Exploring pattern of complexity in mega construction projects

Article

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Exploring Pattern of Complexity in Mega Construction Projects

Abstract

Purpose: Megaprojects are known as complex projects that involve high levels of uncertainty. This interpretive study explores and portrays perceived complexity in mega construction projects by lived experiences of project managers.

Methodology: This study utilises a ground theory approach to analyse data gathered from semi-structured interviews with 18 professionals involved in 11 mega projects.

Findings: Complexity in mega construction projects is defined as a project property that stems from the interaction of project features, uncertain variables/conditions, and managerial actions forming a pattern, which emerges over time, based on the reflections of construction practitioners.

Originality: This study defines complexity based on the reflections of the practitioners in the construction industry and uniquely identifies complexity patterns that may have implications for project management, particularly risk management.

Article Classification: Research Paper

Keywords: Project complexity; Megaprojects; Qualitative data analysis; Grounded theory; Construction management

Introduction

Complexity, as a word, reflects the behaviour of a system that is complex. Indeed, the underlying view of the early studies on complexity carried out by pioneers of complexity theory from the Sante Fe Institute (Waldrop, 1992; Gell-Mann, 1994) is that no single definition of complexity can adequately capture the intuitive notions of what the word ought to mean. Several definitions of complex systems point out the characteristics of systems that make them complex.

According to Valle (2000), a complex system is a whole that consists of several elements interacting with each other in many different ways. Numerous interdependent elements in a complex system continuously interact and spontaneously organise and reorganise themselves into increasingly elaborate structures over time (Dao *et al*., 2017). Ideas on complexity and complex systems have been conceived differently across disciplinary boundaries (Manson, 2001). In the project management domain, projects are defined as complex systems, where Baccarini (1996) provided one of the first attempts to define project complexity systemically. Baccarini (1996) defined complex projects as "consisting of many varied interrelated parts," which can be characterised by differentiation and interdependency. Later, Vidal *et al*. (2011a) defined project complexity as "the property of a project which makes it difficult to understand, foresee and keep under control its overall behaviour, even when given reasonably complete information about the project system," pointing out the uncertainty or limited predictability of behaviour of complex projects.

Project complexity is an inherent and indispensable part of megaprojects due to their size, duration, number of stakeholders involved, high uncertainty, and impact (Kardes *et al*., 2013; van Marrewijk and Smits, 2016; Pitsis *et al*., 2018). Flyvbjerg (2017) defines megaprojects as "large-scale, complex ventures that typically cost US$1 billion or more, take many years to develop and build, involve multiple public and private stakeholders, are transformational, and impact millions of people." Hu *et al.* (2015) indicate that the cost of megaprojects carried out in different countries corresponds to 0.01-0.05% of their Gross Domestic Product (GDP). Haidar and Ellis (2010) define megaprojects based on both their size and level of complexity. Zhai *et al.* (2009) list the characteristics of megaprojects as extreme complexity, substantial risks, long duration, and extensive impact on the community, economy, technological development, and environment of the region or even the whole country. The complexity of megaprojects is brought about by several contributing factors such as tasks, components, personnel, and funding, as well as numerous sources of uncertainty and their interactions (Mihm *et al.*, 2003; Sommer and Loch, 2004). With diverse and conflicting institutional backgrounds, megaprojects involve multi-actor processes. It is often challenging to establish governance mechanisms across institutional regimes and cultures (Levitt and Scott, 2017). The number of project participants, including contractors, sub-contractors, sponsors, governments, suppliers, investors, and funding agencies, leads to increased complexity. Stakeholders often have competing characteristics and goals. Therefore, it is not easy to maintain each stakeholder's interest and find common ground for all. Complexity factors not only include large scale, long period, multiplicity of technological disciplines, number of participants, multi-nationality, interests of stakeholders, high levels of public attention, and political interest but also uncertainty (van Marrewijk *et al.*, 2008). It is difficult to assess cause-effect relationships and performance since many factors potentially influence a particular cause of action and change over time (Flyvbjerg, 2017). Since megaprojects can take several decades from project initiation to completion, during this period, changes occur in the economy, political landscape, and laws and regulations, making uncertainty an indispensable part of megaprojects (Kolltveit and Grønhaug, 2004). Besides, megaprojects are often built on non-standard technology and design, making it difficult to learn from past experience (Prencipe and Tell, 2001), leading to high technology risks. As megaprojects are often built on insufficient data about costs, schedules, and risks, they often lead to cost overruns, delays, and shortfalls that weaken project applicability during project delivery and operations (Flyvbjerg, 2017). Those problems need to be fixed while "flying the plane," leading to challenges during implementation and often megaprojects' failure (Merrow, 2011). Megaprojects have alarming failure rates in meeting their goals, capital budgets, and/or schedules (Hu *et al.*, 2016; Merrow, 2011). Many scholars over the years have studied complexity as a problem that may cause underperformance in megaprojects, and proposed management strategies to deal with complexity and risk. The success of megaprojects has notably been attributed to how complexity and risks are handled, emphasizing the need to reduce complexity (Eren, 2019; Ashkanani and Franzoi, 2022). On the other hand, more research is still needed for a better understanding of megaproject complexity. The necessity of further research on conceptualising and assessing complexity has been mentioned by several researchers (such as Xia and Lee, 2004; Bakhshi *et al*., 2016) as megaprojects are increasing in number and magnitude all over the world (Gransberg *et al*., 2016).

Although extensive research on project complexity exists, researchers have different perspectives on project complexity (Zhu and Mostafavi, 2017; Dao *et al*., 2016). Whitty and Maylor (2009) argue that, without measures for complexity, it is a term that is less than useful. Based on this perspective, project management scholars identified several complexity indicators (Bosch-Rekveldt *et al*., 2011; Geraldi *et al*., 2011; Vidal *et al*., 2011b; He *et al*., 2015) and proposed descriptive models for measuring complexity. Different research methods (e.g., systematic literature reviews, comparative case studies, and questionnaires) have been utilised to propose conceptual frameworks, and different assessment methods were employed to measure complexity (such as Vidal *et al*., 2011a; Botchkarev and Finnigan, 2015). Still, Daniel and Daniel (2018) remark on the lack of agreement on the definition of project complexity and argue that this may lead to a poor understanding of project managers on how to maximise performance in complex projects. Although literature presented several lists of individual factors/dimensions associated with megaprojects, the structures/frameworks that explain the emergence and interactions between various dimensions of complexity are still needed in practice (Chapman, 2016). Various researchers (e.g., Geraldi *et al.*, 2011; Mikkelsen, 2021) pointed out the importance of research on this topic based on lived experiences of practitioners in conceptualising complexity. As Schön (1983) pointed out, practitioners reflect during and after action, and not limiting themselves to theoretical knowledge, they also incorporate the practical experience into their decision-making. In fact, through reflective practice, practitioners think back on a previous experience and make sense of it, especially for uncertain and unique situations where technical experience might be limited (Schön, 1983). Reflection actually goes beyond learning from experience and represents how practitioners think in complex situations (Crawford et al., 2006). Maytorena et al. (2007) highlighted the significance of reflective practitioners for risk management. Moreover, as Green and Schweber (2008) stated, the importance of reflective practice cannot be overlooked when developing theory in the built environment.

Currently, there is a need for empirical evidence on the perceived complexity factors specific to mega construction projects along with their interrelations. A better perception of complexity may have implications on how complexity can be managed in megaprojects and have the potential to improve project performance. From this point of view, the aim of this study is to conceptualise complexity in mega construction projects by referring to lived experiences of project managers and identify factors that can further be used to assess the level of complexity. Complexity factors are aimed to be understood within the context they emerge by considering their mutual interaction. This paper uses the term *pattern of complexity*, which was first introduced by Geraldi and Adlbrecht (2007), to indicate the network of dynamic relations between the identified complexity factors. Based on the gap identified in the literature, this study sought to answer the following research questions:

RQ1. How do practitioners perceive complexity in mega construction projects?

RQ2. How do different complexity factors interact and emerge in mega construction projects?

