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Identifying and assessing complexity emergent behaviour during mega infrastructure construction in Sub-Saharan Africa

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ABSTRACT

Objective: The objective of the article is to identify, assess, and classify complexity indicators based on the impact level of their emergence behaviour during mega infrastructure construction.

Research Design & Methods: The study adopted a quantitative methodology: online questionnaire survey to gather data and Exploratory Factor Analysis (EFA) to analyse data.

Findings: Task difficulty, dispersed remote teams, multiple project locations, and project scope were identified as structural complexity indicators that surged extreme difficult to project managers. In comparison, project duration, project tempo, construction method, and uncertainty in methods were found to trigger uncertainty during construction.

Implications & Recommendations: This study lays foundation for theoretical exploration of an important phenomenon in the global economy, *i.e.* the development of mega infrastructure projects in developing countries. The contextualization of the study in Sub-Saharan Africa builds knowledge of such project complexity in an under-researched context. Practically, the results enable managers to create tools and frameworks to assess overall project complexity level and evaluate their competence incongruently to complexity to select appropriate complexity management strategies. Policy makers are informed about factors which can impede execution of mega infrastructure projects, thus they adjust risk assessment in such projects and better allocate resources to facilitate sustainable development of developing economies.

Contribution & Value Added: The study provides a foundation for extensive research into infrastructure complexity in Sub-Saharan Africa. Additionally, it provides insights to parties willing to explore Public-Private infrastructure initiatives in the region.

Article type: research article
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INTRODUCTION

Sub-Saharan Africa has attracted an more and more investments in infrastructure projects (Gemueva, 2018; Owusu-Manu *et al.*, 2019). However, most of these projects do not meet the originally set deadlines and budgets (Gbahabo & Ajuwon, 2017). These in turn lead to high social and economic costs imposed on already vulnerable societies and economies. Such a systematic inability of project managers to manage complexity of mega infrastructure projects urgently requires empirically supported research to identify, assess, and systematise the complexity problems of such projects.

It is widely accepted that complexity will remain an inherent part of infrastructure development due to the nature of systems that exist when actualizing these projects, coupled with enormous challenges that complexity exerts during construction (Kermanshachi & Safapour, 2019). However, complexity is a discouraging element for businesses' participation in Public-Private Partnerships, i.e. the preferred finance medium for infrastructure building in developing economies. This makes it imperative to elucidate infrastructure complexity in the region in need of more infrastructure investment.

Williams (1999) observes that complexity typically emerges during infrastructure construction from either difficulty surging from the interdependence between project elements and its people (i.e., structural complexity) or incessant change and unknown uncertainty resulting from the interrelationship between both components (i.e., dynamic complexity). Identifying complexity indicators during mega construction based on their emergence behaviour could be a precursor to elucidating and measuring projects' complexity during the planning phase for proactive complexity management (Bakhshi *et al.*, 2016; Lu *et al.* 2015). However, recent studies criticize such an approach as static, possibly misleading project managers to underestimate complexity during the construction phase (Kermanshachi & Safapour, 2019), and failing to reflect complexity emerging characteristics (Luo *et al.*, 2017). Moreover, identifying indicators at the planning stage may not necessarily depict complexity impact during construction. To account for this critique, the study presented in this article aims to identify the actual impact level of each complexity indicator from their emergent behaviour during construction. As such, it can serve as a proactive medium for complexity management to support project managers in their role effectively in the context of Sub-Saharan Africa. At the same time, this approach helps to augment findings from a major recent work of Söderlund *et al.*, 2017, in which complexity indicators are only identified and classified.

In the light above, this article aims to identify, assess, and classify complexity indicators based on the impact level of their emergence behaviour during mega infrastructure construction from the perspective of experienced project managers. The intended contribution is to enable managers, policy makers and potential investors to better comprehend the complex nature inherent within the terrain of inquiry, and to enable them to design strategies that account for peculiarities of Sun-Saharan Africa simultaneously ensuring success of such mega infrastructure projects.

The article is structured as follows. In the next section, relevant literature will be reviewed following the critical literature review method used in recent studies by Sieja and Wach (2019) and Wach (2020) with a specific focus on mega infrastructure project complexity and the identification of its dimensions. Next, methods and data will be presented, and the results of the empirical study will be discussed in relation to the reviewed literature. Finally, implications of the received findings will be discussed.

LITERATURE REVIEW

Mega infrastructure project commands a budget of more than a billion USD and is inherently characterized by the complexity that surges from its large size, scope, numerous task and components, and high uncertainty occurrence resulting from more extended project period, scope change, and contravening political interest (Siemiatycki, 2015). Complexity definition in the construction project management literature remains vague due to researchers' partial and contesting views across time-space (Luo *et al.*, 2017). The earliest definition was by Baccarini (1996) who defines 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 interaction between these components. Williams (1999) uses this definition mainly to describe structural complexity. Furthermore, Williams suggests the need to capture Turner and Cochrane (1993) uncertainty in goals and means as an aspect of complexity. This assertion influenced researchers to conceptualize complexity differently and perhaps it is the reason why today complexity is often associated to project difficulty and risk (Dao *et al.*, 2017).

Notwithstanding the extensive descriptions of complexity in the literature, practitioners have referred to it as difficult, complicated, knotty, unique, lacking clarity, and intricate. Geraldi *et al.* (2011) reiterates that researchers should always provide an unequivocal distinction between complex and complicated systems when discussing the complexity concepts. Cicmil *et al.* (2009) distinguishes the two streams covering complexity discussion in the literature; the first dimension discussed how complexity manifests in a project – complexity in the project. In contrast, the other dimension covers factors that make a project difficult to manage. The study highlights the first dimension to be theoretically driven through the complexity theory lens, while the latter is practitioner-driven with the assertion that identifying complexity factors on a project could enable project managers to define decisions and corresponding actions required to manage complexity (Dao *et al.*, 2017; Kermanshachi & Safapour, 2019).

