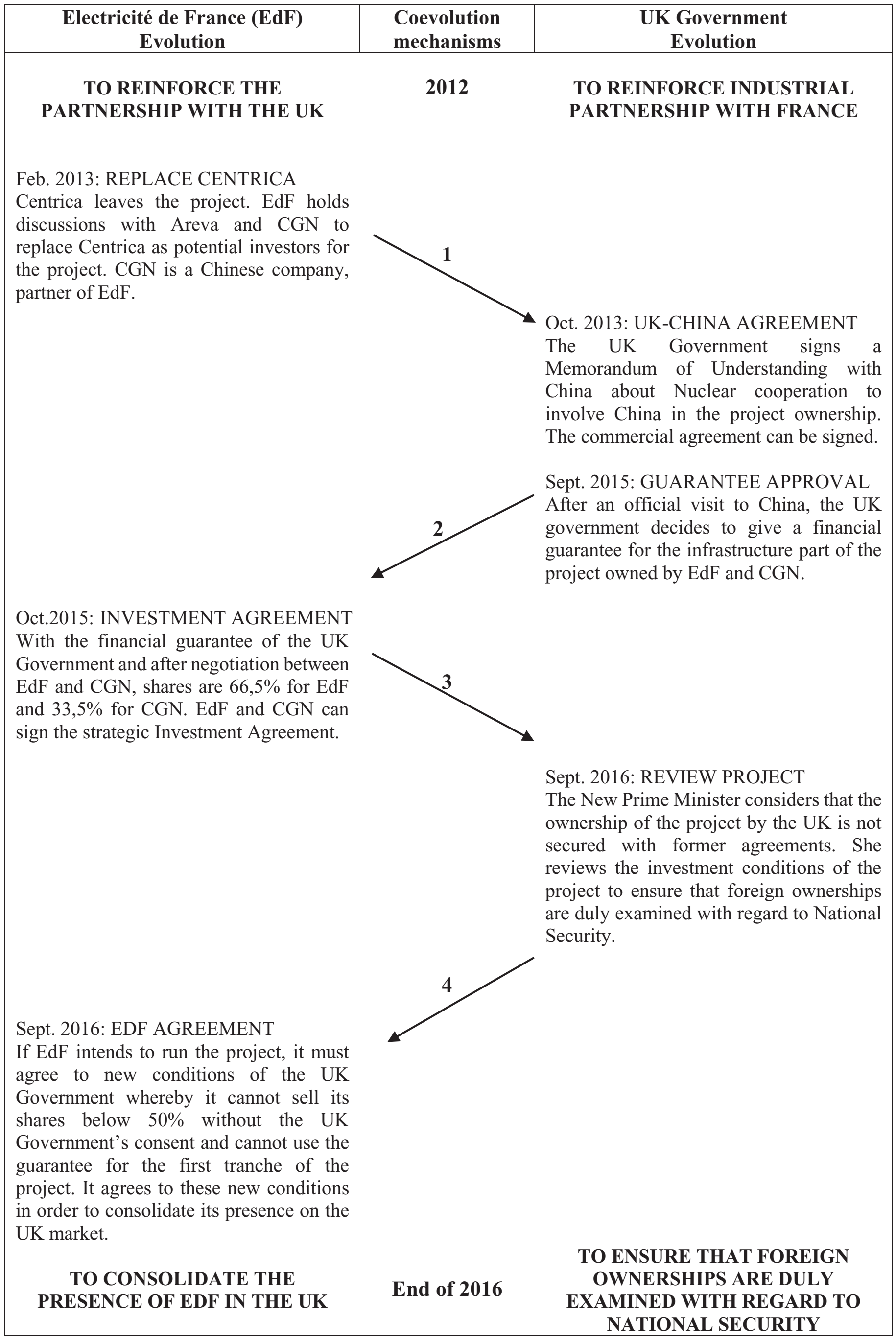

Fig. 5. Causal map of coevolutionary dynamics.

- *Transformations in stakeholders' relations* are modifications of the stakeholders' roles in the context of their relations with other project stakeholders.

Our findings show that the structure of the project is reviewed in the front-end of the project. The transformations impacted the project outputs characteristics and the stakeholder relations. This transformation was induced by stakeholders' entries and information from the environment of the project.

