
The Mediating Role of Project Process Management and the Moderating Role of Risk Management in Achieving Sustainable Project Success through Technology Innovation

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Abstract

This study intends to examine the relationship between Technology Innovation (TI), Project Process Management (PPM), Risk Management (RM), and Sustainable Project Success (SPS) in the construction industry. Specifically, the mediating effect of PPM and the moderating effect of RM on the relationships between TI & SPS and PPM & SPS are measured. A sample of 328 respondents' data was collected from project managers, portfolio managers, and construction managers through structured questionnaires distributed via Google Forms. The results indicate that TI significantly enhances PPM, which then positively impacts SPS. However, the direct impact of TI on SPS was found to be insignificant. Additionally, RM moderates the relationship between PPM and SPS. The findings suggest that while technology innovation alone does not directly lead to sustainable project success, it significantly enhances project process management, which in turn improves sustainable project success. This highlights the importance of integrating innovation within structured project processes. Moreover, strong risk management practices amplify the positive impact of process management on sustainability outcomes. Theoretically, the study contributes by emphasizing the mediating and moderating roles of process and risk management in innovation-sustainability linkages, urging a more integrated approach to achieving sustainable project outcomes.

Keywords: Technology Innovation (TI), Project Process Management (PPM), Risk Management (RM), Sustainable Project Success (SPS).

Introduction

The construction industry stands as a cornerstone of global economic and social development. Its economic significance manifests through its profound impact on economic growth and GDP. As a labor-intensive industry, it not only directly employs a vast workforce but also creates opportunities for diverse skill sets, thus propelling various sectors such as manufacturing, transportation, and finance. This industry's influence extends to crucial sectors like transportation, energy, healthcare, and education, forming the fundamental infrastructure of modern society (Guerra et al., 2021).

The construction industry's primary role is in shaping and maintaining the infrastructure critical for societal functionality. Infrastructure, encompassing roads, bridges, energy networks, and communication systems, facilitates trade and mobility and provides essential services vital for economic growth and social welfare (Peter Adekunle, 2022). The construction industry is a catalyst for economic growth, generating job opportunities across various skill sets and industries. Its

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projects demand a range of skills, serving professionals, experienced workers, and unskilled laborers, thereby greatly influencing the worldwide labor market (Benachio et al., 2020).

Modern construction has seen technical developments such as prefabrication and Building Information Modeling (BIM), which have produced operational effectiveness, improved safety, and streamlined procedures. Sustainability is becoming more and more important as environmentally friendly materials and methods of operation help to lower the industry's impact (Van Tam et al., 2021).

Fundamentally, the building sector is still a major part of the world economy and is very important for infrastructure development as well as employment creation. Its ongoing adaptability and creativity seek to solve the problems presented by urbanization, sustainability, and technology developments, therefore guiding the future built environment (Yifan & Bei, 2022).

Over the past few decades, the building industry has become aware of the need to properly tackle environmental sustainability issues. The industry's significant resource use and carbon emissions have led to efforts to develop environmentally efficient building techniques. These methods cover using sustainable resources, applying energy-efficient designs, and using waste-reducing techniques (Azeem et al., 2020).

Driven by various important trends and challenges, the global building sector is going through a transforming time. As governments all around try to boost economic growth and solve infrastructure shortages, post-pandemic recovery initiatives have driven a rebirth in building activity, especially in infrastructure and homes. With estimates showing consistent increases driven by urbanization, population increase, and the need for sustainable and resilient infrastructure, the worldwide construction market was valued at around \$10 trillion in 2023 (UNECE, 2023).

A study by Ebekoziem et al. (2023) reported that rising material prices, manpower shortages, and supply chain delays are just a few of the main challenges the sector must overcome. The COVID-19 outbreak has been aggravating several initiatives, causing delays and more expenses. Driven by environmental restrictions, investor expectations, and the global endeavor toward meeting the United Nations Sustainable Development Goals (SDGs), the sector is likewise under rising pressure to adopt sustainable practices.

The Pakistani government has implemented measures aimed at fostering sustainable construction practices, including the establishment of a Green Building Code and the provision of incentives. However, there is still untapped potential for promoting the use of sustainable practices within the building sector. Collaborative efforts between governmental entities and industrial stakeholders, tax incentives, subsidies, and various financial motivations could be beneficial as well (Sardar Ahsen et al., 2021).

Statsenko et al. (2023) explained the importance of digital tools used in the construction industry. The building sector is progressively using digital tools and technology including artificial intelligence (AI), drones, and building information modeling (BIM). By offering comprehensive 3D models that combine data over the project life, BIM, especially, is transforming project design, planning, and management. Predictive analytics using artificial intelligence and machine learning is helping to allocate resources more wisely and increase safety on building sites.

Despite the significant contributions of the construction sector to Pakistan's economy, accounting for 2.5% of the GDP and poised to reach an industry value of Rs. 2,705.5 billion by 2028, the industry continues to face persistent challenges in project execution. Delays, cost overruns, and inefficiencies are commonplace, undermining the sector's potential (Prime Minister Office, 2023). The sector also faces mounting legal and financial challenges, with Rs. 1.1 trillion tied up in pending litigation, further highlighting systemic inefficiencies. Addressing these issues, particularly the lack of sustainability, is essential for the sector to achieve its full potential and contribute to long-term economic growth.

