Research Focuses, Trends, and Major Findings on Project Complexity: A Bibliometric Network Analysis of 50 Years of Project Complexity Research

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ABSTRACT

This article analyzes the project complexity research field using bibliometric analysis. The field evolved in three waves (prior to 1985, between 1990 and 2004, and after 2005) from several disconnected seminal works, to a more centralized discussion that began based on efforts to characterize and classify complex projects to focus on the developing models and frameworks that, considering aspects of uncertainty and dynamics, supported managers to adapt and manage their projects. The findings suggest that project complexity is defined by dimensions that include structural, uncertainty, novelty, dynamics, pace, social-political, and regulative. The findings also suggest that the focus is changing from project control to project adaptability, and it is necessary to develop capabilities to manage complex projects, not only in the organization or at the team level, but also through the project's supply chain.

KEYWORDS: project complexity; capability; bibliometric analysis; intellectual base; research trends; research focuses

Project Management Journal, Vol. 49, No. 1, 42–56

Published online at www.pmi.org/PMJ

INTRODUCTION

The management of projects is one of the oldest and most remarkable activities carried out by humankind, resulting in achievements such as the pyramids, ancient cities, great cathedrals and mosques, the Great Wall of China, space exploration, the internet, and computers, among many other marvels and landmarks that show how project management has shaped our evolution through time (Morris, 1994). During the development of these kinds of projects, complexity is one aspect that is always present and it has systematically increased because of issues related to globalization, new technologies, fragmented supply chains, and the demand to deliver more ambitious and costlier projects (Project Management Institute, 2014). The effects of these phenomena in academia are that research and publications now elaborate on project complexity, creating a new field of investigation within the project management research field.

Despite its long existence as a practice (Morris, 1994), project management is a recent research field as an academic discipline (Bredillet, 2010). In universities, project management migrated from a technical perspective in engineering and later computing schools to a more recently managerial perspective in business schools (Bredillet, 2010). In the project management research field, authors such as Artto, Martinsuo, Gemünden, and Murtoaro (2009); Bredillet (2010); Suhonen and Paasivaara (2010); Söderlund (2011); Svejvig and Andersen (2015); Mok, Shen, and Yang (2015); Pollack and Adler (2015); and Li, Lu, Taylor, and Han (2017) have tried to review and consolidate the literature. Conversely, in the project complexity research field, only Thomé, Scavarda, Scavarda, and Thomé (2016) have analyzed the field using a systematic approach, such as bibliometric network analysis. However, their research does not cover a broad analysis of the topic; rather, it is focused on the similarities and differences of complexity, uncertainty, risks, and resilience in the supply chain and temporary multiorganization projects.

Given the lack of discussion and analysis regarding the structure, main findings, and research trends in the project complexity research field, a gap was left unaddressed and some questions remain, such as: What discussions were and are occurring within the project complexity research field? What are the research front terms used in the field? What are the main findings made by the intellectual base of the project complexity research field?

The purpose of this article is to present a bibliometric analysis of the project complexity research field, exploring the bibliographical network from different perspectives, such as cited references and keywords. This article differs from previous studies, as it does not focus on a specific industry or concept, as was done by Thomé, Scavarda, Scavarda, and Thomé (2016); rather, it uses the largest data set possible to present a broader and more precise image of the field. To achieve this objective, the article is organized as follows: The Methods section describes the methods used to search, appraise, and analyze the bibliometric data. The Results and Discussion section presents the findings, analysis, and discussion of the bibliometric analysis. Conclusions and suggested research agenda are presented in the last section.

Methods

Bibliometrics is a subset of scientometrics, which involves the analysis of publications and their properties (Gingras, 2016; Vinkler, 2010) and uses knowledge domain visualization to sense and monitor the development of a knowledge field. As described by Hook and Börner (2005), it can "provide a global view of a particular domain, the structural details of a domain, the salient characteristics of domains (its dynamics, most cited authors and papers, bursting concepts, etc.)" (p. 194). In this article, bibliometric analysis incorporates the method used to answer the research questions, uncovering the discussions, research front terms, main findings, and structure of the project complexity research field.

The quality of a bibliometric analysis is dependent on the quality of the input data set. Therefore, to approach the project complexity literature in an unbiased way, this article used the SALSA framework proposed by Booth, Papaioannou, and Sutton (2013) that embodies a process with four stages—namely, *Search*, *AppraisaL*, *Synthesis*, and *Analysis*, summarized by the mnemonic *SALSA*. These four stages formed the methodological process used in this article and are described in the following paragraphs.

Regarding the first stage, *search*, Booth et al. (2013) explained any search risks missing relevant items, given the parameters chosen to conduct the search. To minimize that problem, the search stage was conducted using the broadest possible terms related to project and program complexity. The Web of Science Core Collection was the main database used to search for the articles related to the topic. The keywords used were (project$ AND complexit*) OR "complex project$" OR (program$ AND complexit*) OR (programme$ AND complexit*) OR (complex program$) OR (complex programme$) in the topic field. This covers the title, abstract, and keywords, which was enough to uncover documents that approached this topic from several perspectives. The Web of Science indexes used were the Science Citation Index Expanded (SCI-EXPANDED), the Social Sciences Citation Index (SSCI), and the Emerging Sources Citation Index (ESCI). Indexes related to conference proceedings, book citations, and other kinds of sources were excluded from the search. Research areas and Web of Science categories related to biology, medicine, and health sciences that use the terms *complexity* and *project* to mention other situations unrelated to project management were excluded from the data set. Finally, the search results from the Web of Science were further refined to include only peer-reviewed articles and exclude other document types from the input data set, in order to contribute to the quality of the input data used in the bibliometric analysis. The output of the bibliometric analysis, on the other hand, contains all kind of documents. The activities executed to analyze the data (input–process–output) are described in the following paragraphs.

