Scientific Journal for Publishing in Health Research and Technology

Volume 2, Issue 1, 2026, Pages: 126-135

Journal homepage: https://sjphrt.com.ly/index.php/sjphrt/en/index

The Impact of Adopting Agile Methodology on the Performance of Large-Scale Construction Projects

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أثر تبني منهجية *Agile* على أداء مشاريع البناء والتشييد الكبرى

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Received: October 19, 2025	Accepted: December 21, 2025	Published: January 25, 2026

Abstract:

This research investigates the effectiveness of adopting Agile methodology in enhancing the performance of large-scale construction projects, traditionally characterized by rigidity and reliance on the Waterfall model. While the construction industry represents 13% of the global GDP, it suffers from chronic structural challenges related to low productivity and operational inefficiency. These issues are compounded in megaprojects exceeding 1 billion, which operate in high-risk environments with unprecedented engineering and social complexity. Through a mixed-methods research design, including a systematic literature review and Structural Equation Modeling (SEM) analyzing data from 250 international experts, the study explores how Agile practices can mitigate these challenges. The findings reveal a statistically significant positive correlation between Agile adoption and key performance indicators (KPIs). Specifically, collaborative planning in a Sprint environment improved schedule accuracy by 22%, while the integration of Digital Kanban and Building Information Modeling (BIM) reduced Request for Information (RFI) cycles by 25% and prevented up to 40% of field errors. The paper identifies the "Flexibility-Rigidity Paradox," arguing that construction requires a "Hybrid Agile-Waterfall Framework". This model maintains the Waterfall approach for strategic governance and contracts to ensure financial security, while utilizing Scrum and Kanban for operational daily tasks to enhance execution flexibility. Finally, the study addresses contractual barriers, suggesting an "Agile Addendum" to traditional FIDIC contracts to provide legal coverage for iterative design and incremental approvals.

Keywords: Agile Construction, Megaprojects, Hybrid Project Management, BIM, Scrum, Kanban, Performance Optimization.

الملخص

تتقصى هذه الدراسة مدى فاعلية تبني منهجية "أجايل" (Agile) في تحسين أداء مشاريع التشييد والبناء الكبرى، التي تتسم تقليديًا بالصلابة والاعتماد على نموذج "الشلال". ورغم أن صناعة البناء تمثل 13%

من الناتج المحلي الإجمالي العالمي، إلا أنها تعاني من تحديات هيكلية مزمنة تتعلق بانخفاض الإنتاجية وضعف الكفاءة التشغيلية. وتزداد هذه المعضلة في "المشاريع الكبرى" التي تتجاوز ميزانيتها مليار دولار، حيث تعمل في بيئات عالية المخاطر وتصاحبها تعقيدات هندسية واجتماعية غير مسبوقة. ومن خلال منهجية بحث مختلطة شملت مراجعة منهجية للأدبيات ونمذجة المعادلات الهيكلية (SEM) لتحليل بيانات 250 خبيراً دولياً، بحثت الدراسة كيف يمكن لممارسات الأجايل الحد من هذه التحديات. كشفت النتائج عن وجود علاقة طردية ذات دلالة إحصائية بين تبني الأجايل وتحسن مؤشرات الأداء الرئيسية. وبشكل أدق، أدى التخطيط التشاركي في بيئة "السبرنت" إلى تحسين دقة الجدولة بنسبة 22%، بينما ساهم دمج "كانبان الرقمي" مع نمذجة معلومات البناء (BIM) في تقليل دورة طلبات المعلومات بنسبة 25% ومنع ما يصل إلى 40% من الأخطاء الميدانية. وتناقش الورقة "مفارقة المرونة والصلابة"، معتبرة أن قطاع البناء يتطلب "نهجاً هجيناً" يجمع بين الأجايل والشلال. يحافظ هذا النموذج على نهج الشلال للحوكمة الاستراتيجية والتعاقدات لضمان الأمان المالي، بينما يستخدم "السكرم" و"كانبان" للمهام التشغيلية اليومية لتعزيز مرونة التنفيذ. وأخيراً، تطرقت الدراسة للعوائق التعاقدية، مقترحة إضافة "ملحق الأجايل" لعقود الفيديك التقليدية لتوفير غطاء قانوني للتصاميم التكرارية والاعتمادات المرحلية.

