Construction Project Complexity: Research Trends and Implications

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Abstract: The rapid growth of complex projects in the construction industry worldwide has triggered a growing number of studies over the past two decades, suggesting that understanding project complexity is a key component of successful construction project management. This study aims to investigate the status and trends in project complexity research through a four-stage literature review that can benefit both researchers and practitioners. Seventy-four relevant articles were identified from studies published during the years 1996–2015, and results indicate that research in construction project complexity primarily focuses on four areas: influencing factors contributing to project complexity, the impact of project complexity, complexity measurement methods, and considerations for managing project complexity. Future research should concentrate on specific factors that drive complexity for different types of construction projects and the development of management guidelines for addressing complexity throughout the project lifecycle. This paper provides both a timely summary of literature in the area of project complexity and insights into opportunities for future study of and guidance for successfully managing complexity in construction projects. **DOI:** 10.1061/(ASCE)CO.1943-7862.0001306. *© 2017 American Society of Civil Engineers.*

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Introduction

In recent years, the construction industry has seen rapid growth in projects of increasing size and complexity. For example, rapid urbanization has increased the number of mega construction projects in all parts of the world, with each mega project costing over US$700 million (He et al. 2015; Hu et al. 2012). These projects are usually very complicated in nature (Chan et al. 2004). Project complexity increases as a result of rapid changes in environment, increased product complexity, and increased time pressure (Williams 1999). Mega projects are usually beset with low performance outcomes, such as cost overruns and schedule delays (Thomas and Mengel 2008), partly because of their increasing complexity and underestimation of this complexity (Williams 1999).

Many studies have shown that project success is dependent on the complexity of a project and that traditional project management methods are not enough to properly address this complexity (Remington and Pollack 2007). Proper understanding of project complexity is essential to ensure effective management; therefore, much research has been undertaken on this subject. Because new researchers rely, in part, on findings from previous studies, a systematic analysis of recent literature would assist researchers in assessing the current status of and future trends in this topic (Tsai and Wen 2005).

This study explores the current literature on construction project complexity in terms of (1) defining complexity, (2) assessing new and innovative research, and (3) identifying potential areas for future research. Twenty years of project complexity research is summarized as it pertains to defining project complexity, determining factors influencing complexity and their impact on project outcomes, measuring complexity, and understanding better ways to manage project complexity. Through this structure, the authors hope to provide both a timely summary of literature in the area of project complexity and insights into opportunities for future study of and guidance for successfully managing complexity in construction projects.

Defining Project Complexity

While research on the concept of project complexity has been conducted for years, there is a lack of consensus on what constitutes project complexity since it is a term that is difficult to define and even harder to quantify; consequently, the concept of project complexity is not entirely clear. Interest in the complex dimensions of projects is fairly new; significant efforts in the study of project complexity began in the late 1990s (Baccarini 1996). Baccarini (1996, p. 202) defined project complexity as "consisting of many varied interrelated parts," which can be characterized in terms of differentiation and interdependency. *Differentiation* is the number of varied components in a project (e.g., tasks, specialists, subsystems, and parts), and *interdependency* is the degree of interlinkages between these components. Williams (1999) highlighted project complexity as structural complexity, or the number and interdependence of those components (following a paper by Baccarini 1996) and uncertainty in goals and means. Other researchers regard project complexity as a subjective and highly dynamic concept. The components making up a project system can react/interact with one another in

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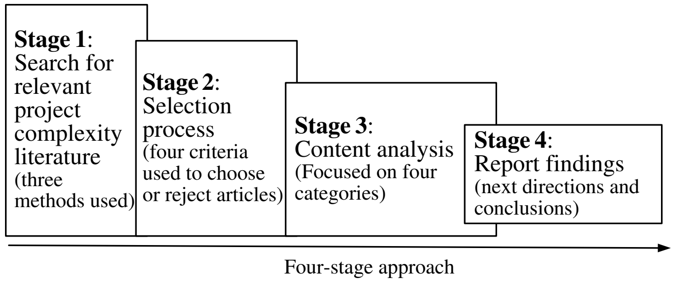

Fig. 1. Research process for conducting literature review related to project complexity

different, often unpredictable ways. Vidal et al. (2011, p. 719) proposed, "Project complexity is the property of a project which makes it difficult to understand, foresee and keep under control its overall behavior, even when given reasonably complete information about the project system." In fact, complexity has been recently addressed as one of the most relevant topics in project management research (Cicmil et al. 2006).

Many project managers use the term *complex projects* to describe the projects they manage, yet there is no clear agreement as to contributing factors. A distinction, however, should be made between *complex projects* and *project complexity*, also referred to as the complexity of a project. The first term refers to a specific class of projects (namely, the complex ones), and the latter term focuses on which aspects define a project as complex (Bosch-Rekveldt 2011). As mentioned above, this has not currently been established, but it is necessary to provide some threshold for the inevitable notion that most projects possess some degree of complexity. Thus, complexity is a variable rather than a binary commodity, and without measures for it, it is a term that is less than helpful, particularly when being used to prescribe what is and is not a complex project (Whitty and Maylor 2009).