In order to address these research questions, an exploratory study has been designed. Interviews were conducted with 18 participants from 11 mega construction projects to uncover complexity dimensions and their interrelations so that a new complexity definition could be developed for mega construction projects. Due to a lack of coherent theory on the complexity of mega construction projects, this study adopts the grounded theory approach (originated by Glaser and Strauss 1967), which has not been widely used in previous research on project complexity. The grounded theory allows drawing conclusions from empirical evidence rather than testing predefined hypotheses and enables deriving theory from carefully collected and analysed data (Strauss and Corbin, 1990). Identifying the complexity factors together with their interactions based on the actuality of projects can fill the gap in the literature by contributing to conceptualising the complexity unique to mega construction projects. The conceptualisation of complexity may pave the way for more informed decision-making, contributing to project success.

This study is a part of a funded research project that aims to develop a visualisation and assessment tool for risk and complexity in mega construction projects. The initial step of the research project was the qualitative analysis of semi-structured interviews to conceptualise complexity using the grounded theory approach. Empirical data collected via a questionnaire has been analysed to investigate the relationship between risk and complexity in mega construction projects (Erol *et al*., 2020). The aim of the current paper is to report findings on the conceptualisation of complexity, which forms the basis of the tool. Thus, the scope of this paper is limited to the findings from semi-structured interviews on perceived complexity that constitute the conceptual foundation for the quantitative assessment method for risk and complexity. Through the grounded theory approach, practitioners' reflections on the emergence and interactions between complexity dimensions in mega construction projects are analysed, and patterns of complexity are empirically presented.

The remainder of the paper is organised as follows. Section 2 reviews the literature on project complexity. Section 3 explains the methodology employed in this research. Section 4 presents the research findings and discusses their implications. Finally, Section 5 concludes the paper by discussing the contributions, limitations, and possible future research directions.

Literature Review

Due to the ever-increasing complexity in projects, complexity research constitutes an integral part of the modern project management literature. Projects are subject to complexity because of their structural characteristics, such as size, number of stakeholders, and technical difficulty, as well as emergent properties caused by the alteration of factors affecting them throughout their lifecycle. As pointed out in the Cynefin framework of Snowden and Boone (2007), complex contexts differ from simple and complicated ones since their cause-effect relationships cannot be perceived in advance. Nonetheless, complexity is not a readily understood concept. Schlindwein and Ison (2004) mention two different scientific approaches in complexity research, mainly descriptive complexity and perceived complexity. The former considers complexity as an intrinsic characteristic of a system, and researchers who adopt this vision try to classify or quantify complexity based on some indicators. On the other hand, the second one, perceived complexity, considers complexity as a subjective concept and explores it through an observer's perception. Perceived complexity has been a subject of various research studies (e.g., Vidal and Marle, 2008; Geraldi et al., 2011; Maylor et al., 2013; Mikkelsen, 2021). "Complexity is a subjective notion, reflecting the lived experience of the people involved" (Maylor et al., 2013), and perceived project complexity is in the eyes of the beholder, influenced by many factors, including the sector, and the beholder's role in the project (Mikkelsen, 2021).

In parallel with this pluralism of approaches in complexity research, project complexity has been defined in different ways (Ahn *et al*., 2017; Dao *et al*., 2017), and researchers have different perspectives/focuses on project features/behaviour (Zhu and Mostafavi, 2017; Dao *et al*., 2016).

Table 1 illustrates some definitions suggested by researchers to exemplify and highlight different features of complex projects.

Table 1. Project Complexity Definitions

Reference Study (year)	Definition	Focus
Turner and Cochrane (1993)	Degree of whether the goals and methods of achieving them are well defined	Feature: Uncertainty of goals and methods
Baccarini (1996)	Project complexity consists of many varied interrelated parts and can be operationalized in terms of differentiation and interdependency	Features: Interrelations and interdependency
Maier (1998)	Operational and managerial interdependence of the elements–emergent behavior	Features: Interdependency and emergence
Edmonds (1999)	Complexity is that property of a model, which makes it difficult to formulate its overall behavior	Behaviour: Difficult to formulate/ understand
Tatikonda and Rosenthal (2000)	The nature, quantity, and magnitude of organizational subtasks and subtask interactions posed by the project	Features: Sub-parts and their interactions
Sbragia (2000)	The number of elements in the project, intensity of interactions between elements, and difficulty of cooperation between the functional areas	Feature: Sub-parts and interactions Behaviour: Difficulty of cooperation
Cicmil and Marshall (2005)	Project complexity invokes ambiguity, paradox and the dimensions of time, space and power of the organizing processes in project settings	Behaviour: Ambiguity and dynamic change
Geraldi and Adlbrecht (2007)	Three types of complexity: faith, fact, and interaction, form the pattern of complexity, which is the minimum manageable context of complexity.	Feature: Interaction and pattern
Remington *et al*. (2009)	A complex project demonstrates a number of characteristics to a degree, or level of severity, that makes it difficult to predict project outcomes or manage project	Behaviour: Difficult to predict and manage
Vidal *et al*. (2011a)	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	Behaviour: Difficult to understand, foresee, control
Hatch and Cunliffe (2012)	Project complexity consists of many different elements with multiple interactions and feedback loops between elements	Feature: Feedback loops between multiple interrelated elements
Kermanshachi *et al*. (2016)	Project complexity is the degree of interrelatedness between project attributes and interfaces, and their consequential impact on predictability and functionality	Feature: Interrelations Behaviour: Hard to predict
Bakhshi (2016)	Project complexity is an intricate arrangement of the varied interrelated parts in which the elements can change and evolve constantly with effect on the project objectives	Feature: Interrelations Behaviour: Constant change and evolution affecting objectives
Mikkelsen (2021)	Project complexity is the interrelatedness of elements causing an emergent nature of the project and challenging the project management	Feature: Interrelatedness Behaviour: Emergent and challenging

Table 1 demonstrates that projects having multiple tasks/elements interacting with each other in different ways where these changes over time have been considered as complex, and these projects are considered as hard to plan, predict, manage and control due to ambiguity and uncertainty. When previous studies on project complexity are considered, most of the studies have been mainly about the identification (or categorisation) of complexity factors (dimensions) and the development of conceptual models to understand complexity. In terms of conceptualisation of complexity, Baccarini (1996) made one of the first attempts. He argued that complexity consists of organisational and technological dimensions. While organisational complexity expresses the excess of organisational structures in the project and the interdependencies of these structures, technological complexity refers to the number and variety of physical work done and the relationships between these works. Later, Vidal and Marle (2008) examined the organisational and technological complexity dimensions defined by Baccarini (1996) and classified them into four subgroups: project system size, project system variety, interdependencies within the project system, and elements of context. Based on this study, later Vidal *et al*. (2011a) identified 18 factors, most of which belong to organisational complexity. The TOE (Technical, Organisational and Environmental) framework developed by Bosch-Rekveldt *et al*. (2011) is one of the most comprehensive complexity frameworks that includes 50 complexity factors under TOE categories. Botchkarev and Finnigan (2015) considered complexity with the System of Systems (SoS) approach and defined various project complexity factors under product, project, and external environment systems. In one of the most comprehensive studies to determine complexity factors, Bakhshi *et al*. (2016) identified 127 complexity factors under the groups of context, autonomy, belonging, connectivity, diversity, emergence, and size by analysing 423 articles published in leading project management journals between 1990 and 2015. Based on a statistical analysis of the survey data collected from 44 projects, Dao *et al*. (2017) identified 34 complexity indicators under 11 categories, distinguishing high-complexity projects from low-complexity projects. Further, Rodríguez Montequín *et al.* (2018) linked complexity to project failure and identified 26 failure (complexity) factors under the headings of "factors related to external environment," "factors related to an organisation," "factors related to project," and "factors related to the project manager and team members." Consequently, the literature on project complexity includes different perspectives (e.g., systems approach) and complexity factors/categories, employs different research methods (e.g., literature survey, empirical studies), and associates complexity with different project outcomes (e.g., project failures).