The second stage, *appraisal*, was developed based on the selection process presented by Booth et al. (2013). In this stage, the title, abstract, and, in some cases, full text identified in the first stage are sifted to guarantee the inclusion of only peer-reviewed articles related to the research topic. Given that the bibliometric analysis focuses on the structure of the research field, the full text sift was executed only when the title and the abstract were not sufficiently clear to decide on whether to include or exclude the document from the data set. During the appraisal stage, articles that used the keywords *programme* or *program* related to software, programming, or a policy, among other topics, were excluded. The same was done with the keyword *complexity* when it related to difficult (needing much effort or skill to accomplish, deal with, or understand) or computational complexity. This led to the extraction of 1,440 articles from Web of Science, ranging from the dates 1965 to 2016. These articles formed the input data.

The third stage, *synthesis*, was put in place to identify patterns in the research field, leading to the development of an analytical framework that comprised the examination of terms and citations, as illustrated in Figure 1. During the synthesis phase, the articles extracted in the second stage were used as the input data set and processed using the CiteSpace software, developed by Chen (2004) and improved by Chen (2006); Chen, Ibekwe-SanJuan, and Hou (2010); and Chen and Leydesdorff (2014); and the VOSViewer software, developed by van Eck and Waltman (2010). During the bibliometric analysis, all articles from the input data set and the documents cited by them were linked, creating a citation network composed of books, articles, and proceedings papers, among other sources. Therefore, the citation network represents the most relevant documents used by project and program complexity researchers and helps form the intellectual base, research front, and research-focus terms and clusters in the field. The intellectual base is formed by the documents cited by researchers and represents the foundation upon which researchers build. The research front, on the other hand, is composed by the citing documents and represents the leading understanding of topics in

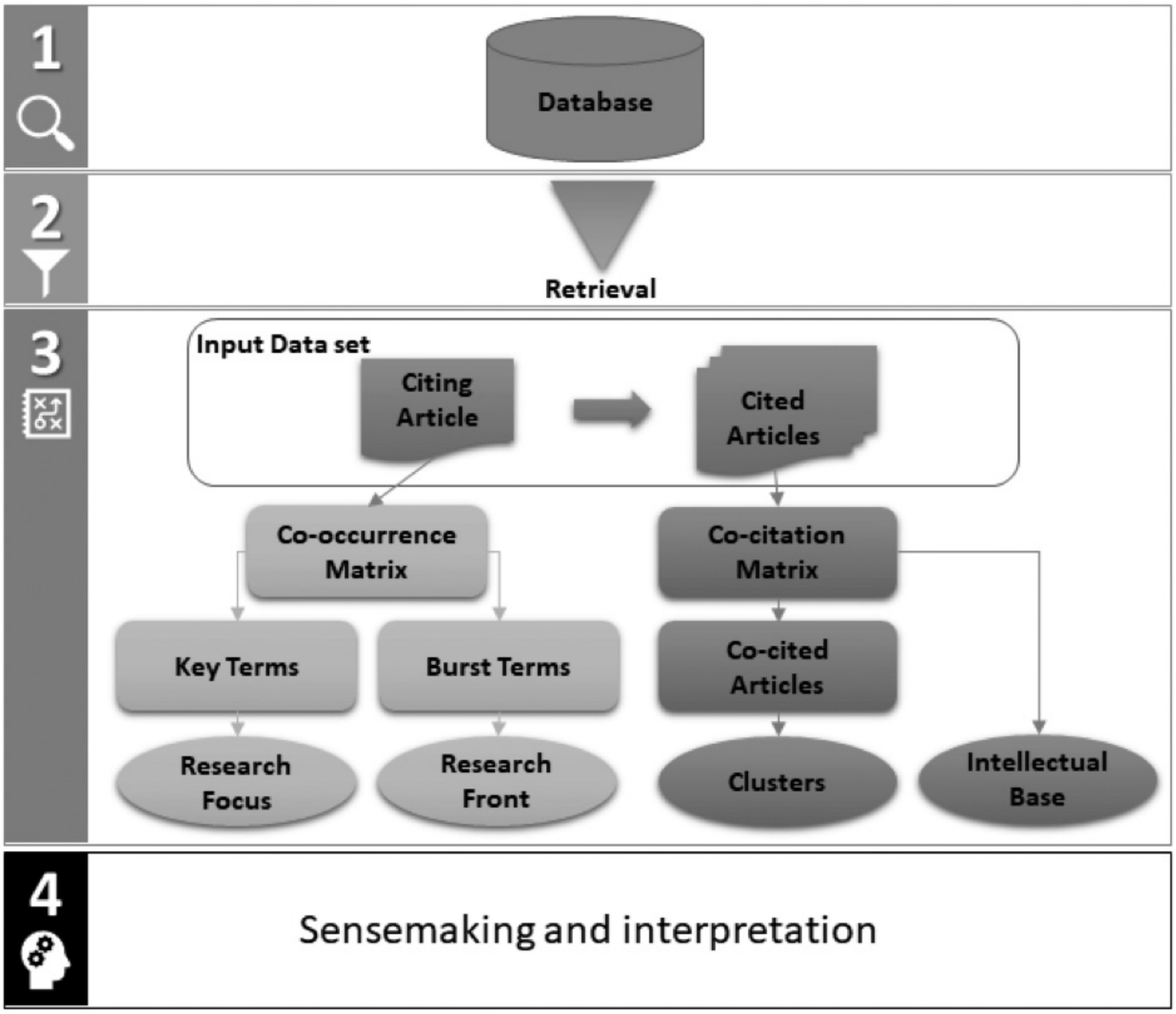

Figure 1: Methodological approach (adapted from Wang, Nathwani, & Wu, 2016).

a given period. A co-occurrence network of keywords chosen by researchers and journals was created to reveal the most relevant research keywords used by researchers and how interest and focus have changed over time.