This becomes clear even in a brief attempt to express and summarize the differences among the concepts of uncertainty, risk, and complexity (Bosch-Rekveldt 2011). Risk is an important contributor to project complexity (Turner and Cochrane 1993). The number of risks and/or their probability and impact can be assumed to contribute to project complexity (Bosch-Rekveldt 2011). Uncertainty can also contribute to project complexity (Sommer and Loch 2004). Sommer and Loch (2004, p. 1343) define complexity as having "two dimensions: system size (the number of influence variables) and the number of interactions among influence variables. Unforeseeable uncertainty refers to the inability to recognize influence variables or interactions at the outset." In a sense, complexity is a project characteristic, and a project could be characterized by its complexity footprint (Bosch-Rekveldt 2011).

Research Methodology

To acquire a more thorough understanding of investigations and findings on project complexity, this study carried out a four-stage literature review to conduct a content analysis of project complexity research (Suhonen and Paasivaara 2011), which is presented in Fig. 1. These research stages partially overlap.

Stage 1: Search for Relevant Project Complexity Literature

Relevant refereed publications were identified and gathered using the following three methods:

1. A comprehensive search was conducted under the *title/abstract/keyword* field from several online databases for the years 1996–2015, including Web of Science, EI Compendex, Google Scholar, and PQDD. The search was limited by using the phrases *project complexity*, *construction*, and *complexity* and subject areas such as *construction management*; *business, management, and accounting*; *decision sciences*; *economics, econometrics, and finance*; *engineering*; *environmental science*; and *social sciences*, with the document type *article or review*.
2. The top journals in the field of construction management were reviewed including Journal of Construction Engineering and Management; International Journal of Project Management; Construction Management and Economics; Journal of Management in Engineering; and Engineering, Construction and Architectural Management. Most of these journals were among the top eight journals in Wing's (1997) ranking.
3. A thorough review of references listed in the publications were identified using the previous two methods.

This approach ensured that no significant sources were missed and resulted in considerable overlap. To refine the number of articles, the researchers used the software program *Endnote version 4* to find and delete duplicate article listings (Smith 2000).

Stage 2: Selection Process

After potential articles were identified, the selection process continued, with an analysis of an article's title and abstract, or, if these did not provide enough information, a full-text analysis. The following criteria were chosen to accept articles:

1. Selected articles that directly addressed project complexity in project management. Papers not related to construction projects (e.g., related to product development), research and organizational change projects, and application software development were eliminated (Turner and Cochrane 1993).
2. Articles published under the broad categories of *editorial*, *book review*, *discussions and closures*, and *letter to the editor* were excluded from the analysis.
3. Articles that did not study project complexity but used complex environments as a context to study some other phenomena were also excluded.
4. Article results that presented duplicate findings, but in different forms (e.g., a journal article and a conference paper), were refined so that journal articles were selected (when available).

After the search and selection process was completed, 74 published articles (including conference papers) and 11 theses and dissertations were identified. Considering most dissertations are often published as multiple journal articles, this literature review primarily centers on journal articles and conference papers. The number of papers published annually over the selected period, presented in Fig. 2, demonstrates that research on construction project complexity is increasing. On average, there have been approximately four papers published per year since 1996, with a majority published after 2004. This interest may coincide with the growing number of large-scale projects designed and constructed worldwide.

Stage 3: Content Analysis

After identifying articles pertinent to this study, a closer analysis of their content was conducted to determine current themes in complexity research. It was found that research interests in project complexity have focused on four areas: influencing factors contributing to project complexity, the impact and implications of project complexity, measurement methods, and management of project

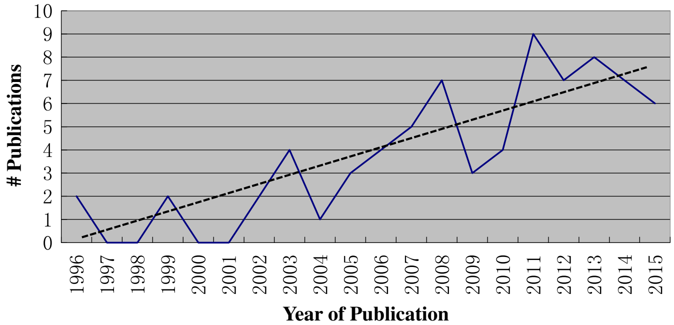

Fig. 2. Number of relevant project complexity papers published annually

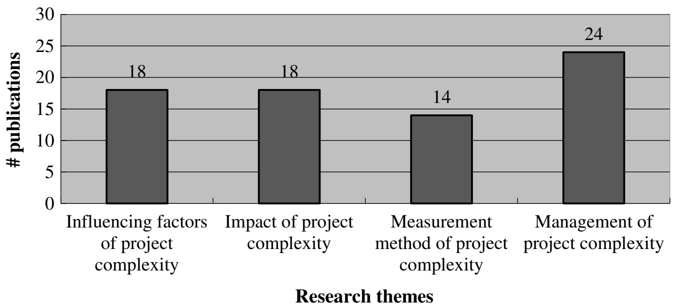

Fig. 3. Current research interests by category pertaining to project complexity

complexity. The category distribution of research themes in project complexity is shown in Fig. 3.

Stage 4: Report Findings

A closer analysis of research interests was conducted, and the research trends of project complexity for construction projects were explored. Finally, the findings were examined for conclusions and possible future research directions.

Literature Review Framework and Results

Research Framework

The overall research framework to study project complexity (shown in Fig. 4) covers the main areas of project complexity as follows: Influencing factors contributing to project complexity by category, impact and implications of project complexity, measurement methods for project complexity, and management of project complexity (distinct from complex project management). This framework shows how certain influencing factors (A) cause various levels of project complexity (B), which, in turn, have an impact on the project results (C). Various methods can be used to measure the extent of complexity (D) with the goal to establish appropriate project management mitigation strategies (E). The literature review is conducted in each of these key areas.

