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Adaptive Project Management Frameworks for Accelerated Delivery in Complex Civil Engineering Environments: A Conceptual Review

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Abstract- Cost overruns, schedule delays and poor performance are all common challenges in a constantly changing area of civil engineering projects and work, particularly in complex and dynamic delivery environments. The traditional linear project management approaches such as Project Management Body of Knowledge (PMBOK) and Waterfall have not been proven beneficial in dealing with uncertainty in large-scale delivery of infrastructure. The concept of adaptive project management (APM) frameworks is introduced in this conceptual review, which could offer a theoretically oriented and practically relevant solution these issues. This review, based on the ideas of Complex Adaptive Systems (CAS), Contingency Theory (CT) and Lean Construction, explores the theoretical justification for adopting an Adaptive approach in the civil engineering sector. It also gathers empirical and conceptual examples of the use of hybrid approaches (e.g., Agile-Waterfall hybrids, Integrated Project Delivery (IPD) and Lean-Agile hybrids) in construction and civil engineering projects. The review outlines some of the enablers and barriers to the adoption of APM including contractual rigidity, regulation, organisational culture and the use of digital technologies (Building Information Modelling (BIM) and digital twins). A conceptual model is proposed that describes the interactions between the adaptive elements and how they can interact with each other to speed up the delivery in a complex environment of a project. Critical gaps are identified such as lack of empirical validation of APM in infrastructure specific contexts, especially in lower resource settings. The review concludes that adaptive frameworks show great promise for transforming the way civil engineering projects are delivered to the world, but that they must be tailored to each context, institutional priorities and governance mechanisms must foster their uptake, and institutional buy-in needs to be gained.

Keywords: Adaptive Project Management (APM), Civil Engineering Projects, Complex Adaptive Systems (CAS), Lean Construction, Integrated Project Delivery (IPD), Building Information Modelling (BIM), Infrastructure Project Delivery.

I. INTRODUCTION

Projects in the civil engineering sector, which include infrastructure like roads, bridges, water systems, and public buildings, continue to be a challenge for governments, development organizations, and private investors. Over the years, the sector has undergone several methodological developments, but still faces common issues of cost overrun, schedule slip and poor quality. A fundamental study by Flyvbjerg et al (2003) has shown that, on average, 28% of the costs of large-scale infrastructure projects exceed initial budget estimates, and that nine out of ten projects experience cost overruns. Cantarelli et al. (2012) and Love et al. (2019) have shown that these patterns have not significantly changed over the last few years, which means they are more of a systemic problem than incidental.

Much of the literature on the subject suggests that using rigid and plan-driven project management techniques is the reason for these failures in an environment which is complex, dynamic and uncertain (Williams, 2005; Bosch-Rekveldt et al., 2011). Typical approaches like the Project Management Body of Knowledge (PMBOK Guide) and Waterfall methodologies assume a project scope, cost and time that are fixed and predictable, which is often not the case in civil engineering projects where stakeholder requirements are constantly changing, regulations are evolving and technical risks are always present.

In turn, adaptive project management (APM) processes such as Agile, Lean Construction, and hybrids of Agile and Waterfall have been suggested as better options in more complex environments for project delivery. APM has been developed in the software industry, but the concepts are starting to be

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considered for transferability to construction and civil engineering (Demir & Theis, 2016; Fernandez & Fernandez, 2009). This review explores the theoretical foundations, practical usage, obstacles and benefits of APM frameworks in the field of civil engineering and suggests a conceptual framework that is integrated for further research.

II. CONCEPTUAL FOUNDATIONS

To understand the concept of adaptive project management in civil engineering, three constructs must be understood: the issue of project complexity, the traditional paradigm of project management and the adaptive/agile alternative paradigm.

2.1 Project Complexity

Project complexity is multi-dimensional, involving the structural, dynamic and socio-political dimensions. Complex projects are projects where the individual components and their relationships with each other and the other stakeholders are interdependent and the result of such interactions creates emergent behaviours that would not occur if the individual components were analyzed in isolation (Vidal et al., 2011). Civil engineering projects are dynamic in nature with technical, environmental and regulatory conditions changing in an unpredictable manner over long time scales (Bosch-Rekveldt et al., 2011). The complexity of socio-politics relates to conflicting interests of stakeholders (clients, contractors, regulators, communities and funders), therefore these need to be negotiated on an ongoing basis (Pinto et al., 2009). While complexity (structural system properties) is distinct from uncertainty (epistemic limitations of decision-makers), civil engineering projects generally tend to have both, with added uncertainty of ground conditions, materials and political risk (Geraldi et al., 2011).

2.2 Traditional Linear Approaches

The first paradigm has been the linear, plan-driven approach which PMBOK (Project Management Institute, 2021) and Waterfall have been based on, and which has assumed sequential phases and a stable baseline for control by planning them up front. This is a good approach for projects that have clear and consistent requirements. In civil engineering projects, these assumptions are rarely met (Laufer et al., 2015) and the prescriptive structure and the sequential rigidity of PMBOK and Waterfall hinder learning and responsiveness particularly under high complexity and uncertainty.

