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Challenges and potential benefits for the implementation of robots in building projects: The case of Perú

Desafíos y beneficios potenciales de la implementación de robots en proyectos de edificación: El caso de Perú

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Abstract

Robotics is a key component of Construction 4.0 and has gained increasing attention in construction projects. However, previous studies have mainly focused on technological development, with limited analysis of the perceived challenges and benefits among industry stakeholders. This study examines these aspects in the Peruvian construction sector. A literature review was conducted to identify potential challenges and benefits, which were validated by six experts, resulting in 11 benefits and 13 challenges. A survey was then administered to construction professionals, and the data were analyzed using Cronbach's coefficient, Relative Importance Index (RII), and Exploratory Factor Analysis (EFA). The results show that the main challenges include weak innovation culture, limited investment capacity, and complex technological requirements. The most significant benefits are improved efficiency through automation and digital interoperability, continuous improvement through industrialized production, and enhanced organizational competitiveness. These findings highlight the importance of strengthening innovative culture, developing regulatory frameworks, and adapting implementation strategies to promote robotics adoption in the construction industry.

Keywords: Benefits; Challenges; Construction 4.0; Robotics; Technology.

Resumen

La robótica es un componente clave de la Construcción 4.0 y ha cobrado cada vez más importancia en los proyectos de construcción. Sin embargo, estudios previos se han centrado principalmente en el desarrollo tecnológico, con un análisis limitado de los desafíos y beneficios percibidos por los actores del sector. Este estudio examina estos aspectos en el sector de la construcción peruano. Se realizó una revisión bibliográfica para identificar posibles barreras y beneficios, que fueron validados por seis expertos, resultando en 11 beneficios y 13 barreras. Posteriormente, se administró una encuesta a profesionales de la construcción, y los datos se analizaron mediante el coeficiente de Cronbach, el Índice de Importancia Relativa (IIR) y el Análisis Factorial Exploratorio (AFE). Los resultados muestran que los principales retos incluyen una cultura de innovación débil, una capacidad de inversión limitada y requisitos tecnológicos complejos. Los beneficios más significativos son la mejora de la eficiencia mediante la automatización y la interoperabilidad digital, la mejora continua mediante la producción industrializada y una mayor competitividad organizacional. Estos hallazgos resaltan la importancia de fortalecer la cultura de innovación, desarrollar marcos regulatorios y adaptar las estrategias de implementación para promover la adopción de la robótica en el sector de la construcción.

Keywords: Beneficios; Retos; Construcción 4.0; Robótica; Tecnología.

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1. Introduction

Compared to other industries such as manufacturing, the construction sector continues to lag in terms of efficiency and productivity, particularly in emerging economies (Woetzel et al., 2017; Mahbub, 2015). This underperformance is largely attributed to slow technology adoption and limited innovation capacity (van der Heijden, 2023), resulting in persistent challenges such as low productivity, inadequate on-site planning, fragmented supply chains, and financial constraints (Barbosa et al., 2017; Gomez & Morales, 2016; Schöttle et al., 2014). In the Peruvian context, these issues are intensified by a high number of paralyzed construction projects caused by contractual breaches, financial limitations, disputes, arbitration processes, and social conflicts, as reported by the Office of the Comptroller General of the Republic, where in addition, events such as the COVID-19 pandemic further disrupted the construction activity and productivity (Madera et al., 2022).

In response to these challenges, Construction 4.0 has emerged as a transformative paradigm integrating digital technologies, data analytics, and automation to improve construction performance (van der Heijden, 2023). Key technologies include Building Information Modelling (BIM), the Internet of Things (IoT), robotics and automation, and virtual and augmented reality, which collectively enhance productivity, quality, safety, and collaboration across construction processes (Siriwardhana & Moehler, 2023). In the construction context, robotics and automation refer to the use of programmable machines and automated systems capable of performing construction tasks with limited human intervention (Pan et al., 2020). These technologies include robotic arms for prefabrication or bricklaying and autonomous or semi-autonomous equipment (Dindorf & Wos, 2024). Among these, robotics has received increasing attention due to its potential to automate construction activities, improve project performance, and reduce occupational risks (Hatoum & Nassereddine, 2020). However, international studies consistently report that robotics adoption is constrained by barriers such as high initial investment costs, resistance to change, lack of skilled labor, limited managerial commitment, and regulatory uncertainty (Mahbub, 2012; Pan & Pan, 2020; Law et al., 2022; Oke et al., 2024; Bademosi & Issa, 2021).