5. Discussion

Each of the four CAS properties presented by Anderson (Anderson, 1999) – agents with schemata, self-organizing network, coevolution to the edge of chaos, recombination and system evolution - could successfully be *analyzed* and *described* in the HPC megaproject. The very conceptual properties presented in Anderson's article in 1999 can be considered as more operational in the HPC megaproject case presented. We believe that it is a first theoretical and

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Table 6
Recombination of Hinkley Point C project.

Exits and Entries	Transformations	
	Project Outputs	Stakeholder Relations
▪ Entry of information about other projects ▪ Entry of new UK Prime minister	*Investment partnership:* ▪ Modification of capital structure ▪ Modification of investment conditions *Contract for Difference:* ▪ Modification of commissioning year in the terms of the contract	▪ Areva becomes only co-contractor of EdF ▪ CGN becomes co-owner with EdF ▪ UK Government becomes guarantor for infrastructure ▪ EdF Group becomes financial guarantor of the project ▪ French Government becomes financial support of EdF in the project

methodological contribution to megaproject management research. Complexity theory applied to organization science frequently has to face critics because of a lack of operationality. It frequently has difficulty going beyond the metaphor. This research is an attempt to deal with this limitation, proposing a research design (*content analysis* and *historical analysis*) able to translate the theoretical concepts into more operational descriptions. Beyond the attempt to validate CAS properties in megaprojects, the research findings reveal megaproject management patterns:

5.1. Megaproject perception of success is multidimensional

Both narratives of EdF and the UK government revealed that their perception of project success is defined through a *common structure* built on three dimensions: *environmental* (economic, technological, political, financial, ecological), *organizational* (macro, *meso*, micro) and *individual* (intentions orientation). However, the comparison of the *perceptions of success* of EdF and the UK Government reveals that their expectations are not aligned. Our case confirms the findings of Turner and Zolin which show that project success is a multidimensional perception, by several stakeholders over several timeframes (Turner and Zolin, 2012).

5.2. Megaproject self-organization is based on each stakeholder's source of control

In the HPC case, EdF controls the project resources while the UK government controls on the project rules. Consequently, each of them has a specific source of control. Our results show that the self-organization mechanism is based on these two sources of control, one being under the influence of EdF, the other being under the influence of the UK government. Each key stakeholder has real, but limited, control over the project. It confirms that the principle of self-organization is rooted in the stakeholders' interrelations (Ruuska et al., 2011), and that the control is shared by the various players involved in the system (Boateng et al., 2015).

5.3. Megaproject coevolution is based on stakeholders' reaction towards new deliverables

The UK government's evolutions were a consequence of EdF's replacement of investors. In parallel, EdF's evolutions were a consequence of the UK government's modifications of investment conditions. The key changes in the megaproject follow a coevolution mechanism. This mechanism is dependent on the position of each key players (Aaltonen et al., 2016; Miller and Hobbs, 2005), as all of the players involved generate constraints for the others, and force them to adapt (Chapman, 2016).

5.4. Megaproject recombination reveals transformations in outputs and stakeholder relations

The four key transformations that appeared between 2012 and 2016 show that key project outputs appeared (creation of a memorandum of understanding), disappeared (removal of a financial entity) or were modified (change in capital structure). They also reveal that stakeholder relations were redefined (CGN becomes co-owner with EdF). These results confirm the concept of multi-temporalities in megaprojects as being temporary forms of organizing processes (Brookes et al., 2017) or episodes in the project (Ruuska et al., 2011).

The conventional project management paradigm, based on traditional management control mechanisms within the project, is rooted in the *cybernetic-control model* (Deming, 1986; Shewhart, 1931). Classical project management practices are based on the managers' capacity to implement processes of control that operate as *negative feedback loops* and maintain the project processes of production in the initial plan. Our results reveal that the HPC megaproject's behavior is in fact influenced by *positive feedback loops* that are sources of *emergent* outputs and outcomes. In practice, the key stakeholders' decisions and actions are influenced by new outputs not expected in the initial plan (Replace Centrica), and the key stakeholders' reactions create new outputs which contribute to amplify the modification of the initial plan (UK-China agreement). Our results suggest that positive feedback loops mechanisms play a key role in the megaproject management and its performance.