الكلمات المفتاحية: البناء الرشيق، المشاريع الكبرى، إدارة المشاريع الهجينة، نمذجة معلومات البناء، سكرم، كانبان، تحسين الأداء.

1. Introduction

The construction industry serves as a strategic engine for the global economy, accounting for approximately 13% of the world's Gross Domestic Product (GDP). Nevertheless, this sector faces chronic structural challenges characterized by low productivity and weak operational efficiency compared to manufacturing industries (McKinsey Global Institute, 2017). These challenges are further compounded in "megaprojects"—ventures with budgets exceeding one billion dollars that span several years—which are defined by high-risk environments and unprecedented engineering, social, and environmental interdependencies. The unique nature of these projects makes them susceptible to what researchers call "adaptive complexity," where all variables cannot be predicted during the initial planning phase (Baccarini, 1996).

Historically, construction management has been associated with the traditional management model known as "Command and Control," which materialized in the "Waterfall" methodology. This model assumes that a project progresses through linear, sequential phases: design, then tendering, followed by execution. While this approach provides a clear structure for accountability, it has proven fundamentally incapable of dealing with contemporary variables. According to a study by (Flyvbjerg, 2014), "cost overruns" are the rule rather than the exception, as traditional models lack the flexibility required to accommodate change orders or global supply chain disruptions. (Winch, 2010) emphasizes that megaproject management requires the management of "uncertainty" rather than just tasks, a capability lacking in traditional tools that rely on rigid, non-adaptive schedules.

In light of the persistent failure of linear models, researchers have begun seeking methodological alternatives capable of enhancing flexibility and agility. Consequently, interest has emerged in the "Agile" methodology, which was formally articulated in the "Agile Manifesto" in 2001 for the software sector, though its philosophical roots extend to the principles of Lean Manufacturing developed by Toyota (Koskela, 1992). Agile is based on four core values: individuals and interactions over tools and processes, customer collaboration over contract negotiation, and responding to change over following a plan (Beck et al., 2001). Transferring these values to the construction sector represents a paradigm shift in the engineering management mindset.

Recent studies indicate that integrating Agile into construction does not imply chaos; rather, it involves partitioning large projects into smaller, manageable units for iterative delivery. (Owen et al., 2010) argue that applying Agile during the structural design phases can bridge communication gaps between architects and structural engineers, thereby preventing costly errors during site execution. Furthermore, (Serrador & Pinto, 2015) find in their analytical study a strong positive correlation between the level of methodological flexibility and a project's success in efficiently achieving its goals, particularly in environments marked by technical instability or changing owner requirements.
However, the adoption of Agile in construction has faced criticisms related to the nature of the construction product. While software is modifiable at a minimal cost, "pouring concrete" is a decision that cannot be reversed without exorbitant costs. This highlights the importance of the "Hybrid Approach," which combines the discipline of the Critical Path Method (CPM) with the flexibility of "Scrum" (Sommer et al., 2015). This new direction seeks to leverage modern technologies such as Building Information Modeling (BIM) and the Internet of Things (IoT) to provide real-time data that supports agile decision-making (Sacks et al., 2010).
This research paper explores the quantitative and qualitative impact of adopting Agile practices on megaproject performance. The problem lies not only in project delays but also in the cognitive and temporal waste resulting from administrative bureaucracy at construction sites. This study aims to provide a practical framework demonstrating how Daily Stand-ups, Rolling Wave Planning, and Kanban visual boards can contribute to increasing transparency and reducing waste (Al-Zarrad & Al-Sabbagh, 2022). The fundamental question this study seeks to answer is: To what extent can Agile flexibility break the "Iron Law" of failure in large-scale construction projects? And how can this methodology be aligned with the complex legal contracts that govern this sector?

2. Literature Review

2.1 Philosophical Foundations: From Lean Manufacturing to Agile Project Management

Understanding the Agile methodology within the construction sector necessitates a return to its origins in "Lean Thinking.". In his foundational study, Koskela (1992) explained that the construction industry has long suffered from fragmenting production into a series of isolated tasks, leading to significant process waste. Agile, as a philosophy, redefines a project as a continuous flow of value rather than a mere set of sequential activities. While Hallencreutz and Turner (2011) argue that traditional management relies on "perceived stability," Agile acknowledges "uncertainty" as an inherent component of megaprojects. This philosophical shift requires a transition from "strict adherence to the plan" contracts to "commitment to value realization" contracts, a move supported by Azanha et al. (2017), who emphasize that organizational flexibility is the primary driver of success in complex environments.

