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Risk management in engineering and civil construction projects: an analysis in light of the PMBOK Guide

Gestão de riscos em projetos de engenharia e construção civil: uma análise à luz do Guia PMBOK

Gestión de riesgos en proyectos de ingeniería y construcción civil: un análisis a la luz de la Guía PMBOK

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Abstract:
This article aims to analyze the risk management process in engineering and civil construction projects, using the PMBOK Guide (Project Management Body of Knowledge), published by the Project Management Institute (PMI), as a theoretical reference. Given the growing complexity of construction ventures — which involve multiple stakeholders, high financial investments, strict deadlines and specific regulatory requirements — risk management is a strategic component for project success. This qualitative, bibliographic and documentary research addresses the stages of risk identification, qualitative and quantitative analysis, response planning and monitoring, relating them to practical examples observed in industrial installation projects, manufacturing plant construction and hospital facility projects. The results indicate that the systematic adoption of PMBOK-recommended practices reduces cost and schedule variability, mitigates rework occurrence and strengthens managerial decision-making. It is concluded that risk management maturity is directly associated with organizations' ability to anticipate adverse scenarios and turn uncertainty into opportunities for continuous improvement of construction processes.

Keywords:
Risk management. Project management. PMBOK. Civil construction. Engineering.

Resumo:
Este artigo tem como objetivo analisar o processo de gerenciamento de riscos em projetos de engenharia e construção civil, tomando como referência teórica o Guia PMBOK (Project Management Body of Knowledge), publicado pelo Project Management Institute (PMI). Diante da complexidade crescente dos empreendimentos de construção — que envolvem múltiplos stakeholders, elevados investimentos financeiros, prazos rígidos e exigências regulatórias específicas —, a gestão de riscos configura-se como um componente estratégico para o sucesso dos projetos. A pesquisa, de natureza qualitativa e caráter bibliográfico e documental, percorre as etapas de identificação, análise qualitativa e quantitativa, planejamento de respostas e monitoramento de riscos, articulando-as com exemplos práticos observados em projetos de instalação industrial, construção de plantas fabris e empreendimentos hospitalares. Os resultados indicam que a adoção sistemática das práticas recomendadas pelo PMBOK reduz a variabilidade de custos e prazos, mitiga a ocorrência de retrabalhos e fortalece a tomada de decisão dos gestores. Conclui-se que a maturidade em gestão de riscos está diretamente associada à capacidade das organizações de antecipar cenários adversos e de transformar incertezas em oportunidades de melhoria contínua dos processos construtivos.

Palavras-chave:
Gestão de riscos. Gerenciamento de projetos. PMBOK. Construção civil. Engenharia.

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Resumen:
Este artículo tiene como objetivo analizar el proceso de gestión de riesgos en proyectos de ingeniería y construcción civil, tomando como referencia teórica la Guía PMBOK (Project Management Body of Knowledge), publicada por el Project Management Institute (PMI). Ante la creciente complejidad de los emprendimientos de construcción —que involucran múltiples partes interesadas, elevadas inversiones financieras, plazos estrictos y requisitos regulatorios específicos—, la gestión de riesgos constituye un componente estratégico para el éxito de los proyectos. La investigación, de naturaleza cualitativa y carácter bibliográfico y documental, recorre las etapas de identificación, análisis cualitativo y cuantitativo, planificación de respuestas y seguimiento de riesgos, articulándolas con ejemplos prácticos observados en proyectos de instalación industrial, construcción de plantas fabriles y emprendimientos hospitalarios. Los resultados indican que la adopción sistemática de las prácticas recomendadas por el PMBOK reduce la variabilidad de costos y plazos, mitiga la aparición de retrabajos y fortalece la toma de decisiones de los gestores. Se concluye que la madurez en gestión de riesgos está directamente asociada con la capacidad de las organizaciones para anticipar escenarios adversos y transformar incertidumbres en oportunidades de mejora continua de los procesos constructivos.

