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Digital Transformation of Construction Projects with an Advanced Agile Tool for Deformation Risk Management

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The Agile Monitoring Tool (AMT), integrated within the Smart Infinity Dimensions (S∞D) modeling platform as part of the Digital Transformation Project Management Platform, enhances safety and efficiency in large-scale construction projects by combining agile risk management with structural health monitoring (SHM). Traditional SHM systems monitor structural changes but often lack agile risk management, safety measures, and preventative safety alert functions. AMT addresses this gap by embedding agile risk management and real-time alerts, notifying key stakeholders to support informed decision-making. Through a five-stage process—identifying risks, notifying stakeholders, coordinating teams, allocating resources, and managing data—the AMT provides construction teams with actionable insights, potentially preventing up to 70% of onsite accidents by addressing risks proactively. While pilot testing indicates substantial accident prevention capabilities, further validation across diverse construction projects is necessary. Developed from six Calgary-based projects, the AMT leverages IoT-enabled Real-Time Monitoring and 3D modeling within the S∞D platform to monitor and optimize resource allocation, reduce energy consumption, and minimize waste and rework costs. Pilot testing highlights AMT's effectiveness as a scalable, cost-efficient tool for high-stakes construction projects requiring rigorous safety management.

Keywords: Digital Transformation (DT); Deformation Monitoring (DM); Smart Infinity Dimension; Agile Risk and Alert Management Monitoring Tool; Comprehensive Project Management Software (CPMS)

Introduction

The Agile Monitoring Tool (AMT) enhances safety and efficiency in structural health monitoring (SHM) for large-scale construction projects, addressing risks like equipment failure, safety non-compliance, and environmental hazards. Integrating agile risk management, real-time alerts, team coordination, and digital data management, the AMT overcomes traditional SHM limitations with proactive safety recommendations for stakeholders. The SHM system's primary function, deformation monitoring, tracks structural changes using sensors like tiltmeters and displacement transducers, robotic surveys, GNSS, and laser scans to enhance accuracy. Integrated photogrammetric and imaging technologies create a secure, searchable database. Central to the AMT is the Project Management Software Package (PMSP) within the IoT-enabled "Smart ∞ Dimensions" platform, combining advanced sensors, imaging, and 3D modeling for real-time asset management. The AMT's five-phase approach uses data from Calgary pilot studies to enable early risk detection and collaborative decision-making. Supporting a Digital Transformation Project Management Platform, the AMT offers a cost-effective, data-driven solution for hazard identification, setting new standards in digital risk management for construction.

Project Objectives

The project's main goal is to create the AMT, merging agile risk management, safety protocols, and digital data infrastructure within an SHM system. Built into the Smart Infinity Dimensions (S∞D) platform, AMT aims to improve safety and efficiency in large-scale construction, setting new standards for complex environments. The Comprehensive Project Management Software (CPMS) package—a key AMT component—combines automated and open-source tools to enhance oversight and reduce risk. The six main objectives are to:

1. Develop a multi-sensor SHM system: Design a high-sensitivity system to monitor structural deformations, assess risks, and guide proactive mitigations using agile processes.
2. Enable agile risk management and alerts: Implement 24/7 automated alerts for continuous stakeholder notifications and timely risk responses.
3. Enhance team coordination: Define roles with the RACI matrix and use agile methods to foster collaboration, creativity, and effective communication.
4. Deploy the CPMS: Integrate SHM and agile data in a CPMS to streamline project oversight, improving safety, quality, and efficiency.
5. Secure data management: Use advanced protocols to organize SHM data securely, ensuring privacy, accessibility, and scalability.
6. Boost safety and efficiency: Reduce onsite accidents by 70% with real-time monitoring and alerts, minimizing delays and optimizing resources.

These objectives create an agile-based management framework that enhances safety, risk management, and data infrastructure in construction, advancing SHM technology integration for future applications aligning with industry needs.