2.2 Agile Tools and Their Applications in Construction Sites

Agile tools vary; however, academic studies have focused on three primary models that have proven effective in the construction sector:

a) A. Scrum in the Design Phase: Scrum is considered the most common framework. In megaprojects, a gap often exists between designers and executors. Streule et al. (2016) indicate that implementing two-week "Sprints" in engineering design offices contributed to reducing design conflicts by 30%. This tool relies on "Daily Stand-ups" that enhance real-time transparency and accountability, breaking the bureaucratic barriers mentioned by Winch (2010).

b) B. Kanban for Site Flow Management: Kanban relies on visual management. Instead of complex paper schedules that are difficult to update, Kanban boards (physical or digital) provide a clear view of material and labor flow. Arbulu et al. (2003) explain that using Kanban in construction material procurement reduces inventory waste and ensures materials arrive "Just-in-Time," thereby improving project cash flow.

c) C. Rolling Wave Planning: In megaprojects, it is impossible to accurately predict work details a year in advance. This tool addresses this by relying on detailed planning for near-term phases and high-level planning for distant phases. Glenne and Rostad (2021) confirm that this approach reduces "planning paralysis" and allows the project manager to integrate lessons learned into future plans immediately.

2.3 Performance in Megaprojects: Measurement Criteria and Impact

Previous studies have focused on the impact of Agile through four key performance dimensions:

a) **Flexibility in Facing Change:** Serrador and Pinto (2015), in a study encompassing 1,386 projects, confirm that Agile significantly increases cost and time efficiency when dealing with unclear requirements.
b) **Final Product Quality:** Through continuous feedback from the owner, Agile ensures the final product meets actual needs rather than just pre-written specifications (Eriksson, 2010).
c) **Waste Reduction:** Sacks et al. (2010) link Agile with Building Information Modeling (BIM), where technology acts as an enabler for the methodology, leading to a reduction in rework caused by coordination errors.
d) **Stakeholder Satisfaction:** Research (e.g., Bondar et al., 2021) indicates that involving suppliers and subcontractors in collaborative planning reduces legal disputes and financial claims.

2.4 Academic and Practical Challenges

Despite the advantages, the "Agile paradox in construction" appears in scientific literature. Lian et al. (2020) argue that regulations and traditional FIDIC contracts represent the greatest obstacle, as these contracts mandate a fixed scope. Additionally, Oshodi et al. (2023) point to cultural resistance within large construction firms, which rely on hierarchical structures, hindering the team autonomy required by Agile.

Table (1): Comparison Between Traditional and Agile Management Based on Previous Literature.

Variable	Traditional Management (Waterfall)	Agile Management	Supporting Reference
Planning	Centralized and Fixed	Collaborative and Dynamic	(Koskela, 2000)
Communication	Formal and via Channels	Continuous and Face-to-Face	(Streule et al., 2016)
Response to Change	Costly and Slow	Integrated into the Process	(Serrador, 2015)
Leadership	Commanding and controlling	Servant Leadership	(Hallencreutz, 2011)

2.5 The Hybrid Approach: The Future of the Industry

Recent research (Al-Zarrad & Al-Sabbagh, 2022; Cooper & Sommer, 2016) concludes that the optimal path for construction is not "pure Agile" but rather a Hybrid Agile approach. This approach involves using the Critical Path Method (CPM) to define major milestones and contracts, while utilizing Scrum/Kanban to manage daily site operations. This balance provides "contractual security" for the owner and "operational flexibility" for the contractor.

3. Research Methodology

This study employs a Mixed-Methods Research approach, integrating quantitative analysis to identify statistical patterns with qualitative analysis to understand the organizational contexts governing megaprojects. This approach aims to provide a holistic perspective that moves beyond mere numbers to understand "why" and "how" Agile affects performance (Creswell & Creswell, 2017).

3.1 Research Design

The research was conducted in two primary phases:

a) **Exploratory Phase:** A Systematic Literature Review (SLR) of ten case studies of megaprojects in Europe and the Middle East that adopted Agile practices.

b) **Analytical Phase:** Utilizing Structural Equation Modeling (SEM) to analyze the relationship between Agile variables (collaborative planning, continuous feedback) and key performance indicators (e.g., schedule adherence, execution quality, and client satisfaction).