As a consequence, our results challenge the conventional project management paradigm, deeply questioning the cybernetic-control model (Deming, 1986; Shewhart, 1931) on the following fundamental functions:

1. *the planning function*: We question the notion of 'principal agent' (Jensen and Meckling, 1976). Our results suggest that no agent is able to define alone a megaproject vision (goals and objectives), and the related actions to be planned. On the contrary, we find that each agent holds a partial and limited vision of the megaproject, that may be sufficiently effective

Table 7
From CAS theory to a revised project management model.

Results from the CAS theory	Towards a revised project management model	Project management new issues
Agents with Schemata *Megaproject perception of success is multidimensional.*	**Shared planning** *The project performance (outputs and outcomes achieved) is a result of shared (partial and limited) agents' visions and goals. The planning function of the project is not in the hands of a principal agent only.*	**Structural perspective** The planning and control functions are 'shared' (partial and limited) by the project agents.
Self-organizing networks *Megaproject self-organization is based on each stakeholder's source of control.*	**Shared control** *The project performance (outputs and outcomes achieved) is a result of shared (partial and limited) agents' capacity to control the outputs during project implementation. The control function of the project is not in the hands of a principal agent only.*	
Coevolution to the edge of chaos *Megaproject coevolution is based on stakeholders' reactions towards new deliverables.*	**Collaborative adaptation of planning** *The project agents adapt their project goals because of other agents producing unexpected outputs. This has a direct impact on their planning function of project. The process of adaptation is a result of a collaborative interaction of agents.*	**Dynamic perspective** The planning and control functions are adapted by the project agents as a result of (in)voluntary collaborative interactions
Recombination and system evolution *Megaproject recombination reveals transformations in the outputs achieved and in the stakeholders' relations and roles in the project.*	**Collaborative adaptation of control** *The project agents make decisions of adaptation resulting in modifications of their roles and actions. This has a direct impact on the control function of the project. This process of adaptation is a result of (in)voluntary collaboration.*	

to drive his/her own actions, but not enough to drive those of other agents.

2. *the control function*: Similarly, we find that no 'principal agent' is able to exercise full control over the project trajectory efficiently, based on his/her own plan. Instead, each agent has a partial and limited capacity to influence and control the project trajectory, and consequently to modify it. The project performance (outputs and outcomes achieved) results from the combination of control capacities of key agents of the megaproject. Our results open up the discussion on a project management 'control function' that is shared by various agents.
3. *the Project Management conditions of stability*: we find that megaproject management cycles do not follow a classic 'Plan-Do-Check-Act' loop. PDCA (known as the Deming wheel) is fundamentally based on a quasi-cybernetic loop of control, which aims at maintaining the project performance (outputs and outcomes achieved) in conformity with the plan. Our results open up the discussion on a project management process that would adapt its planning and control functions, based on new conditions linked to emerging outputs and outcomes. Moreover, we find that this project management process of adaptation is not in the hands of a 'principal agent', but is the result of collaborative interactions, which may be volontary or involuntary.

In the following table (Table 7), we propose a revision of the classic project management model in conditions of complexity.

6. Conclusion

The conventional Project Management paradigm applied to megaprojects creates lack of long-term performance (Morris, 2010). A non-deterministic approach based on the complexity theory and the emergence principle can give a new perspective to understand the mechanisms of change in implementation of megaprojects, and its impact on the project's success. The Complex Adaptive Systems theory (Anderson, 1999) is a conceptual framework that helps analyze the mechanism of emergence in organizations.

This paper offers three contributions. The first contribution is to enrich the megaproject management field of research through the application of the Complex Adaptive System theory as a conceptual framework to describe complexity in megaprojects. The second contribution is to propose a theory of emergence in project management that would go beyond mere analogy, which meets actual expectations in the project management field (Padalkar and Gopinath, 2016b). To do so, we provide models in order to represent patterns of complexity in projects. The third contribution is to propose to practitioners a case study questioning the classical '*planning and control*' paradigm of project management, suggesting that control can no longer be in the hands of a single player, but that it is the result of multiple agents, under conditions of self-organization and coevolution.

In terms of managerial implications, our findings highlight the necessity to revise the conventional project management model, emphasizing the strategic role of collaborative planning and control, in a project management process that is built on adaptation. The following figure (Fig. 6) shows that the project management functions interact with the project performance during implementation, following a dynamic process of adaptation generated by all the key megaproject agents.