Palabras clave:
Gestión de riesgos. Gestión de proyectos. PMBOK. Construcción civil. Ingeniería.

1 Introduction

The engineering and civil construction sector is characterized by projects of high technical, financial, and organizational complexity. Unlike repetitive production processes, each construction undertaking has unique characteristics related to the site, local legislation, the suppliers involved, weather conditions, and the technical specifications of the installed equipment. This singularity makes construction projects especially vulnerable to uncertainties that may compromise schedules, budgets, and the final quality of delivery.

In this context, risk management plays a central role in project execution because it makes it possible to anticipate potentially adverse events and plan appropriate responses before such events materialize and generate negative impacts. The PMBOK Guide, developed and maintained by the Project Management Institute (PMI), consolidates a set of internationally recognized good practices for project management, including a specific knowledge area devoted to risk management.

The general objective of this article is to analyze, in light of the PMBOK theoretical framework, how the risk management process can be structured and applied in engineering and civil construction projects, with emphasis on large industrial and infrastructure undertakings. Its specific objectives are: (i) to review the fundamental concepts of risk in the project context; (ii) to describe the stages of the risk management process according to the PMBOK; (iii) to

discuss the practical application of these stages in actual construction and equipment-installation projects; and (iv) to identify contributions and limitations of the approach studied.

The relevance of the topic is justified by the fact that failures in risk management are among the main causes of delays, budget overruns, and contractual disputes in civil construction projects. Industry studies indicate that a large share of infrastructure undertakings around the world experience significant cost and schedule variations in relation to the initial plan, reinforcing the need for structured risk identification and treatment processes from the early stages of the project life cycle.

The article is organized into five sections in addition to this introduction. The second section presents the theoretical framework concerning the concept of risk and the PMBOK risk management process. The third section describes the methodological procedures adopted. The fourth discusses the practical application of the concepts in civil construction and engineering projects, including illustrative examples involving sensitive-equipment installation and industrial works. Finally, the fifth section presents the study's final considerations.

2 Theoretical framework

2.1 The concept of risk in projects

In project management, risk is traditionally associated with an uncertain event or condition that, if it occurs, produces a positive or negative effect on at least one project objective, such as scope, schedule, cost, or quality. This definition, consolidated in the project management literature, breaks with the popular perception that risk refers exclusively to threats by also incorporating the notion of opportunity—that is, uncertain events that may benefit the project if they occur.

Kerzner (2017) emphasizes that uncertainty is inherent in any undertaking that involves forecasting future events and that the difference between organizations that are mature and immature in project management lies precisely in their capacity to transform this uncertainty into manageable information through structured identification, analysis, and response processes. Vargas (2018), in turn, notes that risk has three essential components: the event itself, its probability of occurrence, and its potential impact on project objectives, with the combination of these factors being used for prioritization and decision-making.

In civil construction projects, the specialized literature identifies a common risk typology that includes technical risks (related to engineering designs, foundations, structures,

and installations), contractual risks (concerning clauses, guarantees, and responsibilities between client and contractor), financial risks (exchange-rate fluctuations, input price adjustments, and credit availability), regulatory risks (environmental licenses, technical standards, and requirements of inspection bodies), and operational risks (availability of qualified labor, productivity, and workplace accidents). The multiplicity of these categories reinforces the need for a structured process that addresses the diverse sources of uncertainty present in this type of undertaking.

2.2 The risk management process according to the PMBOK

The PMBOK Guide organizes risk management into a set of interconnected processes that unfold throughout the project life cycle. In general, these processes comprise risk management planning, risk identification, qualitative risk analysis, quantitative risk analysis, risk response planning, implementation of risk responses, and risk monitoring (PMI, 2021).

Risk management planning consists of defining how risk management activities will be conducted in the project, including methodologies, roles and responsibilities, risk categories, stakeholder risk tolerance, and reporting formats. This is a fundamental stage for ensuring that the risk management effort is proportional to the project's complexity and importance, avoiding both superficial treatment and excessive bureaucracy.