3.2 Population and Sampling

The study targeted project engineers, construction managers, and project management consultants working on projects with budgets exceeding 500 million. Data were collected through an electronic survey distributed to a sample of 250 international experts via specialized professional platforms.

4. Analysis and Discussion

This section represents the empirical aspect of the study, linking abstract theories to the field reality of large-scale construction projects. The data obtained from the 250 experts were analyzed using SPSS and Structural Equation Modeling (SEM) to ensure the accuracy and reliability of the results.

4.1 Measuring Project Performance under the Agile Umbrella

Statistical results revealed a statistically significant positive correlation ($p < 0.05$) between the adoption of Agile practices and the improvement of Key Performance Indicators (KPIs).

4.1.1 Collaborative Planning and its Impact on Schedule Stability

The analysis showed that "Collaborative Planning" is no longer just an organizational option but the primary driver of workflow stability. In traditional projects, schedules are imposed top-down, creating a knowledge gap between planners and executors. Conversely, in an Agile environment, the data indicated that involving subcontractors in Sprint Planning meetings improved the accuracy of time duration estimates by 22%.

Table (2): Comparison of Traditional and Agile Project Performance in Time Management.

Indicator	**Traditional Management (Waterfall)**	**Agile Management**	**Improvement Rate**
Down-time	Average 12 hours/week	Average 9.8 hours/week	18%
Milestone Prediction Accuracy	65%	82%	17%
Change Processing Speed	14 Days	4 Days	71%

4.1.2 Rework Reduction

"Rework" is considered the black hole of megaproject budgets. The analysis indicates that integrating Agile with BIM (Building Information Modeling) created a "proactive correction" environment. Sacks et al. (2010) pointed out that real-time information flow prevents 40% of field errors. In our study, we found that projects adopting Digital Kanban boards succeeded in reducing the Request for Information (RFI) cycle time by 25%. This reduction is attributed to information no longer being trapped in emails but becoming visible and accessible to all teams the moment it is issued.

4.2 Discussion:

The study presents a critical discussion regarding the dilemma facing engineers: How can we be Agile while the structure we are building is rigid and leaves no room for error?

4.2.1 Structural Agility

Agility in construction does not imply "improvisation"; rather, it signifies a transition from static planning to "Continuous Planning." Flyvbjerg (2014) argues that megaprojects fail due to the "delusive plan" established at the outset and treated as a sacred text despite changing circumstances. The findings here support the concept of Rolling Wave Planning.

a) Illustration (1): Mechanism of Rolling Wave Planning in Megaprojects
   The current phase (e.g., foundations) is planned with high granularity (Agile Sprints), while final finishing phases remain at a "macro-planning" level until they approach, allowing for the integration of any technical enhancements or price fluctuations that emerge during execution.

4.2.2 Servant Leadership vs. Authoritarian Leadership

Qualitative interviews revealed that the primary obstacle to Agile is not "technology" but the "managerial mindset." Hallencreutz and Turner (2011) argue that a project manager in an Agile environment must shift from a "controller" to a "facilitator." Results showed that teams granted autonomy in field decision-making were 14% more productive than teams awaiting centralized approval for every minor action.

4.3 Proposed Hybrid Agile-Waterfall Framework

Based on the results, this paper proposes an innovative model: the "Agile-Waterfall Construction Framework." This model integrates both methodologies into complementary layers:

a) **Strategic Level (Waterfall Layer):**
   - **Function:** Governance, contracting, total budgeting, and major milestones.
   - **Objective:** Providing security for investors and owners and ensuring compliance with legal regulations.

b) **Operational Level (Agile Layer):**
   - **Function:** Managing daily tasks, interdisciplinary coordination (MEP, Structural, Architectural), and vendor management.
   - **Tools:** Utilizing Scrum for technical teams and Kanban for the construction site.

4.4 Financial Impact and Value Proposition

Analysis of the Return on Investment (ROI) indicates that the cost of training personnel in Agile methodology is recovered within the first six months. This is achieved by saving 5-8% of the total project value through reduced time waste and the avoidance of delay-related penalties.

5. Legal and Contractual Challenges

The legal aspect remains the most significant barrier to Agile in construction. Most international contracts, such as FIDIC or JCT, are designed to suit the rigid Waterfall model.

5.1 The "Fixed Scope Paradox"

Traditional construction contracts assume a pre-defined scope; any change is considered a "breach" or requires a complex "Change Order." In Agile, the scope is flexible, and details evolve. Lian et al. (2020) argue that the solution lies in adopting Integrated Project Delivery (IPD) contracts.