The document citation and keywords networks were created using the 100 most cited documents of each five-year period between 1965 and 2016, which resulted in a network composed of 45,715 references. No pruning method was used to remove connections between documents. The networks created were examined using structural and temporal metrics, such as modularity and silhouette in the network level and betweenness centrality and burst detection in the document level. Modularity is attributed to the network and it measures, on a scale between 0 and 1, the "extent to which a network can be divided into independent blocks" (Chen et al., 2010, p. 8). A high modularity score indicates a well-structured network. The silhouette is a metric that ranges from −1 to 1 and it is used to estimate "the uncertainty involved in identifying the nature of a cluster" (Chen et al., 2010, p. 8), where 1 is a totally separated cluster. The betweenness centrality score was attributed to all nodes in the network; it measures "the extent to which the node is in the middle of a path that connects other nodes in the network" (Chen et al., 2010, p. 8), helping to identify potentially revolutionary scientific publications or connectors of different subjects (clusters). Burst detection is a temporal metric implemented by Kleinberg (2003) that identifies when a citation count of a particular article or keyword, depending on the network, has a statically significant surge, evidencing a change of focus or interest in that particular topic. The creation of such networks and the metrics calculated reveals the patterns and characteristics of the project and program complexity research field.

The fourth stage, the *analysis* of the networks, was conducted to understand the meaning of the patterns and data revealed during the synthesis stage. The sensemaking and interpretation of the data and patterns of the citation and co-occurrence networks helped us understand how arguments, interests, and research questions have evolved over time and what will tend to be the focus in the future.

Results and Discussion

This section presents the results from the bibliometric analysis and discusses their meanings from three perspectives, which leads to findings regarding the research focuses and research front terms at a macro level and the most relevant topics and ideas raised by the intellectual base in the field.

Research Focuses

The citation links among the articles revealed research focuses in the project complexity research field, given that those links establish conversations around specific topics. The project complexity research network is formed by 38 clusters or focuses with a modularity score of 0.7779, indicating a well-structured network. The network also has a mean silhouette score of 0.8724, indicating a low uncertainty level involving the identification of the nature of its clusters. The core of the network is characterized by several clusters with old documents and a main cluster with the most relevant discussions.

The structure and organization of the research field are illustrated in Figure 2, which groups documents with similar topics in clusters. The documents are represented by circles, as illustrated in the legend of Figure 2, which vary in size according to the number of citations received, highlighting the importance of the document and its cluster. The document circles are composed of different layers that represent the citations in a single time slice, indicating how the research community discussed that document over time. Moreover, the tones are also used to understand how the research field evolved, analyzing not only the documents, but also the citation links (year of the first co-citation) and groups (mean citee year) between them. In some cases, an external bold layer is added to the document to represent its betweenness centrality score, which is discussed later in this article.

Despite the variety of topics covered by the main focuses, several other topics are discussed in these clusters. Three main themes emerged from the analysis of these clusters: software development, new product development, and project complexity management. The software development theme was discussed in several clusters until 2000, such as numbers 03, 05, 06, 09, and 10, covering aspects such as complexity and software metrics, function point analysis, managing life cycle software production, systemic approach, software reuse, software engineering environment, software factories, software development groups, complexity and size of software systems, process maturity, and information systems development methods. The new product development theme was also composed of inactive clusters, such as numbers 01, 04, 08, 11, and 15, discussing important topics, such as concurrent engineering, complex engineering project, development cycle time, integrated project delivery, high-technology issues, product innovation, uncertainty, enhancing team performance, coordination structure, knowledge transfer, complex negotiation, and total quality until 1999. The project complexity management theme was composed of clusters 02, 12, 13, and 16, and they discussed topics such as resource-constrained projects, project scheduling, neural network, problem decomposition, problem-solving system coordination, interorganizational collaboration, governance, dynamic decisions, knowledge networks, delays, major projects, conflicts, and misperception until 2006. These themes and topics formed the foundation of the project complexity research field and some continue to be researched, although from another perspective in cluster 00, which is the current active focus and is focused on project complexity knowledge integration, project size, multiproject scheduling, resource constraints, complex engineering projects, and collaborative new product development teams.

The analysis of Figure 2 also reveals three periods in the life of the project complexity research field. The first is characterized by the production of few documents until 1989; although not directly related to project complexity, some of these documents are seminal works that introduced important ideas related to organizational structure and dynamics, innovation, major projects, system thinking, complexity theory, scheduling, and resource allocation. The second period, from 1990 to 2004, is characterized by a vibrant discussion about project complexity in several clusters, which led to the development of several of the most relevant documents in the field. During that period, the discussion started by peripheral clusters focused on scheduling, resource allocation, and programming rapidly converged to a central discussion regarding classifications of complex projects, organizational adaptability and learning, innovation, system dynamics, uncertainty, and ambiguity. The third and current period of discussion started in 2005 and is characterized by discussions on the central focus of the network, cluster 00, where the effort to classify complex projects during the second period was transformed into frameworks and models that incorporated aspects, such as uncertainty and system dynamics, which ultimately tried to measure complexity and find strategies or approaches to prepare organizations and managers to manage complex projects.