But there are some methodological limitations in this study. Firstly, this study on one megaproject was conducted in two specific national contexts, France's power industry and EdF on the one hand and the UK's power industry and the UK government on the other. Thus, readers should be cautious when extrapolating the findings to different cultural contexts. Secondly, (Anderson, 1999) suggests that 'Agents might be

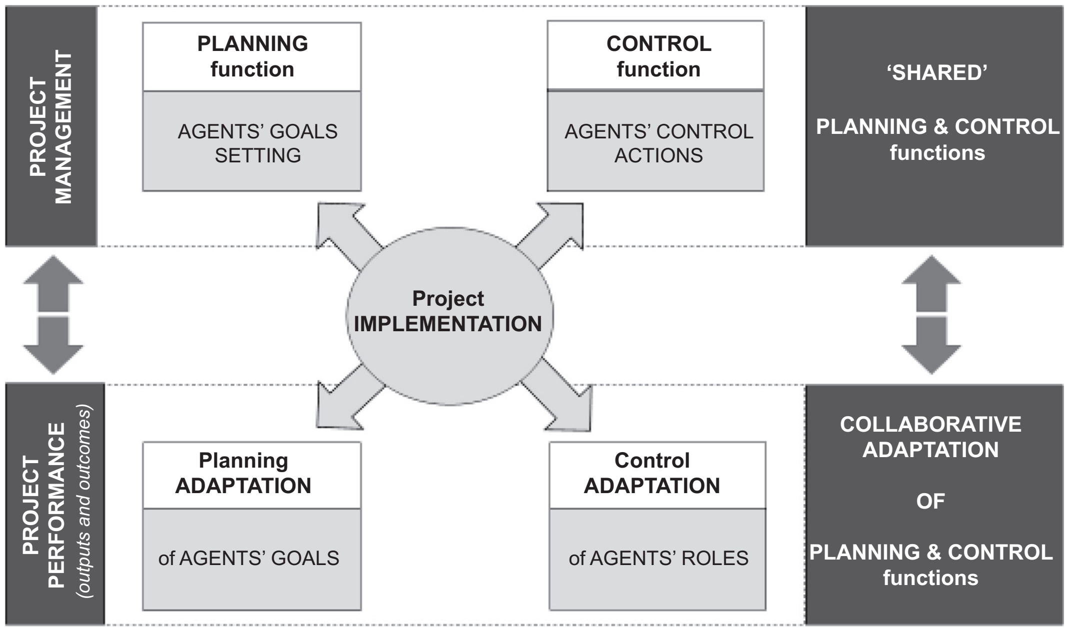

Fig. 6. Revised Project Management model based on Complex Adaptive Systems.

individuals, groups or coalitions of groups'. This study focused on only two agents that represent two key organizations in the HPC megaproject. We considered these organizations as a unified group of individuals. Our research perspective does not take into account the multiple behaviors and interpretations that could exist in each of these organizations. And third, this study is based on public and official narratives of two agents: EdF and the UK government. Consequently, our analyses are solely based on official statements that can only partly explain the intentions and perceptions of players.

Our research reveals that the project management functions of planning and control in megaprojects are not in the hands of one principal agent only. We believe that future research should focus on understanding the advantages, constraints and limitations of collaborative planning and control in megaprojects.

The CAS theory helps to describe the dynamics of instability that operate in megaprojects, but it does not provide clear results on the 'planning and control' functions that should be applied in conditions of project instability and emergence. Future research should study the role and impact of techniques and methods promoting shared goals and collaborative actions of control. Future research would benefit from establishing the impacts of such project management practices on the project trajectory, and more specifically on the emergence of the project performance (the outputs and the outcomes achieved).

In recent years, there has been a growing scientific and societal interest for grand challenges (e.g. climate change, global health, sustainable cities, justice and equality, transformative technology). We believe that such grand challenges are strongly dependent on the performance of megaprojects and on our human capacity to understand how collaboration can support project management teams in coping with emergence and instability.

References

Aaltonen, K., Kujala, J., Havela, L., Savage, G., 2016. Stakeholder dynamics during the project front-end: the case of nuclear waste repository projects. Proj. Manag. J. 46 (6), 15–41.

Anderson, P., 1999. Complexity theory and organization science. Organ. Sci. 10 (3), 216–232.