The current study aligns with the latter dimension as it aims to investigate complexity that causes difficulties from the project manager's perspective. Hence, the notion for adopting Xia and Chan (2012) complexity definition as project characteristics that are complicated, multi-faceted, and composed of many interconnected parts.

Research investigating infrastructure project complexity had been conducted from various dimensions over the years. However, no consensus taxonomy clearly describes what complexity constitutes or how its occurrences could be managed (Bakhshi *et al.*, 2016). Most researchers confine to studying complexity dimensions and their effects on project performance with the firm belief that if a project manager perceives complexity from the highlighted indicators, then the right decisions and corresponding actions required to manage complexity could be defined (Dao *et al.*, 2017; Kermanshachi & Safapour, 2019).

Gidado (1996) broadly categorizes complexity sources on construction projects into two distinct groups: elements inherent to performing individual tasks that may resonate from a combination of the project's intrinsic complexity and components necessary to form a workflow, sequence rigidity, and construction elements overlap. Girmscheid and Brockmann (2008) classify project complexity on large-scale engineering projects into overall complexity, task complexity, social complexity, and cultural complexity. Their study described task complexity as the density of work that could be managed by decision-making and coordination to depict structural and dynamic complexity.

Lessard *et al.* (2014) investigated the various project properties and features that attribute complexity and highlighted technical and institutional complexity as complexity dimensions. Nguyen *et al.* (2015) identified organizational, technological, environmental, socio-political, infrastructure, and scope as complexity dimensions on transport projects using fuzzy analytic hierarchy process. Kermanshachi and Safapour (2019) categorize construction project complexity indicators attributes into stakeholder management, governance, fiscal planning, quality, legal, interfaces, execution target, design and technology, location, scope definition, and project resources. Mirza and Ehsan (2017) classify complexity factors based on schedule constraints during infrastructure development into time, scope, cost, quality, resource, and risk complexity.

He *et al.* (2015) used the content analysis technique to explore existing literature in which complexity was categorized into technological, organizational, goal, environmental, cultural, and information complexity. Further, Bosch-Rekveldt *et al.* (2011) describe complexity as technical, organizational, and environmental (TOE). Chapman (2016) classifies complexity indicators on rail megaproject into three categories, the delivery team (who), delivery process (how), and project characteristics (what).

Despite these proposed classifications, meagre studies categorize complexity indicators based on the properties of their emergence behaviour on infrastructure projects. Remington and Pollack (2016) categorize complexity influencing factors into structural, technical, directional, and temporal complexity. Williams (1999) highlights that complexity emerges from structural uncertainty and uncertainty. Lu *et al.* (2015) proposes using task and organization perspectives to determine the dynamic emergence effects of complexity influencing construction projects' factors. According to the study, defining the complexity indicators underlying emergence behaviour could enable project managers to understand better infrastructure project complexity, which subsequently improves overall project performance. In this view, the study focused on the emergence behaviour of complexity indicators (*i.e.*, structural and dynamic) within the project construction site, as seen from the table in the Appendix (Kian Manesh Rad & Sun, 2014).

RESEARCH METHODOLOGY

The scope of this study was limited to the project execution phase, because in general construction management challenges exacerbating complexity are mainly domiciled on the construction site. Studies capturing complexity in other regions adopted the Delphi survey method to assess, rank, and weigh complexity indicators on various project types from distinct dimensions. However, a different approach was preferred for this study, grouping complexity indicators based on the impact level of their emergent behaviour from the project manager's perspective.

Through an extensive literature review, seventy-three complexity indicators prevalent on the construction site were identified and used to design a nominal scale pilot study questionnaire. The first section required participants to either agree or disagree if a complexity indicator applies during infrastructure construction. In the next section, participants either ticked structural (S), dynamic (D), or both (B), the attributes which apply to each complexity indicator emergent behaviour. Seven built environment academicians – three tutors and four postgraduate students with prior experience developing mega infrastructure – and ten field professionals were selected to ascertain the minimum sample requirement of 10 participants for a pilot study (Hill, 1998).

In this pilot study, sequel to distributing the questionnaire form online, a video-conference call was conducted to explain and clarify details and ensure participants understood all concepts and questions asked in the survey. The researchers confirmed that repetitiveness, ambiguity, and redundancy were eliminated from the final complexity indicator assessment questionnaire based on gathered data. Forty-nine indicators were identified to be prevalent on the construction site, 21 into the structural dimension, and 28 formed the dynamic dimension seen from the Appendix.

The final version of the main questionnaire design captured how project managers perceive complexity indicator intensity based on its emergence behaviour. The questionnaire contained 55 survey questions that required answers, structured into three sections. Section 1 captured participant's demography. Section 2 entailed structural complexity indicators. Project managers were required to select the extent to which they perceive an indicator contributes to the overall project complexity on an 11-point Likert-type scale, where 0 stands for no impact and 10 for extremely high impact towards increased project difficulty level. Section 3 captured dynamic complexity indicators. Participants were required to select between 0 (no influence) and 10 (extremely high influence) the extent to which an indicator leads to uncertainty that predisposes project managers. The Likert-types scales were used to measure complexity based on previous studies, which also employed Likert scales to investigate construction project complexity: Luo *et al.* (2017), Dao *et al.* (2017), and Mirza and Ehsan (2017).