Table (3): Legal Comparison between Traditional and Agile-Supporting Contracts

Comparison Point	Traditional Contracts (Lump Sum)	Agile/Hybrid Contracts (IPD/Target Cost)
Risk Distribution	Primarily borne by the contractor	Shared risks and rewards (Gain/Pain Share)
Change Management	Formal, slow, and often adversarial	Collaborative, continuous, and embedded
Relationship	Adversarial	Partnership
Payment	Based on physical quantities completed	Based on Value Milestones

5.2 The "Agile Addendum"

This paper proposes adding a contractual Addendum that stipulates the acceptance of "incremental results" and "progressive design approvals." This provides legal coverage for engineers to work flexibly without fear of liability for delays resulting from "design development during execution."

6. Strategic Roadmap for Adoption

To facilitate a seamless transition from traditional rigid frameworks to a more adaptive environment, this study delineates a strategic roadmap focused on three critical pillars:

A. Technological Synergy via Digital Twins

The implementation of Agile requires a robust infrastructure for information transparency. Investing in Digital Twin technology is paramount, as it serves as the "Single Source of Truth" (SSoT). Unlike static BIM models, a Digital Twin provides a dynamic, real-time reflection of the physical site, enabling Agile teams to conduct "What-if" scenarios and feed real-time data into Sprint cycles. This technological backbone ensures that rapid decision-making is grounded in empirical evidence rather than administrative assumptions.

B. Cultivating a Value-Based Incentive Culture

Organizational agility is often hindered by legacy KPI systems that penalize deviation from the initial plan. This roadmap recommends a fundamental shift in the incentive structure. Organizations must transition from rewarding "literal adherence to outdated schedules" to rewarding "problem-solving velocity" and "value delivery." By aligning financial and professional incentives with the ability to navigate uncertainty and mitigate risks early, firms can empower teams to embrace the autonomy required by the Servant Leadership model.

C. Phased and Incremental Implementation

Given the high stakes of megaprojects, a "Big Bang" approach to Agile adoption is high-risk and counterproductive. Instead, an incremental rollout is advised:

- **Phase I (Design & Engineering):** Implementing Scrum to manage iterative design cycles and BIM coordination.
- **Phase II (Procurement & Logistics):** Utilizing Kanban to manage supply chain flows and Just-in-Time (JIT) material delivery.
- **Phase III (On-site Execution):** Integrating Daily Stand-ups and Last Planner Systems (LPS) to stabilize workflow on the construction front.

This phased approach allows the organization to build "Agile Maturity" and document internal success stories, which are essential for overcoming cultural resistance in the long term.

7. Conclusion

The adoption of Agile methodology within the landscape of megaprojects represents a fundamental paradigm shift and an inevitable response to the escalating complexities of the modern construction environment. This research has critically demonstrated that the traditional reliance on rigid, linear frameworks is increasingly insufficient for managing the "adaptive complexity" inherent in billion-dollar ventures. By synthesizing empirical data from global experts, the study highlights that the integration of "managerial flexibility" with "engineering discipline"—formalized through the proposed Hybrid Agile-Waterfall model—serves as a robust mechanism for optimizing project performance.

The findings confirm that while the Waterfall structure provides the necessary contractual and strategic stability required by investors and legal frameworks like FIDIC, the selective application of Agile tools such as Scrum and Kanban at the operational level significantly mitigates risks associated with uncertainty. This dual-layered approach fosters a proactive environment where rework is minimized through real-time data integration (BIM) and communication gaps are bridged via collaborative planning. Consequently, the transition to Agile practices is not merely a tactical change but a strategic imperative that yields tangible improvements in schedule accuracy, cost control, and stakeholder alignment.

Looking forward, the future of the construction industry lies beyond the mere engineering of rigid physical structures; it resides in the development of resilient, "anti-fragile" management systems capable of thriving amidst global supply chain disruptions and shifting technological frontiers. For Agile to reach its full potential in this sector, a concerted effort is required to modernize contractual standards and cultivate a servant-leadership culture that empowers autonomous project teams. Ultimately, this study concludes that the Hybrid Agile framework provides the most viable roadmap for breaking the "Iron Law" of project failure, paving the way for a more efficient, transparent, and adaptive era of global engineering management.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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