Despite these barriers, literature also highlights significant benefits associated with robotics implementation in construction. Prior studies indicate improvements in productivity, construction quality, and operational efficiency, along with reductions in rework and cycle times (Hatoum & Nassereddine, 2020; Boya et al., 2022). From an occupational health and safety perspective, robotics and automation can reduce workers' exposure to hazardous tasks and lower injury rates, while human–robot collaboration combines human expertise with robotic precision to improve task performance (Davila et al., 2019; Aghimien et al., 2022; Brosque et al., 2020).

However, the perception and relevance of these barriers and benefits vary between developed and developing countries. While studies in developed economies emphasize cost-effectiveness, regulatory frameworks, and technological maturity (Fleming et al., 2019), research in developing contexts highlights cost constraints, limited technological infrastructure, skills shortages, and regulatory gaps as dominant challenges (Ojha et al., 2022; Pradhananga et al., 2021; Oke et al., 2024). Evidence from Latin America remains limited, and existing studies indicate that the adoption of emerging technologies such as drones and robotic systems in construction is still incipient and largely restricted to pilot projects or large organizations.

This situation reveals a gap between the availability of technological solutions and the development of technical skills, regulatory frameworks, and organizational capacities required for their effective implementation (Concha et al., 2025). This situation reveals a gap between the availability of technological solutions and the development of technical skills, regulatory frameworks, and organizational capacities required for their effective implementation (Xu et al., 2025). Given this context, it is important to better understand the factors influencing the adoption of robotics in emerging construction markets. Therefore, this study aims to identify and analyze the key challenges and potential benefits of implementing robotics in building projects based on the perceptions of professionals in the Peruvian construction sector.

The remainder of this paper is organized as follows. Section 2 presents the literature review on robotics implementation in the construction industry. Section 3 describes the research methodology, including expert validation and survey design. Section 4 presents the results of the data analysis, including the Relative Importance Index (RII) and Exploratory Factor Analysis (EFA). Section 5 discusses the main findings and their implications for the construction sector. Finally, Section 6 presents the conclusions and recommendations for future research.

2. Background

Previous studies have widely examined the barriers and benefits associated with the adoption of robotics in the construction industry. Several factors influence the decision to adopt robotic technologies, including organizational support, competitive pressure, and perceived technological

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advantages (Pan & Pan, 2020). However, economic barriers are consistently identified as one of the most significant challenges. High acquisition costs, maintenance expenses, and uncertainty regarding return on investment are frequently reported as key obstacles to the implementation of robotics in construction projects (Mahbub, 2012; Law et al., 2022; Oke et al., 2021). In addition to financial barriers, other challenges include resistance to technological change, lack of skilled labor, and limited technological maturity in construction processes (Bademosi & Issa, 2021). These barriers identified in the literature are summarized in Table 3. Despite these limitations, literature highlights several benefits associated with robotics implementation. These include improvements in productivity, construction quality, and operational efficiency, as well as reductions in rework and project cycle times (Hatoum & Nassereddine, 2020; Boya et al., 2022). Robotics can also improve occupational safety by reducing workers' exposure to hazardous tasks and enabling human–robot collaboration (Davila et al., 2019; Aghimien et al., 2022; Brosque et al., 2020).

The adoption of robotics in construction varies depending on the technological and economic conditions of each country. While studies conducted in developed countries emphasize technological maturity, regulatory frameworks, and long-term economic benefits (Fleming et al., 2019), research in developing countries highlights financial constraints, technological infrastructure limitations, and shortages of skilled labor as the most critical barriers (Ojha et al., 2022; Pradhananga et al., 2021; Oke et al., 2021).

These differences suggest that the perception and impact of robotics adoption may vary considerably depending on the national context. Therefore, understanding the barriers and benefits associated with robotics implementation in specific regions is essential for developing appropriate strategies for successful adoption. In this regard, analyzing the perceptions of professionals in the Peruvian construction sector provides valuable insights into the challenges and opportunities associated with robotics implementation in emerging construction markets.

3. Methodology

A mixed-method approach was adopted in this study, integrating qualitative and quantitative data to provide a comprehensive understanding of the research phenomenon (Hamui, 2013). This approach is particularly suitable for complex research questions, as it allows for deeper analysis and supports the explanation, categorization, and generalization of results (Davila et al., 2019).

The research methodology is illustrated in Figure 1 and consists of four main stages: (1) literature review, (2) expert judgment validation, (3) survey of professionals, and (4) statistical data analysis.