Literature Review

Numerous scholars and experts argue that adopting agile over traditional methods in software development improves efficiency (Hooda et al., 2023) and increases productivity (Cardozo et al., 2010). Since 2001, methodologies like XP, Scrum, Lean Software Development, Feature-Driven Development, and Crystal have become widely recognized frameworks (Ali, et al., 2023; Narasimman, 2024). Scrum is the most widely adopted Agile framework, with a minimum of 75% of respondents either implementing Scrum or utilizing a hybrid approach with Scrum as a core component (Digital.ai, 2020). Rooted in computer science, agile methods have extended beyond IT, especially in new product development (Digital.ai, 2020; Hooda et al., 2023). Studies have suggested the feasibility of agile approaches in diverse project contexts. Specifically, Conforto et al. (2014) surveyed agile practices across 19 medium-to-large companies, concluding that the Agile Project Management (APM) approach could be adapted for non-software industries. Despite widespread adoption, the construction industry remains underexplored in terms of APM, highlighting a need for research. This literature review identifies four key research gaps:

1. Limited use of agile methods in Engineering, Procurement, and Construction (EPC) projects: Most studies rely on traditional approaches for safety, risk, and data management.
2. Underdeveloped agile tools for SHM and MMS data: Tools for managing safety, risk, and digital data infrastructures remain insufficient.

3. Lack of integration: Risk, safety, and data management are often treated separately in research, without a unified agile framework.
4. Unexplored link between agile and SHM: The relationship between APM and SHM lacks study, as do comprehensive performance metrics.

This project addresses these gaps by developing a unified, agile-based approach for managing construction projects integrated with SHM systems. Decades of SHM research since the 1970's has led to few routine applications in industry. SHM encompasses a wide range of applications across diverse structures, each with unique requirements (Cawley, 2018).

Agile Management in Non-Software Industries

Evidence supports APM's effectiveness in software development, with studies demonstrating improved project efficiency and team productivity (Digital.ai, 2020; Ali et al., 2023). Despite these successes, research on agile approaches in non-software sectors remains limited, though some studies suggest potential benefits across industries (Conforto et al., 2014). Publications on APM practices have noted opportunities to extend agile principles to SHM, emphasizing the advantages of agile integration in these areas (Sliger & Broderick, 2008; Cawley, 2018). By incorporating agile principles into construction project management, this research provides a breakthrough in managing risk, safety, and digital data infrastructure specifically within the construction industry (Outbuild, 2024; PMA Consultants, 2024).

Traditional vs. Agile: Literature Review

Traditional management methods in construction are often labour-intensive, time-consuming, risky, and costly. The 14th State of Agile report indicates that by the end of 2019, agile methodologies were adopted by 95% of surveyed organizations (Digital.ai, 2020). Despite this, evidence of APM's effectiveness in the construction industry remains sparse, in Canada and globally. Efficiencies between traditional and agile management are shown in Table 1 and Figure 1.

Table 1. Traditional vs. Agile Management

No.	Traditional	Agile
1	Plan all in advance	Plan as you go
2	Functional specs	User stories
3	Gantt chart	Release plan
4	Deliver at the end	Deliver as you go
6	Follow the plan	Adapt everything
7	Manage tasks	Manage team

Agile Lifecycle and Management Approach

Agile is defined by Conforto and Amaral (2010) as "an approach based on a set of principles aimed at making project management simpler, more flexible, and iterative, achieving better performance (cost, time, and quality) with less management effort and higher levels of innovation and added value for the customer". Methods like Lean, Scrum, Extreme Programming (XP), and Feature-Driven Development (FDD) have increasingly influenced fields such as construction and engineering. Numerous authors have published books and studies on agile project management (Ali et al., 2023; Hooda et al, 2023). The growing popularity of agile methods is reflected in their widespread use today (Nutcache, 2017).