In general, the current body of literature on sustainable project management in the construction industry exhibits theoretical deficiencies. Given the antecedents posited within this discourse, it is crucial to undertake more investigation into additional determinants to provide a more comprehensive understanding of the fluctuations in sustainable project management and project success within the construction sector.

The significance of this study lies in its contribution to enhancing sustainable practices and improving project success rates within the construction industry. By exploring the relationships between technology innovation and sustainable project success, alongside the mediating role of project process management and moderating roles of risk management, this research provides valuable insights for project managers, portfolio managers, and team leaders. It provides a structure for including sustainability into building operations by pointing out important elements influencing project results. Such integration is a major obstacle in guaranteeing the timely, reasonably priced, high-quality delivery of building projects.

Literature Review

The relationship between technology innovation and sustainable project success has garnered significant attention in academic literature, as organizations increasingly prioritize sustainability alongside traditional project metrics like cost, time, and quality. Sustainable project success is often defined as achieving project objectives while minimizing environmental impact, promoting social responsibility, and ensuring economic viability over the long term (Anser et al., 2020). Technology innovation, encompassing advancements such as automation, data analytics, and green technologies, is recognized as a critical driver in achieving these multifaceted goals. Studies consistently demonstrate that innovative technologies enhance project efficiency, reduce resource consumption, and align projects with sustainability principles, thereby contributing to their overall success.

One key mechanism through which technology innovation impacts sustainable project success is by improving resource efficiency and reducing environmental footprints. For instance, Baghalzadeh Shishehgarkhaneh et al. (2022) found that the adoption of Building Information Modeling (BIM) in construction projects significantly reduced material waste and energy consumption, leading to more sustainable outcomes. Similarly, the integration of Internet of Things (IoT) technologies in project management enables real-time monitoring of resource use, allowing for proactive adjustments that minimize environmental harm (Ghosh et al., 2021; Khurshid et al., 2025). These technologies not only streamline processes but also ensure compliance with environmental regulations, a critical factor in sustainable project success. By

optimizing resource allocation and reducing waste, technology innovation directly supports the environmental pillar of sustainability while maintaining project performance.

Furthermore, technology innovation fosters stakeholder collaboration and social sustainability, which are integral to sustainable project success. Advanced communication platforms and collaborative tools, such as cloud-based project management software, enhance transparency and stakeholder engagement, ensuring that social and community needs are addressed (Babalola & Harinarain, 2024). Projects leveraging digital platforms for stakeholder input have been shown to improve social acceptance and equity, key indicators of sustainable success. Additionally, technologies like artificial intelligence (AI) enable predictive analytics that anticipate stakeholder concerns, allowing project managers to address potential conflicts proactively. This alignment with social sustainability principles strengthens the positive impact of technology innovation on project outcomes (Sutrisno et al., 2023).

Economic sustainability, another critical dimension of project success, is also enhanced through technology innovation. Studies indicate that innovative technologies, such as renewable energy systems and smart grids, reduce long-term operational costs, thereby improving the economic viability of projects (Shou et al., 2023). Technology-driven process improvements, such as automation and machine learning, increase project efficiency, reducing delays and cost overruns (Animi & Owusu-Manu, 2021). These economic benefits, coupled with environmental and social gains, underscore the significant positive impact of technology innovation on sustainable project success. Based on the above literature, following hypothesis is formed:

H1: Technology innovation has a significant positive impact on Sustainable Project Success.

Technology innovation has emerged as a pivotal factor in enhancing project process management, which encompasses the planning, execution, monitoring, and control of project activities to achieve objectives efficiently. Project process management relies on streamlined workflows, effective communication, and accurate decision-making, all of which are significantly improved by innovative technologies such as automation, data analytics, and collaborative platforms (Kaufmann & Kock, 2022). The literature consistently highlights that technology innovation optimizes process efficiency, reduces errors, and enhances adaptability, thereby positively impacting project outcomes. This review synthesizes key findings to demonstrate the significant positive influence of technology innovation on project process management.

One primary way technology innovation enhances project process management is through automation and digital tools that streamline workflows and improve efficiency. For instance, the adoption of Building Information Modeling (BIM) in construction projects has been shown to automate design and scheduling processes, reducing manual errors and improving coordination among teams (Latif et al., 2021). Similarly, project management software like Microsoft Project or Primavera leverages algorithms to optimize resource allocation and task scheduling, minimizing delays (Nusraningrum et al., 2020). These tools enable real-time updates and data-driven insights, allowing project managers to maintain control over complex processes. By reducing repetitive tasks and enhancing precision, technology innovation directly improves the efficiency of project process management.

Moreover, technology innovation enhances decision-making and risk management, critical components of effective project process management. Advanced data analytics and artificial intelligence (AI) tools enable predictive modeling, allowing managers to anticipate potential risks and adjust processes proactively (Wamba-Taguimdje et al., 2020). For example, AI-driven platforms can analyze historical project data to forecast cost overruns or schedule deviations, enabling timely interventions (Mariani et al., 2023). Additionally, Internet of Things (IoT) technologies provide real-time monitoring of project activities, such as equipment performance or resource utilization, ensuring processes remain on track (Regona et al., 2022). These innovations empower managers to make informed decisions, mitigating risks and enhancing process reliability.