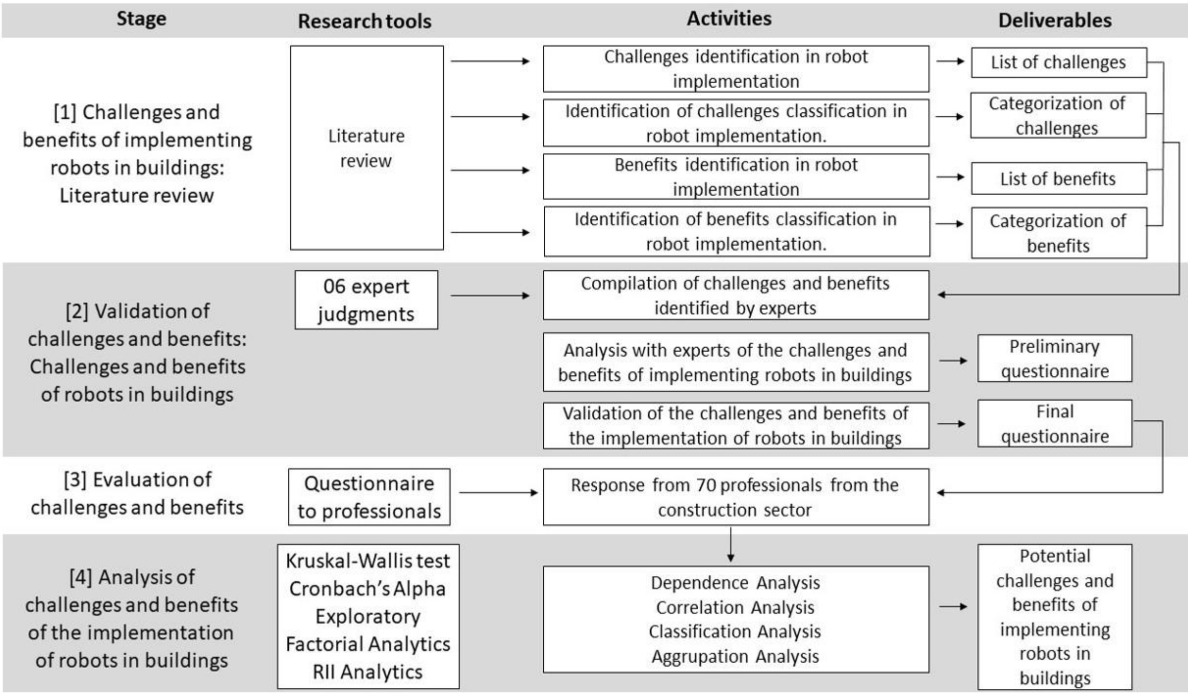

Figure 1. Diagram with the main stages of the investigation.

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In the first stage, a literature review was conducted to identify challenges and benefits associated with robotics implementation in construction. A total of 41 scientific articles were retrieved using the keywords "robotic AND challenges", "robotic AND factors", and "robotic AND barriers" from international databases, including Scopus and Web of Science, complemented by Google Scholar. These databases were selected due to their broad coverage and relevance to construction research.

The second stage involved expert judgment to validate and refine the identified challenges and benefits. Six experts with more than 10 years of professional experience in construction, project management, research, and university teaching participated in this process. The experts reviewed the lists, suggested additional items, and formally validated the final set of challenges and benefits used in the survey. The experts' information is in the following table 01:

Table 1. Expert judgment information.

Expert	Academic qualifications	Experience (years)	Type of project experience
E01	Civil Engineer	10+	• Construction project management • Transportation infrastructure projects • Lean and BIM implementation
E02	Civil Engineer, MBA	10+	• Building construction projects • Airport remodeling
E03	Civil Engineer	12+	• Residential, office, and hotel projects • Costing, planning, and production management • Building remodeling projects
E04	Civil Engineer	14	• Industrial projects • BIM implementation in public works • Modern Methods of Construction (MMC)
E05	Civil Engineer, MSc	10	• Building construction • Retail projects • Warehousing facilities
E06	Civil Engineer, MBA	15+	• Reconstruction projects • IT installations • Residential and commercial developments.

In the third stage, a questionnaire survey was distributed among Peruvian civil engineers with more than one year of experience in building projects. Respondents assessed the importance of each identified challenge and benefit using a five-point Likert scale (1 = not important at all; 5 = very important). Additional information was collected regarding professional experience, organizational role, project type, and company size.

In the fourth stage, the collected data were analyzed using statistical techniques to examine stakeholder perceptions regarding robotics adoption in the construction sector. First, Cronbach's alpha was calculated to assess the internal consistency and reliability of the survey instrument. Subsequently, the Relative Importance Index (RII) was used to rank the identified challenges and benefits according to their perceived importance among respondents. Finally, Exploratory Factor Analysis (EFA) was conducted to identify potential underlying groupings among the variables and to classify the challenges and benefits into meaningful categories.

3.1 Data Collection

Qualitative data were collected to characterize respondents in terms of occupation, company size, organizational role, work sector, and most frequent project type. Quantitative data included years of professional and building experience, as well as responses to 27 items measuring perceived barriers and benefits of robotics implementation using a five-point Likert scale (1 = not important at all; 5 = very important). The survey was administered in Spanish and distributed via email and LinkedIn to facilitate access to construction professionals. A total of 70 valid responses from civil engineers were collected and used for subsequent analysis.