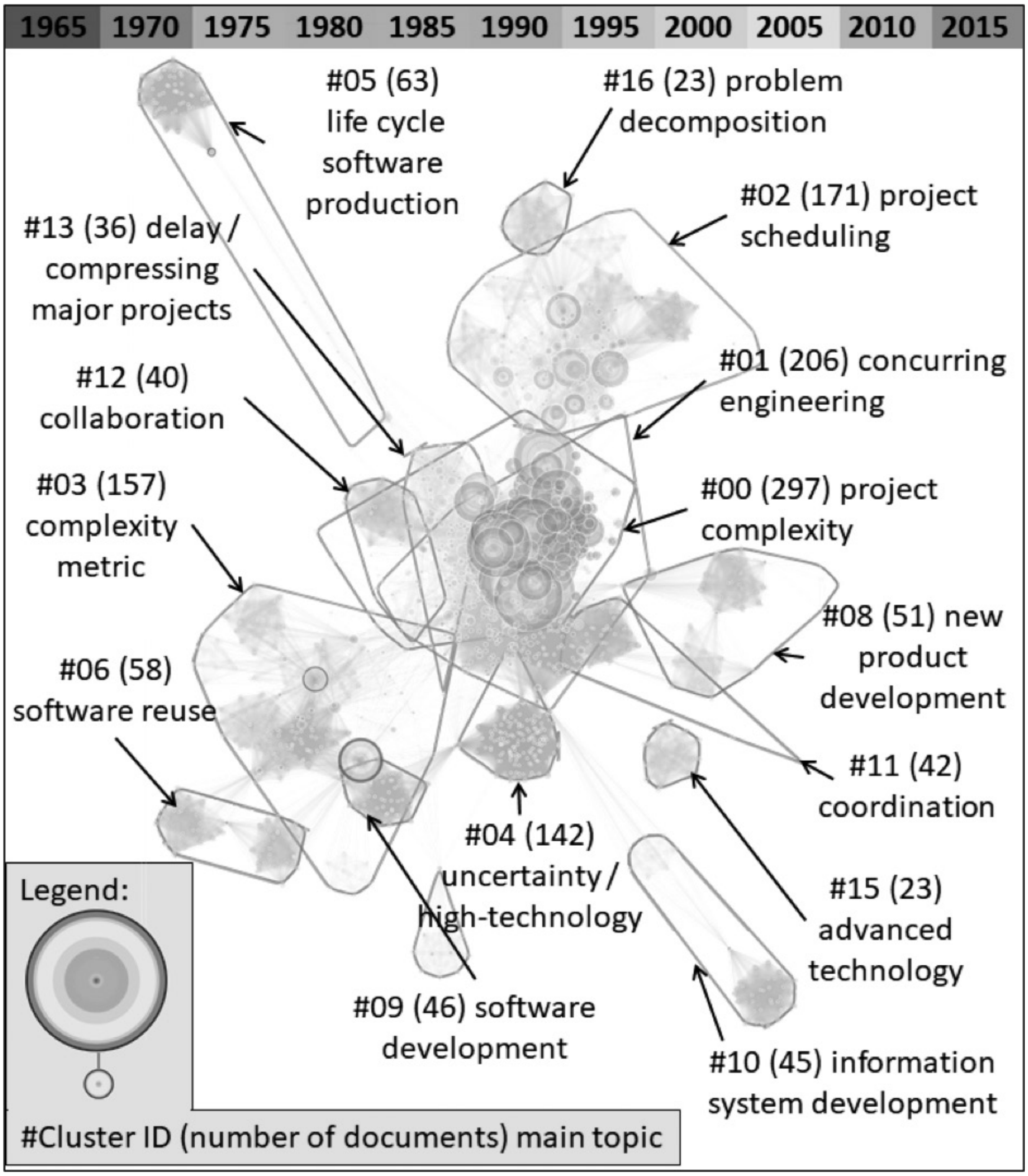

Figure 2: Project complexity research field focuses.

The focuses mentioned previously reveal the topics researched in the project complexity research field and how they evolved. The most mentioned topics and focuses over the past years show that the research field evolved from a disconnected collection of seminal works to a more centralized discussion, starting with the characterization and classification of complex projects to a focus on developing models and frameworks that considered aspects of uncertainty and dynamics and helped managers adapt and manage their projects. In summary, the themes discussed in the project complexity research field—namely, software development, new product development, and project complexity management—are aligned with Bredillet's (2010) statement that advanced studies in project management migrated from a technical perspective in engineering and later computing schools to a more recently managerial approach in business schools. The evolving periods of the project complexity research network also highlight the change in focus and the intensity of interest for more multidisciplinary discussions.

Research Trends

The change of focus in the research field is also captured by the choice of keywords made by the research front authors. The keywords most cited over the years are presented in Figure 3, and analysis shows that some topics shaped the research focus of the project complexity research field over the years. The keyword *model* has been the most mentioned. With other keywords, such as *framework* and *strategy*, it reveals a concern regarding the development and discussion of ways to understand and manage project complexity, especially during the third period of the field's life cycle. *System*, the second most commonly mentioned keyword, was frequently used to explain project complexity through the lens of systems theory. Along with the keywords *design* and *network*, the keyword *system* reveals a research stream that focuses on the importance of interdependences to project complexity since 2010. The keywords *performance*, *success*, and *optimization* show that researchers are concerned about the factors capable of affecting the performance of teams and organizations and the success of complex projects. The keyword *uncertainty* was associated with several other keywords and was usually used to highlight the research of a topic under uncertain situations. *Product development* is a research focus that has been present since the second period of the research field; it concerns the development process—in other words, project complexity during the execution phase. The keyword *innovation* was related to topics such as novelty, newness, and uncertainty in projects, and has been discussed since the second period of the field. The keywords *organization* and *knowledge* helped understand the social aspects related with project complexity, such as organizational structure, teamwork, learning, and knowledge management, among others. Keywords

Rank	Keyword	Total	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1	Model	198	5	6	6	10	13	15	16	17	26	27	31
2	System	182	4	6	8	5	17	21	15	16	24	20	27
3	Performance	158	5	5	3	7	12	12	18	13	17	18	32
4	Uncertainty	126	0	11	7	6	3	8	10	14	13	25	17
5	Design	125	0	6	2	11	7	12	11	11	13	14	15
6	Innovation	113	5	2	5	5	6	5	7	8	12	8	21
7	Product development	98	2	5	7	4	5	3	10	8	9	9	15
8	Organization	88	4	2	3	8	5	7	5	7	9	14	13
9	Framework	74	4	3	0	5	6	3	3	9	4	16	14
10	Knowledge	70	0	2	3	3	0	9	6	7	9	10	11
11	Success	65	0	2	4	0	0	3	10	16	15	12	8
12	Strategy	62	0	5	0	0	4	5	4	9	3	11	7
	Technology	62	3	4	0	2	0	5	4	6	7	2	9
13	Construction	59	0	0	2	0	5	10	3	6	8	11	10
14	Network	54	0	2	4	7	2	3	6	6	0	7	7
15	Optimization	53	0	3	0	2	3	2	3	7	8	10	9
16	Simulation	52	0	3	3	5	0	2	11	0	5	6	6

Figure 3: Most cited keywords.