Collaboration and communication, essential for seamless project process management, are also significantly improved by technology innovation. Cloud-based platforms, such as Asana or Trello, facilitate real-time collaboration among geographically dispersed teams, ensuring alignment on project goals and processes (Sacks et al., 2020). Studies show that digital communication tools reduce misunderstandings and enhance stakeholder engagement, leading to smoother process execution (Mariani et al., 2023). Furthermore, virtual reality (VR) and augmented reality (AR) technologies enable immersive process simulations, allowing teams to refine workflows before implementation (Vrchota et al., 2021). By fostering collaboration and transparency, these technologies strengthen the management of project processes. In light of the existing literature, we have formulated the following hypothesis:

H2: Technology innovation has a significant positive impact on Project Process Management.

Project process management, encompassing the systematic planning, execution, monitoring, and control of project activities, plays a pivotal role in achieving sustainable project success, which balances environmental, social, and economic objectives alongside traditional project metrics (Alkhlaifat et al., 2019). Sustainable project success is characterized by delivering project goals while minimizing environmental impact, promoting social equity, and ensuring long-term economic viability. Effective process management ensures that sustainability principles are integrated into every project phase, from initiation to closure, thereby enhancing outcomes. The literature consistently demonstrates that robust project process management fosters efficiency, stakeholder engagement, and alignment with sustainability goals, significantly contributing to sustainable project success (Animi & Owusu-Manu, 2021; Kanwal et al., 2025).

One critical way project process management supports sustainable project success is by embedding sustainability considerations into planning and execution processes. According to Armenia et al. (2019), structured process frameworks, such as those aligned with the Project Management Body of Knowledge (PMBOK), enable managers to incorporate environmental and social criteria into project plans, such as selecting eco-friendly materials or prioritizing community needs. For instance, lifecycle assessment tools integrated into process management help evaluate the environmental impact of project decisions, reducing carbon footprints (Barajei et al., 2023). By systematically addressing sustainability in planning, process management ensures that projects align with environmental regulations and stakeholder expectations, enhancing their sustainability outcomes.

Effective project process management also improves resource efficiency and risk mitigation, both essential for sustainable project success. Well-defined processes, including resource allocation and scheduling, minimize waste and optimize the use of materials, energy, and labor (Al-Kuhail et al., 2021). Lean project management techniques, which emphasize process efficiency, have been shown to reduce material waste in construction projects, contributing to environmental sustainability (De Souza et al., 2022). Additionally, robust risk management processes identify and address potential sustainability risks, such as regulatory non-compliance or community opposition, ensuring projects remain viable across their lifecycle (Kabirifar et al., 2020). These process-driven efficiencies directly support the environmental and economic dimensions of sustainable success.

Furthermore, project process management enhances stakeholder collaboration and social sustainability, key components of sustainable project success. Structured communication processes, such as regular stakeholder consultations and feedback loops, ensure that social concerns, such as community welfare or labor rights, are addressed throughout the project (Roxas et al., 2023). Projects employing participatory process frameworks have demonstrated higher social acceptance and equity, as stakeholders feel their voices are heard (Hussain et al., 2023). Process management strengthens social sustainability by fostering transparency and inclusivity, ensuring projects deliver long-term societal benefits alongside operational goals. Based on the literature reviewed above, the following hypothesis has been formulated:

H3: Project process management has a significant positive impact on Sustainable Project Success.

The interplay between technology innovation and sustainable project success is increasingly recognized in project management literature, with project process management posited as a critical mediator in this relationship. Sustainable project success is achieving project objectives while ensuring environmental stewardship, social equity, and economic viability (Ajibike et al., 2022). Technology innovation, including tools like Building Information Modeling (BIM), artificial intelligence (AI), and Internet of Things (IoT), enhances project efficiency and sustainability but often requires structured processes to translate these benefits into sustainable outcomes (Hussain et al., 2022). Project process management, encompassing systematic planning, execution, monitoring, and control, serves as the conduit through which technology innovations are effectively implemented to achieve sustainable project success. This review synthesizes evidence to demonstrate that project process management mediates the relationship between technology innovation and sustainable project success.

Technology innovation provides the tools and capabilities to improve project outcomes, but its impact on sustainable project success is amplified through effective project process management. For instance, BIM facilitates resource optimization and waste reduction in construction projects, yet its successful implementation depends on well-defined processes for data integration and stakeholder coordination (Akbar et al., 2024; Kiradoo, 2020). Kuen et al. (2009) argue that structured process frameworks, such as those aligned with the Project Management Body of Knowledge (PMBOK), enable the systematic adoption of technologies by ensuring alignment with sustainability goals. Without robust process management, the potential of innovations like AI-driven analytics or IoT-enabled monitoring may be underutilized, limiting

their contribution to environmental, social, and economic sustainability. Thus, process management acts as a mediator by operationalizing technological advancements.

Project process management mediates the relationship by embedding sustainability principles into the application of innovative technologies. Structured processes ensure that technologies are deployed to address specific sustainability metrics, such as carbon footprint reduction or community engagement (Wamba-Taguimdje et al., 2020). Similarly, process-driven stakeholder management frameworks enhance the social sustainability of technology-driven projects by facilitating transparent communication and inclusivity. These processes ensure that technology innovations are not applied in isolation but are integrated into a holistic strategy that prioritizes sustainable project success (Scott-Young & Samson, 2018).