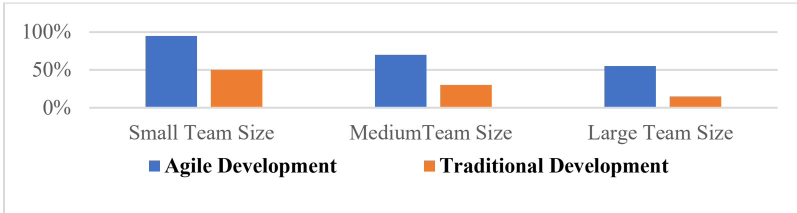

Figure 1. Efficiencies between traditional and agile development (Narasimman, 2024)

Structural Health Monitoring (SHM)

Structural Health Monitoring (SHM) is essential in modern engineering, enabling continuous assessment of infrastructure safety, efficiency, and functionality. Using sensors and predictive analytics, SHM tracks structural integrity to detect early signs of damage in bridges, detect shifts, cracks, and foundation issues in buildings, and to monitor water pressure, seepage, and stability in dams and reservoirs, among other applications. SHM provides automated early warnings to prevent structural failures, reducing repair and major maintenance costs and the need for manual inspections The goal is to identify and predict issues, allowing timely, targeted interventions to improve safety. efficiency and reduce costs.

Deformation Monitoring

Deformation Monitoring (DM) identifies structural changes using multiple sensors, including robotic total stations and laser scanners, to measure movements within 2mm accuracy, particularly for tracks and retaining walls. High-precision instruments like GNSS, inclinometers, and extensometers ensure accuracy, meeting project specifications (Figure 2).

Figure 2. Smart ∞Dimensions IoT

A deformation monitoring project was contracted by the City of Calgary to monitor LRT track stability near construction zones. The system used SHM sensors, alert devices, and daily robotic total station surveys, supported by continuous GNSS and weekly laser scans, to detect and report deformations in real time. Photogrammetry, strain gauges, and imaging solutions further enhance data accuracy. SHM software has been successfully used in Alberta-wide mega projects such as the Syncrude retaining wall, Telus Sky towers, NCL project, Manulife projects, and Brookfield project.

Smart Infinity Dimensions (S∞D) and IoT Platform

Used in Calgary City Hall renovations, the S∞D IoT Platform streams, archives, and monitors real-time stress, strain, and deflection data, issuing alerts for sudden deformations. Sensor data is analyzed for optimal decision-making, with telephoto lenses capturing precise deflection measurements (Figures 2-4). Data archiving and analytics allow decision-makers to monitor trends over time. Telephoto lenses capture images of the steel surface with retro-reflective stickers for automatic recognition, continuously reporting deflection values (Figure 4).

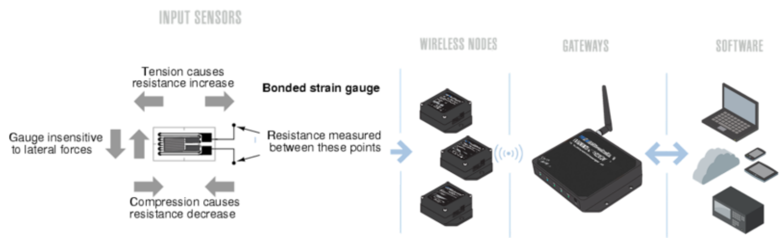

Figure 3. Smart∞Dimensions IoT

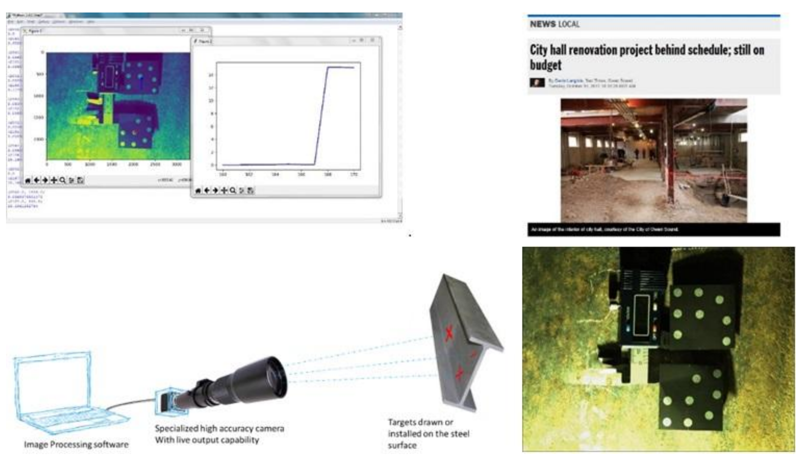

Figure 4. IoT platform sensor setup for deformation monitoring

Figure 5 and Figure 6 show the capabilities of the S∞D system to present 3D models with IoT sensor data and other data sources layered on the point-cloud and 3D models of the environment.