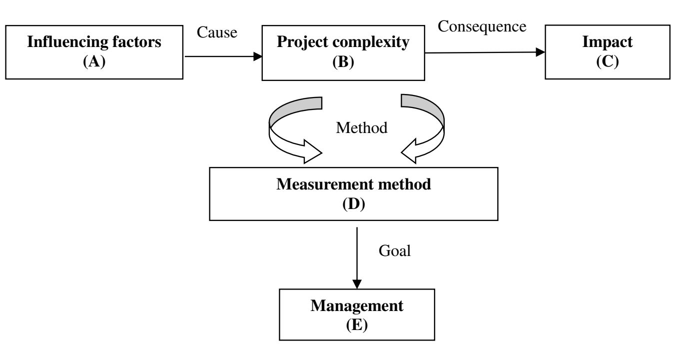

Fig. 4. Framework of current project complexity research

Results

Influencing Factors Contributing to Project Complexity by Category

The majority of project complexity research attempts to determine which elements make a project complex. After defining a project's complexity, a traditional study of project complexity analyzes the influencing factors on the project as a whole. Although there is an implicit acknowledgment among practitioners and academics that construction projects are becoming more complex, there is still a great deal of confusion about the factors driving this complexity (Bosch-Rekveldt 2011). Much recent scholarship has concentrated on the influencing factors and categories of project complexity. Fig. 5 shows a timeline of project complexity research and the interrelationships among studies, divided into influencing factors (e.g., interdependency, uncertainty factors, and organization interactions) and complexity categories pertaining to organizational complexity and technological complexity. Key relationships among research studies are shown by lines and arrows.

Gidado (1996) placed the sources of project complexity into two categories. Category I consists of the components that are inherent to the operation of individual tasks; these may originate from either the resources employed or the environment and include inherent complexity (e.g., technical complexity, analyzability, and task difficulty) and uncertainty factors. Category II is composed of the components necessary to form a workflow, including interdependencies among different kinds of technologies (with or without repetitive roles), rigidity of sequence, and overlap of construction elements. Based on these categories, Williams (1999) defined the number and interdependence of elements as structural complexity, adding the additional factor of uncertainty in goals and means.

Many scholars continued to do further study on the influencing factors of complexity, such as Remington and Pollack (2007), who divided influencing factors into four dimensions: experience and ability of organization members, project organizational structure and its exchange and coordination with other key participants, project culture, and project business process. Maylor et al. (2008) identified the elements of complexity in project management as the project's mission, organization, delivery, stakeholders, and team. Vidal (2008) classified the principal factors as project size, project variety, project interdependence, and project context. Wood and Ashton (2010a) identified six main project complexity influencing factors: organizational complexity, uncertainty, overlap of construction elements, inherent complexity, rigidity of sequence, and number of trades. Lebcir and Choudrie (2011) also designed a project complexity framework, which includes four factors driving project complexity in construction projects: project uncertainty, infrastructure newness, infrastructure interconnectivity, and infrastructure size. Xia and Chan (2012) identified six key measures of project complexity for building projects: (1) building structure and function, (2) construction method(s), (3) urgency of the project schedule, (4) project size/scale, (5) geological conditions, and (6) neighboring environment. Expanding on the traditional three-dimensional (cost, schedule, technical) project management approach, Shane et al. (2015) developed a five-dimensional model,