Keyword	Strength	Begin	End	Burst Timeline: 1990–2016
metrics	5.5232	1992	2007	
algorithm	4.0438	1992	2000	
concurrent engineering	4.5401	1994	2003	
scheduling	3.4716	1994	2001	
technology	3.7757	1995	1998	
innovation	3.9344	1998	2006	
construction industry	3.9286	2000	2007	
prediction	3.8035	2000	2008	
validation	3.3825	2000	2009	
product development	3.3443	2001	2003	
project scheduling	3.9469	2006	2010	
risk analysis	3.3386	2007	2013	
allocation	3.4323	2010	2013	
system	3.8466	2010	2011	
architecture	3.486	2012	2014	
…	…	…	…	…
team	2.5579	2013	2016	
decision making	2.4701	2014	2016	
construction project	2.3319	2014	2016	
governance	2.8266	2014	2016	

Figure 4: Keywords citation burst between 1990 and 2016.

such as *technology*, *construction*, and *product development* highlighted industries affected by project complexity problems. The 16th keyword most mentioned is *simulation*, related to system dynamics, agent-based models, and risk simulations, among other things.

The most mentioned keywords in the past years are also the most mentioned keywords, with some minor changes in their rank, as shown in Figure 3. They constitute the research front terms in the project complexity research field and are the ideas that will shape the field in the future, especially the keywords in the top-right corner of Figure 3: *performance*, *model*, and *system*. Some new keywords, such as *complex project*, *supply chain*, *infrastructure project*, *public–private partnership*, and *dynamic capacity*, among other less cited keywords, were mentioned only from 2015 on, and may mark the beginning of a new research trend in project complexity. The term *complex projects* suggests the creation of a new category to classify projects, similar to the appearance of words, such as *mega-projects*, *major projects*, or *capital projects*. The keyword *supply chain* reveals that the research focus regarding project complexity is expanding from the organizational environment to the complete supply chain of the project. The term *infrastructure project* shows a concern regarding this kind of project and, to a certain extent, a parallel can be made with the keywords *product development*, *technology*, and *construction*, focusing on a specific industry or project. The term *public–private partnership* reveals research regarding this approach to deal with project complexity, especially in public infrastructure projects. *Dynamic capability* is related to the idea that organizations must adapt in a timely manner and react properly to changing situations that are common in complex projects, moving the research focus from control to adaptation.

Some keywords previously mentioned received more attention during a specific period, as highlighted by the burstiness strength score and timeline illustrated in Figure 4. The algorithm used to detect the burstiness strength of the keywords was calibrated to detect the keywords that have been trending in the last years, highlighting topics such as *team*, *decision making*, *construction project*, and *governance*. The keyword *team* specifies the general interest previously explained by the keyword *organization* and shows that the human aspect of project complexity is growing in interest. Increased complexity in the projects managed by organizations is leading to a growing interest in the "decision-making" process in scenarios of project complexity. Finally, the keyword *governance* reveals a growing interest in project complexity research at the project portfolio level.

The new discussions and the recently burst terms in the past years reveal the trends of the research front in the project complexity research field, highlighting the research being done now and what can be expected in the future. Recent trends show a change from control to adaptability when dealing with complex projects. There is a focus on developing capabilities, not only in the organization or at the team level, but also through the supply chain of the project to manage complex projects.

Intellectual Base

Chen (2006) argued that the research front can be considered state of the art in a field, and what was cited by the research front constitutes the intellectual base, or a "footprint in scientific literature, an evolving network of scientific publications cited by researchers," as explained by Wang et al. (2016, p. 2). Therefore, the intellectual base of project complexity is composed by the cited articles and, because of that, it constitutes the foundation of this field. The relevance of each document can be analyzed based on the citation count in the network, given that those links establish the conversations among authors and topics. Table 1 presents the most cited articles in the project complexity research field.

The articles mentioned in Table 1 highlight the main contributions to the project complexity research field and will be summarized from the oldest to the newest contribution to understand how authors used others' findings to build what we take for granted in project complexity today. The seminal work of Burns and Stalker (1961) contributed to the development of the contingency theory and presented the idea of mechanistic and organic organizational structures, arguing that organizations must use different organizational structures to cope with the level of dynamic and uncertainty in the environment they operate. Thompson (1967) used the ideas of Burns and Stalker (1961), among others, to explore several aspects of organizational theory, in particular, the contingency theory

Rank	Citations	Author/Date	Title
1	75	Baccarini (1996)	The concept of project complexity—a review
2	60	Thompson (1967)	Organizations in action; social science bases of administrative theory
3	54	Pich et al. (2002)	On uncertainty, ambiguity, and complexity in project management
4	50	Williams (1999)	The need for new paradigms for complex projects
5	47	Shenhar (2001)	One size does not fit all projects: Exploring classical contingency domains
6	46	Clark (1991)	Product development performance: Strategy, organization, and management in the world auto industry
7	41	Brucker, Drexl, Möhring, Neumann, and Pesch (1999)	Resource-constrained project scheduling: Notation, classification, models, and methods
8	40	Tatikonda and Rosenthal (2000)	Technology novelty, project complexity, and product development project execution success: A deeper look at task uncertainty in product innovation
9	39	Wheelwright and Clark (1992)	Revolutionizing product development: Quantum leaps in speed, efficiency, and quality
10	35	Eisenhardt and Tabrizi (1995)	Accelerating adaptive processes: Product innovation in the global computer industry
	35	Saaty (1980)	The analytic hierarchy process
11	34	Shenhar and Dvir (2007)	Reinventing project management: The diamond approach to successful growth and innovation
	34	Shenhar and Dvir (1996)	Toward a typological theory of project management
12	33	Henderson and Clark (1990)	Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms
13	28	Geraldi, Maylor, and Williams (2011)	Now, let's make it really complex (complicated)
	28	Burns and Stalker (1961)	The management of innovation
14	27	Sommer and Loch (2004)	Selectionism and learning in projects with complexity and unforeseeable uncertainty
	27	Engwall (2003)	No project is an island: Linking projects to history and context
	27	Flyvbjerg (2003)	Megaprojects and risk: An anatomy of ambition
	27	Morris (1987)	The anatomy of major projects: A study of the reality of project management
	27	Sterman (2000)	Business dynamics: Systems thinking and modeling for a complex world
	27	Cohen and Levinthal (1990)	Absorptive capacity: A new perspective on learning and innovation