Homogenous sampling was used for its potential to obtain a representative sample with similar characteristics (Sharma, 2017). This technique ensured that the selected sample was better positioned to define how intense complexity indicator emergence characteristics contribute to overall project difficulty and uncertainty during construction from their experiences working on this type of projects. Being aware of the problems of conducting surveys in different cultures and in the context of developing economies reported by Bartosik-Purgat and Jankowska (2017), the designed questionnaire was administered online but was preceded and followed by personalized inquiries. The target was 358 project managers working on mega infrastructure projects and registered with the Federation of Construction Industry (FOCI) database (*N*=358). The FOCI publishes a regularly updated list of approved large construction contractors in the region. The survey was conducted on Qualtrics platform with the university address to ensure respondents received this as an academic study. Data collection lasted from September 1st, 2020, to November 29th, 2020. A broad description of the research project was given in the introductory section together with research ethics forms required by the authors' institutions.

When the survey was closed, 189 entries were recorded. Next, researchers screened for partially completed entries, which led to the final sample of 142 entries (n=142), representing a 41% response rate. Respondent's industry experience ranged between 6-30 years, with the majority (57%) having over 16 years of work experience. In terms of professional expertise, most respondents were civil engineers (51%), which is a common practice on mega construction sites.

A popular software package (IBM SPSS) was used to conduct the Exploratory Factor Analysis (EFA) and categorize complexity indicators into dimensions describing their emergent behaviour's intensity level. This technique was employed because it allows finding underlying factor structure for the complexity indicators. The EFA was conducted for each complexity dimension.

The minimum amount of data needed to perform factor analysis was satisfied using likewise deletion – the final sample size for the first dimension was 121, and 117 for the second dimension. The sample size threshold of 100 cases suggested by Gorsuch (1997) and Kline (2014), or five samples per variable, (Cattell, 2012; Gorsuch, 1997) was achieved.

The structural complexity dimension captured indicators that increase complexity emerging from the project structural attribute. Conducting the EFA, data were subjected to factor analysis using Principal Axis Factoring and oblique Promax rotation. The Kaiser-Meyer-Olkin (KMO) values for individual items were above 0.5 for a sample size less than 200 (MacCallum *et al.*, 1999), and the KMO measure for sampling adequacy was 0.81, which indicates that the sample data is meritorious to conduct EFA (Tabachnick *et al.*, 2019). Bartlett's test of sphericity c2 (210)=3122.09, p<.001 showed a patterned relationship exists between the items. Using an eigenvalue cut-off of 1.0, four factors were found to explain a cumulative variance of 73%. Table 1 depicts factor loading after using a significant factor level of 0.40 suggested by Field (2014). With the exemption of 'project density' and 'the lack of technical know-how,' all elements were above the 0.40 significant factor level.

Additionally, elements from the established factor scale must have demonstrated internal consistency of at least 0.60 for Cronbach α coefficient. This was achieved, and alpha if-item-deleted was collectively found to be less than Cronbach α coefficient, in line with widely used procedures suggested by Nunnally and Bernstein (1978). Corrected- item-total correlation for each element in a classified group was greater than the 0.500 thresholds suggested by Cristobal *et al.*, (2007), which signified that each element was highly consistent with the sum of other elements. Details are presented in Table 1.

After completion of the above-mentioned tests, the final instrument for structural complexity indicator consisted of 19 elements. These were classified into four factors, to explain the emergence behaviour intensity level. The structural complexity intensity factors were labelled as extremely high (F1), high (F2), moderate (F3), and low (F4) based on Thamhain's (2013) overall project complexity level dimension taxonomy. The defined complexity intensity clusters captured more than three elements (Tabachnick *et al.*, 2019), demonstrating the intensity each indicator contributes to overall project complexity from the project manager's perspective during mega infrastructure construction.

Table 1. The EFA result for structural complexity indicators

Element	Factor loading	Eigenvalue	CITC	Alpha if item deleted	Cronbach's
Extremely high		10.930			0.931
Difficulty of task	0.792		0.797	0.919	
Rigidity of sequence	0.855		0.883	0.911	
Project scope	0.720		0.765	0.922	
Availability of skilled workforce	0.946		0.854	0.914	
Physical locations	0.749		0.711	0.927	
Multiple locations	0.846		0.762	0.923	
Site topography	0.519		0.706	0.929	
High		1.732			0.885
Type of structure	0.404		0.758	0.758	
Number of project participants	0.516		0.685	0.685	
Project budget	0.896		0.805	0.830	
Quality requirement	0.734		0.767	0.849	
Moderate		1.469			0.848
Structure height	0.545		0.505	0.854	
Numerous task	0.768		0.765	0.791	
High variety of task	0.425		0.669	0.815	
Project scheduling	0.561		0.624	0.828	
Construction method	1.037		0.743		
Low		1.283			0.870
Site perimeter	0.757		0.707	0.860	
Number of elements	0.837		0.826	0.752	
Required engineering hours	0.756		0.727	0.838	

Source: own study.

The second questionnaire section established the level to which dynamic complexity indicator emergence behaviour contributed to uncertainty and incessant change during mega infrastructure construction from the project manager's perspective. Factor analysis using Principal Axis Factoring and oblique Promax rotation was performed on the data set. Individual items KMO value was above 0.5, and the KMO measure was 0.843, which shows the sample was adequate to conduct EFA. Bartlett's test of sphericity of c2 (378)=3602.392, p<.001 depicted that a patterned relationship existed between the items, and factor analysis may have been applied on this sample. Eigenvalue cut-off of 1.0 was adopted, and six common factors were extracted to explain the cumulative variance of 75.196% (Table 2). The significance factor level of 0.40 threshold was set, and each extracted factor label showed an internal consistency above 0.60 for Cronbach α coefficient. Besides, all indicators had a corrected-item-total correlation above the 0.300 prescribed threshold.

The final instrument result consisted of 23 indicators, classified into four-factor labels after elimination of factor F5 and F6 due to low internal consistency, and deployment of workers indicator, because it loaded below the 0.40 threshold. Perhaps, this could be due to the local procurement strategies which involve specialist subcontractors. Project managers tend to focus on the lead subcontractor rather than on their work team (Rosli *et al.*, 2018).