Methodology

This project employs a mixed-methods approach, combining qualitative and quantitative data. Project management is integrated with data monitoring and quality control for iterative improvements (Figure 7). Figure 8 outlines the AMT framework with five components: risk, alert, team, safety, and data management. Researchers collaborate with practitioners to identify building risks and develop safety plans, analyzing SHM data from six mega-projects alongside a literature review and industry pilot studies. Structured interviews provide participant insights. To address data security and privacy, the AMT incorporates encryption protocols to safeguard data transmission and storage. System access is restricted through role-based permissions and security audits identify and mitigate vulnerabilities, protecting construction project data and ensuring regulatory compliance. Managing digital data requires robust encryption, access controls, and regular audits to protect sensitive information. The learning curve and training requirements for users are key considerations in AMT adoption. Comprehensive tailored training, including workshops, online tutorials, and support documentation, is essential. The tool's user-friendly interface minimizes complexity, while training programs equip construction teams with the skills needed for efficient use and successful implementation.

Figure 5. IoT platform data streaming

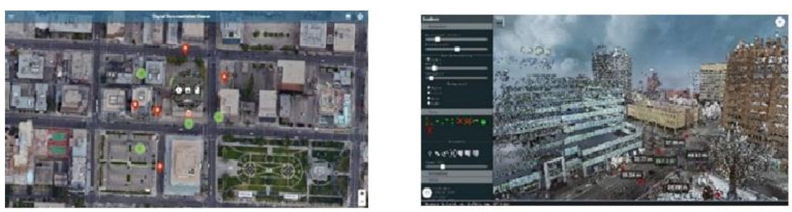

Figure 6. IoT streaming data, images, and text documents

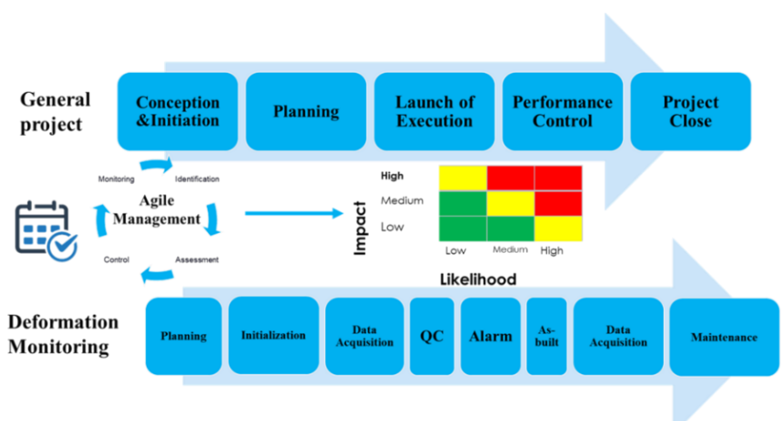

Figure 7. A Deformation Monitoring workflow

The Agile Monitoring Tool

An Agile Monitoring Tool (AMT) is a system of procedures for managing risk, safety, and digital data in construction projects emphasizing risk identification, data analysis, team coordination, and large dataset management (Weshah et al., 2014). Projects proceed in five phases:

- Phase 1: Agile Risk Management for SHM—Hazards are identified using past data and stakeholder input. Risks are identified and ranked in a Risk Matrix. High risks prompt immediate action; lower risks are logged for monitoring as shown in Figure 9.
- Phase 2: Agile Alert Management for SHM—Automated alerts notify stakeholders of high and medium risks, enabling rapid responses. Real-time data monitoring adjusts alert levels as risks evolve, while low risks remain logged as shown in Figure 10.
- Phase 3: Agile Team Management for SHM—Roles are assigned with a Responsibility Assignment Matrix (RAM) to ensure accountability and responsiveness.
- Phase 4: Agile Safety Management for SHM—Safety protocols are tailored to risk severity, including compliance tracking, resource allocation, and ongoing documentation.
- Phase 5: Digital Data Infrastructure Management for SHM—Data is centralized for easy retrieval and analysis using advanced 3D mapping, GIS data, and georeferenced images.
- At the project end, all SHM data, risk assessments, and safety protocols are compiled into a final report, including lessons learned to inform future projects.

The study identified critical risks, including structural movements, environmental hazards, and material handling issues (Figure 9). Risks were prioritized using severity scores from historical data and expert evaluations. For instance, horizontal shifts over 2.5cm in retaining walls triggered alerts, prompting timely action that reduced downtime by 25% and prevented structural failures. Other risks, like overloaded structures, were also mitigated, enhancing safety and efficiency (Table 2). Table 3 highlights the importance of monitoring vertical and horizontal movements in construction and how AMT prioritizes safety-focused interventions.