Table 1: Most cited articles.

and the interdependencies between and within organizations—namely, pooled, sequential, and reciprocal interdependencies. In a different research stream, Saaty (1980) presented the Analytic Hierarchy Process (AHP), a tool that helps deal with complex decision making by reducing the complexity through a series of pairwise comparisons. Morris (1987) presented a series of case studies related to major project overruns and explored the idea of project success, analyzing project objectives and their viability, technical uncertainty and innovation, politics, community involvement, scheduling duration and urgency, financial, legal and contractual matters, and the structure of project implementation. Henderson and Clark (1990) presented the distinctions among modular, radical, incremental, and architectural innovation and, similar to Burns and Stalker (1961), argued that different people skills and organizations are always needed. Cohen and Levinthal (1990) presented the concept of absorptive capacity as the organizational and personal abilities of exploiting external knowledge, recognizing its value, assimilating it, and applying it internally. Clark (1991) presented several aspects of new product development projects, including topics related to problem solving, leadership styles, integration mechanisms, development time, product quality, technology newness, and performance, among others. Similar to Clark (1991), Wheelwright and Clark (1992) presented an extensive synthesis about new product development and discussed important lessons regarding project management, resource allocation, learning, and development capacity. Eisenhardt and Tabrizi (1995) studied the impact of two approaches in product innovation projects to cope with assumptions regarding uncertainty: the compression and experimental models. Baccarini (1996), the most cited document, presented a concept of project complexity and outlined it as organizational and technological complexity, stressing the aspects of interdependence (connection among elements of the project) and differentiation (quantity and/or variety of elements in the project) among the project complexity factors. Parallel to Baccarini (1996), Shenhar and Dvir (1996) and Shenhar (2001) presented a two-dimensional model based on system scope and technological uncertainty to classify projects and analyze the main characteristics of each kind of project. Shenhar and Dvir (2007) incorporated new complexity dimensions to what they named a diamond framework to express the effects of pace in projects, classifying it as regular, fast-competitive, critical or blitz, and novelty, classifying it as derivative, platform, or breakthrough. Williams (1999) reviewed the main discussions in the field and explained project complexity in two dimensions—namely, structural complexity, as presented by Baccarini (1996), and uncertainty, dividing the latter into uncertainty of goals and uncertainty of methods. In the scheduling and resource allocation research stream, Brucker, Drexl, Möhring, Neumann, and Pesch (1999) described a classification scheme and provided a unified notation that helps study the resource-constrained project scheduling problem. Tatikonda and Rosenthal (2000) researched the correlation among technology novelty (product and process technology novelty), project complexity (technology interdependence, objective novelty, and project difficulty), and achievement of objectives (technical performance, unit cost, time to market, and combination of objectives). Sterman (2000) is a seminal work, regarding system dynamics that brought several concepts, tools, and examples of the application of system dynamics to solve complex problems, including complex projects. Pich et al. (2002) discussed the differences among uncertainty, ambiguity, and complexity, and presented the strategies to cope with those aspects—namely, instructionism, learning, and selectionism—similar to Cohen and Levinthal (1990) and Eisenhardt and Tabrizi (1995). Engwall (2003) argued that projects must be analyzed based on the context and its history, bringing important ideas regarding the role of pre-project politics, experiences from the past, institutionalized norms, consequences to the post-project future, technical content of the project mission, and events occurring in parallel in the context of the project. Flyvbjerg (2003) presented several characteristics and risks involving megaprojects and discussed the role of confirmation bias and strategic misrepresentation in megaprojects, especially because of the political history of the project, as also argued by Engwall (2003). Similar to Pich et al. (2002), Sommer and Loch (2004) compared the advantages of selectionism and learning as strategies to cope with innovation in situations facing unforeseeable uncertainty and complexity. Finally, Geraldi et al. (2011) summarized the findings of several of the previously mentioned authors and developed a framework composed of five dimensions of project complexity: structural, uncertainty, dynamics, pace, and social political complexity.

Some focuses illustrated in Figure 2 are connected by articles with a higher betweenness centrality score. According to Chen (2006), “nodes with high-betweenness centrality tend to be found in paths connecting different clusters” (p. 362) and can help identify a pivotal point in the research field. The project complexity research network has only two articles related to software development with a betweenness centrality score worth mentioning: Boehm (1981) and McCabe (1976). Boehm (1981) is an important book that introduced a method to quantify the cost of developing and maintaining software. McCabe (1976) discussed the measurement of software complexity using concepts from graph theory, arguing that “complexity is independent of physical size (adding or subtracting functional statements leaves complexity unchanged) and complexity depends only on the decision structure of a program," (p. 308) so an argument based on a systemic perspective of complexity in terms of differentiation and interdependency.

The articles mentioned in Table 1 constitute some of the most relevant references in the intellectual base of project complexity research field. However, some references received considerable attention from researchers during specific periods, despite not having the highest citations scores, as detailed in Figure 5.