Each of the four complexity factor labels consisted of at least three indicators, defined using Thamhain's (2013) overall degree of project uncertainty taxonomy, to describe how project managers perceived each indicator contribute to uncertainty and continuous change during the construction phase. The dynamic complexity factor labels were Chaos (F1), Unforeseen Uncertainty (F2), Foreseen Uncertainty (F3), and Variations (F4), described below.

The received results are discussed in the following chapter.

RESULTS AND DISCUSSION

Structural complexity

Extremely high emergent effect (F1)

The extremely high dimension (F1) depicted elements that require competent project managers to manage complexity intensity exerted during mega infrastructure construction (International Centre for Complex Project Management, 2012; Remington, 2016). Sequence rigidity leads to construction freeze due to the difficulty it enacts in performing tasks onsite. This occurrence leads to high complexity for managers, as found in the survey. Similarly, managers could be overwhelmed if the project scope is enormous, as Bosch-Rekveldt *et al.* (2011) points out that scope size plays a crucial role in increasing structural complexity.

The absence of skilled workers to manage the project scope and execute tasks during construction is a major complexity. Skilled workforce is pivotal on the construction site (Dale, 2013). Kermanshachi and Safapour (2019) showed that primary stakeholders on construction projects in the United States found the absence of skilled workers to contribute to complexity negligibly. However, in the current study, project managers in Sub-Saharan Africa found this indicator to lead to substantial complexity on the construction site. This disparity could be explained by prevalence of automation on construction sites in the United States. Even more so, there is a massive resource pool of skilled immigrant workers, which is the contrary to the reality of work in developing nations where the absence of skilled workers is prevalent (Jarkas, 2017).

Problems identified in previous research: physical location of the project in terms of access (Dao *et al.*, 2017), existing infrastructure onsite (Chapman, 2016), impact on the execution plan (Kermanshachi & Safapour, 2019), the location remoteness (Bosch-Rekveldt *et al.*, 2018), and site topography (Xia & Chan, 2012), were all found to lead to high structural and technical complexity onsite, overwhelming project managers extensively. If the project must depend on multiple projects for technical input and human resources, the complexity becomes enormously high, just as identified in the current study.

High complexity emergent effect (F2)

The high complexity level (F2) dimension captured four indicators that project managers found to contribute to project difficulty during the construction phase exuberantly. The infrastructure type and its function play a pivotal role in determining the number of project participants (Dao *et al.*, 2017), the expected quality requirement (Xia & Chan, 2012), and the overall required budget (Bosch-Rekveldt *et al.*, 2011). Constructing a new project type would require a higher budget to purchase innovative technology and employ specialist subcontractors to support the project manager. When provided funds are insufficient, the tendency towards high complexity increases as the manager is constrained. Correspondingly, when sufficient funds are provided, coordinating numerous participants, and employing new technology is certainly a source of added complexity as much time would be expended to get the project team acquainted with the novel approach.

Delivering projects with minimal defects is a horrendous task for managers, since attaining maximum quality would require continuous supervision, coordination, and monitoring of the numerous workforce. This study established how these indicators contributed to high complexity and suggested that project managers should employ proactive project management strategies, ameliorate management of complexity emerging from these indicators during construction, confirming insights from the study of Nguyen *et al.* (2015).

Moderate emergent effect (F3)

This dimension comprises five indicators that moderately contribute to complexity when managing mega infrastructure construction projects. Managers might find height to moderately influence difficulty because the mega infrastructure structures are considerably high in most instances, which results in a need for various equipment to support work at height, and the prospect of coordinating workers on-site becomes lower, thus leading to complexity (Xia & Chan, 2012). The higher the project, the greater the number and variety of tasks to be performed, which in turn requires innovative construction methods and effective scheduling of artisans and materials to manage complexity (Gajić & Palčič, 2019). Nguyen *et al.* (2015) showed that the number of tasks leads to organizational complexity, which experienced project managers in the current study found to moderately trigger difficulty as professionals get accustomed to project height from participating in various infrastructure construction projects (Kermanshachi & Safapour, 2019).

Lastly, unfamiliar construction methods such as prefabrication contribute to high complexity on building projects (Xia & Chan, 2012). Participants in this study opined this as moderately contributing to complexity, while moderate complexity indicators can be managed by adopting reactive project management strategies that support managers to optimally supervise task performance and coordinate schedules (Ochieng & Hughes, 2013). These complexity elements are peculiar to every project type. Findings of this study suggest that participating project managers have developed their competencies to contend their emergent behaviour effect over the years.

Low emergent effect (F4)

The F4 category captured three elements that according to project managers slightly contributed to difficulty in managing mega infrastructure construction. These elements inherently form part of overall project characteristics. Mirza and Ehsan (2017) identified site perimeter, required engineering hours, and numerous elements as complexity indicators that impact project performance during infrastructure development with no mention of their effect level. Xia and Chan (2012) highlighted that large magnitude does not necessarily reflect high complexity on large building projects, which aligns with findings from this study. It was found that size surges minimal complexity at the construction stage. Further evidence to this finding was from the study of Lebcir and Choudrie (2011) that indicated that size has a low influence on project cycle time, leading to complexity.

Theoretically, the larger the project size, the more physical elements and required engineering hours. Ahn *et al.* (2017) established that numerous project elements lead to meagre complexity when adopting interface management on construction projects. At the construction phase, Gidado (1996) highlights how the high number of elements forming a workflow triggers complexity, with no mention of the extent to which these indicators lead to complexity. The current study addressed this gap by identifying that the number of elements that form a project and the hours required during the construction phase contribute to minimal complexity on mega infrastructure construction, according to project managers in Sub-Saharan Africa. Perhaps this could be due to the sophisticated machinery and advanced technology found on this project type (Ofori, 2015).