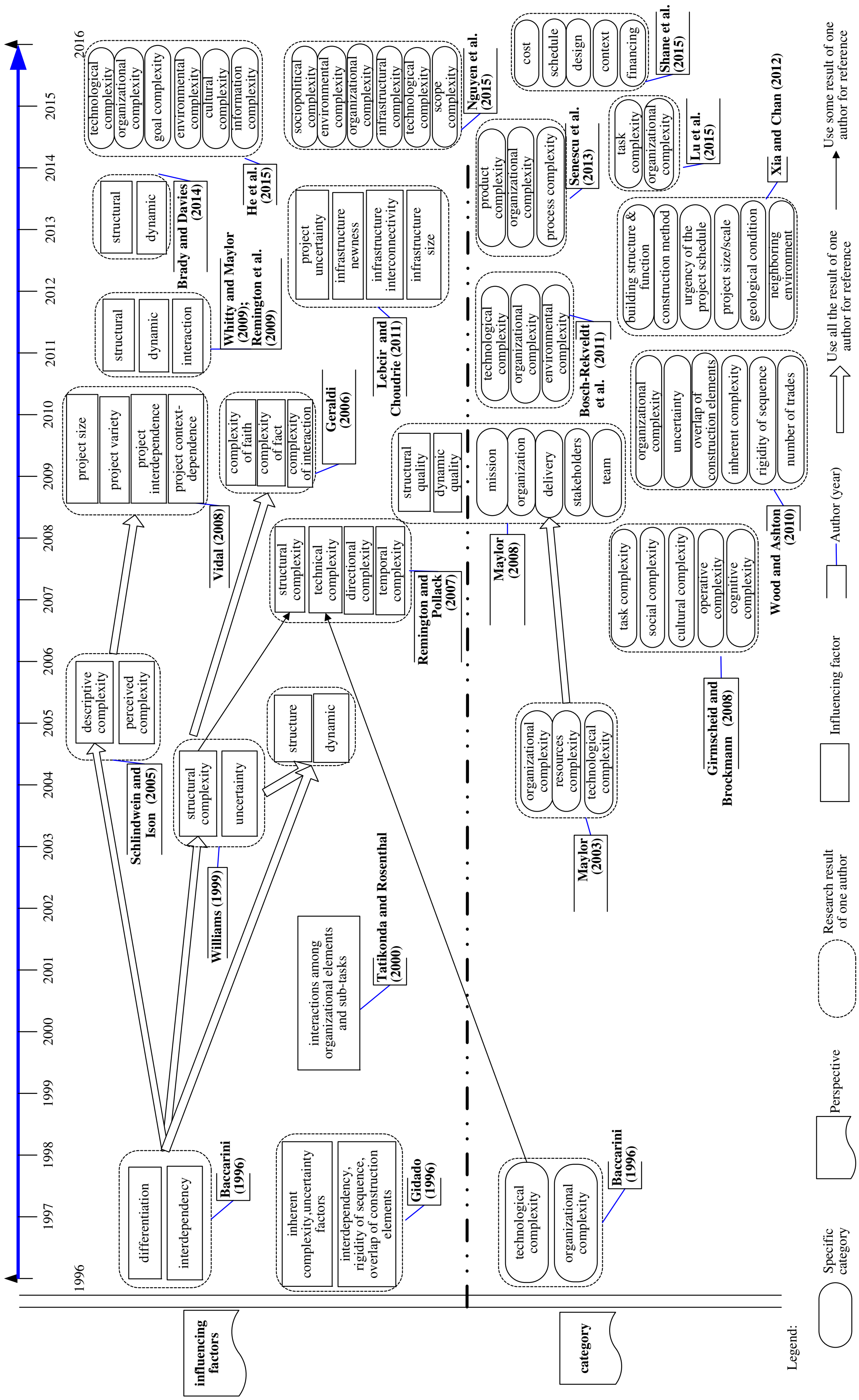

Fig. 5. Project complexity influencing factors and categories

adding context and finance, which were previously regarded as external risks.

From the above findings, it can be seen that most scholars emphasized the interdependency among the project components and their effects on project complexity (Gidado 1996; Tatikonda and Rosenthal 2000). Moreover, interactions among the project elements (Whitty and Maylor 2009), dynamic nature of project elements (Williams 1999), and the lack of clear project goals (Gidado 1996) are the important factors influencing project complexity. Thus, project complexity, as an attribute of construction projects, is a result of interactions among numerous and varied elements that are structural, dynamic, and uncertain in nature.

In addition, one overarching classification of project complexity does not exist. When referring to project complexity, it is important to clearly state the type of complexity being discussed (Baccarini 1996). Therefore, some scholars have tried to disaggregate project complexity and explore specific types of project complexity (Table 1). While most research has presented different categories of project complexity, there is general consensus on certain larger classifications, such as organizational complexity (Baccarini 1996; Bosch-Rekveldt et al. 2011) and technological complexity (Baccarini 1996; Bosch-Rekveldt et al. 2011).

Impact and Implications of Project Complexity on Project Performance

Research on the impact and implications of project complexity has primarily investigated the direct effect of project complexity on team communication and project performance. In their analysis on team communication, Senescu et al. (2013) proposed a trend between increased product, organization, and process (POP) complexity and increased communication challenges in the architecture, engineering, and construction industry. Through a case study, they found that communication problems increase as complexity increases. Antoniadis et al. (2009) argued that the effects of complexity on project team selection can enable the development and implementation of project actions. This promotes efficient complexity management of interconnected structures that link various objects, rather than management of the objects themselves. Their results showed that as project complexity (e.g., multiplicity and ambiguity) increases, higher and more sophisticated communication levels are needed to achieve optimal performance; a project activity's complexity can actually be reduced with an increase in workers' and project managers' experience and skill.

In a large-scale study on project performance, Puddicombe (2012) undertook an analysis of more than 1,300 projects and