3.2 Population and sample

A non-probability sampling approach was adopted, combining convenience and snowball sampling techniques to reach construction professionals who met the study criteria. These methods are commonly used in construction management research when access to specialized respondents is

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required (Leighton et al., 2021; Oke et al., 2024). In total, 200 construction professionals in Peru were contacted, resulting in 70 valid responses and a response rate of 35%. This response rate is consistent with similar studies and falls within the acceptable range for self-administered questionnaires, supporting the adequacy and representativeness of the sample (Fellows & Liu, 2015). The data collected were considered sufficient for conducting reliable statistical analyses. Table 2 presents the demographic profile of the survey respondents.

3.3 Validity test and data analysis

Data analysis was conducted using SPSS v24, including reliability analysis, descriptive statistics, Relative Importance Index (RII), and Exploratory Factor Analysis (EFA). Reliability was assessed using Cronbach's alpha for both challenges and benefits, with values above 0.70 considered acceptable (Rodríguez & Reguant, 2020). RII analysis was performed using Microsoft Excel to prioritize barriers and benefits according to project phase, project type, and company size. EFA was applied to group challenges and benefits with shared characteristics, following approaches used in similar construction research (Oke et al., 2021). Data adequacy was verified using the Kaiser–Meyer–Olkin (KMO) measure and Bartlett's test of sphericity. Factor extraction was conducted using Principal Component Analysis (PCA), retaining factors with communalities above 0.50. Varimax orthogonal rotation was applied to improve interpretability of the factor structure (Fabrigar et al., 1999).

4. Results

This section presents the results obtained from the survey conducted among construction professionals in Peru. The analysis focuses on identifying and prioritizing the main challenges and benefits associated with the implementation of robotics in building projects.

Table 2 presents the demographic profile of the survey respondents, summarizing key characteristics such as professional experience, experience in building projects, type of company, and company size. These variables provide an overview of the professional background of the participants and help contextualize their perceptions regarding the challenges and benefits associated with robotics implementation in construction projects. Understanding these characteristics is important for interpreting the survey results, as the experience level and organizational context of respondents may influence their evaluation of technological adoption in the construction industry.

Table 2. Demographic profile of respondents.

Profile	Demographic characteristics	Frequency	Percentage
Professional Experience	1 to 5 years old	19	27.14%
	11 to 15 years	14	20.00%
	15 to 20 years	10	14.29%
	6 to 10 years	19	27.14%
	More than 20 years old	8	11.43%
Building experience	1 to 5 years	41	58.57%
	11 to 15 years	9	12.86%
	15 to 20 years	7	10.00%
	6 to 10 years	9	12.86%
	More than 20 years	4	5.71%
Type of company	Construction	48	68.57%
	Consulting	3	4.29%
	Project design and formulation	8	11.43%
	Maintenance and related	3	4.29%
	Suppliers	3	4.29%
	Subcontractor	1	1.43%
	Others	4	5.71%
Company Size	micro (1 to 10 people)	7	10.00%
	small (10 to 50 people)	14	20.00%
	medium (50 to 250 people)	20	28.57%
	large (More than 250 people)	29	41.43%

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4.1 Descriptive analysis of challenges and benefits

Following the literature review, six expert interviews were conducted to validate the identified challenges and benefits. This process confirmed a final list of 13 challenges and 11 benefits and led to the inclusion of an additional benefit related to the reduction of occupational health and safety costs. The validated items were assessed by construction professionals using a five-point Likert scale. Reliability analysis for the challenges yielded a Cronbach's alpha value of 0.839, indicating satisfactory internal consistency. The challenges were subsequently ranked using the Relative Importance Index (RII), as summarized in Table 3.

Table 3. Challenges for robot implementation.

Challenges	Code	Bibliographic source
Weak innovation culture	IN-01	(Davila et al., 2019), (Pradhananga et al., 2021)
Lack of robotics legislation	IN-02	(Galin & Mamchenko, 2021), (Fleming et al., 2019)
Low investment capacity	FI-01	(Stewart et al., 2004), (Davila Delgado et al., 2019)
Short-term managerial vision	FI-02	(Warszawski & Navon, 1998), (Jäkel et al., 2022)
Limited collaboration and trust	CT-01	(Ojha et al., 2022), (Bademosi & Issa, 2021)
Lack of skilled labor	CT-02	(Hu et al., 2020), (Pradhananga et al., 2021)
Fear and distrust toward robots	CT-03	(Galin & Mamchenko, 2021), (Hatoum & Nassereddine, 2020)
Data security and reliability concerns	CT-04	(Fiatech, 2004), (Ojha et al., 2022)
Limited robot functionality	CT-05	(Afsari et al., 2021), (Kumar et al., 2008)
Complex technological requirements	CT-06	(Bademosi & Issa, 2021),(Mahbub & Humphreys, 1998)
Incompatibility with current practices	CT-07	(Strukova & Liska, 2012), (Mahbub, 2015), (Yahya et al., 2019)
Poor supply chain	EO-01	(Ojha et al., 2022), (Carra et al., 2018)
Lack of standards for human-robot interaction.	EO-02	(Fiatech, 2004), (Liang et al., 2021), (Pan et al., 2018)