Table 2. EFA result for dynamic complexity indictors

Element	Factor loading	Eigenvalue	CITC	Alpha if item deleted	Cronbach's
Chaos		**11.741**			**0.929**
Project duration	0.545		0.599	0.939	
Project tempo	0.915		0.849	0.909	
Construction method	0.809		0.837	0.911	
Uncertainty in methods	0.876		0.864	0.906	
Reliance on other projects	0.859		0.795	0.916	
Project teams' capability	0.837		0.820	0.913	
Unforeseen uncertainty		**3.380**			**0.910**
Uncertainty in scope	0.545		0.779	0.779	
Change in project scope	0.542		0.773	0.892	
Change in the project specification	0.664		0.844	0.874	
Inability to estimate accurately time and budget	0.849		0.763	0.893	
Quantity of information to analyse	0.745		0.722	0.900	
Foreseen uncertainty		**1.898**			**0.904**
Multiple project goal	0.545		0.631	0.901	
Variety of perspective	0.768		0.791	0.882	
Form of contract	0.425		0.673	0.895	
Disperse teams	0.561		0.690	0.893	
Multiple locations	1.037		0.779	0.883	
Multiple time zone	0.507		0.693	0.893	
Project drawings and detailing	0.877		0.763	0.885	
Variations		**1.573**			**0.855**
Geological condition	0.500		0.630	0.835	
Immediate project environment	0.438		0.626	0.837	
Plant deployment	0..654		0.610	0.840	
Regulations	0.708		0.747	0.807	
Lack of clear project goal	0.690		0.743	0.805	
Medium Variation		**1.368**			**0.696**
High number of goals	0.673		0.458	0.670	
Scope of work	0.871		0.601	0.493	
Ambiguity of scope	0.459		0.482	0.642	
Low Variation		**1.095**			**0.500**
Multiple project goal	0.455		0.355	–	
Number of information source	0.575		3.335	–	

Source: own study.

Dynamic complexity

Chaos (F1)

This classification consists of six indicators that attribute to unexplainable change during infrastructure construction. Project managers are unable to explain how these elements negatively impact performance. They are inherent project characteristics and influence every project type (Thamhain, 2013) and their effect is unforeseeable at the planning stage (Flyvbjerg, 2017).

Mirza and Ehsan (2017) highlighted project duration as the primary source of schedule complexity in infrastructure development projects. Overstaying on the project site may lead to problems with the morale of the project team and negatively influence project tempo (Chapman, 2016). The need to keep up a high tempo during construction requires the manager to be provided with an umpteenth supply of resources, which, if unavailable, prevent the manager from effectively managing the construction site (Xia & Chan, 2012).

This study found that the selected construction method and its uncertainty lead to chaotic construction sites in Sub-Saharan Africa. The problem could be associated with the lack of experience using innovative construction methods and the absence of capable staff to implement these methods (Jarkas, 2017). In most instances, managers are left to rely on other projects for technical support, limiting their ability to enact control on the construction site. This study suggested methods and strategies that support framing and decimating project information in real-time which can be used to ensure minimal impact from these indicators, while managers are informed how to identify chaotic projects more accurately during the planning phase.

Unforeseen Uncertainty (F2)

The study identified five indicators that project managers found to be unpredictable when constructing mega infrastructure. These indicators are identifiable and known to proliferate uncertainty and continuous change, yet managers find it challenging to determine their occurrence frequency during construction and manage these scenarios.

At the planning stage, poorly defined project scope lay the grounds for avoidable and incessant rework during construction, potentially derailing project performance through delay and cost overrun (Bosch-Rekveldt *et al.*, 2011; Gajić & Palčič, 2019). Scope uncertainty during construction is the major cause of design change that leads to project specification change onsite (Nguyen *et al.*, 2015). When this scenario occurs with no contingency provision for materials and manpower to curtail the situation, managers cannot accurately estimate project time and budget. This potentially increases uncertainty on the construction site, decapitating managers from coordinating and controlling work in a manner that ensures the project performs to its set out goals. To condone the dynamic complexity effect emancipating from the project scope, project managers should look to adopting reactive project management strategies (Maylor *et al.*, 2008). Thus, elements in this category would enable managers to determine a project susceptible to uncertainty and incessant change before moving to the site.

Foreseen Uncertainty (F3)

This factor label comprises seven indicators that contribute to constant changes during construction. However, with an effective management plan, these indicators can be adequately managed. Their occurrence leads to contingencies during infrastructure construction, attributed to incessant delay and budget increase (Thamhain, 2013). Managing multiple stakeholders' goals and their contesting perspective to what the project should be is an occurrence that is unavoidable on mega infrastructure sites. In the same vein, Gajić and Palčič (2019) found that on an international development project, the inability to clarify such contesting goals was a major cause of uncertainty on-site, since managers were unable to accurately determine the project scope.

Furthermore, relying on multiple locations to support the site – just as seen in having a batching plant outside the construction site – exposes the project to uncertainty, because dependence on virtual teams working across different time zones increases the project manager's dynamic complexity. When there is a need to clarify the work drawings on-site and the manager cannot contact the design team at a different time zone immediately, manager's ability to respond in time and make comprehensive decisions on site is constrained.

Variations (F4)

This dimension consists of indicators that project managers recognise as prompting uncertainty during mega infrastructure construction. Their impact level is well known and can be effectively managed by adopting project management guidelines and tools suggested by Remington, 2016. These indicators are attributable to the request for information (RFI) and variation cost to manage uncertainty. Potentially, managers expect uncertainty to emerge from the project environment, the lack of clear goals, and plant deployment, which could only slow the project tempo with no disruption to construction output on-site.