2.3 Adaptive and Agile Paradigms.

Adaptive project management starts by making no definite assumptions and allows planning and decision-making to be iterative and responsive. The Agile Manifesto (Beck et al., 2001) espouses values oriented towards collaboration and being responsive to change, which are operationalised through Scrum, Kanban and Extreme Programming. Lean Construction, as developed for the Toyota Production System (TPS) in construction, focuses on waste elimination, value flow and empowerment of the front line (Koskela et al., 2002) and the Last Planner System is a scheduling system that facilitates collaborative scheduling and commitments. Hybrid solution of Agile and Lean with Plan-driven methodologies have come up to find a balance between stability and flexibility.

III. THEORETICAL UNDERPINNINGS

Theories underpinning the case for adaptive project management in complex civil engineering environments are based on three complementary traditions.

3.1 Complexity Theory and Complex Adaptive Systems

The most direct foundation is Complexity theory which is stated as Complex Adaptive Systems (CAS) theory (Holland, 1992). CAS theory is based on the premise that complex systems have non-linear interactions, emergent properties that could not be predicted from the properties of the components, and adaptive capacity. The outcomes of civil engineering are the result of designers, contractors, regulators, clients and communities interacting with each other, adapting their behaviour throughout the design process (Baccarini, 1996). When outcomes are emergent, rather than deterministic, then up-front control is systematically ineffective, and CAS theory favours adaptation; sensing, learning, and responding

(Snowden and Boone, 2007). These are operationalized by Snowden (1999) who identifies complex domains, whose cause-and-effect can only be understood after the fact, and simple, complicated and chaotic domains. Civil engineering projects are often complex, and therefore, adaptive, rather than analytical approaches are more appropriate.

3.2 Contingency Theory

Contingency theory says that there is no best way to manage; it depends on the situation (Lawrence & Lorsch, 1967). The level of methodological effectiveness is dependent on the context of the project, the complexity, uncertainty, size, technology and stakeholder configuration (Shenhar, 2001). The Diamond Model developed by Shenhar and Dvir (2007) categorizes projects based on their novelty, technology, complexity and pace, and prescribes different approaches to them: high-complexity and high-uncertainty infrastructure projects will have higher adaptive capacity and flexible contracting, compared to stable and well understood projects. The idea of contingency theory, therefore, motivates context-specific choices and customisation of adaptive frameworks.

3.3 Lean Construction Principles

A third tradition is Lean Construction which is inspired by Koskela's (1992) production theory. Transformation-Flow-Value (TFV) model questions the conventional transformation view on construction, by adding in two concepts, flow (sequencing and reliability of the work) and value (meeting client needs). This is achieved through the Last Planner System (LPS) (Ballard, 2000) which is a planning system that embraces collaboration and commitment planning at master, phase, lookahead and weekly level, and eliminates constraints prior to work release to ensure reliable workflow under uncertainty. The empirical evidence in the literature supports the adaptive logic of Lean Construction as LPS implementation was found to be related to significant schedule performance improvements by Hamzeh et al. (2012).

IV. ADAPTIVE FRAMEWORKS IN PRACTICE: SYNTHESIS ACROSS SECTORS

The adaptive frameworks in civil engineering have been developed from their early experimental application to more systematic application, with adaptation of software and manufacturing experience to the unique constraints of construction. The Hybrid Agile-Waterfall models take the "reality" of building and contractual obligations into account. Demir and Theis (2016) suggested that the sequential logic found in the design and procurement phase of Waterfall should be maintained and the Agile iteration should be implemented at the execution phase, allowing changes to the scope without disrupting the structure. Fernandez and Fernandez (2009) were able to identify the positive impacts of the Agile principles on the team and task levels even when operating under a plan-driven governance.

Integrated Project Delivery (IPD) takes an even more radical approach to aligning the contractual, relational and operational aspects of collaborative, and risk/reward sharing, between owner, designer and contractor, thereby encouraging early problem solving (American Institute of Architects, 2007). In IPD projects, significant gains were reported in the performance of the projects, and this was due to the facilitation of continuous learning, according to Fischer et al. (2017). Promising Lean-Agile combinations that combine LPS with Agile retrospectives, which were introduced and tested by Tillmann et al. (2012), helped to increase schedule reliability as well as learning at team level. Overall, this literature shows that adaptive frameworks have the potential to be a useful tool for improving performance in civil engineering, but their transferability is subject to the specific context and the fidelity at which they can be implemented is still a challenge.

V. CRITICAL ANALYSIS: BARRIERS AND ENABLERS

Enabling and constraining factors on the contractual, regulatory, cultural and technological levels have an impact on the adoption of APM in civil engineering.