Various studies consider "uncertainty" as a part of project complexity. Williams (1999) grouped two complexity dimensions of Baccarini (1996) into a single dimension as "structural complexity," which is related to the number of parts and their interdependence and added uncertainty as another dimension of project complexity by considering uncertainty in goals and methods as complexity drivers. Later, Geraldi *et al*. (2011) added dynamic, pace, and socio-political dimensions of complexity to Williams's model (1999). Dynamic complexity relates to project changes, such as changing specifications or goals. The urgency to deliver the project causes pace complexity, whereas socio-political complexity is related to human-induced communication and interaction issues. Maylor and Turner (2017) modified the framework of Geraldi *et al*. (2011) by including "pace" into structural complexity and combining "uncertainty" and "dynamics" into a dimension called "emergent complexity." The word emergent is defined by Maylor *et al*. (2008) as all variability and dynamism and by Geraldi and Adlbrecht (2007) as the amount and effect of change. Maylor *et al*. (2008) stated emergent complexity as "a change that occurred over time." Emergent complexity is also related to the concept of "uncertainty," leading to the "unpredictability" of project outcomes. For example, emergent complexity may stem from changes in scope, the emergence of new technology, changes in pace caused by the imposition of a new project deadline, or socio-political changes. When such changes are not well communicated and managed by the team, they may lead to high disorganisation, rework, or inefficiency. The fact that projects are changing not only from the "outside-in" but also from the "inside-out" triggers the change in the team motivation or the formation of internal politics (Geraldi *et al*., 2011). According to Whitty and Maylor (2009), a high level of project complexity includes structural, dynamic, and interacting elements. Describing projects as complex adaptive systems or socially constructed entities (Cicmil *et al*., 2006), complexity in projects is considered to be related to such structural elements, dynamic elements, and their interaction. Thus, there is an agreement between researchers on static factors leading to project complexity, some time-varying factors, as well as the level of complexity that changes over time due to evolving interrelations between emergent and static factors (indicated as the temporal dimension by Geraldi *et al*., 2011). Based on this idea, Geraldi *et al*. (2011) and Chapman (2016) argue that understanding the pattern of complexity would give a more informed approach for studying the complexity in projects.

It is evident that previous studies have contributed to improving the collective understanding of project complexity. According to Brockmann and Girmscheid (2007), there is nothing that illustrates complexity as completely as megaprojects. Some studies focused mainly on the complexity of megaprojects (He *et al*., 2015; Hu *et al*., 2015; Kardes *et al*., 2013; van Marrewijk *et al*., 2008; Pitsis *et al*., 2018). Most previous studies are descriptive and utilised systematic literature review (e.g., Vidal and Marle, 2008; Bakhshi *et al.*, 2016; and Thomé *et al*., 2016) to identify complexity factors and develop frameworks. Based on these studies, some researchers synthesised existing models/lists into an overarching schema/framework (e.g., Geraldi *et al.*, 2011; Chapman, 2016) or conducted questionnaires and statistical analyses to prioritise complexity indicators (e.g., Dao *et al.*, 2017). Some researchers used the case study approach (e.g., the comparative case study by Brady and Davies, 2014 and Davies *et al.*, 2016) to explore how complexity emerges and is managed in projects proposing managerial recipes for complex projects. Some studies employed an inductive approach. Bosch-Rekveldt *et al.* (2011) used findings from 18 interviews from six case projects to explore mega construction project complexity. However, the major focus of that research was on identifying how often a certain factor was mentioned by an interviewee and how the saturation matches with literature, rather than qualitative analysis of interview transcripts to understand interrelations between the concepts. Maylor *et al.* (2008) and Brockman and Girmscheid (2007) also used the grounded theory approach to explore complexity in megaprojects; however, the scope of these studies differs from the current study. Maylor *et al.* (2008) investigated the question of what makes a project complex to manage by conducting workshops and referring to the experiences of experts from several project-based industries (e.g., defence, telecommunication) involved in the workshops. Brockmann and Girmscheid (2007) conducted interviews to understand task, social and cultural complexity in international construction joint ventures that were carried out on a design-bid basis. However, the interrelatedness of complexity dimensions was not within the scope of these studies.

Albeit providing valuable insights, the literature lacks studies exposing the complexity dimensions specific to mega construction projects along with their interactions. The aim and research method of the current study differ from the previous studies in that an inductive approach was utilised, no definition or framework was adopted at the start of this research, and the interrelation between the complexity factors was investigated within the context of mega construction projects. It is believed that cases on mega construction projects can offer a way of explaining the pattern of complexity, paving the way for the development of strategies to control or manage them. Balancing managerial functions based on the level and type of megaproject complexity can control the impact of complexity on the project and thus improve performance and success (De Toni and Pessot, 2021). Thus, this study aims to understand the perceived complexity within the context of mega construction projects in Turkey and identify the pattern of complexity that could help better project management.

Research Methodology

Since this study aims to establish a detailed description of project complexity in mega construction projects, it follows an inductive qualitative research strategy based on the grounded theory approach. The grounded theory methodology, first proposed by two sociologists Glaser and Strauss, is defined as "the theory that was derived from data, systematically gathered and analysed through the research process; in this method, data collection, analysis, and conclusive theory stand in close relationship to one another" (Strauss and Corbin, 1990). The philosophy of grounded theory lies in symbolic interactionism, which assumes that meaning is socially constructed, negotiated, and changes over time through the reflexive interaction of individuals (Charmaz, 2000; Mansourian, 2006). Researchers (e.g., Loosemore, 1999; Green et al., 2010; Rahmani and Leifels, 2018; Mac Donald et al., 2020) in the construction and project management domain used, and some remodelled, grounded theory to understand and represent practical issues grounded in empirical data.

The classic grounded theory method originated in the 1960s by Glaser and Strauss (1967). Following a solely inductive procedure, this "Glaserian" approach was utilised in the construction management domain with various focuses (Dainty, 2000; Fox and Skitmore, 2007; Sithambaram, 2021). Over time, the methodological procedures were adapted, and grounded theory's initial development was diversified. The "Straussian" approach developed by Strauss and Corbin (1990, 1998) supports literature to guide the research design (e.g., Mac Donald et al., 2020; Chen et al., 2022). Some researchers combined strategies and methodologies. For instance, while initially designing a study according to Strauss and Corbin (1990), Jia et al. (2017) followed the Glaserian approach in conceptualising safety management and behavioural outcomes. Some studies utilised a combination of inductive and deductive approaches, where researchers iterate between existing literature (e.g., theories, frameworks, models) and empirical data. This approach is called iterative ground theory (Orton, 1997; Green et al., 2010). Moreover, Rahmani and Leifels (2018) incorporated abductive reasoning into grounded theory and applied it to an early contractor involvement case study. Rahmani and Leifels (2018) also portrayed an array of variations of the grounded theory applied in the management domain, where researchers selected strategies suitable to their domain based on their style and research context.

This study uses the version developed by Strauss and Corbin (1990, 1998) with minor modifications. Strauss and Corbin (1998) used complex coding methods as strategies to examine the interface between structure and process. They proposed three levels of coding known as open, axial, and selective coding. Theoretical memos are used throughout the process to follow the analysis and guide when needed. The use of literature to research with prior knowledge and enhance the research's theoretical sensitivity is also allowed in the grounded theory studies developed by Strauss and Corbin. This research study follows the same principles. On the other hand, unlike Strauss and Corbin's perspective, the adopted method does not follow a silently authored process. While memoing, the researcher and participants interacted to elicit multiple meanings, as suggested by Charmaz (2000). In the framework of Charmaz (2014), researchers interact with data in iterative reflexive steps for developing and interpreting codes (Burga et al., 2022).

According to the originators of grounded theory, concepts and conceptual relationships are abstracted from data rather than deducing testable hypotheses from existing theory. Since the approach aims to construct a data-driven theory (Glaser, 1978, 1992; Glaser and Strauss, 1967;

Strauss, 1987), the strength of the methodology of this study is mainly based on data collection and analysis. Theory development proceeds concurrently with the data collection and analysis processes. Strauss and Corbin (1998) noted that many techniques, including storylines and diagrams, can be useful for integrating concepts. This study used conceptual mapping to observe the relationship between the concepts in the interviews. The concept maps are representations of meaning, where concepts/perceptions are connected with labelled arrows, revealing their relationship (Novak, 1990). The conceptual mapping and coding processes are performed in parallel to group and associate concepts. Figure 1 shows the process for conceptualising complexity.