CONCLUSIONS

In general, findings derived from this research will help various stakeholders to be more cautious on project complexity effects. More specifically, they will help project managers to better assess overall project complexity by focusing on indicators with excruciating effects, emphasize developing project management strategies that support managers contend with complexity, and appropriately allocate project resources. For project managers who are new to the context of developing economies, this article, based on insight from experienced managers of mega infrastructure projects in Sub-Saharan Africa, can serve as a guide to develop their competencies further, in order to contend with difficulties inherent in complex infrastructure projects. As such, this article can be an important reading for project managers who plan to work in locations with the transforming and convoluted institutional environment described by Kenneth-Southworth *et al.* (2018). For policy makers, a reading of this article should help identify risk areas where delays and budget overruns could cause particularly painful effects, and thus save resources of already vulnerable local economies and communities. This could help to ensure more investments in infrastructure development to be attracted to Sub-Saharan Africa to support its industrialization, advocated by the Infrastructure Consortium for Africa (2018).

This article opens a fertile ground for extension and replication studies to devise project management strategies that contend with complexity trajectories on infrastructure projects. Insights from a recent review of work on development of knowledge during the internationalization process of developing economy firms (Głodowska *et al.*, 2019) suggest that extensions accounting for more social-cultural variables offer a particularly promising way of advancing findings from this study. Specifically, we call for research that could explain how international sharing of knowledge might mitigate problems of complexity of projects in infrastructure firms in various institutional environments.

Future research should also confirm whether the categorization of complexity adopted here is consistently applicable beyond land infrastructure mega-projects being built in Sub-Saharan Africa. Along these lines, the size of investment in infrastructure in China and involvement of international entrepreneurs in developing economies, in particular high numbers of foreign entrepreneurs in China (Lemanski, 2018), suggests a need to test factors which contribute to an increase in projects' complexity elaborated in this study in the context of China and other developing economies.

REFERENCES

Ahn, S., Shokri, S., Lee, S., Haas, C.T., & Haas, R.C. (2017). Exploratory study on the effectiveness of interface-management practices in dealing with project complexity in large-scale engineering and construction projects. *Journal of Management in Engineering, 33*(2), 04016039. https://doi.org/10.1061/(asce)me.1943-5479.0000488

Baccarini, D. (1996). The concept of project complexity–a review. *International Journal of Project Management, 14*(4), 201-204. https://doi.org/10.1016/0263-7863(95)00093-3

Bakhshi, J., Ireland, V., & Gorod, A. (2016). Clarifying the project complexity construct: Past, present and future. *International Journal of Project Management, 34*(7), 1199-1213. https://doi.org/10.1016/j.ijproman.2016.06.002

Bartosik-Purgat, M., & Jankowska, B. (2017). The Use of Social Networking Sites in Job Related Activities: A Cross-cultural Comparison. Entrepreneurial Business and Economics Review, 5(2), 177-193. http://dx.doi.org/10.15678/EBER.2017.050210

Bosch-Rekveldt, M., Bakker, H., & Hertogh, M. (2018). Comparing project complexity across different industry sectors. *Complexity, 2018*. https://doi.org/10.1155/2018/3246508

Bosch-Rekveldt, M., Jongkind, Y., Mooi, H., Bakker, H., & Verbraeck, A. (2011). Grasping project complexity in large engineering projects: The T.O.E. (Technical, Organizational and Environmental) framework. *International Journal of Project Management, 29*(6), 728-739. https://doi.org/10.1016/j.ijproman.2010.07.008

Cattell, R. (2012). *The scientific use of factor analysis in behavioral and life sciences*: Berlin: Springer Science & Business Media.

Chan, C.T. (2012). The principal factors affecting construction project overhead expenses: an exploratory factor analysis approach. *Construction Management and Economics, 30*(10), 903-914.

Chapman, R.J. (2016). A framework for examining the dimensions and characteristics of complexity inherent within rail megaprojects. *International Journal of Project Management, 34*(6), 937-956. https://doi.org/10.1016/j.ijproman.2016.05.001

Cicmil, S., Cooke-Davies, T., Crawford, L., & Antony, K. (2009). Exploring the complexity of projects: Implications of complexity theory for project management practice. *PMBOK Guide.* Retrieved from https://doi.org/10.1002/pmj.20136 on January 2021.

Cristobal, E., Flavian, C., & Guinaliu, M. (2007). Perceived e-service quality (PeSQ). *Managing Service Quality: An International Journal,* 17(3), 317-340. https://doi.org/10.1108/09604520710744326

Dale, L.B. (2013). *Skilled Labor Shortage in the Construction Industry? It's Not Demonstrated in the Numbers*. Retrieved from: https://www.leg.state.nv.us/App/NELIS/REL/79th2017/ExhibitDocument/OpenExhibitDocument?exhibitId=30799&fileDownloadName=0220b_staw.pdf on April 2021.

Dao, B., Kermanshachi, S., Shane, J., Anderson, S., & Hare, E. (2017). Exploring and assessing project complexity. *Journal of Construction Engineering and Management, 143*(5), 04016126. https://doi.org/10.1061/(asce)co.1943-7862.0001275

Field, A. (2014). *Discovering statistics using IBM SPSS statistics*: Thaousand Oaks: Sage.

Flyvbjerg, B. (2017). *The Oxford handbook of Megaproject Management*: Oxford: Oxford University Press.

Gajić, S., & Palčič, I. (2019). A new framework for complexity analysis in international development projects–Results from a Delphi study. *Advances in Production Engineering & Management, 14*(2), 225-238. https://doi.org/10.14743/apem2019.2.324

Gbahabo, P.T., & Ajuwon, O.S. (2017). Effects of project cost overruns and schedule delays in Sub-Saharan Africa. *European Journal of Interdisciplinary Studies, 3*(2), 46-59.