Note: The challenges listed in this table were identified through a literature review and later validated through expert interviews before survey design.

The reliability results indicate that the dataset is appropriate for subsequent statistical procedures, including the Exploratory Factor Analysis (EFA), which is used to identify underlying groupings among the challenges affecting robotics implementation in construction projects.

In the same way as the analysis of challenges, the same process was carried out to analyze the list of benefits, obtaining the following results. It should be noted that the Cronbach's coefficient was calculated, and it was found that for the list of benefits, it was 0.879, which was higher than 0.7. Therefore, it can be assured that the data are valid for the development of this research. Below is the list of benefits ordered in decreasing order of their RII (Relative Importance Index).

Table 4. List of benefits of the implementation of robotics.

Benefit	Code	Bibliographic source
Increased competitive advantage	VC-01	(Aghimien et al., 2022)
Higher stakeholder satisfaction	VC-02	(Boya et al., 2022), (John et al., 2022)
Reduced labor and rework costs	OE-01	(Hatoum & Nassereddine, 2020)
Reduced overhead costs	OE-02	(Davila et al., 2019), (John et al., 2022)
Reduced OSH-related costs	SL-01	Expert Judgment
Reduced injuries and hazardous exposure	SL-02	(Davila et al., 2019), (Aghimien et al., 2022)
Continuous improvement and automation	PC-01	(Pan & Pan, 2019), (Demirkesen & Tezel, 2021)
Enhanced process control	PC-02	(Hatoum & Nassereddine, 2020)
Simplification of construction processes	PC-03	(Afsari et al., 2021)
Improved construction quality	PC-04	(Liang et al., 2021), (Pan & Pan, 2019)
Interoperability with digital technologies	PC-05	(Hatoum & Nassereddine, 2020)

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4.2 Descriptive analysis of challenges and benefits

4.2.1 For challenges

To further explore how the perceived challenges vary across organizations, the impact of challenges on robotics implementation was analyzed according to company size. The results are presented in Table 5, which summarizes the relative importance of each challenge for different organizational scales.

Table 5. Impact of challenges to robotics implementation by company size.

Challenges	Microenterprise	Small Enterprise	Medium enterprise	Large enterprise	RII Total
IN-01	71,43%	85,83%	84,00%	80,00%	81.71%
CT-06	74,29%	75,83%	86,00%	80,69%	79.14%
FI-01	80,00%	80,00%	78,00%	78,62%	79.14%
FI-02	80,00%	80,00%	74,00%	76,55%	77.71%
CT-02	68,57%	76,67%	76,00%	80,69%	77.43%
EO-01	80,00%	77,50%	80,00%	75,86%	77.43%
CT-01	71,43%	80,83%	74,00%	73,79%	76.00%
IN-02	68,57%	77,50%	76,00%	75,86%	75.71%
CT-07	80,00%	73,33%	80,00%	72,41%	74.57%
CT-05	80,00%	69,17%	70,00%	73,79%	72.29%
EO-02	60,00%	68,33%	78,00%	72,41%	70.57%
CT-03	68,57%	70,83%	70,00%	69,66%	70.00%
CT-04	62,86%	70,00%	70,00%	68,97%	68.86%

Note: *Note: The results indicate that financial and technological challenges tend to be perceived as more critical by professionals working in medium and large companies, while cultural and organizational challenges are reported across all company sizes.*

Exploratory Factor Analysis was performed to group those challenges that share similar characteristics. We began by determining the Kaiser–Meyer–Olkin (KMO) measure and Bartlett's test of sphericity. The results of these tests are presented in Table 6.

Table 6. KMO values and Barlett's test of sphericity of the challenges list.

Kaiser-Meyer-Olkin measurement		0.737
Barlett's test for sphericity	Approx. chi-quare	302.257
	Sig.	0.000

Then, the communality values were determined from the Principal Component Analysis (PCA) for the list of challenges and benefits. All values were greater than 0.5, so that all items in both lists remain as factors for the PCA. Finally, Vari-max orthogonal rotation was used for the rotation and interpretation of the grouping of variables, which allowed a better and simpler interpretation of the data. Next, the factor loadings obtained from the Exploratory Factor Analysis are presented in Table 7. Based on these results, the grouping categories were assigned the following names: (1) Innovation and challenging regulatory framework, (2) Financial constraints and strategic obstacles, (3) Cultural and technological challenges, and (4) Operating environment.