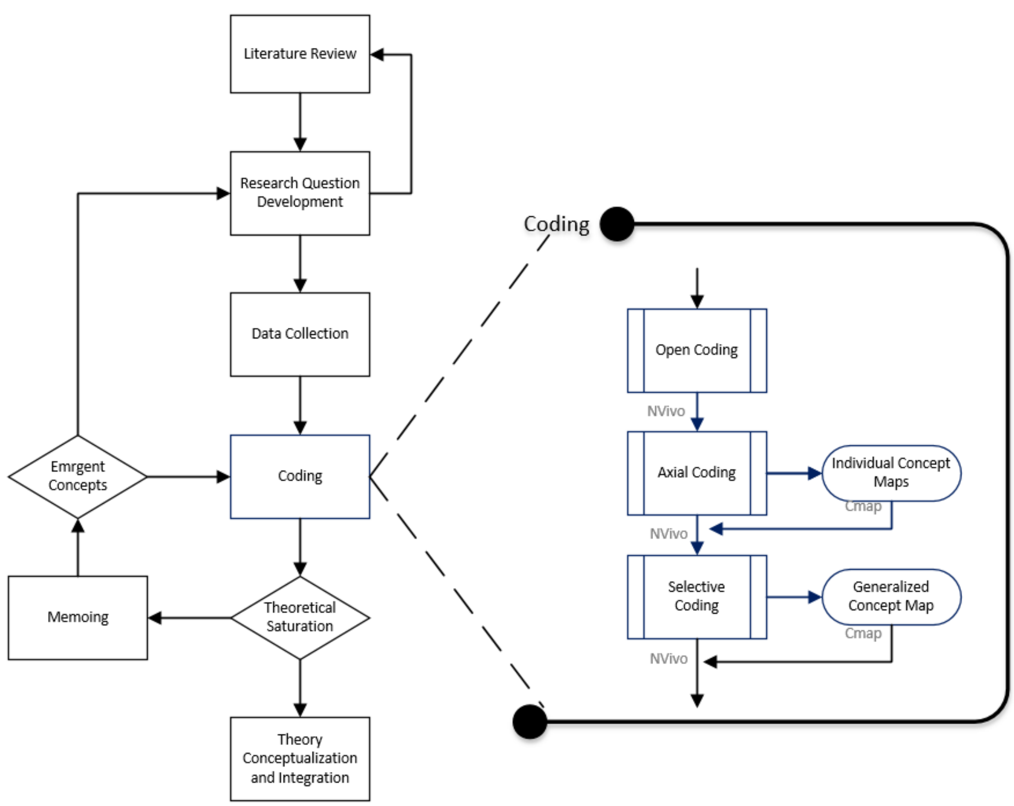

Figure 1. Research Flowchart

First, through an iterative process of familiarisation with concepts, this study associated literature review with research question development and formulated the initial interview questions. Data collection and analysis are dynamic processes that include, in a sense, an iterative relationship of data collection, coding, concept mapping, and memoing, where memoing is theorising write-up ideas about codes. The data collected via interviews and observations were transcribed and coded through the stages of open, axial, and selective coding. Concurrently and iteratively, concept maps of interviews were generated to portray the conceptual relationships. From the first coding session to the end of the analysis, there was a constant interaction between memos and the concepts in coding. The back loop to the formulation of interview questions shows the readjustment of interview questions to add emerging issues to the following interview. When theoretical saturation, specifically representativeness and consistency, of categories is achieved, theory contextualisation and integration enable theoretical grounding, during which reformed theory is generalised.

Data Collection

The methodology started with reviewing project complexity literature, including a critical examination of existing conceptualisations and frameworks. After an in-depth review, a series of interviews were planned with industry experts. As an initial step, projects suitable for the context of this research were explored using public documents, press releases, company reports, and other internet sources. Since cost is a decisive feature for megaprojects, the main criterion for the selection of the projects was their cost. Although different values are suggested by researchers, the cost threshold was selected as 0.02% of GDP, as suggested by Hu *et al*. (2015). Then, companies involved in these projects were contacted by email to request their participation. As a result, 18 participants from 11 mega construction projects agreed to supply data for this research. The criteria for the interviewees were to have experience in complex projects and work at the management levels in mega construction projects. Table 2 and Table 3 show details of the projects and interviewees, including the number of transcribed words (with a total of 113320 words). Since interviewees were assured of confidentiality, they were assigned unique interviewee numbers, and the names of the projects (project IDs) were symbolised with letters.

Table 2. Information About Projects

Project ID	Project Type	Cost ($ Billion)	Project Status	Number of transcribed words
A	Power Plant	0.782	Under construction	6403
B	Metro	1.200	Completed	6712
C	Hospital	0.600	Completed	10398
D	Hospital	0.300	Under construction	8374
E	Pipeline	0.413	Completed	15708
F	Hospital	0.290	Under construction	22478
G	Airport	0.275	Completed	8889
H	Pipeline	1.788	Completed	11354
I	Railway	3.600	Completed	8832
J	Highway	7.500	Completed	7436
K	Power Plant	0.632	Completed	6736

Table 3. Information About Participants

Project ID	Interviewee Number	Position	Respondents' Experience in years
A	Int. 1 Int. 2	Contract Manager Lead Planning Engineer	13 11
B	Int. 3	Project Coordinator	13
C	Int. 4 Int. 5	General Coordinator Technical Manager	32 15
D	Int. 6	Technical Office and Contracts Manager	20
E	Int. 7 Int. 8	Planning and Contracts Manager Technical Manager	15 23
F	Int. 9 Int. 10	Technical Office Manager - Project Controls Manager	22 14
G	Int. 11 Int. 12	Deputy General Manager Project Finance & Business Development Executive	31 8
H	Int. 13	Head of Project Controls	25
I	Int. 14 Int. 15	Deputy Project Manager Construction Manager	33 18
J	Int. 16 Int. 17	Technical Coordinator Construction Manager	22 37
K	Int. 18	Project Director	17

Interview questions were designed as open-ended to encourage free discussion. The main focus was to get the interviewees to talk about their experiences in handling different issues for megaprojects they were involved in. Each interview followed a framework of common questions reflecting on the phenomena under investigation. During the interviews, further questions were asked based on the responses received to clarify the subject. The core questions are as follows:

Q1. Could you briefly explain the scope of the project?

Q2. Can you call this project a complex project? If yes, what are your main reasons for naming it as complex?

Q3. Can you please give some examples about sources/events/factors/dimensions that made your project complex?

The first and second authors of this paper conducted the interviews in 100 minutes on average, over a period of 9 months. They recorded and took notes of each interview separately to review after the interviews.

Data Analysis

Transcription and analysis of the interviews began immediately after completing each interview. The latest version of the QSR NVivo qualitative data analysis software tool assisted in organising and analysing the transcriptions, since it can facilitate reliability, validity, and transparency.

Open coding, the first stage, is a repetitive process that is carried out separately for each interview. Open coding facilitated dimensionalising the concepts and identifying categories and their properties. The initial step for open coding was incident-by-incident coding. The interview data were broken down into discrete incidents, ideas, and acts. Next, axial coding, not strictly sequential, reassembled fractured data and revealed how categories were related. It enabled identifying the context, causes, contingencies, consequences, and conditions affecting categories, interactions, and interdependencies. Concurrently, concept maps of each interview were generated using the Cmap software tool. They facilitated seeing the categories, subcategories and their relations visually. Accordingly, axial coding and concept mapping enabled locating the recurring interactions in the data and tracing the conditions that might influence them.

Links between subcategories and categories were deepened with memos, and selective coding continued to enrich the categories, integrate the coding, and reveal the core categories. In parallel, individual interviews' concept maps were aggregated to develop a generalised concept map. Patterns, including correspondence, sequence, frequency, and causation in the codes and concept maps are used to develop the generalised concept map, and ground the emerging categories and relationships. The theoretical saturation was reached when the evaluation of the interviews ceased adding new dimensions and categories, achieving consistency and representativeness.