Contractual structures are likely to be the toughest obstacle. Traditional procurement models are based on delivery of a fixed scope and an adversarial approach to apportioning risk, making it difficult to deliver in a collaborative and iterative way (Walker & Lloyd-Walker, 2015). Although more enabling, relational contracts like alliance and IPD contracts have not taken off widely, due to institutional inertia and lack of familiarity by public sector clients.

Regulatory environments also inhibit adaptive practice by setting parameters in stone before construction is commenced, such as planning permission, environmental impact assessment (EIA) and safety cases, before the iterative process of adaptation is carried out (Gil et al., 2012). Organisational culture also presents a challenge; the hierarchical authority, risk aversion and blame attribution are all in opposition to the "psychological safety" and "distributed decision making" adaptive frameworks required (Edmondson, 1999). The greater the complexity of stakeholders (regulators, communities, political actors and tiers of subcontractors) the higher the transaction costs in the arena of adaptive governance.

On the enabler side, the digital technologies enable real-time information sharing and collaborative decision-making (Eastman et al., 2011) and are the technical infrastructure. Complementing these automated features is the ability to perform collaborative design iteration with BIM Level 2/3 implementations and the dynamic monitoring on construction and operation with digital twins. Senior leadership commitment together with a learning culture is always mentioned as an essential human enabler for the successful implementation of APM (Dikmen et al., 2006).

VI. TOWARDS AN INTEGRATED CONCEPTUAL FRAMEWORK

Based on an analysis of theory and practice, a conceptual framework is proposed that outlines how the adaptive elements can work together to speed up delivery in complex civil engineering domains, divided into four domains: Governance and Contracting, Methods and Processes, Technology and Information, and Culture and Capability. Governance and Contracting – collaborative forms of contracting (such as IPD and alliance contracting) establish shared risk/reward, which drives adaptive behaviours and early problem identification, offering the contracting space for the application of adaptive approaches. Methods and Processes — hybrid Agile-Waterfall frameworks, Lean Construction are provided by the operational mechanisms such as the Last Planner System, that enable iterative planning and continuous improvement. Adaptive decision-making needs real-time data visibility, which can be achieved through technology and information, such as those based on BIM, digital twins and integrated project information systems. Culture and Capability relate to human conditions of sustained adaptation: Leadership commitment, psychological safety, Team-level capability investment.

An acceleration in delivery happens when this cycle of mutual reinforcement is in place: collaborative governance provides the environment for adaptive approaches, the generation of information needs that is met through technology, and technology-enabled transparency that contributes to the learning culture that creates further adaptive capability. A lack of any one of these elements – adversarial contracts, no digital infrastructure or risk averse culture – can offset any of the advantages of the others. The framework, therefore, integrates the concepts of contingency theory, CAS and Lean Construction in a coherent way to provide a description of the circumstances under which adaptive project management will enable better project performance in complex civil engineering environments.

VII. GAPS IN THE LITERATURE

Although APM is a topic of increasing research interest in the civil engineering field, many important research gaps have not been addressed. First, empirical studies validating the adaptive frameworks in the infrastructure and civil engineering context, as opposed to building construction or software development contexts, are relatively rare in the literature and much of the evidence is conceptual or it is based on a small number of case studies, which may not be generalisable (Demir & Theis, 2016).

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Second, the performance of adaptive frameworks in lower-resource and developing country contexts has never been studied, with the exception of very few reports in the informal literature.Second, the performance of adaptive frameworks in lower-resource and developmental country context, in which institutional capacities, digital infrastructures, and relational contracting experience may be less developed, is virtually untouched in the peer-reviewed literature. Thirdly, long term effects of sustained APM implementation on the learning of organisations have not been systematically studied. Fourth, how certain adaptive practices (e.g., retrospective cycles or lookahead planning) lead to delivery improvements at the micro level is still not well understood.

VIII. RECOMMENDATIONS

More in-depth longitudinal studies, especially in an infrastructure setting as well as governance and contracting arrangements are recommended for further research. The APM maturity models need to be defined and validated for civil engineering organisations, in the context of the organisation. Enabling reforms to public procurement mechanisms (especially emerging economies) to allow the use of collaborative contracting models should be investigated by practitioners and policy makers. The strategic investment in digital capability, such as BIM and data literacy is suggested as an enabler of adaptive practice. Last, industry groups should back pilot schemes of Lean-Agile approaches to civil infrastructure delivery that are supported by a strong performance measurement system, from the project start.

IX. CONCLUSION

The purpose of this conceptual review is to investigate adaptive project management (APM) as a theoretically supported approach to dealing with ongoing civil engineering cost overruns, delays and complexity. The review demonstrates that APM can provide a coherent alternative to the deterministic linear frameworks, which are encapsulated in CAS, contingency theory and Lean construction. Some of the evidence shows that the hybrid Agile-Waterfall and IPD and Lean-Agile implementations bring measurable benefits such as better schedule reliability, better stakeholder engagement and better learning capacity. In addition to contractual and cultural hurdles, the proposed framework outlines four mutually reinforcing areas (governance and contracting, methods and processes, technology and information, and culture and capability) that must be aligned for APM to be realised.

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