Table 1. Types of Project Complexity

Researcher (year)	Types of project complexity
Baccarini (1996)	*Organizational* complexity (the vertical and horizontal differentiation, and the degree of operational interdependencies and interaction among the project organizational elements) and *technological* complexity (the variety or diversity of some aspect of a task, and interdependencies among tasks and teams)
Maylor (2003)	*Organizational* complexity (including the number of members, departments, organizations, regions, nations, languages, time zones, level of the organization, and power structure); *technological* complexity (including technology, innovation system, uncertainty of the process or demand); and *resource* complexity (including project scale and budget size)
Geraldi (2008)	*Complexity of fact* (refers to the complexity in dealing with a very large amount of interdependent information), *complexity of faith* (refers to the complexity involved in creating something unique or solving new problems), and *complexity of interaction* (interfaces among systems or locations of complexity)
Girmscheid and Brockmann (2008)	*Task* complexity (density of activities in a spatial and temporal frame), social complexity (number and diversity of actors), *cultural* complexity (diversity of the cultural human mindset), *operative* complexity (the degree of independence when defining operations to achieve given goals), and *cognitive* complexity (the level of a person or a group)
Remington and Pollack (2007)	*Technical* complexity (interconnection among multiple interdependent solution options); *structural* complexity (difficulty in managing and keeping track of the large number of different interconnected tasks and activities); *directional* complexity (ambiguity related to multiple potential interpretations of goals and objectives); and *temporal* complexity (uncertainty regarding future constraints, the expectation of change, and possibly even concern regarding the future existence of the system)
Bosch-Rekveldt et al. (2011)	*Organizational* complexity (including size, resources, project team, trust, and risk); *technological* complexity (including goals, scope, tasks, experience, and risk); and *environmental* complexity (including stakeholders, location, market conditions, and risk)
Senescu et al. (2013)	*Organizational* complexity (organizational multiplicity and organizational openness), *product* complexity (quantity of building components and level of detail at which building components are considered by the project team), and *process* complexity (process interdependence and process causal connections)
He et al. (2015)	*Organizational* complexity (involves project staff, organizational structure, and various teams); *technological* complexity (building type, overlapping of design and construction works, and dependency on project operation); *goal* complexity (various project participants' requirements, project task complexity, and limited resources); *environmental* complexity (the complexity of the context in which a project operates, such as the natural, market, political, and regulatory environment); *cultural* complexity (the diversity of the cultural human mindset); and *information* complexity (complicated communication among a great number of project stakeholders under complicated contractual arrangements)
Lu et al. (2015)	*Organizational* complexity (amount and complexity of organizational members and complexity of organizational structure) and *task* complexity (amount and complexity of task and complexity of dependency among tasks)
Nguyen et al. (2015)	*Organizational* complexity (contractual conditions, number of contract/work packages, coordination of stakeholders, and project planning and scheduling); *technological* complexity (characterized by the variety of technologies employed and technological newness of the project); *sociopolitical* complexity (including administrative policies/procedures, number of applicable laws and regulations, local experience expected from parties, and influence of politics); *environmental* complexity (local climatic conditions, geographic conditions, and environmental risks); *infrastructural* complexity (site compensation and clearance, transportation systems, and qualifications required for contractors); and *scope* complexity (ambiguity of project scope, and project size in terms of capital)

demonstrated that technical complexity and novelty are important characteristics of a project that have distinct effects on project performance. Antoniadis et al. (2011) conducted five case studies to analyze the effects of socio-organizational complexity, and found that socio-organizational complexity, if not managed, could lead to a reduction in performance. Lebcir and Choudrie (2011) built a framework for project complexity for construction projects and evaluated the impact on project cycle time through a system dynamics (SD) simulation model integrating project complexity, project operations, and time performance. They found that project uncertainty is the most influential factor on project cycle time. Carvalho et al. (2015) found that project complexity has a significant effect on two aspects of project success: margin and schedule.

Some researchers have set project complexity as a moderating factor to analyze the relationships between other factors. For instance, Muller et al. (2012) investigated the moderating effect of project complexity on the relationship between the leadership competence of project managers and their success in projects. Results showed that emotional and managerial leadership competences are correlated with project success, but are differently moderated by complexity. Using data collected from 60 cross-functional project teams, McComb et al. (2007) found that two dimensions of project complexity (multiplicity and ambiguity) moderate the flexibility–performance relationship, and this moderating relationship is dependent upon the type of complexity faced by the teams. Liu (1999) examined the effects of two moderators, goal commitment and project complexity, on the perceived project performance of project participants. They concluded that there is a positive monotonic relationship between goal difficulty and performance, but that it is moderated by project complexity. Kennedy et al. (2011) conducted virtual experiments to examine team communication and performance when teams work under varying types and levels of project complexity, and they indicated that project complexity influences the communication–performance relationship. Hurk and Verhoest (2015) explored the interfering complexities on governance and performance of public-private partnerships. Brahm and Tarziján (2015) concluded that complexity strongly moderates the relationship between formal and relational contracting.

Above all, scholars primarily adopted questionnaire survey methodologies to perform empirical analyses about the impact of project complexity on project performance. They found that project complexity is negatively correlated with project performance, meaning that increasing levels of complexity reduce project performance. However, they did not investigate further the relationship between different types of complexity and performance.

Measurement Methods for Project Complexity

Project complexity is an emerging but critical topic in construction project management. Researchers have increasingly recognized the importance of complexity measurement in project diagnosis and sought to measure project complexity from multiple perspectives. The primary research on project complexity measurement is summarized in Table 2. These measurement methods can be summarized as case studies, surveys, and mathematical methods.

Case studies: In one relevant example, Giezen (2012) conducted a case study on the advantages and disadvantages of reducing complexity in mega project planning. An international research team's detailed study of 18 complex projects was used to develop a *complexity footprint* (Gransberg et al. 2013). Their radar diagram displayed all of the complexity scores of each of the five project management dimensions for the projects studied. The project experts interviewed during the case studies were asked to rate their projects on each of the five project management dimensions using a scale of 10–100. Lu et al. (2015) chose the Shanghai World Expo construction project as a case study to test the synchronous relationship between hidden workload and project complexity as well as to provide validation of their proposed method.

Surveys: Researchers have established several approaches to survey models and questionnaire design. For example, Bosch-Rekveldt et al. (2011) designed a framework for characterizing project complexity based on a literature review and an empirical method consisting of 18 interviews pertaining to 6 projects. Wood and Ashton (2010b) created a model consisting of two stages, each containing a number of questions in relation to the five themes of project complexity, to measure complexity at an early stage in a project. Xia and Chan (2012) conducted a three-round Delphi questionnaire survey to measure the degree of building project complexity, and produced a complexity index (CI) based on the identified measures and their relative importance. Targeted data collection from experts has been a key area of focus for survey development in project complexity research. For instance, Maylor et al. (2008) developed a grounded model with an investigation into the perceptions of project managers; Remington et al. (2009) revealed a wide range of project complexity factors by interviewing 25 project managers; and Gidado (1996) collected the views and opinions of practitioners on the issue of project complexity through structured interviews with selected building industry experts.