Some documents with strong burstness scores were also ranked as the most cited documents in the network, such as (in order of strength of the score) Baccarini (1996), Geraldi et al. (2011), Shenhar (2001), Flyvbjerg (2003), Shenhar and Dvir (2007), Pich et al. (2002), Williams (1999), and Eisenhardt and Tabrizi (1995), and because of that, will not be discussed further. Conversely, the remaining documents are presented in chronological order to help understand how knowledge accumulated. Simon's (1962) seminal article explored the role of hierarchy in complex systems, arguing that complex systems exhibit a hierarchical structure as is commonly observed in nature, because complexity evolved from simplicity. Steward (1981) introduced an important tool to manage complex projects, the Design Structure System, which helped managers determine the interdependencies among variables to make decisions about their projects. Kolisch, Sprecher, and Drexl (1995) described a project generator capable of creating instances to help research on project scheduling problems, based on several project characteristics. Browning (2001), based on Steward (1981) and others, developed the Design Structure Matrix (DSM) as a tool to manage complex projects, presenting four alternatives of DSMs—namely, component-based DSM, team-based or organizational DSM, activity-based or schedule DSM, and parameter-based DSM. Williams (2005) reviewed traditional and flexible project management methods or philosophies to understand why projects fail and concluded that projects are subject to structural complexity, uncertainty, and severe time limitations, then suggested that a balance between those methods would be necessary and should depend on the project's complexity. Loch, De Meyer, and Pich (2006) approached project complexity through structural complexity, using DSM, and uncertainty, using learning and selectionism as strategies. Danilovic and Browning (2007) developed the Domain Mapping Matrix, a method to integrate two or more Design Structure Matrices and cope with complexities created by interdependencies among several aspects of the project. Thomas and Mengel (2008) analyzed the evolution of project management and project management education to present the requirements for preparing project managers to deal with complexity. Finally, Whitty and Maylor (2009) analyzed the competency standard for complex project managers developed by the College of Complex Project Managers and concluded that complex projects can be described in terms of dynamic and structural complexity and suggested that "personal skills, competencies, thinking processes, attitudes and abilities that underpin high performance in

Author(s)/Date	Strength	Begin	End	Burst Timeline: 1965–2016
Kolisch, Sprecher, and Drexl (1995)	6.0960	1999	2010	
Steward (1981)	6.1476	2003	2014	
Eisenhardt and Tabrizi (1995)	6.0121	2005	2010	
Browning (2001)	6.7541	2006	2013	
Pich et al. (2002)	7.1937	2007	2016	
Williams (1999)	6.3459	2008	2016	
Shenhar (2001)	7.8145	2008	2016	
Baccarini (1996)	13.1121	2008	2016	
Shenhar and Dvir (2007)	7.2018	2009	2016	
Simon (1962)	6.3308	2010	2014	
Williams (2005)	6.7187	2010	2016	
Danilovic and Browning (2007)	6.3352	2011	2014	
Whitty and Maylor (2009)	6.6854	2011	2016	
Thomas and Mengel (2008)	6.7801	2011	2016	
Geraldi et al. (2011)	10.2296	2013	2016	
Flyvbjerg (2003)	7.7420	2013	2016	
Loch, De Meyer, and Pich (2006)	6.0044	2013	2016	

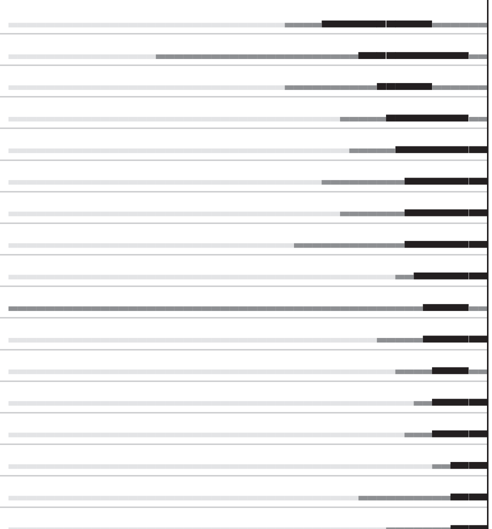

Figure 5: Document citation burst between 1965 and 2016.

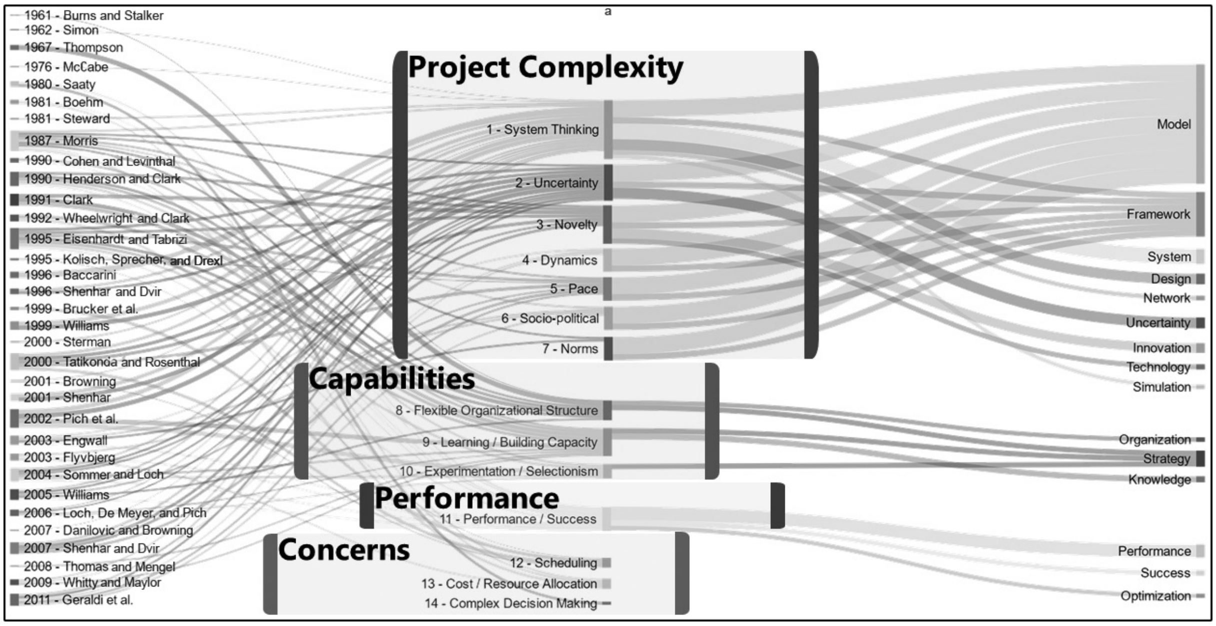

Figure 6: Major topics in project complexity research.

complex projects" (p. 309) should be considered.