Moreover, project process management mitigates risks and enhances the scalability of technology innovations, further mediating their impact on sustainable project success. Technology adoption often introduces complexities, such as training requirements or integration challenges, which can hinder sustainability outcomes if not addressed (Rymchuk & Steshenko, 2024). Robust risk management and monitoring processes, as part of project process management, proactively address these challenges, ensuring that technologies like renewable energy systems or smart grids deliver long-term economic and environmental benefits (Latif et al., 2021). By providing a structured framework for implementation, process management bridges the gap between the potential of technology innovation and the realization of sustainable project goals, making it a critical mediator. In light of the aforementioned literature, the following hypothesis has been proposed:

H4: Project Process Management mediates the relationship between Technology Innovation and Sustainable Project Success.

The relationship between project process management and sustainable project success is well-documented, with structured processes enhancing the achievement of environmental, social, and economic objectives. However, the strength of this relationship is influenced by risk management, which serves as a moderating factor by addressing uncertainties that could undermine sustainability goals (Scott-Young & Samson, 2018). Sustainable project success requires balancing traditional metrics like cost and time with long-term sustainability outcomes, while project process management involves systematic planning, execution, and control to achieve these goals (Al-Kuhail et al., 2021). Risk management, encompassing the identification, assessment, and mitigation of potential threats, moderates this relationship by ensuring that processes remain robust under varying conditions. This review synthesizes evidence to demonstrate that effective risk management strengthens the positive impact of project process management on sustainable project success (Ajibike et al., 2022).

Risk management moderates the relationship by mitigating uncertainties that could disrupt the effectiveness of project processes in achieving sustainable outcomes. Structured process management frameworks, such as those aligned with the Project Management Body of Knowledge (PMBOK), rely on consistent execution, but unforeseen risks such as regulatory changes or resource shortages can derail sustainability objectives (Adu Gyamfi et al., 2024; Ahmed et al.,

2023). Alkhlaifat et al. (2019) found that proactive risk management in public-private partnership projects ensured that environmental compliance processes were not compromised by budget overruns. By identifying risks early and implementing mitigation strategies, risk management enhances the reliability of processes like resource allocation and stakeholder engagement, thereby strengthening their contribution to sustainable project success.

Furthermore, risk management moderates the relationship by safeguarding the social and economic dimensions of sustainable project success. Projects with strong stakeholder engagement processes can falter if risks, such as community opposition or labor disputes, are not addressed (Divya Sankar et al., 2022). Effective risk management employs tools like risk registers and scenario planning to anticipate social risks, ensuring that communication processes remain inclusive and transparent (Khurramov & GANIEV, 2021). Similarly, economic sustainability is supported when risk management mitigates financial uncertainties, such as cost escalations, allowing process management to maintain budget discipline while pursuing sustainability goals (Kiradoo, 2020). This moderating effect ensures that project processes deliver consistent sustainability outcomes despite external pressures.

The moderating role of risk management is particularly evident in complex projects where sustainability goals face heightened uncertainties. For example, infrastructure projects integrating green technologies often encounter technical risks, such as equipment failures, which can undermine process efficiency (Ahmad et al., 2023; Loukola-Ruskeeniemi et al., 2022). Robust risk management practices, including contingency planning and regular risk audits, enable project teams to adapt processes dynamically, ensuring alignment with environmental objectives (Khurramov & GANIEV, 2021). Studies suggest that projects with high risk management maturity achieve greater sustainable success, as risks are managed in a way that supports rather than disrupts process execution (Urbański et al., 2019). Thus, risk management amplifies the effectiveness of project process management in delivering sustainable outcomes. Building upon the insights gathered from the existing literature, we can articulate the following hypothesis:

H5: Risk Management moderates the relationship between Project Process Management and Sustainable Project Success.

Theoretical Support

This article is strongly supported by Project Management Theory, particularly through its emphasis on structured methodologies and best practices that align project activities with strategic objectives to achieve desired outcomes. At its core, Project Management Theory advocates for integrating knowledge areas such as scope, time, cost, quality, human resources, communications, risk, procurement, and stakeholder management to ensure project success. In the context of this study, the theory provides a foundation for exploring how Project Process Management (PPM) encompassing initiation, planning, execution, monitoring, controlling, and closing acts as a systematic approach to transforming inputs such as Technology Innovation (TI) into outputs like Sustainable Project Success (SPS) (Richardson, 2010).

Moreover, the study aligns with principles from the PMBOK (Project Management Body of Knowledge) framework, which emphasizes that project success depends not only on the

execution of processes but also on managing project risks and leveraging innovations effectively. The inclusion of Risk Management (RM) as a moderating variable is directly supported by Project Management Theory, which views risk management as an essential component that can significantly influence project outcomes when integrated into all project lifecycle phases. This theoretical grounding validates the study's hypothesis that risk management enhances the relationship between project processes and success by mitigating uncertainties and improving decision-making (Project Management Institute, 2021).

Furthermore, modern advancements in Project Management Theory increasingly stress the role of innovation and adaptability in dynamic sectors like construction. The theory now encompasses agile practices, lean construction principles, and digital transformation, which all underscore the necessity of Technology Innovation as a driver of efficiency, flexibility, and sustainability. Therefore, this article's model, which includes TI, PPM, and RM as key constructs impacting SPS, demonstrates a comprehensive application of Project Management Theory in addressing contemporary challenges in the construction industry.