Table 2. Measuring Project Complexity

Researcher (year)	Measurement method	Results
Gidado (1996)	Survey	Developed a numerical approach to measure the effect of project complexity on project success
Maylor et al. (2008)	Survey	Reported a grounded model for managerial complexity
Remington et al. (2009)	Survey	Identified a wide range of project complexity factors
Bosch-Rekveldt et al. (2011)	Survey	Developed a framework for characterizing project complexity
Vidal et al. (2011)	Analytic hierarchy process	Formulated a project complexity measurement model
Giezen (2012)	Case study	Analyzed the advantages and disadvantages of reducing complexity in mega project planning
Gransberg et al. (2013)	Case study	Developed a "complexity footprint" for complex projects
Shafiei-Monfared and Jenab (2012)	Managerial and technical graphs; complexity design structure matrix	Measured the relative complexity of design projects
Xia and Chan (2012)	Survey	Measured the degree of building project complexity and developed a complexity index (CI)
Nguyen et al. (2015)	Fuzzy analytic hierarchy process, case study	Proposed a quantitative measure of complexity level (CL) to measure overall project complexity
He et al. (2015)	Fuzzy analytic network process, case study	Developed a complexity measurement model
Lu et al. (2015)	*ProjectSim* software	Proposed a measurement model of project complexity

Mathematical methods: Vidal et al. (2011) used the analytic hierarchy process (AHP) and formulated a project complexity measure model to assist in project managers' decision making. As an extension of AHP, Nguyen et al. (2015) employed the fuzzy analytic hierarchy process (fuzzy AHP) method to determine the weights of the components and parameters of project complexity, and they proposed a complexity level (CL) to measure the overall project complexity. He et al. (2015) formulated a complexity measurement model using a fuzzy analytic network process (FANP). Shafiei-Monfared and Jenab (2012) measured the relative complexity of design projects using managerial and technical graphs and a complexity design structure matrix (CDSM). In their mapped complexity graph, the y-axis represents the initial ranking of projects based on technical and managerial complexity aspects, and the x-axis represents the relative complexity among projects. The relative complexity is the result of the product of the CDSM and the initial ranking vector; this measurement can be used by designers to facilitate resource allocation and cost estimation during the design phase for individual projects (Shafiei-Monfared and Jenab 2012).

In summary, many scholars have tried to adopt different methods to measure project complexity. Case studies are chosen on some construction projects for obtaining a comprehensive analysis and understanding of the rules. Surveys used for developing a complexity index combine the questionnaire survey and expert scoring to reflect the complexity degree of the whole project. Different parties have a different understanding of project complexity; thus, the evaluation system should consider the position of the various project stakeholders. Mathematical methods have some limitations that can only measure the specific project at a certain point in time.

Through these measurement methods, the research results were summarized as follows: (1) Measure factors attributed to project complexity and build frameworks in order to assist decision making. Complexity scales and subscales are defined in order to highlight the most complex alternatives and their principal sources of complexity within the set of criteria and subcriteria that exist in a given hierarchical structure. (2) Measure relative complexity to facilitate resource allocation, based on the complexity of individual projects. Relative complexity and similarity measures can be used to estimate required resources and associated costs. (3) Measure the complexity level for stakeholders to assess degrees of project complexity and better manage potential risks that might result in different levels of project complexity.

Management of Project Complexity

Managing project complexity is perhaps the final goal of project complexity research. Much of the research produced to date in the construction field to improve project performance is directed toward critical project management practices or strategies for dealing with project complexity and ensuring the successful delivery of construction projects. These methods and strategies can be grouped into three main categories: risk management, management style, and adaptability.

Project Complexity and Risk Management. The complexity of a project leads to another, related network of interdependent risks (Fang and Marle 2013). Therefore, some researchers have attempted to address project complexity through risk management. For example, Austin et al. (2002) adopted analytical design planning techniques and design structure matrices (DSM) to manage design projects. Fang and Marle (2013) presented a matrix-based method for modeling risk interactions and reevaluating risks in terms of various indicators. This approach assists project managers in prioritizing certain risks and designing more effective response actions. For example, corrective actions are often designed for the critical risks such as a decrease in return profit and available cash flow decrease to reduce losses. Lehtiranta (2011) examined relational risk management in construction projects and supported a flexible managerial framework. Giezen (2012) found that complexity reduction strategies can be a beneficial approach for infrastructure mega projects, such as decision-making processes that accommodate outside influences and strategic input, to keep uncertainty within a manageable domain of risk. In an effort to improve the effectiveness and accuracy of stakeholder and risk analysis, Yang et al. (2016) adopted the social network analysis method in their study, modeling the interactive networks of different stakeholders in green building projects to identify potential risks within these networks.