Antoniadis, D.N., Edum-Fotwe, F.T., Thorpe, A., 2011. Socio-organo complexity and project performance. Int. J. Proj. Manag. 29 (7), 808–816.

Aritua, B., Smith, N.J., Bower, D., 2009. Construction client multi-projects – a complex adaptive systems perspective. Int. J. Proj. Manag. 27 (1), 72–79.

Baccarini, D., 1996. The concept of project complexity—a review. Int. J. Proj. Manag. 14 (4), 201–204.

BCG-PMi, 2015. Connecting Business Strategy and Project Management, Benefits Realization Management. Project Management Institute.

Benbya, H., McKelvey, B., 2006. Toward a complexity theory of information systems development. Inf. Technol. People 19 (1), 12–34.

Boateng, P., Chen, Z., Ogunlana, S.O., 2015. An analytical network process model for risks prioritisation in megaprojects. Int. J. Proj. Manag. 33 (8), 1795–1811.

Bosch-Rekveldt, M., Jongkind, Y., Mooi, H., Bakker, H., Verbraeck, A., 2011. Grasping project complexity in large engineering projects: the TOE (technical, organizational and environmental) framework. Int. J. Proj. Manag. 29 (6), 728–739.

Brady, T., Davies, A., 2014. Managing structural and dynamic complexity: a tale of two projects. Proj. Manag. J. 45 (4), 21–38.

Brookes, N., Sage, D., Dainty, A., Locatelli, G., Whyte, J., 2017. An island of constancy in a sea of change: rethinking project temporalities with long-term megaprojects. Int. J. Proj. Manag. 35 (7), 1213–1224.

Burnes, B., 2005. Complexity theories and organizational change. Int. J. Manag. Rev. 7 (2), 73–80.

Chapman, R.J., 2016. A framework for examining the dimensions and characteristics of complexity inherent within rail megaprojects. Int. J. Proj. Manag. 34 (6), 937–956.

Cicmil, S., Williams, T., Thomas, J., Hodgson, D., 2006. Rethinking project management: researching the actuality of projects. Int. J. Proj. Manag. 24 (8), 675–686.

Cooke-Davies, T., 2002. The "real" success factors on projects. Int. J. Proj. Manag. 20 (3), 185–190.

Cooke-Davies, T., Cicmil, S., Crawford, L., Richardson, K., 2007. We're not in Kansas anymore, Toto: mapping the srange landscape of complexity theory, and its relationship to project management. Proj. Manag. J. 38 (2), 50–61.

Corsaro, W.A., Heise, D.R., 1990. Event structure models from ethnographic data. Sociol. Methodol. 1–57.

Crawford, L., Pollack, J., England, D., 2006. Uncovering the trends in project management: journal emphases over the last 10 years. Int. J. Proj. Manag. 24 (2), 175–184.

Daniel, P.A., Daniel, C., 2018. Complexity, uncertainty and mental models: from a paradigm of regulation to a paradigm of emergence in project management. Int. J. Proj. Manag. 36 (1), 184–197.

Daniel, P., Turner, R., 2015. Vision-Implementation-organization: the VIO approach for complex projects and programmes. Ed. In: Lecoeuvre, L. (Ed.), The Performance of Projects and Project Management (Gower).

Davis, K., 2016. A method to measure success dimensions relating to individual stakeholder groups. Int. J. Proj. Manag. 34 (3), 480–493.

Deming, W.E., 1986. Out of the Crisis. M.I.T. Press.

Eden, C., Ackermann, F., Williams, T., 2005. The amoebic growth of project costs. Proj. Manag. J. 36 (1), 15–27.

Eduardo Yamasaki Sato, C., de Freitas Chagas Jr., M., 2014. When do megaprojects start and finish? Redefining project lead time for megaproject success. Int. J. Manag. Proj. Bus. 7 (4), 624–637.

Eweje, J., Turner, R., Müller, R., 2012. Maximizing strategic value from megaprojects: the influence of information-feed on decision-making by the project manager. Int. J. Proj. Manag. 30 (6), 639–651.

Flyvbjerg, B., 2006. Five misunderstandings about case-study research. Qual. Inq. 12 (2), 219–245.

Flyvbjerg, B., 2014. What you should know about megaprojects and why: an overview. Proj. Manag. J. 45 (2), 6–19.

Flyvbjerg, B., Turner, J.R., 2018. Do classics exist in megaproject management? Int. J. Proj. Manag. 36 (2), 334–341.