The combination of the findings identified and discussed in the project complexity intellectual base and in the research trends revealed patterns in the project complexity research field. Figure 6 illustrates these patterns. It is composed of a timeline of the intellectual base on the left side, the research trends on the right side, and the most relevant ideas in the project complexity research field in the center.

The documents most cited—with higher betweenness centrality and with a strong citation burst score—help underline the intellectual base of the project complexity research field. The key trends in the field also strengthen the patterns highlighted by the intellectual base, suggesting that researchers usually approach project complexity research questions from four perspectives: project complexity, capabilities, performance, and concerns. The first perspective, project complexity, reveals that it is possible to analyze a complex project from different dimensions—namely, structural, uncertainty, novelty, dynamics, pace, social- political, and regulative complexity. There is no consensus regarding the concept of project complexity, although the dimensions highlighted by the first perspective can be used to conceptualize project complexity as a condition of a project, where many interdependent parts interact, leading it to experience a nonlinear emergent behavior that can be explained only by principles and patterns, given uncertain, novel, dynamic, paced, social-political, and regulative issues. The second perspective shows that, to manage a complex project, it is necessary to build capabilities related to people, organizations, and into the supply chain and to adopt strategies to integrate, learn, or select the best solution ex-post. The assumption of using capabilities to manage project complexity underline the notion that project complexity is not a condition that could be analyzed in isolation; conversely, project complexity is a condition in which the perception of it depends on the capability of the structure put in place to manage it, and this capability depends on the perception of project complexity, resulting in interactive feedback between project complexity and capabilities. The third perspective reveals the constant pursuit of better performance and success in complex projects, and results from project complexity and the capability faced. The fourth and last perspective highlights important concerns of researchers in regard to project complexity—namely, the need to address scheduling, cost, resource allocation, and complex decision-making problems.

Conclusion

The purpose of this article was to fill the gap regarding the structure, main findings, and research trends in the project complexity research field, answering questions, such as: What discussions were and are occurring in the project complexity research field? What are the research front terms used in the field? What are the main findings made by the intellectual base of the project complexity research field?

The methodological approach used to answer these questions was designed using the SALSA framework (Booth et al., 2013) to approach the data set in a systematic way and the bibliometric network analysis to analyze the 1,440 articles extracted from the Web of Science database from 1966 to 2016. The data set was analyzed using CiteSpace (Chen, 2004) and VOSViewer (van Eck & Waltman, 2010) to explore the research field through the lens of document and keyword citation analysis.

The findings from the bibliometric analysis revealed that the project complexity research field evolved in three waves. The first, prior to 1985, focused on organizational structure and dynamics, innovation, major projects, system thinking, complexity theory, scheduling, and resource allocation. The second wave, from 1990 to 2004, was characterized by numerous interconnected articles focusing on topics such as scheduling, resource allocation, and programming, and rapidly converged toward a central discussion regarding classifications of complex projects, organizational adaptability and learning, innovation, system dynamics, uncertainty, and ambiguity. The third and current wave began in 2005 and discussed topics such as project complexity, knowledge integration, project size, multiproject scheduling, resource constraints, complex engineering projects, and collaborative new product development teams. In summary, the project complexity research field evolved from several disconnected seminal works to a more centralized discussion that began based on efforts to characterize and classify complex projects to focus on the developing models and frameworks that, considering aspects of uncertainty and dynamic, supported managers in adapting and managing their projects. These trends in the research focus are confirmed by current research front terms, such as *model*, *performance*, *system*, *uncertainty*, *framework*, *design*, *innovation*, and *organization*, among others.

Based on the research focus and research front terms used, it is possible to conclude that the focus is changing from project control to project adaptability when dealing with complex projects, and it is necessary to develop capabilities to manage complex projects, not only in the organization or at the team level, but also through the project's supply chain. These conclusions are also rooted in the intellectual base findings, which suggest that project complexity is defined by structural, uncertainty, novelty, dynamics, pace, social-political, and regulative complexity dimensions; and because of that, different capabilities must be developed at all levels of the project and strategies, such as learning, selectionism, and integration, to cope with project complexity and improve performance and success.

Given the limitations created by the aims of this research, it would be fruitful to pursue research on questions deriving from it, such as: How can the project complexity dimensions be used to analyze a project? What are the capabilities used in a project complexity scenario? How do those capacities affect the performance and success of complex projects? A possible direction to address these questions would be to review articles identified in the project complexity intellectual base to consolidate the main articles in the field and develop a comprehensive model to analyze complex projects. It would be productive to identify the main personal, organizational, and supplier capabilities needed to support the execution of a complex project and correlate it with project complexity factors to understand the impact on performance and success. It would also be productive to review recent articles related to the project complexity research front terms to understand recent discussions taking place and expanding the project complexity research frontier.

The findings uncovered by this article summarize and fill the existing gap in the literature regarding the structure, main findings, and research trends in the project complexity research field. The implications to practitioners and researchers are that they can use the identified intellectual base and the research focuses and trends to understand the main topics researched thus far, to know the questions the research front is trying to answer, and then engage in the debate more effectively. Researchers can use these findings to develop their research, based on the most relevant trends and using the most relevant findings in the field.

Acknowledgments

The authors are grateful for the suggestions provided by the editorial board and the anonymous reviewers. We would also like to thank Dr. Paul Chan, Dr. Fiona Saunders, and Dr. Richard Kirkham for their helpful feedback during the initial discussions regarding this article.

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Research Focuses, Trends, and Major Findings on Project Complexity

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