Project Complexity and Management Style. It is crucial for a project manager to master project complexity (Macheridis and Nilsson 2004). Several researchers have investigated successful management with increasing levels of complexity and uncertainty in project environments. Whitty and Maylor (2009) suggested that reflective personal skills, competencies, and thinking processes underpin project managers' high performance in complex projects, and practitioner development would focus more on enabling reflective practitioners rather than providing skilled technicians. Antoniadis (2013) addressed the effects of leadership style and socio-organizational complexity and developed a framework that enables the management of the effects of socio-organizational complexity through a transformational leadership style. Thomas and Mengel (2008) discussed the advanced level of project management education and skill development required to confidently navigate dynamic organizational environments and complex projects facing project managers today. Ramazani and Jergeas (2015) suggested that educational institutions should explore methods to further integrate critical thinking and other soft skills into curricula to better prepare future project managers.

Project Complexity and Adaptability. Adaptive capacity is the ability to adapt to actual changes in context, or changes in the perception of context, by the actors involved (Giezen et al. 2015). Giezen et al. (2015) established the concept of adaptive capacity using organizational learning theory, taking empirical data from a mega project to identify the moments of adaptation and to discern the mechanisms that enhance or limit adaptive capacity within the decision-making and planning processes. Brady and Davies (2014) affirmed the ability to be adaptive and responsive as one of the approaches to managing complexity considering structural and dynamic characteristics of project complexity. Salet et al. (2013) offered different proactive approaches to complexity and uncertainty, including learning processes, which enable project teams to deal with emerging realities, and balancing of the need to generate and reduce the variety of complex decision-making processes to identify flexible solutions.

Given the above, the current research on management of project complexity has made some achievements from the perspectives of risk management, management style, and adaptability, which could provide substantial insights to practitioners. However, as a new theory of project management, project complexity management is still in the early stages of development. By far, management research of project complexity that either focuses on the management strategy or focuses on the methods and measures is based on qualitative analysis of project complexity. As a result, this qualitative and descriptive analysis of complexity lacks an accurate quantitative basis for the establishment of management strategies and countermeasures, which is difficult to apply in practice. Therefore, it is necessary to strengthen the attention on how to manage and control project complexity and carry out quantitative analyses on the different types of complexity for informing better management decisions.

Implications for Future Research

Based on the review of the literature, existing research on project complexity in construction has centered on four areas: influencing factors, impact, measurement methods, and management. The following section identifies future research directions for each of these main areas of complexity as summarized in Fig. 6.

Influencing Factors of Project Complexity

Construction projects are often referred to as being complex; however, there seems to be no universally accepted definition of the term project complexity in the construction industry. While many scholars have suggested different frameworks for the influencing factors and types of project complexity, thus far, there has not been a comprehensive framework that includes and integrates all the identified aspects of project complexity in the context of construction projects. Based on these findings, it is suggested that future research should focus on which specific factors drive project complexity for different types of construction projects. More specifically, researchers should undertake analysis of influencing factors of project complexity from different perspectives within a project, such as owners, designers, and contractors; factors should also be identified and analyzed within different phases of the project lifecycle.

Impact of Project Complexity

Researchers have achieved consensus that project complexity has a negative effect on project performance; technical complexity, in particular, has long been considered a factor that affects project performance (Antoniadis et al. 2011). However, while past research analyzed the effect of project complexity, indices of project performance are usually carried out at a macro level and lack practical applications, especially in the construction industry. In addition, researchers themselves have more often investigated the general concept of project complexity in project management, seldom taking into consideration the characteristics of the construction industry.

One important potential direction for future research should focus on the relationship between project complexity and success outcomes. Successful project management requires analysis of how project complexity affects project constraints, such as quality, time, and cost. Project managers need this knowledge in order to efficiently manage the dynamic nature of large-scale construction projects (Macheridis and Nilsson 2004). Although existing research has addressed some important factors regarding project complexity and how it relates to project management, this can be extended in different directions. Inclusion of other performance indicators (e.g., client satisfaction and stakeholder profitability) will enable more accurate measurement of the impact of project complexity