Gann, D.M., Salter, A.J., 2000. Innovation in project-based, service-enhanced firms: the construction of complex products and systems. Res. Policy 29 (7–8), 955–972.

Geraldi, J., Maylor, H., Williams, T., 2011. Now, let's make it really complex (complicated). Int. J. Oper. Prod. Manag. 31 (9), 966–990.

Griffin, L.J., 1993. Narrative, event-structure analysis, and causal interpretation in historical sociology. Am. J. Sociol. 98 (5), 1094–1133.

Hargadon, A.B., Douglas, Y., 2001. When innovations meet institutions: Edison and the design of the electric light. Adm. Sci. Q. 46 (3), 476–501.

Hertogh, M., Westerveld, E., 2010. Playing with complexity. Management and Organisation of Large Infrastructure Projects. Erasmus University Rotterdam.

Jensen, M.C., Meckling, W.H., 1976. Theory of the firm: managerial behavior, agency costs and ownership structure. J. Financ. Econ. 3 (4), 305–360.

Kieser, A., 1994. Why organization theory needs historical analyses-and how this should be performed. Organ. Sci. 5 (4), 608–620.

Killen, C.P., Kjaer, C., 2012. Understanding project interdependencies: the role of visual representation, culture and process. Int. J. Proj. Manag. 30 (5), 554–566.

Klakegg, O.J., 2009. Pursuing relevance and sustainability: improvement strategies for major public projects. Int. J. Manag. Proj. Bus. 2 (4), 499–518.

Lenfle, S., 2011. The strategy of parallel approaches in projects with unforeseeable uncertainty: the Manhattan case in retrospect. Int. J. Proj. Manag. 29 (4), 359–373.

Li, Y., Lu, Y., Taylor, J.E., Han, Y., 2018. Bibliographic and comparative analyses to explore emerging classic texts in megaproject management. Int. J. Proj. Manag. 36 (2), 342–361.

Locatelli, G., Mariani, G., Sainati, T., Greco, M., 2017. Corruption in public projects and megaprojects: there is an elephant in the room! Int. J. Proj. Manag. 35 (3), 252–268.

Lu, Y., Luo, L., Wang, H., Le, Y., Shi, Q., 2015. Measurement model of project complexity for large-scale projects from task and organization perspective. Int. J. Proj. Manag. 33 (3), 610–622.

Lyneis James, M., Ford David, N., 2007. System dynamics applied to project management: a survey, assessment, and directions for future research. Syst. Dyn. Rev. 23 (2–3), 157–189.

Maylor, H., Vidgen, R., Carver, S., 2008. Managerial complexity in project-based operations: a grounded model and its implications for practice. Proj. Manag. J. 39 (S1), S15–S26.

Meyer, A.D., Gaba, V., Colwell, K.A., 2005. Organizing far from equilibrium: nonlinear change in organizational fields. Organ. Sci. 16 (5), 456–473.

Miller, R., Hobbs, B., 2005. Governance regimes for large complex projects. Proj. Manag. J. 36 (3), 42–50.

Morgan, G., Smircich, L., 1980. The case for qualitative research. Acad. Manag. Rev. 5 (4), 491–500.

Morris, P.W.G., 2010. A brief history of project management, Chapter 1. In: Morris, P.W.G., Pinto, J.K., Söderlund, J. (Eds.), The Oxford Handbook of Project Management. Oxford University Press, New York, pp. 35–59.

Murmann, J.P., 2013. The coevolution of industries and important features of their environments. Organ. Sci. 24 (1), 58–78.

Padalkar, M., Gopinath, S., 2016a. Are complexity and uncertainty distinct concepts in project management? A taxonomical examination from literature. Int. J. Proj. Manag. 34 (4), 688–700.

Padalkar, M., Gopinath, S., 2016b. Six decades of project management research: thematic trends and future opportunities. Int. J. Proj. Manag. 34 (7), 1305–1321.

Pajunen, K., 2005. Comparative Causal Analysis in Processual Strategy Research: A Study of Causal Mechanisms in Organizational Decline and Turnarounds *Strategy Process*. Emerald Group Publishing Limited, pp. 415–456.

Pinto, J.K., Winch, G., 2016. The unsettling of "settled science:" the past and future of the management of projects. Int. J. Proj. Manag. 34 (2), 237–245.