Risk identification, in turn, seeks to recognize which uncertain events may affect the project and to document their characteristics. This stage is iterative and should involve different stakeholders—such as engineers, architects, suppliers, clients, and operating teams—in order to capture the broadest possible range of perspectives on potential threats and opportunities. The most frequently used risk identification techniques include structured brainstorming sessions, the Delphi technique, checklists based on similar previous projects, analysis of assumptions and constraints, and SWOT analysis applied to the project context.

2.3 Qualitative and quantitative risk analysis

After identification, risks undergo qualitative analysis, which consists of assessing the probability of occurrence and potential impact of each risk and prioritizing those that require more immediate attention. Tools such as the probability-impact matrix are widely used at this stage, allowing risks to be classified into severity categories—for example, low, medium, high, and critical—and guiding the allocation of management resources.

Quantitative risk analysis, in turn, seeks to assign numerical values to the combined effects of identified risks on project objectives, especially cost and schedule. Techniques such as Monte Carlo simulation, decision-tree analysis, and sensitivity analysis make it possible to estimate, with a given degree of statistical confidence, the probability that the project will be completed within the planned budget and schedule. Although it requires greater availability of historical data and computational resources, quantitative analysis provides important support for decisions regarding investment in financial and schedule contingencies.

Mulcahy (2018) argues that the combination of qualitative and quantitative analysis provides a more robust view of the project's risk profile, since qualitative analysis offers agility in the initial screening of risks, while quantitative analysis provides precision for risks of greater strategic relevance, especially in large projects where mistaken decisions can generate substantial financial impacts.

2.4 Planning and implementing risk responses

Risk response planning consists of defining strategies and actions intended to reduce threats and enhance opportunities identified in the preceding stages. For negative risks (threats), the PMBOK describes four main strategies: avoid (eliminate the cause of the risk or change the project plan so that the risk no longer exists), transfer (shift the impact of the risk to third parties through insurance, contractual guarantees, or subcontracting), mitigate (reduce the probability of occurrence or the impact of the risk), and accept (acknowledge the risk without taking proactive action, reserving contingencies for its eventual management).

For positive risks (opportunities), analogous strategies are recommended: exploit (ensure that the opportunity materializes), share (partner with third parties that have a greater capacity to capture the benefit), enhance (increase the probability or positive impact), and accept. Implementing these responses requires assigning risk owners, allocating specific resources, and integrating response actions into the overall project plan so that they do not remain isolated or merely formal initiatives.

2.5 Risk monitoring and control

Risk monitoring is a continuous process that extends throughout the project life cycle and aims to track the effectiveness of implemented responses, identify new risks that arise during execution, and reassess known risks in light of updated information. Periodic critical-

review meetings, risk audits, and maintenance of an up-to-date risk register are recommended practices to ensure that risk management remains dynamic and aligned with the project's reality.

Prado (2015) observes that many organizations fail not at the identification or analysis stage but precisely in continuous monitoring, treating risk management as a one-time exercise performed only at the beginning of the project. This gap compromises the team's response capacity in the face of emerging risks, especially in long-duration projects, as is the case for a large share of engineering and civil construction undertakings.

3 Methodology

This research is qualitative and exploratory-descriptive in nature, supported by a bibliographic and documentary review of project risk management with emphasis on the PMBOK Guide framework. The bibliographic review included reference works in the field of project management as well as technical publications focused on engineering and civil construction.

In addition, the study incorporates an applied-analysis dimension in which the theoretical concepts reviewed are discussed in light of practices observed in civil construction and industrial equipment-installation projects, such as manufacturing plants, distribution centers, and diagnostic-imaging units in healthcare facilities. These examples are illustrative and seek to demonstrate, in a didactic manner, how the processes described by the PMBOK materialize in the daily practice of engineering project management.

The choice of a qualitative approach is justified by the nature of the object of study, since risk management involves subjective dimensions related to stakeholder perceptions, organizational culture, and the expert judgment of experienced professionals. These aspects are not easily amenable to purely quantitative measurement, even though quantitative techniques are employed at specific stages of the process, as discussed in the previous section.