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Table 7. Exploratory Factor Analysis: Factors for Challenges.

TYPE	CODE	FACTOR			
		1	2	3	4
Innovation and a challenging regulatory framework	IN-01			0.849	
	IN-02			0.578	
Financial constraints and strategic obstacles	FI-01		0.824		
	FI-02		0.706		
Cultural and technological challenges	CT-01	0.723			
	CT-02	0.589			
	CT-03	0.689			
	CT-04	0.613			
	CT-05	0.617			
	CT-06	0.597			
	CT-07	0.671			
Operating environment	EO-01				0.504
	EO-02				0.865

4.2.2 For benefits

To further examine how the perceived benefits vary across organizations, the impact of robotics implementation benefits was analyzed according to company size. The results are presented in Table 8, which summarizes the relative importance of each benefit across different organizational scales.

Table 8. Impact of benefits to robotics implementation according to company size.

Benefit	Microenterprise	Small Enterprise	Medium enterprise	Large enterprise	RII Total
PC-01	80,00%	86,67%	94,00%	84,14%	86.00%
PC-05	80,00%	88,33%	86,00%	84,14%	85.43%
PC-04	77,14%	89,17%	88,00%	81,38%	84.57%
VC-01	88,57%	84,17%	82,00%	84,83%	84.57%
OE-01	91,43%	85,83%	78,00%	83,45%	84.29%
SL-02	68,57%	83,33%	84,00%	84,14%	82.29%
SL-01	74,29%	77,50%	90,00%	84,14%	81.71%
OE-02	82,86%	84,17%	80,00%	79,31%	81.43%
PC-02	71,43%	85,00%	84,00%	77,93%	80.57%
VC-02	85,71%	78,33%	78,00%	76,55%	78.29%
PC-03	74,29%	80,00%	78,00%	77,93%	78.29%

Note: The results indicate that benefits related to competitive advantage, efficiency improvement, and economic optimization tend to be consistently valued across companies of different sizes, highlighting the strategic importance of robotics adoption in construction projects.

To further explore the relationships among the identified benefits, an Exploratory Factor Analysis (EFA) was conducted. Before the analysis, the suitability of the dataset was evaluated using the Kaiser–Meyer–Olkin (KMO) measure and Bartlett's test of sphericity. The results are presented in Table 9.

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Table 9. KMO values and Barlett's test of sphericity of benefits list.

Kaiser-Meyer-Olkin measurement		0.832
Barlett's test for sphericity	302.257	302.257
	0.000	0.000

Next, Principal Component Analysis (PCA) with Varimax orthogonal rotation was applied to identify the underlying factor structure among the benefits. The rotated factor matrix is presented in Table 10.

Table 10. Factors of the Exploratory Factor Analysis for Benefits.

TYPE	CODE	FACTOR			
		1	2	3	4
Efficiency and process improvement in construction	VC-01				0.879
	VC-02				0.742
Economic optimization in construction processes	OE-01		0.83		
	OE-02		0.849		
Improved occupational health and safety	SL-01			0.9	
	SL-02			0.825	
Competitive advantage and stakeholder satisfaction	PC-01	0.786			
	PC-02	0.739			
	PC-03	0.783			
	PC-04	0.867			
	PC-05	0.845			

5. Discussion

This section discusses the main findings related to the barriers and potential benefits of robotics adoption in construction projects. The results obtained in the previous section allowed the research objectives presented in the introduction to be addressed. Specifically, the study identified the main barriers and benefits associated with robotics implementation in building projects in Peru, evaluated their relative importance, and grouped them into meaningful categories through Exploratory Factor Analysis. In addition, the analysis considered how these perceptions vary according to company size, providing further insights into the conditions that may influence the adoption of robotics in the construction sector.

5.1 Discussion of barriers to robotics implementation in construction

Following the analysis, challenges were grouped into four categories: Challenging Innovation and Regulatory Framework, Financial Constraints and Strategic Obstacles, Cultural and Technological Challenges, and Operating Environment.

5.1.1 Challenging Innovation and Regulatory Framework

This cluster comprises two challenges: IN-01, weak innovation culture for the implementation of robots in construction processes (AFE = 0.849), and IN-02, lack of legislation regulating the use of robots in construction (AFE = 0.578). The results suggest that a weak innovation culture is the most critical challenge in this category, particularly for small firms with limited resources, confirming previous findings by Davila et al. (2019). Although the lack of legislation is less strongly perceived in the Peruvian context, its relevance lies in ensuring safety and risk mitigation. As highlighted by Liang et al. (2021), clear regulations are essential to address safety concerns in human–robot collaboration, emphasizing the need for an enabling regulatory framework to support robotics adoption.