Discussion of Research Findings

Open Coding, Axial Coding, and Conceptual Mapping

The open coding process enabled dimensionalising the concepts and identifying categories. During the interviews, participants mentioned both the complexity created by the coexistence of several factors in the project, and the complexity of the factors triggering others or increasing their impact. Based on such insights, five conceptual labels emerged explaining complexity: cause, source, category, trigger, and consequence. "Cause" depicts a specific complexity factor. "Source" describes the concepts that create complexity. "Category" groups similar complexity factors. "Trigger" explains which concepts come together or trigger the factor to create or change the level of complexity. Finally, "Consequence" explains the implications of complexity in terms of risks and challenges. Table 4 shows the initial labelling examples for two quotes from the transcript of Project A, along with the memoing.

Table 4. A Sample of Open Coding

		Statement 1	Statement 2
	Quote	"...Everything is very congested. First, the project is a very big one, and the main milestones are always set one month apart. Completing three units every month makes the work very critical. Tasks are carried out in parallel, not linear. There are a lot of parallel tasks involved in this project. While the foundation is constructed, pipes of the bridge pass over the top, the cables are pulled on the other side. One month apart, you need to commence all critical works and proceed. The project becomes very hectic."	"…Mobility is an issue, not personnel, but more equipment and vehicle mobility. During infrastructure works, since the surface is open [dug], cranes can not pass through. Not getting such large equipment through, you need to find alternative ways. And this creates complexity, build and dismantle, assemble and disassemble…."
Code Labels	Category	Work Schedule	Construction site
	Source	Congestion of work schedule	Insufficient mobility of equipment on the construction site
	Cause	Large amount of work carried out in parallel in the field	Narrow construction site
	Trigger	Large size of the project	High degree of equipment mobility in the field
	Consequence	Problems related to construction coordination	Rework/reconstruction
	Memoing	Concurrent activities on large and hectic projects increase complexity	The existence of several factors may lead to a challenge. Equipment mobility on a narrow construction site with obstacles create complexity

Iterative identification and analysis of codes revealed the main factors associated with the concept of complexity (mainly categories, sources, causes, and triggers) in mega construction projects. Reviewing all interview data revealed the total number of references to the complexity factors in the transcripts, as 213 factors and 23 categories (see Table 5). For example, during data analysis, the size of the area to be constructed, amount of resources involved, size of the workforce, and volume of financial resources were coded as *physical size* and *monetary size* of the project, then the category of "project size" was formed to include these subcategories. Table 5, row 15 shows that the *size of the project* is referenced 26 times, capturing *physical size* and *monetary size* of the project.

Table 5. Complexity Factors

No	Categories	# of Coding References	Subcategories
1	Difficulty in project management	156	Inadequacy of project management system; Inadequacy of communication channels; High level of unnecessary bureaucracy; Vagueness about project role descriptions; Slow decision-making mechanisms; Inadequacy of stakeholder management system; Misaligned expectations and requirements
2	Interactions between stakeholders	142	Level of interactions between various elements within and outside the project system; High degree of public interaction; Inadequacy of information exchange between stakeholders; Level of interactions between stakeholders; Excess political pressure; Coordination problems; Lack of interfaces between various project teams; Unbalanced information exchange between project disciplines; High level of interdependency/interaction between project elements including tasks and organizational units; High number of suppliers, contractors, vendors involved in the project
3	Lack of experience	100	Lack of experience with the project type; Lack of experience in working with the stakeholders; Teams' lack of experience in working with each other; Lack of country-related experience; Lack of technical experience; Unbalanced experience level between stakeholders
4	Physical and environmental constraints	69	Narrowness and congestion of construction site; Tough weather conditions; Location of the construction site
5	Inadequacy of contract clauses	68	The vagueness in contractual terms; Inflexible contract clauses
6	Variety of the stakeholders' strategic goals	56	Lack of common goal; Lack of common understanding; Inadequacy of organizational harmony; Lack of sense of belonging; High level of diversity in stakeholders' project objectives; Lack of trust among stakeholders
7	Concurrent activities	44	A high number of parallel processes and activities
8	Political and macroeconomic uncertainties in the country	44	Uncertainties related to the political structure; Uncertainties related to the economic condition; Unstable political influence
9	Technical novelty of the project	37	Novelty of product or construction process; Novelty of technological applications; Newness of construction methods
10	Technical uncertainties	34	Ambiguity in design processes; Lack of awareness or understanding of technical processes; Unfamiliarity with norms and standards; Ill-defined scope and methods adopted; Conflicting norms and standards
11	Scope changes	34	Changes in project goals, methods, tasks, deliverables, structure, teams, and elements; Changes due to laws and regulations
12	Unrealistic project targets	34	Unclear and unrealistic goals; Unclear definitions/meanings; Hidden agendas; Aggressive project goals
13	Country conditions	33	Country's political and economic problems; Effect of inflation; Political interventions

Table 5 Cont'd. Complexity Factors

No	Categories	# of Coding References	Subcategories
14	Inadequacy in project planning	31	Incomplete and inadequate planning
15	Size of the project	26	Physical size of the project; Monetary size of the project
16	Strategic importance of the project	25	Importance of the project for the company; Political and macroeconomic importance
17	Cultural diversity	23	Diversity of cultural structure among stakeholders; Number of workers from different cultures involved in the project; Number of different languages used
18	Shortage of resources	23	Resource constraint due to shared use; Dependence on a specific raw material; Market conditions; Competition; Lack of qualified workforce
19	Mobility at the construction site	19	Mobility of equipment
20	Financial uncertainty	14	Uncertainty related to the payments
21	Originality of design	12	Innovation and originality in design concepts
22	Uncertainty in logistics	10	Uncertainty in supply chain
23	Operational uncertainty	3	Uncertainty in the operation period

According to Table 5, participants mainly focused on problems experienced in the project while discussing the concept of complexity. It has to be noted that all of the participants indicated their projects as complex. Table 5 includes not only the factors referred to as complexity indicators in the previous descriptive frameworks but also the factors that affect the complexity of a project due to poor management practices and capabilities. For example, *lack of experience* is a factor that increases the vulnerability of the project and may result in higher perceived complexity. Some project characteristics, which have been widely discussed in the literature, such as the high number of stakeholders and technical novelty, were stated as important factors. On the other hand, some managerial problems (highlighted as project management flaws by Bosch-Rekveldt *et al.* 2011), such as inadequacy of communication channels and poor coordination, were also mentioned by interviewees as factors that increase perceived complexity. Thus, Table 5 includes all related complexity constructs, whether they are indicators of complexity (e.g., *project size*), sources of vulnerability (e.g., *lack of trust among stakeholders*), or ineffective management practices/actions (e.g., *unbalanced information exchange between project disciplines*).

Parallel with coding, conceptual mapping helped reveal complexity patterns. For instance, Figure 2 depicts the conceptual map of Project A. It exposes the individual complexity factors (both indicators and vulnerabilities) in a mega construction project and how these factors come together to create additional complexity, revealing the connections (e.g., causation, hierarchy, correspondence).