Gemueva, K. (2018). Chinese Infrastructure Projects in Sub-Saharan Africa: Credit Financing. *Outlines of global transformations: politics, economics, law* (Center for Crisis Society Studies).https://doi.org/ 10.23932/2542-0240-2018-11-5-55-73

Geraldi, J., & Adlbrecht, G. (2008). On faith, fact, and interaction in projects. *IEEE Engineering Management Review, 2*(36), 35-49. https://doi.org/10.1109/emr.2008.4534318

Geraldi, J., Maylor, H., & Williams, T. (2011). Now, let's make it really complex (complicated) A systematic review of the complexities of projects. *International Journal of Operations & Production Management, 31*(9), 966-990. https://doi.org/10.1108/01443571111165848

Gidado, K. (1996). Project complexity: The focal point of construction production planning. *Construction Management & Economics, 14*(3), 213-225. https://doi.org/10.1080/014461996373476

Girmscheid, G., & Brockmann, C. (2008). The Inherent Complexity of Large Scale Engineering Projects. *Project Perspectives, 29*, 22-26.

Głodowska, A., Maciejewski, M., & Wach, K. (2019). How Entrepreneurial Orientation Stimulates Different Types of Knowledge in the Internationalization Process of Firms from Poland? *Entrepreneurial Business and Economics Review, 7*(1), 61-73. https://doi.org/10.15678/EBER.2019.070104

Gorsuch, R.L. (1997). Exploratory factor analysis: Its role in item analysis. *Journal of personality assessment, 68*(3), 532-560. https://doi.org/10.1207/s15327752jpa6803_5

He, Q., Luo, L., Hu, Y., & Chan, A.P. (2015). Measuring the complexity of mega construction projects in China—A fuzzy analytic network process analysis. *International Journal of Project Management, 33*(3), 549-563. https://doi.org/10.1016/j.ijproman.2014.07.009

Hill, R. (1998). What sample size is "enough" in internet survey research. *Interpersonal Computing and Technology: An electronic journal for the 21st century, 6(3-4)*, 1-12.

Infrastructure Consortium for Africa. (2018). *Infrastructure financing trends in Africa: I.C.A. annual report 2018*. Retrieved from https://www.icafrica.org/en/knowledge-hub/infrastructure-financing/ on June 19, 2019.

International Centre for Complex Project Management. (2012). *Complex Project Manager Competency Standards*. Retrieved from Commonwealth of Australia (Department of Defence on October 17, 2020).

Jarkas, A.M. (2017). Contractors' perspective of construction project complexity: Definitions, principles, and relevant contributors. *Journal of Professional Issues in Engineering Education and Practice, 143*(4), 04017007. https://doi.org/10.1061/(asce)ei.1943-5541.0000337

Kermanshachi, S., Dao, B., Rouhanizadeh, B., Shane, J., & Anderson, S. (2018). Development of the project complexity assessment and management framework for heavy industrial projects. *International Journal of Construction Education and Research, 16*(1), 24-42. https://doi.org/10.1080/15578771.2018.1499568

Kermanshachi, S., & Safapour, E. (2019). Identification and quantification of project complexity from perspective of primary stakeholders in U.S. construction projects. *Journal of Civil Engineering and Management, 25*(4), 380-398. https://doi.org/10.3846/jcem.2019.8633

Kian Manesh Rad, E., & Sun, M. (2014). *Taxonomy of project complexity indicators in energy megaprojects*. Paper presented at the International Scientific Conference People, Buildings and Environment Kroměříž, Czech Republic.

Kline, P. (2014). *An easy guide to factor analysis*: London: Routledge.

Lebcir, R.M., & Choudrie, J. (2011). A dynamic model of the effects of project complexity on time to complete construction projects. *International Journal of Innovation, Management and Technology, 2*(6), 477. http://ijimt.org/papers/179-A10002.pdf

Lemanski, M. (2018). Foreign Entrepreneurs in China. *Entrepreneurial Business and Economic Review, 6*(4), 7-10.

Lessard, D., Sakhrani, V., & Miller, R. (2014). House of Project Complexity—understanding complexity in large infrastructure projects. *Engineering Project Organization Journal, 4*(4), 170-192. https://doi.org/10.1080/21573727.2014.907151

Lu, Y., Luo, L., Wang, H., Le, Y., & Shi, Q. (2015). Measurement model of project complexity for large-scale projects from task and organization perspective. *International Journal of Project Management, 33*(3), 610-622. https://doi.org/10.1016/j.ijproman.2014.12.005

Luo, L., He, Q., Jaselskis, E.J., & Xie, J. (2017). Construction project complexity: research trends and implications. *Journal of Construction Engineering and Management, 143*(7), 04017019. https://doi.org/10.1061/(asce)co.1943-7862.0001306

MacCallum, R.C., Widaman, K.F., Zhang, S., & Hong, S. (1999). Sample size in factor analysis. *Psychological Methods, 4*(1), 84. https://doi.org/10.1037/1082-989x.4.1.84

Maylor, H., Vidgen, R., & Carver, S. (2008). Managerial complexity in project-based operations: A grounded model and its implications for practice. *Project Management Journal, 39*(1_suppl), S15-S26.

Mirza, E., & Ehsan, N. (2017). Quantification of project execution complexity and its effect on performance of infrastructure development projects. *Engineering Management Journal, 29*(2), 108-123. https://doi.org/10.1080/10429247.2017.1309632

Nguyen, A., Nguyen, L., Le-Hoai, L., & Dang, C. (2015). Quantifying the complexity of transportation projects using the fuzzy analytic hierarchy process. *International Journal of Project Management, 33*(6), 1364-1376. https://doi.org/10.1016/j.ijproman.2015.02.007

Nunnally, J.C., & Bernstein, I. (1978). *Psychometric Theory.* New York: McGraw-Hill. https://doi.org/10.3102/00028312005003431

Ochieng , E., & Hughes, L. (2013). Managing project complexity in construction projects: The way forward. *Journal of Architectural Engineering Technology, 2*(1), e111. https://doi.org/10.4172/2168-9717.1000e111

Ofori, G. (2015). Nature of the construction industry, its needs and its development: A review of four decades of research. *Journal of Construction in Developing Countries, 20*(2), 115.