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5.1.2 Financial constraints and strategic obstacles

This category includes FI-01, low investment and limited company resources for robot implementation (AFE = 0.824), and FI-02, lack of management interest due to a short-term vision (AFE = 0.706). Financial constraints appear to be among the most significant challenges, particularly among micro and small firms, where limited budgets restrict long-term technological investments. These findings suggest that economic limitations outweigh strategic considerations in hindering robotics adoption, consistent with Davila et al. (2019). Similar results were reported by Jäkel et al. (2022), who noted that high upfront costs pose a major challenge for smaller companies seeking to implement robotic technologies.

5.1.3 Cultural and Technological Challenges

This group comprises seven challenges related to collaboration, skills, safety perceptions, data security, technological complexity, and compatibility with existing practices. Among them, the most relevant challenge is CT-06, referring to the complex technological requirements and the difficulty of on-site installation of robots. Medium and large companies perceive challenges related to skills and technological integration more strongly, while micro and small firms are more affected by distrust, limited collaboration, and safety concerns. These findings align with previous studies highlighting resistance to change, lack of technological knowledge, and safety concerns as major obstacles to robotics adoption (Hatoum & Nassereddine, 2020; Ojha et al., 2022).

5.1.4 Operating Environment

This category includes EO-01, poor supply chain for robot adoption (AFE = 0.504), and EO-02, lack of bodies and standards regulating human–robot interaction (AFE = 0.865). The absence of regulatory institutions and standards was identified as the most significant challenge, particularly among medium-sized companies that face coordination challenges without the resources of larger firms. Fragmented supply chains and limited interoperability hinder effective robotics implementation, as also noted by Hatoum and Nassereddine (2020). The findings reinforce the need for open standards and institutional support to improve coordination and facilitate the adoption of robotics within the Construction 4.0 environment (Ojha et al., 2022).

5.2 Discussion of potential benefits

The benefits identified in this study were grouped into four categories based on the results of the exploratory factor analysis.

5.2.1 Efficiency and Process Improvement in Construction

This category includes VC-01, increased competitive advantage through the use of technology (AFE = 0.846), and VC-02, increased stakeholder satisfaction due to improved processes (AFE = 0.783). For small and medium-sized enterprises (SMEs), robotics can significantly improve operational efficiency by optimizing time, resources, and construction workflows, enabling them to compete more effectively in demanding markets. Although VC-01 is more strongly perceived by large firms, SMEs can also benefit from enhanced professionalism and improved project delivery, which can increase client confidence and market opportunities. These findings align with Construction 4.0 principles, where automation and robotics contribute to faster execution, improved quality, and greater process reliability (Aghimien et al., 2022; Mahbub, 2015).

5.2.2 Economic Optimization in Construction Processes

This group comprises OE-01, reduction of labor and rework costs (AFE = 0.843), and OE-02, reduction of overhead costs due to increased productivity (AFE = 0.814). These benefits are particularly relevant for SMEs, where labor-intensive processes represent a substantial portion of project costs. Although the initial investment in robotics may be challenging, the long-term reduction in rework, waste, and manual labor can lead to significant economic gains. From a Construction 4.0 perspective, automation and robotics enable SMEs to improve cost control, increase productivity, and enhance profitability, consistent with findings by Boya et al. (2022) and Pan and Pan (2019).

5.2.3 Improvement in Occupational Safety and Occupational Health

This category includes SL-02, reduction of injuries and removal of workers from hazardous tasks (AFE = 0.823), and SL-01, reduction of occupational health and safety costs (AFE = 0.817). For small and medium-sized companies, which often face greater safety risks due to limited safety management systems, robotics can play a key role in reducing exposure to dangerous activities such as working at heights or handling heavy equipment. By automating high-risk tasks, SMEs can lower accident rates, reduce downtime, and avoid costs associated with injuries. These

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results are consistent with Construction 4.0 studies highlighting robotics as a key enabler of safer construction environments (Aghimien et al., 2022; Liu et al., 2024).

5.2.4 Competitive Advantage and Stakeholder Satisfaction

This group includes benefits related to continuous improvement, interoperability with digital technologies, improved quality, and enhanced process control, with PC-01 and PC-05 being the most highly perceived. For SMEs, robotics adoption supports continuous improvement by enabling more standardized, automated, and interoperable construction processes. The integration of robots with other Construction 4.0 technologies allows SMEs to optimize workflows, reduce non-productive tasks, and improve coordination among stakeholders. These advantages enhance competitiveness and reliability in project delivery, which is critical for SMEs operating in highly competitive markets (Yahya et al., 2019; Oke et al., 2024).