Theoretical Framework

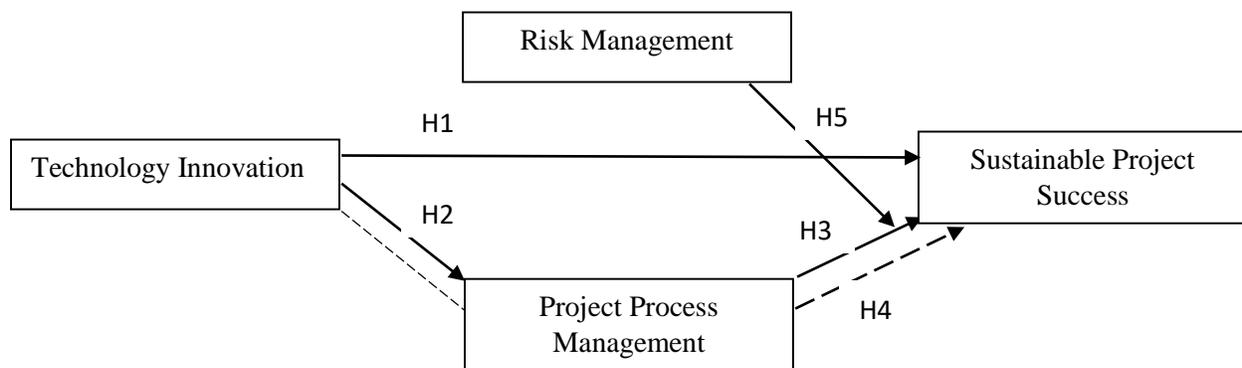


Figure 1: Theoretical Framework

Research Methodology

The study investigates the links between technology innovation, project process management, risk management, and sustainable project success using a quantitative research methodology. Because it can offer objective, quantifiable, and statistically significant insights into the interactions among the study variables (Plonsey et al., 2007).

The questionnaire was built to reflect the viewpoints of Project Managers, Portfolio Managers, and Construction Managers regarding Technology Innovation (TI), Project Process Management (PPM), Risk Management (RM), and Sustainable Project Success (SPS) in the construction industry, guaranteeing a well-structured and effective data collecting process (Krosnick, 2018).

Sample Size and Technique

This study targeted professionals in the building sector including Project Managers, Portfolio Managers, and Construction Managers. Targeting people with relevant knowledge in

managing building projects using a purposive sampling approach guarantees that the data gathered is extremely relevant and reflects the project management methods of the sector (Rahman et al., 2022). A total of 360 questionnaires were distributed, and 328 completed responses were used for data analysis (Memon et al., 2020).

Procedure

Google Forms were employed for data collection, thus ensuring respondents' convenience and accessibility. Focusing on individuals actively involved in construction project management, the questionnaire link was sent via email and professional networks. Participants were provided with an informed consent statement prior to commencement which ensured anonymity and voluntary participation.

Instrument

The primary tool for gathering data in this research was the survey questionnaire. The questionnaire was separated into various sections with a focus on demographic details and primary study variables to ensure ease and clarity of response (Zaza et al., 2000). This study adopted 08 items of technology innovation from (Mojtaba Noghabaei, 2019), 15 items of project process management from (Kwak & Ibbs, 2000; Kwak & Ibbs, 2002), 22 items of risk management from (De Bakker et al., 2011), and 17 items of sustainable project success from (Hughes et al., 2004; Kuen et al., 2009). The questionnaire is suitable for statistical analysis as its design and standardization ensure uniformity in all the respondents. Closed-ended questions, typically with Likert scales (e.g., 1 = strongly disagree to 5 = strongly agree), allow respondents to rate their agreement with statements on the research variables (Saunders, 2009).

Analysis

This study used Partial Least Squares Structural Equation Modeling (PLS-SEM). To enable strict statistical confirmation of the model of the study, this study examined the measurement and structural models.

Results and Discussions

Descriptive Analysis

The demographic analysis of the respondents provides valuable insights into the characteristics of the sample population. Table 1 shows the majority of respondents were male (78%), while female participants constituted 22% of the total sample. This reflects the male-dominated nature of the construction industry, where men typically hold a larger proportion of managerial and technical roles. Regarding age distribution, the largest group of respondents fell within the 26-35 age bracket (43%), followed by those aged 36-45 (35%). This indicates that most participants are in their mid-career stage, bringing significant professional experience to the research. A smaller proportion of respondents were 18-25 years old (10%) or 46 and above (12%), suggesting that early-career and senior professionals were less represented (Cheah et al., 2020).