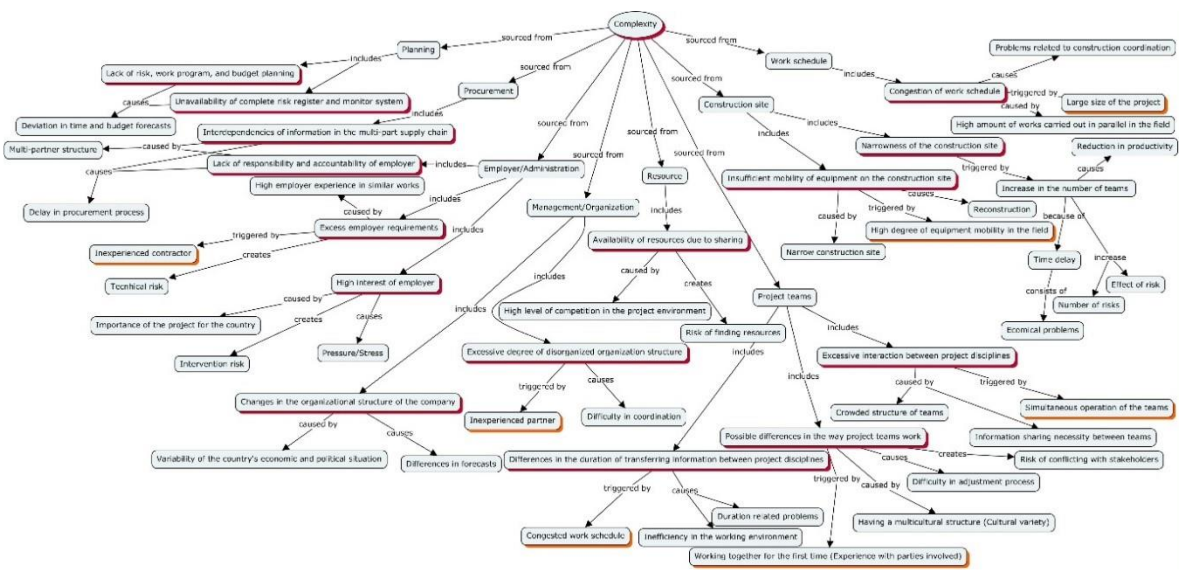

Figure 2. Conceptual Map of Project A

Selective Coding

Analysing the complexity factors, their categories, and relations through axial coding and conceptual mapping led to a general framework explaining the key categories contributing to complexity in megaprojects. Figure 3 presents the relative importance of concepts. As Langley (1999) mentioned, the theory-building process can be enriched using several strategies, including visual representations and mapping. Complexity factors listed in Table 5 are represented as "stars" in Figure 3. The concept of complexity is at the centre because it is the phenomenon under investigation, and the relevant factors are located around it considering two specific criteria: the size of the star and its distance from the centre. While the size of the star indicates the number of related sub-elements encoded into the relevant factor, the distance from the centre indicates the number of references (frequency) encoded for each factor.

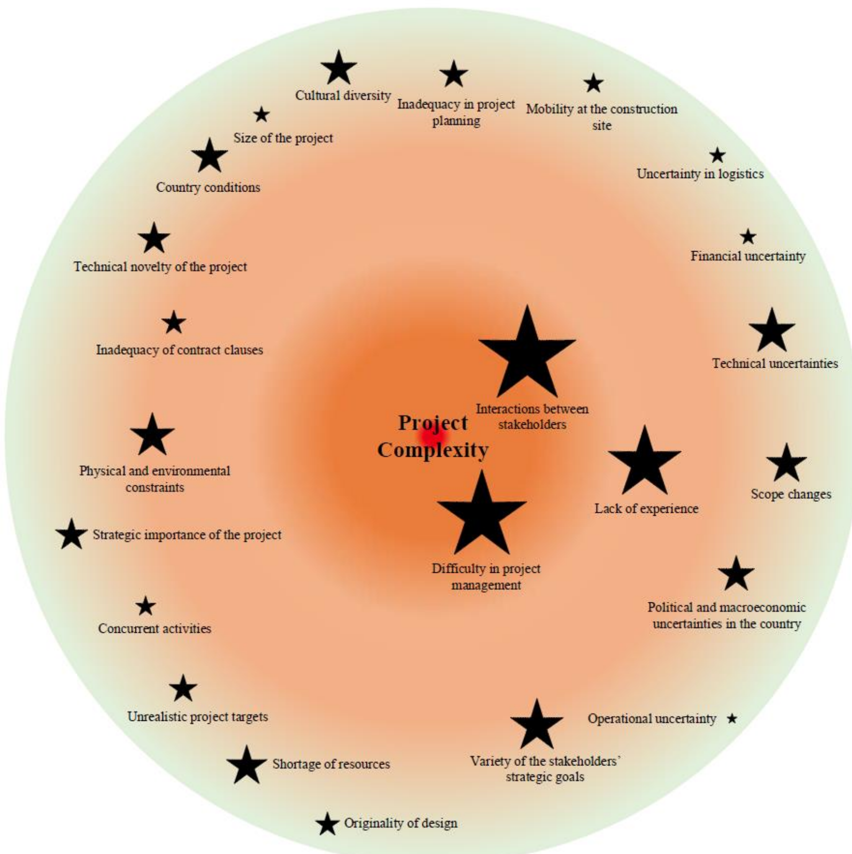

Figure 3. Visual Representation of Project Complexity and Related Factors

Figure 3 demonstrates that the interviewees perceived *difficulty in project management*, *interactions between stakeholders*, and *lack of experience* as the top three factors affecting/related to the project complexity. Construction industry-specific factors related to physical and environmental constraints (e.g., congestion of the construction site) have also been perceived as essential complexity factors. On the other hand, operational factors, such as *operational uncertainty*, *uncertainty in logistics,* and *originality of design,* have been identified as relatively less influential factors. Findings on the complexity factors' relative importance considerably match the findings of Vidal *et al*. (2011b) and Dao *et al*. (2016). For example, Dao *et al*. (2016) found the statistical significance of differences between low-complexity and high-complexity projects, and identified the most significant complexity categories as stakeholder management, resource management, governance, and fiscal planning; whereas design and technology-related factors had relatively low significance. Furthermore, previous research findings (e.g., Vidal and Marle, 2008; Bosch-Rekveldt *et al*., 2011; Qureshi and Kang, 2015) determined that the role of organisational complexity factors and their significance are the major drivers of complexity. Contract and country-related (e.g., political and economic) uncertainties were mentioned more frequently during the interviews when compared with design-related and technical uncertainties.

Although these findings cannot be generalised as they depend on the opinions of a limited number of professionals, findings largely match with the general literature on indicators of mega construction project complexity. Such similarities may be due to the fact that similar contractual forms are used, culturally diverse project teams from different countries are involved in the majority of megaprojects around the globe, and projects in the data set show similar performance problems with international mega construction projects. Factors leading to higher perceived complexity due to incapability and project vulnerability, such as lack of experience and poor project management practices, has the potential to contribute to current knowledge.

Uncertainty perceived as a part of complexity implies that risk and complexity are considered as related concepts by the participants. Although several studies offer insights into the link between risk and complexity (e.g., Jensen and Aven, 2018; Thomé et al., 2016), the role of project complexity in risk management has not been studied in detail (Erol et al., 2020). Geraldi et al. (2011) and Chapman (2016) argue that as uncertainty (as a part of complexity) is managed in projects through risk management, the process of managing risk can be broadened to complexity management. Findings from the interviews reinforce the idea that risk and complexity should be assessed and managed together, as uncertainty is a part of both concepts (Erol et al., 2020).

While Figure 3 reveals the core complexity dimensions and their perceived significance for mega construction projects, various examples given by interviewees demonstrated that the complexity factors could cause a high degree of complexity in the project if they coexist and interact with each other. For instance, when difficulty in project management (e.g., high level of unnecessary bureaucracy and slow decision-making mechanism), uncertainty in logistics (supply chain), and concurrent activities coexist in a megaproject, the level of complexity increases. The existence of concurrent activities, lack of experience in similar projects, and difficulty in project management increase complexity.

To reflect the relationships (causal, coexistence and triggering), all interactions in the individual conceptual maps are combined in a generalised map. Complex as it is, it is hard to trace around a hundred relations on the map. Hence, the appendix portrays the interrelations between the complexity factors in a matrix form. “X” on the map denotes the existence of a relationship, including causal, triggering, or coexistence. It represents which factors interact and affect the perceived level of complexity. The factors come together in various combinations of twos, threes, or fives, “X” denotes at least one coexistence or triggering relationship. For simplicity, only the existence of a relationship is acknowledged in this matrix. The frequency (how many times a complexity factor is cited in the transcripts) and strength of the relations are not shown in the matrix; however, the factors are ranked from most cited/influential to least cited/influential complexity factors. Since the relationships in the generalised map only represent 11 projects, it may not cover all possible interactions between project complexity factors. However, both the matrix and the map clarify that the interactions are critical in understanding complexity; it is not enough to identify individual complexity factors or clusters of factors.