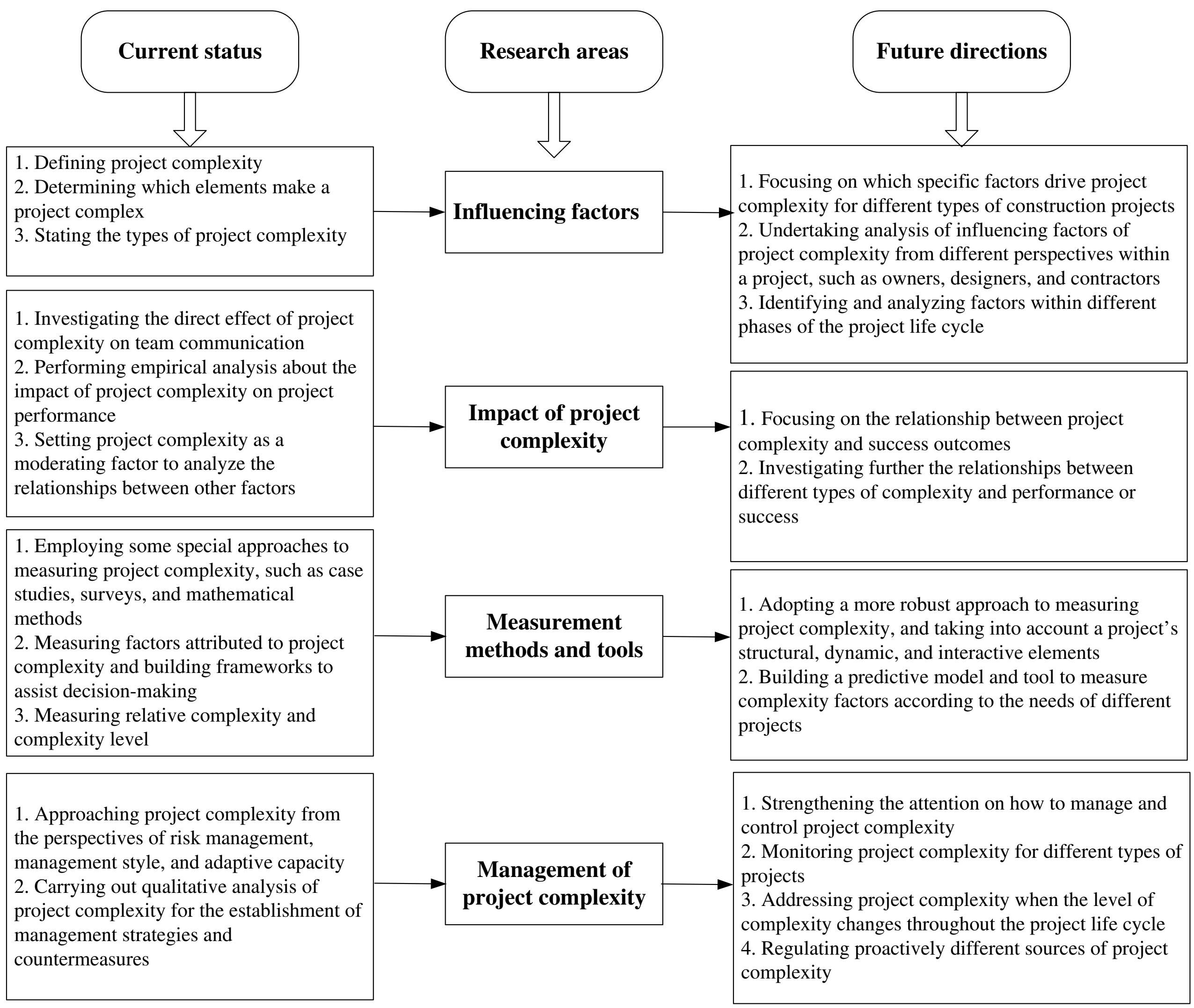

Fig. 6. Conceptual framework of project complexity research

on project success. Furthermore, the relationships between different types of complexity and performance should be investigated as part of future research as this can help project managers improve their chances of achieving construction project success.

Measurement Methods and Tools

Research on measurement methods for project complexity is very limited, with most studies addressing conceptual frameworks of project complexity. Each of the above studies employs a special approach to measuring project complexity. However, as stated by Mihm et al. (2003), project complexity results from the interaction of numerous and varied elements and contains structural, dynamic, and uncertain properties. In other words, effective management of project complexity through treatment of individual factors as separate processes is difficult to achieve because of the system dynamics and interactive nature of a project system. Therefore, future studies should adopt a more robust approach to measuring project complexity, taking into account a project's structural, dynamic, and interactive elements.

In addition, as noted above, a single overall definition of project complexity does not exist. Different areas of project complexity, such as technical complexity, organizational complexity, and environmental complexity, have been shown to play a role in determining a project's complexity; however, some projects are more complex in their organizational aspects, while others more so in their environmental and/or technical aspects (Bosch-Rekveldt 2011). Therefore, an important next step is to build a predictive model and tool to measure complexity factors according to the needs of different projects.

Managing Project Complexity

Most research in the area of project complexity management has attempted to approach project complexity from the perspectives of risk management, management style, and adaptive capacity. However, these methods are difficult to translate into direct application for construction projects. For researchers considering future study in project complexity management that will yield productive, concrete results, the following questions should be addressed: How should project management best monitor complexity for different types of projects? How should project management address project complexity when the level of complexity changes throughout the project lifecycle? How should project management proactively regulate different sources of project complexity?

Conclusions

With project complexity increasing internationally across the construction industry, traditional project management approaches are not enough to ensure successful project outcomes. As a result, project complexity has become an important topic for researchers and industry experts exploring effective management practices. This paper provides a timely and comprehensive summary of literature in the area of project complexity as well as insights for future study of and guidance for successfully managing complex construction projects. Ideally, clarity on the current state of research could result in successful project management and a reduction in the risks associated with project complexity.

A four-stage literature review was conducted in order to summarize existing research and identify future research directions for project complexity in construction. Seventy-four published papers relating to project complexity were reviewed. Through this analysis, it was found that project complexity research primarily centers on four areas: contributing to project complexity's influencing factors, the impact of project complexity, measurement methods for project complexity, and project complexity management. It can be concluded that there is no universally accepted definition of project complexity in the construction industry, but it appears that organizational complexity and technological complexity are the main categories driving project complexity. Each of the research studies employed a special approach to measuring project complexity, with most studies addressing conceptual frameworks of project complexity. Researchers have achieved consensus that project complexity has a negative effect on project performance and thus have focused their efforts in the areas of risk management, management style, and adaptive capacity.

Based on the existing research and implications, future research could examine the following areas: influencing factors of project complexity from the perspective of different stakeholders and different phases of a project's lifecycle; the relationship between project complexity and project success; project complexity measurement that takes into account structural, dynamic, and interactive elements; and management of project complexity for different project types and increased project complexity during a project's lifecycle.

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