

Prioritizing RFID Applications in Civil Engineering: A Hierarchical Approach

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INTRODUCTION & AIM

Introduction: Recent technological advancements, particularly Radio Frequency Identification (RFID), have profoundly transformed the construction industry by enhancing efficiency, safety, and management processes. While the benefits of RFID in civil engineering are widely acknowledged, existing literature reviews often rely on simplistic metrics like publication counts, which are insufficient for strategic decision-making. This approach fails to capture the multifaceted nature of technology adoption, overlooking critical factors such as implementation cost, technological maturity, regulatory drivers, and potential return on investment.

Research Gap: A significant research gap exists for a structured, multi-criteria framework that can systematically evaluate and prioritize RFID applications based on a holistic set of criteria relevant to both industry practitioners and academic researchers.

Study Aim: This study aims to fill that gap by developing and applying a novel Multi-Criteria Decision-Making (MCDM) model. This model provides a more nuanced and actionable prioritization of RFID technologies in civil engineering, enabling stakeholders to make informed, strategic decisions aligned with the sector's most critical needs and opportunities.

METHOD

Hybrid Methodology: This study employed a multi-stage, mixed-methods approach to develop a robust and replicable prioritization framework. This methodology was designed to systematically integrate quantitative bibliometric data with qualitative expert judgment.



Stage 1: Systematic Literature Review (SLR): A systematic literature review was conducted following PRISMA guidelines, analyzing a final corpus of 86 academic articles from Scopus and Web of Science.

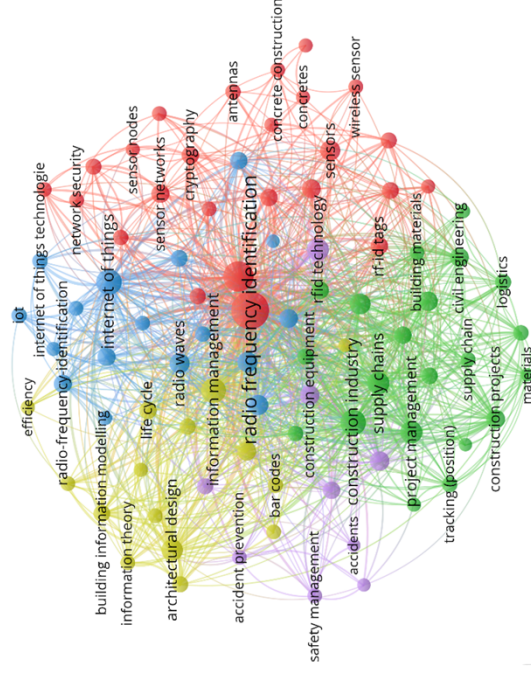
Stage 2: Bibliometric and Thematic Analysis: Keyword co-occurrence analysis using VOSviewer and qualitative thematic analysis were performed. This identified research hotspots, thematic clusters, and key themes related to drivers, barriers, benefits, and challenges of RFID applications.

Stage 3: Delphi Method and Expert Panel: To ensure the validity and reliability of criteria weights, the Delphi method was employed. A panel of 15 experts, with at least 10 years of experience in construction technology, reached a high level of consensus over three rounds (Kendall's $W = 0.82$) on evaluation criteria.

Stage 4: Hybrid AHP-TOPSIS Prioritization: A hybrid MCDM model was utilized, combining the Analytic Hierarchy Process (AHP) for criteria weighting and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) for ranking 10 main RFID application areas (alternatives). AHP's strength in capturing expert judgments for weighting and TOPSIS's robustness in ranking were leveraged. The Consistency Ratio (CR) for AHP was 0.07, confirming the reliability of expert judgments.

RESULTS & DISCUSSION

The keyword co-occurrence analysis, performed using VOSviewer on the 86 selected articles, revealed five distinct thematic clusters mapping the intellectual structure of RFID research in civil engineering. Cluster 1 (Red) represents "Core Technology & Sensor Integration," focusing on fundamental RFID technology and its integration with sensors, such as in concrete. Cluster



The TOPSIS analysis provided a nuanced prioritization of RFID applications. "Construction Site Safety & Security" emerged as the top-ranked application, maintaining its lead due to its high maturity and clear return on investment. Notably, "Structural Health Monitoring (SHM)" experienced a significant rise, jumping 3 ranks from a basic publication-count analysis, driven by its strong long-term value, sustainability contributions, and considerable cost-saving potential. Conversely, applications such as "Transportation Engineering" and "Urban Planning" saw their rankings decrease; despite considerable research interest in these areas, experts perceived their practical viability as lower. Finally, "Disaster Management" was identified as a rising niche, demonstrating a significant increase in priority despite lower publication counts, primarily due to its critical safety impact.

CONCLUSION

This research successfully developed a robust, multi-criteria decision-making framework, integrating a systematic literature review, bibliometric analysis, the Delphi method, and a hybrid AHP-TOPSIS model, to prioritize RFID applications in civil engineering. This approach moved beyond the limitations of simplistic publication-count metrics. Our findings confirm the paramount importance of 'Construction Site Safety & Security' applications due to their high technological maturity and clear return on investment. A key insight is the significant rise in the strategic importance of 'Structural Health Monitoring', a value not evident in simpler analyses, driven by its strong potential for long-term cost savings and contribution to infrastructure sustainability. Conversely, the study identified a notable disparity between academic research volume and practical industry priorities, particularly in areas like 'Transportation Engineering.' This framework offers actionable guidance for industry leaders, researchers, and policymakers to align investments and initiatives with the most critical needs and opportunities in the civil engineering sector. Future research should apply this framework to other emerging technologies and conduct longitudinal studies to assess evolving priorities.