Theory Conceptualisation and Integration

This stage uses an empirically established explanation of the interrelationships and interdependencies between concepts/categories, so that theory generalisation begins. In this direction, Table 6 compiles some quotations from the participants of this study to illustrate the themes they highlighted while explaining the complexity of their projects. Examples given by the participants demonstrate that complexity is associated with the factors both known at the outset and emerging over time. For instance, Int. 7 speaks of the complexity they expect due to contract clauses, whereas Int. 3 explains how the delayed approval processes during construction resulted in major complexity in the project.

Although each complexity factor has a particular impact, in order to assess the level of complexity in a project, rather than analysing the factors individually as proposed in previous research studies, it is necessary to assess their combined effects by considering how the patterns emerge over time. Besides the references to the individual factors, the overall examination of the transcripts revealed the interviewees' holistic perceptions of complexity. Table 6 also includes several examples of interactional complexity caused by the combination of different factors. For instance, Int. 1 remarks that in almost all projects, project and country-related factors impact each other, increasing the level of project complexity. Int. 6 perceives that the country's unstable political and economic conditions, combined with inadequate planning, create high levels of procurement uncertainty, and this is irrecoverable for hospital projects. According to Int. 9, the reason for the increase in project complexity was that factors such as an inexperienced team, difficulties in procurement, and complex contractual arrangements have interacted with unstable country conditions. Similarly, Int. 11 mentions the combination of unrealistic demands of the client, inexperienced project teams, and unstable political and economic situations while explaining the complexity of their project. For railway project I, Int. 14 talks about the uncertainty and complexity caused by the combination of the originality of design, technical novelty, working with an inexperienced client, the existence of time pressure, and concurrent activities on the construction site together with unstable macroeconomic conditions. Finally, after speaking of several project features such as the high-risk level in the host country, project delivery system, contract payment type, and ambitious schedule targets set by the private investor, Int. 18 stresses that the coexistence of all these factors causes him to label the project as complex.

Table 6. Example Quotations About Complexity Factors

Interviewee	Quotation	Focus
Int. 3	The project was significantly delayed due to the delayed approval processes. Because of the delayed approval processes, the construction works were slowed down, and uncertainty of approval times made planning impossible, creating major complexity.	Delay in approval times
Int. 4	Design-build projects are always complex. Almost in all of them, design and construction processes are concurrent. There may be some places that have not been finalized or decided during the construction phase, which leads to a high level of uncertainty and complexity in construction works.	Project delivery system
Int. 6	It was not possible to pour concrete during the day as construction equipment was not allowed to enter the city centre. We could only progress the work at night. The fact that the location of the construction site was in the city centre caused difficulties in mobilization and logistics and created complexity.	Physical constraints
Int. 7	We anticipated that due to vague and strict contract clauses, we would experience difficulties. Thus, the contract was an issue that created complexity. Being able to manage this was one of our biggest challenges in the project.	Contract
Int. 11	It was difficult to meet all the stakeholder expectations, which were sometimes conflicting. The complexity of the project stemmed from different stakeholder expectations, priorities, and difficulty in managing their interactions.	Stakeholders
Int. 18	We experienced difficulties in the project due to the complexity of the design. For example, the gas turbines and generators, which were produced to be placed outdoors, had to be placed indoors. The cables had to be buried under the ground, and huge concrete channels had to be constructed for these cables within a very restricted area. They really created complexity for us during construction.	Design

Table 6 Cont'd. Example Quotations About Complexity Factors

Interviewee	Quotation	Focus
Int. 1	In almost all projects, project and country-related factors come together, and the level of project complexity increases.	Interactional complexity: Project and country-related factors
Int. 6	When unstable political and economic conditions of the country are combined with inadequate planning, it creates a high level of procurement uncertainty. This is something irrecoverable for this type of project.	Interactional complexity: Political and economic conditions and inadequacy in planning
Int. 9	This project is an association of people, resources, and project structures. These mostly interact with other entities and elements in their environments. In our case, an inexperienced team, difficulties in procurement, and complex contractual arrangements have interacted with unstable country conditions, increasing project complexity.	Interactional complexity: Inexperience, difficulties in procurement, contract, country conditions
Int. 11	The combination of unrealistic demands of the client, inexperienced project teams, and unstable political and economic situations made the project highly complex.	Interactional complexity: Client, inexperience, and political and economic situations
Int. 14	In our project, the combination of the originality of design, technical novelty, working with an inexperienced client, the existence of time pressure, and concurrent activities on the construction site resulted in unpredictable results. Uncertainty and complexity have further increased with unstable macroeconomic conditions.	Interactional complexity: Design, novelty, (inexperienced) client, time pressure, concurrent activities, and macroeconomic conditions
Int. 18	The project took place in a very high-risk country. It was an EPC type of project, tendered on a lumpsum basis. It was constructed for a private investor who set very ambitious schedule targets. When we consider them all together, this is what I call a complex project.	Interactional complexity: Risk level in the host country, project delivery system, contract payment type, client, and schedule targets

Not only patterns of relations but also how they emerge over time is key for conceptualising complexity. Overall complexity can be visualised as an emergent pattern of interacting elements changing, reinforcing, and triggering each other. For example, a quotation from Project D (Int. 6) explains these dynamic relations between several factors, such as technical complexity first leading to logistical complexity, and then financial problems due to the complexity of the financial package:

"... At the start of the project, the most important problem was technical complexity due to the seismic isolators being used, which also led to delays due to long waiting times for testing and also logistical problems. Then, when the logistical problems were solved, we had a financial problem because of delay of progress payments due to technical problems experienced and differing requirements of the high number of financial institutions involved..."

Figure 4 is an abstract representation of the emergence of project complexity based on the perceptions of the professionals. The overall level of complexity may change during the project with changing levels or existence/non-existence of individual complexity factors and their interactions. The factors' changing interactions result in dynamic complexity patterns that evolve over the project life cycle.

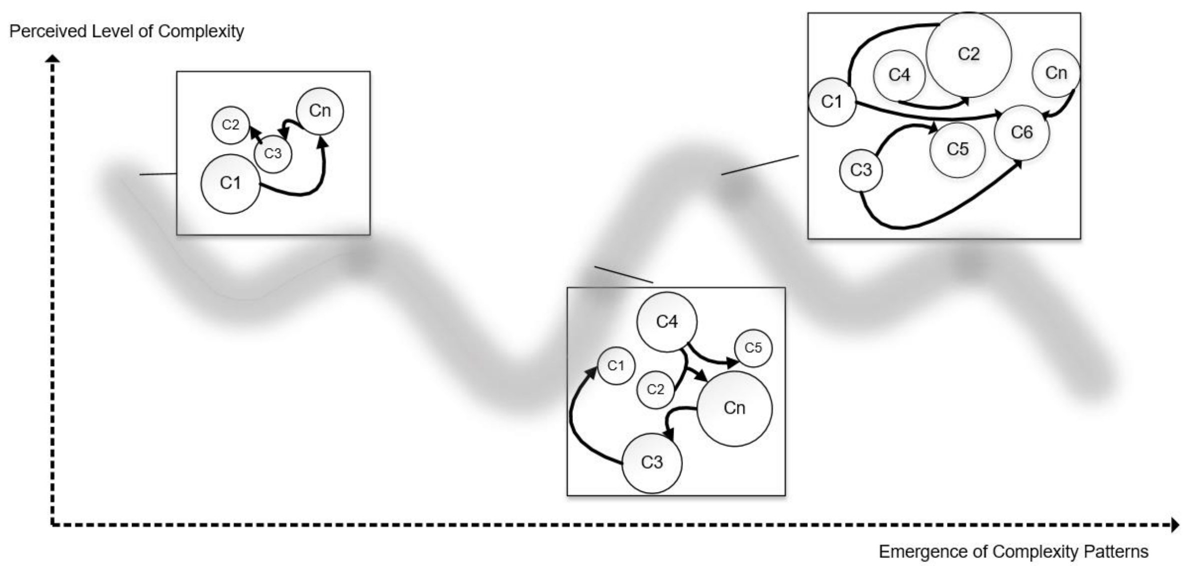

Figure 4. The Emergence of Complexity Patterns

Finally, the project complexity definition that builds up on the interviews is as follows: *In mega construction projects, complexity is a project property that stems from the interaction of* *project features (e.g., size, stakeholders, and strategic importance), uncertain variables/conditions (e.g., scope and country factors), and managerial actions that form a pattern, which emerges over time.*

This definition reinforces the argument that the degree of complexity that project characteristics and uncertainty factors create when they come together in different combinations and affect each other is not the same as the totality of individual impacts. Moreover, it pinpoints an emergent pattern that leads to changes in project complexity over time. Thus, assessing and managing project complexity requires an understanding of dynamic patterns of complexity.