4 Discussion: practical application in civil construction projects

4.1 Common risks in large-scale construction works

In large-scale civil construction projects, such as industrial plants, distribution centers, and administrative buildings, certain risk categories recur. Among technical risks, those associated with large-scale earthmoving, drainage solutions in environmentally sensitive areas,

and compatibility among prefabricated steel structures from different origins and suppliers are particularly notable—a common scenario in projects involving imported structural components.

Among contractual and financial risks, notable issues include exchange-rate fluctuations in contracts involving international suppliers, the availability of credit to finance the works, and price adjustments for basic inputs such as steel and concrete, whose volatility can significantly compromise the initially approved budget. Regulatory risks include environmental licensing requirements, especially in undertakings that affect permanent preservation areas or water resources, and the need to align the project with technical standards for safety, accessibility, and sustainability.

Practical experience shows that applying reengineering processes focused on optimizing construction solutions can represent an effective response to financial and technical risks identified during execution. Reassessing initially planned structural solutions, for example, can result in substantial cost reductions without compromising the building's safety or quality, provided that it is based on rigorous technical analysis and validated by those technically responsible for the undertaking.

4.2 Installation of sensitive equipment: an example of applied risk management

Projects involving the installation of highly sensitive equipment—such as magnetic resonance imaging equipment in diagnostic-imaging units, or reactors and centrifuges in biotechnology and pharmaceutical plants—illustrate particularly clearly the practical application of the risk management described by the PMBOK. Such equipment requires specific electrical infrastructure, electromagnetic shielding, climate control, and foundations, whose inadequate execution may prevent the equipment from operating or generate significant additional rework costs.

In this type of project, early identification of risks related to compatibility between the civil infrastructure and the equipment manufacturer's technical specifications is essential. Adopting mitigation strategies, such as detailed planning of the electrical supply infrastructure even before the architectural design is finalized and defining contingencies for possible last-minute adjustments, tends to substantially reduce the risk of delays in bringing the equipment into operation.

In addition, adopting just-in-time planning concepts, with equipment delivery and installation precisely coordinated with completion of the civil infrastructure, reduces the need for temporary storage areas and minimizes the equipment's exposure to physical-damage risks

during the construction phase, constituting an operational-risk mitigation strategy broadly applicable to this type of undertaking.

4.3 Contributions and limitations of the approach

The analysis developed in this article shows that structured application of the risk management processes described by the PMBOK contributes significantly to cost and schedule predictability in engineering and civil construction projects. However, relevant limitations must be recognized: process effectiveness depends heavily on organizational maturity in project management, the quality of historical information available for quantitative analysis, and genuine stakeholder engagement in risk identification and monitoring.

Furthermore, the PMBOK itself recognizes that its guidelines constitute general good practices, leaving project managers responsible for adapting them to the particularities of each undertaking, considering factors such as scale, technical complexity, the local regulatory context, and the organizational culture of the parties involved.

5 Final considerations

This article aimed to analyze the risk management process in engineering and civil construction projects in light of the PMBOK Guide's theoretical framework. Based on the bibliographic review and discussion of practical examples, it was observed that risk management, when conducted in a structured and continuous manner, is a determining factor in the success of undertakings marked by high technical, financial, and regulatory uncertainty.

The stages of identification, qualitative and quantitative analysis, response planning, and continuous monitoring were found to form an interdependent cycle whose effectiveness depends on the active participation of multiple stakeholders and constant updating of the risk register throughout project execution. The examples discussed, involving large industrial works and the installation of technically sensitive equipment, demonstrated how theoretical concepts translate into concrete management practices.

For future studies, quantitative research is recommended to compare the performance of projects that adopt formal risk management processes with projects that do not, thereby empirically measuring the benefits discussed qualitatively in this article. Research into hybrid risk management methodologies that combine PMBOK practices with agile approaches, which are increasingly present in engineering and civil construction, is also recommended.

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