Pollack, J., Biesenthal, C., Sankaran, S., Clegg, S., 2018. Classics in megaproject management: a structured analysis of three major works. Int. J. Proj. Manag. 36 (2), 372–384.

Remington, K., Pollack, J., 2007. Tools for Complex Projects (Gower, London).

Ribbers, P.M.A., Schoo, K.-C., 2002. Program management and complexity of ERP implementations. Eng. Manag. J. 14 (2), 45–52.

Ruuska, I., Ahola, T., Artto, K., Locatelli, G., Mancini, M., 2011. A new governance approach for multi-firm projects: lessons from Olkiluoto 3 and Flamanville 3 nuclear power plant projects. Int. J. Proj. Manag. 29 (6), 647–660.

Saynisch, M., 2010. Beyond frontiers of traditional project management: an approach to evolutionary, self-organizational principles and the complexity theory-results of the research program. Proj. Manag. J. 41 (2), 21–37.

Serra, C.E.M., Kunc, M., 2015. Benefits realisation management and its influence on project success and on the execution of business strategies. Int. J. Proj. Manag. 33 (1), 53–66.

Serrador, P., Turner, R., 2015. The relationship between project success and project efficiency. Proj. Manag. J. 46 (1), 30–39.

Sheffield, J., Sankaran, S., Haslett, T., 2012. Systems thinking: taming complexity in project management. On the Horiz. 20 (2), 126–136.

Shenhar, A.J., Dvir, D., Levy, O., Maltz, A.C., 2001. Project success: a multidimensional strategic concept. Long Range Plan. 34 (6), 699–725.

Shewhart, W.A., 1931. Economic Control of Quality of Manufactured Product. Van Nostrand, New York.

Smyth, H., Lecoeuvre, L., Vaesken, P., 2018. Co-creation of value and the project context: towards application on the case of Hinkley point C nuclear Power Station. Int. J. Proj. Manag. 36 (1), 170–183.

Sterman, J.D., 1992. System Dynamics Modeling for Project Management.

Sterman, J.D., 2000. Learning in and about complex systems. Reflections 1.

Turner, J.R., 2009. The Handbook of Project-Based Management. 3rd ed. McGraw-Hill, New York.

Turner, R., Zolin, R., 2012. Forecasting success on large projects: developing reliable scales to predict multiple perspectives by multiple stakeholders over multiple time frames. Proj. Manag. J. 43 (5), 87–99.

Turner, R., Huemann, M., Anbari, F., Bredillet, C., Dalcher, D., Gareis, R., Staal-Ong, P.L., Westerveld, E., Williams, T., 2010. Perspectives on Projects. Routledge Taylor & Francis Group.

Vaara, E., Lamberg, J.-A., 2016. Taking historical embeddedness seriously: three historical approaches to advance strategy process and practice research. Acad. Manag. Rev. 41 (4), 633–657.

Van Marrewijk, A., Ybema, S., Smits, K., Clegg, S., Pitsis, T., 2016. Clash of the titans: temporal organizing and collaborative dynamics in the Panama Canal megaproject. Organ. Stud. 37 (12), 1745–1769.

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Vidal, L.A., Marle, F., 2008. Understanding project complexity: implications on project management. Kybernetes 37 (8), 1094–1110.

Whitty, S.J., Maylor, H., 2009. And then came complex project management (revised). Int. J. Proj. Manag. 27 (3), 304–310.

Williams, T.M., 2002. Modelling Complex Projects. John Wiley & Sons.

Williams, T., 2003. Assessing extension of time delays on major projects. Int. J. Proj. Manag. 21 (1), 19–26.

Winter, M., Smith, C., Morris, P., Cicmil, S., 2006. Directions for future research in project management: the main findings of a UK government-funded research network. Int. J. Proj. Manag. 24 (8), 638–649.

Xia, W., Lee, G., 2005. Complexity of information systems development projects: conceptualization and measurement development. J. Manag. Inf. Syst. 22 (1), 45–83.

Xue, Y., Turner, J.R., Lecoeuvre, L., Anbari, F.T., 2013. Using results-based monitoring and evaluation to deliver results on key infrastructure projects in China. Glob. Bus. Perspect. 1 (Number 1).

Yin, R.K., 2013. Case Study Research: Design and Methods. SAGE Publications.

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