This definition has some implications for project management. First of all, considering that complexity emerges over time due to interactions between several dimensions (e.g., technological, organisational, financial), management of these dimensions should not be considered static and distinct tasks. This coincides with the argument of Whyte and Davies (2021) on the necessity of reframing systems integration by moving beyond a static approach to consider the emergence of complexity across technological and organisational boundaries. While some complexity factors, such as the high number of stakeholders and operational complexity, can be managed by deliberate strategies (exploitation), uncertainty and ambiguity due to interrelated factors require emergent strategies (exploration). Although some deliberate strategies can be developed at the start of a mega construction project considering the structural/static factors, emergent factors require an agile project management approach and a resilient project system with qualities such as absorptive capacity, adaptive capacity, and restorative capacity (Francis and Bekera, 2014). Depending on the relative level of complexity due to emergent patterns over time, different organisational responses (e.g., system design, contingency planning) can be utilised to manage risk and complexity.

Conclusion

Summary

This paper presents the findings of an exploratory study to conceptualise complexity in mega construction projects through the reflections of practitioners. Due to complexity and uncertainty in megaprojects, project teams need to react flexibly, adjusting common practices through pragmatic inquiry and reflective thinking (Biesenthal, 2016). Similar to Schön (1983)'s idea, managers would be limited if they applied only technical rationality under complex and unexpected situations, but instead, they perform reaction-in-action. Jia et al. (2017) resemble the research process in the grounded (data-driven) approach to the reflective practitioners' problem-framing in generating personal knowledge. This article focuses on practice-oriented research in project management and follows a grounded approach in conceptualising project managers' reflections to reveal their understanding of complexity in mega construction projects. The grounded theory approach was adopted to process data obtained through semi-structured interviews with 18 participants from 11 mega construction projects carried out by Turkish contractors in partnership with international companies. The qualitative analysis findings uncovered which characteristics comprise and which factors contribute to mega construction project complexity, and findings were compared with literature. This study exhibited 23 complexity factor categories with their sub-factors, specific to mega construction projects. Some perceived complexity factors stem from the known characteristics of the project, such as size, novelty, and strategic importance, some of them are due to uncertainty stemming from operational, political, economic, and financial conditions, and some are due to project vulnerability and managerial factors. Areas of commonalities exist between current research findings and previous research about complexity indicators (Vidal and Marle, 2008; Williams, 1999; Qureshi and Kang, 2015; Geraldi and Adlbrecht, 2007; Geraldi *et al.*, 2011). This study built on the reflections of interviewed practitioners and how they framed their experiences. While different researchers undertake similar research, the findings are likely to be similar but not identical due to different project contexts and perceptions. Independent complexity dimensions are shown to be partial in representing project complexity. Current research demonstrates how different constructs come together and evolve in time, leading to complexity in mega construction projects. The reflections of practitioners portray that coexistence and interrelations between complexity factors were the main sources of complexity in the case projects. This finding reinforces the idea that project complexity should be better conceptualised and assessed by a pattern emerging over time rather than a list or hierarchy of individual complexity factors. Hence, this study extends the leading ideas in the field, and contributes to mega construction project complexity with empirical data. Based on how the practitioners observed, defined, and reacted to the complexity, the frequency of references in the coding showed that project management, interactions between stakeholders, and lack of experience were the top three factors affecting the project complexity. However, it should be considered that this is an interpretive study focused on understanding complexity rather than prioritising complexity indicators.

Implications

This research study has the potential to contribute to the body of knowledge of project management by identifying a complexity pattern based on interviews with experts involved in 11 mega construction projects and comparing findings with previous studies. The concepts and interactions identified in this study can be further utilised to develop quantitative models to predict the level of complexity in mega construction projects. This study confirms that assessment of the level of complexity requires a dynamic modelling approach. System dynamics would be a better modelling approach for risk and complexity assessment rather than techniques such as multi-criteria rating methods, including Analytical Hierarchy Process. Our findings may also have some implications for the management of complexity. Forthcoming studies are necessary to test whether or to what extent organisational responses (e.g., establishing resilient project systems) may influence the success of mega construction projects. Our findings also provide some insights into the process of managing risk in projects. As also highlighted by Chapman (2016), risk management practices would benefit from complexity frameworks. Uncertainty as a source and consequence of complexity implies that complexity should be considered during risk assessment and management.

Limitations and Research Direction

The limitation of this study is that the posited complexity conceptualisation is based on a limited number of mega construction projects, predominantly carried out in Turkey, reflecting the experience of Turkish practitioners. The dataset included projects of different types. Mikkelsen (2021), based on questionnaire findings of more than 1000 practitioners, argued that mental models on complexity are much influenced by the project role of the respondent and less so by the type of the project and sector. It is believed that findings may be applicable to all types of construction projects and other project-based sectors. However, it has to be noted that the findings are context-specific, and the aim of the research is not to seek laws/generic rules. Further studies should be conducted to test their relevancy for different contexts, such as different countries, other project-based industries, and specific types of construction projects. As another limitation, in this study, the reflections of the participants were acquired through interviews once. Experts considered lessons learned throughout the project; however, they may have an availability bias and selective memory regarding the complexity factors prevailing towards the end of projects. Moreover, perceived complexity reflects the perspective of managers working in contracting companies. Different stakeholders, such as the client and designer, may have different perceptions of project complexity regarding the same projects. In order to have a more holistic perspective on perceived complexity, new studies should be conducted with the participation of more diverse stakeholder groups.

This paper only qualitatively discerned dimensions of complexity. Future studies can also involve a proof-of-concept stage with a quantitative measurement. This study excludes specific operational responses in relation to dealing with the challenges at varying dimensions of complexity; however, managerial practices mentioned by the interviewees to manage complexity were included in the model. Testing the success of various complexity management strategies is beyond the intended scope of this work. On the other hand, based on the identified factors, the impact of implemented strategies can be evaluated, and managerial suggestions can be developed by future studies. The relationship between project complexity and project success moderated by project management competencies, organisational responses, and/or implemented strategies can be empirically tested in forthcoming studies.

Data Availability Statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
C1						X	X							X	X							X	
C2	X			X	X	X		X	X	X		X	X	X	X					X			
C3	X				X		X					X	X	X				X			X		
C4	X	X				X		X	X	X	X	X		X					X				
C5	X	X	X			X				X													
C6	X	X		X	X			X	X			X			X	X					X		
C7	X		X							X	X								X			X	
C8		X		X		X	X	X	X	X		X		X				X				X	
C9	X	X		X		X		X		X		X											X
C10		X		X				X						X				X					
C11	X						X																
C12	X	X		X		X		X	X	X	X												
C13	X	X	X			X		X			X				X			X		X		X	
C14	X	X		X				X		X									X	X	X	X	X
C15	X	X				X	X			X			X				X		X	X			
C16	X	X										X											
C17	X	X	X																				
C18	X		X										X										
C19	X			X			X								X								
C20		X											X	X	X			X			X		
C21										X	X			X				X		X			
C22	X			X			X					X											
C23																				X			

Note: The definitions of complexity factors C1-C23 are presented in Table 5.

X denotes that the factors are interrelated.