Table 1: Descriptive Analysis

Gender	<i>f</i> (n=328)	%
Male	256	78%
Female	72	22%

Age		
18-25	32	10%
26-35	141	43%
36-45	115	35%
46 or above	40	12%
Education		
Diploma	72	22%
Graduate	181	55%
MS/M.Phil.	49	15%
Others	26	8%
Project Management Certification (PMP)		
Yes	108	33%
No	220	67%
Job Position		
Manager	124	38%
Project Manager	138	42%
Team Manager	51	16%
Others	15	5%

Respondents' educational background shows that 55% are graduates, 22% have a diploma, and 15% have an MS/M.Phil. degree. Only an 8% of respondent is in the "Others" category, which may be industry-specific certificates or other credentials. Interestingly, a mere 33% of respondents are certified as Project Management Professional (PMP), which shows that although a percentage of construction professionals are professionally certified, most (67%) depend on work experience and other types of training. In terms of job designation, the survey is evenly split, with Project Managers (42%) and Managers (38%) being the prominent groups, followed by Team Managers (16%) and others (5%). This allocation guarantees that the research picks up perspectives from different levels of project leadership and implementation, adding to the research results' robustness.

Measurement Model

Construct Reliability and Validity

Table 2: Reliability and Validity

Constructs	Items	Factor Loadings	Cronbach's alpha	Composite reliability	Average variance extracted (AVE)
Project Process Management	PPM1	0.816	0.841	0.881	0.578
	PPM2	0.679			
	PPM3	0.806			
	PPM4	0.830			
	PPM5	0.617			

Constructs	Items	Factor Loadings	Cronbach's alpha	Composite reliability	Average variance extracted (AVE)	
	PPM6	0.922				
	PPM7	0.933				
	PPM8	0.910				
	PPM9	0.803				
	PPM10	0.797				
	PPM11	0.928				
	PPM12	0.859				
	PPM13	0.561				
	PPM14	0.882				
	PPM15	0.879				
	Risk Management	RM1	0.598	0.950	0.960	0.573
		RM2	0.617			
		RM3	0.501			
		RM4	0.798			
		RM5	0.839			
RM6		0.735				
RM7		0.621				
RM8		0.592				
RM9		0.754				
RM10		0.561				
RM11		0.786				
RM12		0.739				
RM13		0.809				
RM14		0.813				
RM15		0.835				
Sustainable Project Success	SPS1	0.754	0.960	0.963	0.612	
	SPS2	0.679				
	SPS3	0.738				
	SPS4	0.751				
	SPS5	0.745				
	SPS6	0.786				
	SPS7	0.787				
	SPS8	0.858				
	SPS9	0.805				
	SPS10	0.824				

Constructs	Items	Factor Loadings	Cronbach's alpha	Composite reliability	Average variance extracted (AVE)
	SPS11	0.789			
	SPS12	0.780			
	SPS13	0.747			
	SPS14	0.715			
	SPS15	0.771			
	SPS16	0.776			
	SPS17	0.862			
Technology Innovation	TI1	0.843	0.910	0.915	0.613
	TI2	0.829			
	TI3	0.854			
	TI4	0.749			
	TI5	0.859			
	TI6	0.88			
	TI7	0.855			
	TI8	0.789			

The validity and reliability test of the constructs in this research prove high internal consistency and measurement precision. Cronbach's alpha measures of all the constructs are above the minimum requirement of 0.7, which signifies high reliability. More precisely, Project Process Management (PPM) measures 0.816, Risk Management (RM) measures 0.950, Sustainable Project Success (SPS) measures 0.960, and Technology Innovation (TI) measures 0.910. These findings verify that the items for each construct uniformly measure the target latent variables. Composite Reliability (rho_a and rho_c) also exceed 0.9 for RM, SPS, and TI, solidifying high construct reliability. PPM, whose rho_c equals 0.881, is also showing enough internal consistency (Hair et al., 2017).

The Average Variance Extracted (AVE) scores also show that all the constructs have high convergent validity since they exceed 0.50 (PPM = 0.578, RM = 0.573, SPS = 0.612, and TI = 0.613). It implies that over 50% of each construct's variance is accounted for by its own indicators. While a few of the individual item loadings (e.g., RM3 = 0.501, PPM13 = 0.561) are slightly less than the others, the overall values for AVE establish sufficient construct validity. These findings present strong evidence that the measurement model is valid and reliable in measuring the relationships between Technology Innovation, Project Process Management, Risk Management, and Sustainable Project Success in the construction sector.

Heterotrait-Monotrait (HTMT)

Table 3: Heterotrait-Monotrait (HTMT)

	PPM	RM	SPS	TI	RM x PPM-> SPS
PPM					
RM	0.822				
SPS	0.805	0.804			

	PPM	RM	SPS	TI	RM x PPM-> SPS
TI	0.523	0.798	0.486		
RM x PPM-> SPS	0.133	0.095	0.074	0.126	

The Heterotrait-Monotrait (HTMT) ratio is another method used to assess discriminant validity in a structural equation model. Unlike the Fornell-Larcker Criterion, which compares the square root of Average Variance Extracted (AVE) with construct correlations, HTMT evaluates the degree of similarity between two constructs based on their indicators. A commonly accepted threshold for HTMT is 0.85, where values above this threshold indicate a lack of discriminant validity due to high similarity between constructs. Some researchers adopt a more lenient threshold of 0.90, depending on the context (Afthanorhan et al., 2021).

In the given results, most HTMT values fall within the acceptable range, indicating adequate discriminant validity. The HTMT value between PPM and RM is 0.822, which is below the 0.85 threshold, suggesting that these two constructs are related but still sufficiently distinct. Similarly, PPM and SPS (0.805), as well as RM and SPS (0.804), also fall within the acceptable range, indicating that they measure distinct but interrelated concepts. However, TI and RM (0.798) are close to the threshold, which may require further validation through confidence interval testing to ensure they are adequately differentiated (Yusoff et al., 2020).