Ofori, G., & Toor, S.-u.-R. (2012). Leadership and Construction Industry Development in Developing Countries. *Journal of Construction in Developing Countries, 17*, 1-21.

Owusu-Manu, D.-G., Jehuri, A.B., Edwards, D.J., Boateng, F., & Asumadu, G. (2019). The impact of infrastructure development on economic growth in sub-Saharan Africa with special focus on Ghana. *Journal of Financial Management of Property and Construction*, *24*(3), 253-273. https://doi.org/10.1108/JFMPC-09-2018-0050

Remington, K. (2016). *Leading complex projects*. London: Routledge.

Remington, K., & Pollack, J. (2016). *Tools for complex projects.* London: Routledge.

Rosli, N.M., Mustaffa, N.E., & Ariffin, H.L.T. (2018). *A Review of Domestic Subcontract in Construction Industry.* Paper presented at the Regional Conference on Science, Technology and Social Sciences (RCSTSS 2016).

Sharma, G. (2017). Pros and cons of different sampling techniques. *International Journal of Applied Research, 3*(7), 749-752.

Sieja, M., & Wach, K. (2019). The Use of Evolutionary Algorithms for Optimization in the Modern Entrepreneurial Economy: Interdisciplinary Perspective. *Entrepreneurial Business and Economics Review*, 7(4), 117-130. https://doi.org/10.15678/EBER.2019.070407

Siemiatycki, M. (2015). *Cost Overruns on Infrastructure Projects: Patterns, Causes and Cures.* Toronto: IMFG Perspectives.

Söderlund, J., Sankaran, S., & Biesenthal, C. (2017). The past and present of megaprojects. Los Angeles, CA: SAGE Publications Sage CA.

Tabachnick, B.G., Fidell, L.S., & Ullman, J.B. (2019). *Using multivariate statistics* (Vol. 5). Boston: Pearson Boston, MA.

Thamhain, H. (2013). Managing risks in complex projects. *Project Management Journal, 44*(2), 20-35. https://doi.org/10.1002/pmj.21325

Turner, J.R., & Cochrane, R.A. (1993). Goals-and-methods matrix: coping with projects with ill defined goals and/or methods of achieving them. *International Journal of Project Management, 11*(2), 93-102. https://doi.org/10.1016/0263-7863(93)90017-h

Wach, K. (2020). A Typology of Small Business Growth Modelling: A Critical Literature Review. *Entrepreneurial Business and Economics Review*, 8(1), 159-184. https://doi.org/10.15678/EBER.2020.080109

Williams, T.M. (1999). The need for new paradigms for complex projects. *International Journal of Project Management, 17*(5), 269-273. https://doi.org/10.1016/s0263-7863(98)00047-7

Xia, B., & Chan, A.P. (2012). Measuring complexity for building projects: a Delphi study. *Engineering, Construction and Architectural Management, 19*(1), 7-24. https://doi.org/10.1108/09699981211192544

Appendix:

Structural Complexity Element		
Constructs	**Elements**	**Source**
Size	Structure height	(Baccarini, 1996; Bosch-Rekveldt *et al.*, 2011; Chapman, 2016; Dao *et al.*, 2017; Gajić & Palčič, 2019; Geraldi & Adlbrecht, 2008; He *et al.*, 2015; Jarkas, 2017; Kermanshachi *et al.*, 2018; Kermanshachi & Safapour, 2019; Lebcir & Choudrie, 2011; Lessard *et al.*, 2014; Mirza & Ehsan, 2017; Nguyen *et al.*, 2015; Xia & Chan, 2012)
	Structure type	
	Site area	
	Density	
	Number of elements	
	Number of participants	
	Number of engineering hours	
	Budget	
Task	Numerous tasks	
	High variety of task	
	Difficulty of task	
	Project scheduling	
	Rigidity of sequence	
	Quality requirement	
	Construction methods	
	Lack of technical methods	
	Availability of skilled workforce	
Design complexity	Level of detailing	
	Structural elements	
	Clarity of functions	
	Variety of drawings	
	Project scope	
	Physical location	
	Multiple locations	
	Site topography	
Dynamic Complexity Element		
Project Features	Project duration	(Ahn *et al.*, 2017; Baccarini, 1996; Bosch-Rekveldt *et al.*, 2011; Chapman, 2016; Dao *et al.*, 2017; Gajić & Palčič, 2019; Geraldi & Adlbrecht, 2008; He *et al.*, 2015; Jarkas, 2017; Kermanshachi *et al.*, 2018; Kermanshachi & Safapour, 2019; Lebcir & Choudrie, 2011; Lessard *et al.*, 2014; Mirza & Ehsan, 2017; Nguyen *et al.*, 2015; Xia & Chan, 2012)
	Project tempo	
	Construction methods	
	Uncertainty in methods	
	Reliance on other projects	
	Project team's capability	
	Geological conditions	
	Immediate environment	
	Multiple time zone	
	Disperse team	
	Deployment of plants	
	Form of contract	
Project Goals	High number of goals	
	Lack of clear project goal	
	Multiple project goals (multidisciplinary members)	
	Variety of perspective	
Project Scope	Scope ambiguity	
	Scope uncertainty	
	Project detail and drawing.	
	Change in project scope	
	Change in project specification	
	Inability to estimate accurately (timeline and budget)	
	Quantity of information to analyse	
	Quantity of information source	

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Conflict of Interest

No conflict of interest was declared for this study.

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