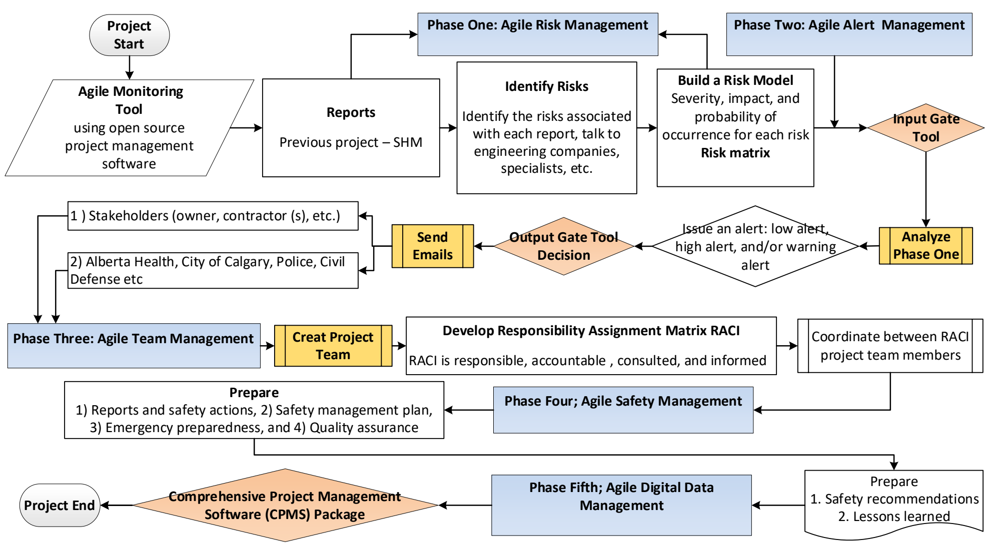

Figure 8. Agile Monitoring Tool framework

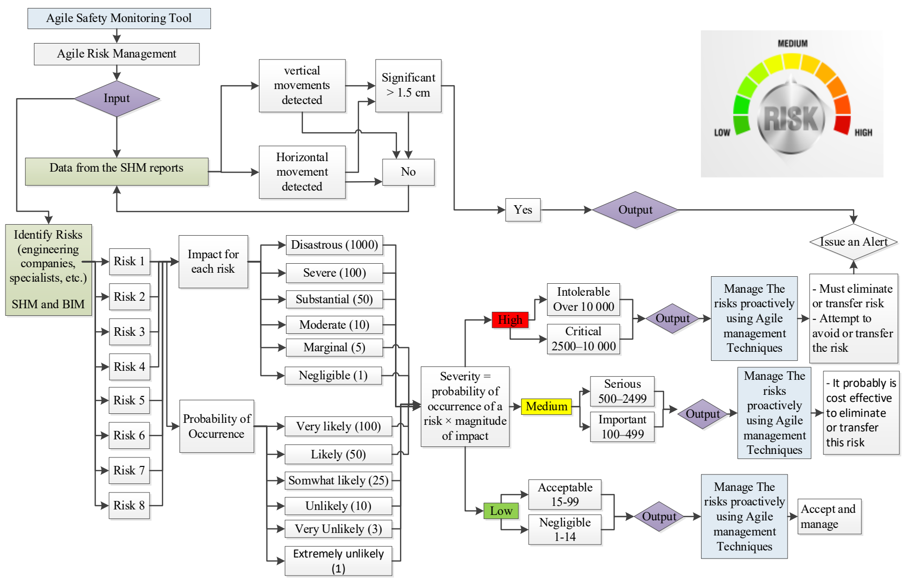

Figure 9. Phase one—Agile Risk Management

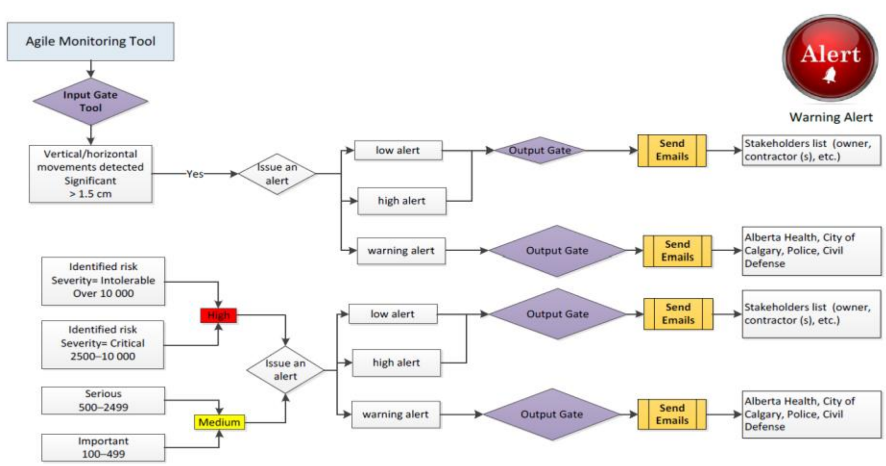

Figure 10. Phase two—Agile Alert Management

The Agile Monitoring Tool (AMT) advances construction safety by integrating APM with SHM for real-time hazard assessment and response. It enhances collaboration through automated alerts, reporting, and actionable feedback, fostering a proactive safety culture with clear roles, compliance tracking, and emergency preparedness. The agile framework allows real-time customization, aligning safety standards with resource optimization. The AMT supports sustainable, cost-effective management, reducing accident risks and long-term costs. Pilot studies on six Calgary projects showed up to 70% reduction in onsite accidents, though broader validation is needed. Robust data security measures like encryption, access controls, and audits are critical for stakeholder trust. Effective adoption requires technical readiness, comprehensive training, and ongoing support to maximize safety and efficiency.

Table 2. Risk mitigation using the AMT during pilot studies on six projects

Risk Factor	Example	Validation
Structural Deformation Risks	Horizontal movement of 2.2 cm was detected in a retaining wall. A 'critical alert' was sent to the engineering team to avoid structural failure.	Structural deformation risks comprised 25% of critical alerts, with early detection enabling issue resolution within 24 hours
Wall Deformation in Structural Frames	Horizontal deformation of 2.5 cm was detected in a key wall frame. The AMT issued a 'high alert,' prompting immediate reinforcement.	Wall deformation risks accounted for 20% of high alerts, with timely responses ensuring the safety of the structure.
Overloaded Temporary Structures	AMT flagged overloaded top floor scaffolding as 'medium alert. Weight redistribution and reinforcement prevented collapse.	Overloaded temporary structures were 18% of medium alerts, allowing safe weight distribution in 90% of cases.