The interaction term $RM \times PPM$ shows very low HTMT values across all constructs (ranging from 0.074 to 0.133), suggesting that the interaction effects are well-differentiated from the main constructs. This is a positive sign, indicating that the moderation effect of RM on PPM is statistically distinct and not confounded by multicollinearity. The results suggest that the constructs maintain an acceptable level of discriminant validity, though the relationship between RM and TI (0.798) should be further validated.

Hypothesis Testing

Table 4 indicate TI and PPM have a significant relationship with ($\beta = 0.425$; p-value < 0.000). The results show an insignificant association between Technology Innovation (TI) and Sustainable Project Success (SPS) with ($\beta = -0.053$; p-value < 0.156). The result shows that the relationship between Project Process Management (PPM) and Sustainable Project Success (SPS) is significant with ($\beta = 0.489$; p-value < 0.000) is significant. The result shows a strong mediation role of Project Process Management (PPM) between Technology Innovation (TI) and Sustainable Project Success (SPS) with ($\beta = 0.208$; p-value < 0.000). The results show the strong moderating role of Risk Management (RM) on the link between Project Process Management (PPM) and Sustainable Project Success (SPS) with ($\beta = 0.075$; p-value < 0.002). Figure 2 explains the two-way interaction plot of the Risk Management (RM) on the relationship between Project Process Management (PPM) and Sustainable Project Management (SPS).

Table 4: Hypothesis Testing

		β	Standard error	t-value	p-value	Results
H1	TI -> PPM	0.425	0.048	8.931	0.000	Supported
H2	TI -> SPS	-0.053	0.038	1.419	0.156	Not Supported

		β	Standard error	t-value	p-value	Results
H3	PPM -> SPS	0.489	0.050	9.695	0.000	Supported
H4	TI -> PPM -> SPS	0.208	0.032	6.47	0.000	Supported
H5	RM x PPM -> SPS	-0.075	0.025	3.027	0.002	Supported

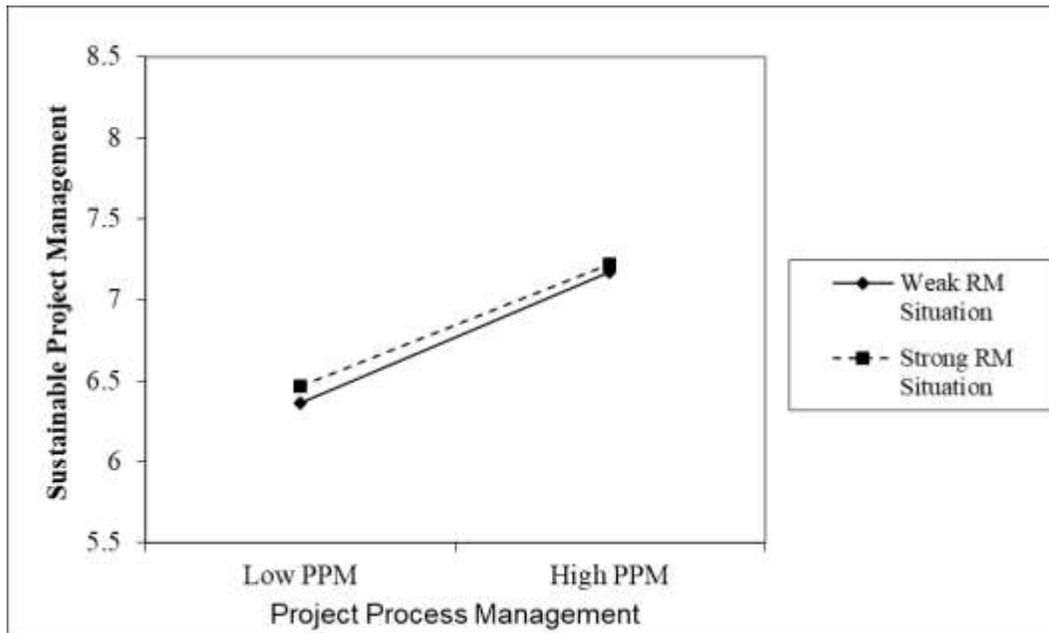


Figure 2: Two-way Interaction

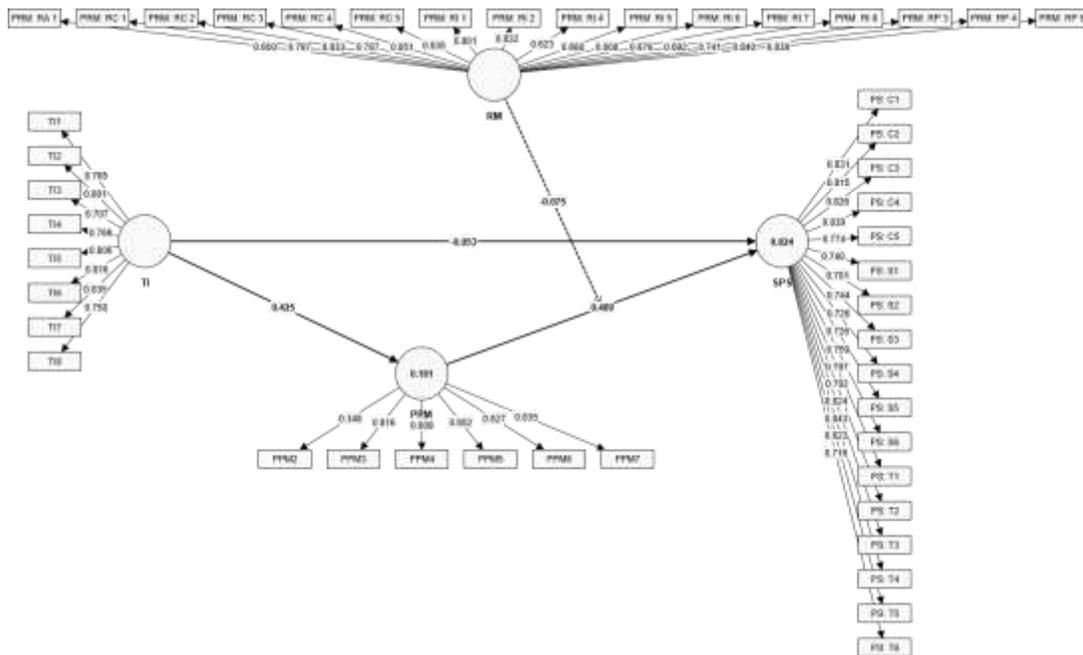


Figure 3: Measurement Model

Conclusion and Research Implications

This research makes important contributions to the knowledge of how Technology Innovation (TI), Project Process Management (PPM), Risk Management (RM), and Sustainable Project Success (SPS) influence one another in the construction sector. The findings indicate that there is no direct effect between Technology Innovation and Sustainable Project Success which is in contrast with the prior studies (Raharjo, 2023). Yet, Technology Innovation significantly contributes to improving Project Process Management, which then translates into improved sustainability results. The outcome of this study is in line with the previous studies suggesting the significant relationship between TI and PPM (Pomaza-Ponomarenko et al., 2023). This observation draws attention to the indirect contribution of technology in promoting project sustainability, indicating that only the uptake of new technologies is not enough. Rather, such technologies have to be integrated into project management methodologies to realize appreciable gains in project results. The strong correlation between Technology Innovation and Project Process Management highlights that technology tools, automation, and intelligent construction techniques can streamline project stages, eliminate inefficiencies, and enhance the quality of execution, eventually leading to successful project delivery.

The research also validates that Project Process Management has a great impact on Sustainable Project Success, further stating that proper structured project management processes like planning, execution, monitoring, and control are key elements for ensuring goals of sustainability are attained in building projects. The conclusions of this study are in line with the prior studies (Bhatti & Nazir, 2024). In addition, the outcomes reveal that Risk Management acts as a mediator between Project Process Management and Sustainable Project Success. This implies that even if project processes are well developed, issues like cost overruns, unexpected delays, and regulatory issues can also destabilize project sustainability. Previous studies also suggested the mediating role of intrinsic motivation among different relationships (Kallow et al., 2023).

These results hold practical importance for the construction sector. In order to attain sustainable project success, companies need to pursue an integrated approach, whereby Technology Innovation, Project Process Management, and Risk Management function together. Merely embracing new technologies for construction will not result in sustainable outcomes if they are not ingrained within robust project management practices. In addition, organizations need to ensure sound risk management techniques to protect their projects from uncertainties. By addressing these interrelated factors, construction companies can maximize efficiency, reduce risks, and promote long-term sustainability, ultimately influencing improved project results and enhancing the industry as a whole.

Research Limitations & Directions for Future Research

Despite its contributions, this research has certain limitations. Firstly, the study relies on self-reported survey data, which may be subject to response bias or subjectivity. Although statistical methods were used to ensure reliability and validity, future studies could incorporate objective performance metrics to strengthen the findings. Secondly, the research focuses on the construction industry, and while the results are relevant to this sector, they may not be

generalizable to other industries such as manufacturing, healthcare, or IT. Future research could explore alternative analytical approaches, such as machine learning techniques, to enhance predictive accuracy and deeper pattern recognition. Addressing these limitations will contribute to a more comprehensive understanding of the impact of technology and risk management on project success in diverse settings.

Although this research offers insightful observations regarding the interactions between Technology Innovation, Project Process Management, Risk Management, and Sustainable Project Success in the construction sector, a number of research directions remain to be explored. One of them is investigating industry-specific differences since various construction fields (e.g., residential, commercial, infrastructure) can potentially have different influences of technology and risk management on sustainability performance. Future research would also explore the use of new technologies like artificial intelligence (AI), blockchain, and digital twin technology to further improve project management practice. Longitudinal studies could also be carried out for analyzing the long-term impact of technology adoption and risk management practices on sustainable project outcomes, gaining more insights into their dynamic interaction over the course of time.

Another avenue for future research is the examination of external factors, such as regulatory frameworks, economic conditions, and cultural differences, that may influence the effectiveness of technology and risk management in construction projects. Since this study focused on quantitative data, qualitative research involving interviews or case studies could provide richer contextual insights into how project managers and construction firms perceive and implement technological innovations and risk management practices. Furthermore, cross-country comparisons could be conducted to understand how different regulatory environments and industry practices impact the relationships examined in this study.

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