Table 3. Summary of vertical and horizontal movement-related risk factors

Movement Type	Example	Validation
Vertical Movements > 1.5 cm	SHM detected 2.3 cm movement in a critical beam. A 'high alert' was issued; immediate reinforcement prevented structural instability.	These movements caused 25% of critical alerts; risk of structural failures was reduced by 30%.
Horizontal Movements > 1.5 cm	Displacement of 2.2 cm was flagged in a support wall. The AMT issued a 'critical alert; bracing was installed to stabilize the structure.	These displacements constituted 20% of high alerts; timely bracing prevented long-term damage.
Vertical Movement in Load-Bearing Columns	Vertical movement of 1.8 cm was detected; proactive measures were implemented to avoid failure.	These caused 18% of alerts; soil stabilization and reinforcement resolved issues in 48hrs.
Combined Vertical and Horizontal Movements in Foundations	Movements exceeding 3 cm were identified in the foundation. A 'critical alert' initiated soil grouting and structural reinforcements to prevent major damage.	These movements accounted for 22% of critical alerts; early interventions prevented significant delays and structural risks.

Conclusion and Future Directions

Developed from six Calgary projects, the AMT has proven effective in identifying risks and providing actionable safety recommendations. It integrates SHM, agile methods, and stakeholder-focused design to enhance safety, efficiency, and productivity. The AMT lays the foundation for a broader Digital Transformation Platform for EPCM, optimizing workflows, managing risks, and improving communication. While pilot testing shows promise in accident prevention, further research is needed to assess its generalizability across diverse projects, locations, and conditions. Future studies will address scalability, integrate AI-driven analytics, and incorporate user feedback for iterative improvements.

References

Ali, F., Usman, M., Abrar, M. F., Rahman, S. U., Khan, I., & Niazi, B. (2023). Practices of de-motivators in adopting agile software development methods at large scale development teams from management perspective. *IEEE Access, 11*, 1-12.

Cardozo, E., Neto, A., Barza, A., França, C., & da Silva, F. (2010). SCRUM and productivity in software projects: A systematic literature review. In *EASE'10 Proceedings of the 14th International Conference on Evaluation and Assessment in Software Engineering* (pp. 131–134).

Cawley, P. (2018). Structural health monitoring: Closing the gap between research and industrial deployment. *Structural Health Monitoring, 17*(5), 1225–1244.

Conforto, E. C., & Amaral, D. C. (2010). Evaluating an Agile Method for Planning and Controlling Innovative Projects. *Project Management Journal*, *41*(2), 73–80.

Conforto, E. C., Fabian Salum, F., Amaral, D. C., da Silva, S. L., & de Almeida, L. F. M.. (2014). Can Agile Project Management Be Adopted by Industries Other than Software Development? *Project Management Journal, 45*(3), 21–34.

Digital.ai. (2020). *The 14th Annual State of Agile Report.* https://www.qagile.pl/wp-content/uploads/2020/06/14th-annual-state-of-agile-report.pdf

Hooda, S., Sood, V. M., Singh, Y., Dalal, S., & Sood, M. (2023). *Agile software development*. John Wiley & Sons.

Narasimman, P. (2024). *Agile project management vs. traditional project management*. KnowledgeHut. https://www.knowledgehut.com/blog/agile/agile-project-management-vs-traditional-project-management

Nutcache (2017). 8 Top Project Management Methods, Approaches, Techniques. Retrieved from http://www.nutcache.com/blog/8-top-project-management-approaches-methods-techniques/

Outbuild (2024). *The power of agile methodology for boosting construction efficiency*. Retrieved from https://www.outbuild.com

PMA Consultants. (2024). *Agile project management in construction: Improving risk and safety management with agile principles*. Retrieved from https://www.pmaconsultants.com

Sliger, M., & Broderick, S. (2008). *The software project manager's bridge to agility*. Addison-Wesley Professional.

Weshah, N., El-Ghandour, W., Cowe Falls, L., & Jergeas, G. (2014). Enhancing Project Performance by Developing Multiple Regression Analysis and Risk Analysis Models for Interface Management. *Canadian Journal of Civil Engineering, 41*, 929–944.