The most important challenges are PC-1, PC-2, PC-3, and VC-1, and belong to the groups "Challenging Innovation and Regulatory Framework" and "Financial Constraints and Strategic Obstacles". These challenges relate specifically to the lack of an innovative culture and the absence of specific legislation, which hinders the adoption of robotic technologies. Weaknesses in innovative culture impede the introduction of new technologies, especially in small companies with limited resources. In addition, the lack of a clear regulatory framework increases the perception of risk, thus hindering investment in robotic technologies. In financial terms, low investment and limited resources, together with a lack of managerial interest due to a short-term vision, represent significant obstacles. These financial challenges are particularly critical for micro and small enterprises, which face budget constraints and a reduced ability to make long-term investments. Additionally, cultural and technological challenges, such as poor collaboration and distrust, a lack of skilled labor, and perceived fear of robots, reflect resistance to change and a lack of technological competencies necessary for effective robot implementation. Finally, challenges related to the operating environment, such as the technological complexity of robots and their installation on site, indicate that the technical requirements and integration of robots into existing construction environments are significant challenges.

For large companies, which may have more capacity to overcome these challenges, a lower impact of RII was observed compared to micro and small companies. However, even for large companies, the need for a clear regulatory framework and a culture of innovation remains crucial. In summary, to overcome these challenges and promote the adoption of robotics in construction, it is essential to foster a culture of innovation, develop a clear regulatory framework, increase investment in emerging technologies, and train the workforce in advanced technological skills. The most important benefits are PC-1, PC-4, PC-5, and VC-1, and belong to the "Competitive advantage and stakeholder satisfaction" and "Efficiency and improvement in construction processes" groups. These benefits are specifically related to gaining an advantage with the use of technology through the automation of repetitive tasks; generating more efficient construction processes by optimizing work, time, and resources; and improvements in production quality, which is related to improved customer satisfaction. For large companies, which are the most likely to use this technology, a high value of RII was seen concerning the great competitive advantage they could take advantage of these technologies in the construction market as they improve their ability to compete in terms of automation, production and is key to the modernization and sustainability of companies, allowing better management of resources and costs, and significantly raising the quality of projects, thus keeping customers satisfied.

6. Conclusions

This study analyzed the main barriers and potential benefits associated with the implementation of robotics in construction projects in Peru. The findings suggest that several organizational, financial, cultural, and technological factors influence the adoption of robotic technologies in the construction sector. Among the most relevant barriers identified are the lack of an innovation culture, limited financial capacity for technological investment, and the absence of clear regulatory frameworks governing the use of robotics in construction processes. At the same time, the results highlight important potential benefits, including improvements in productivity, construction efficiency, and occupational safety, as well as the possibility of achieving greater competitive advantages through the integration of automation and digital technologies.

The main contribution of this research lies in providing empirical evidence regarding the barriers and benefits associated with robotics adoption in the construction industry within a developing country context. By applying methods such as the Relative Importance Index and Exploratory Factor Analysis, the study identifies and categorizes the key factors influencing robotics implementation. This contributes to the existing literature on Construction 4.0 by offering a structured understanding of how organizational, financial, and technological conditions affect the adoption of robotic systems in building projects.

From a theoretical perspective, the findings contribute to the growing body of knowledge on digital transformation and automation in construction by identifying critical factors that influence robotics adoption in emerging markets. For practitioners, the results provide useful insights for construction companies, policymakers, and industry stakeholders. Specifically, the study suggests that fostering an innovative-oriented organizational culture, promoting investment in emerging technologies, and developing clear regulatory frameworks may facilitate the implementation of robotics in construction projects. In addition, training programs and technological capacity-building initiatives may help reduce cultural and technological barriers identified in the study.

Despite its contributions, this study has several limitations that should be acknowledged. First, the sample consisted of construction professionals working primarily in building projects in Peru, which may limit the generalizability of the results to other countries or construction sectors. Second, the study did not differentiate companies according to their level of technological maturity, such as the adoption of modern construction approaches, including Lean Construction, Modern Methods of Construction (MMC), or other advanced digital technologies. In addition, factors such as the level of digitalization within firms or differences between public and private sector organizations were not explicitly analyzed. These aspects could influence the perception of robotics adoption and, therefore, represent potential areas for further investigation.

Future research could expand this work by analyzing robotics adoption in different construction sectors and geographical contexts. Further studies may also explore the relationship between robotics implementation and other Construction 4.0 technologies, such as Building Information Modeling, artificial intelligence, and digital twins. In addition, future research could examine how organizational factors such as digital maturity, innovation capability, and workforce skills influence the successful implementation of robotic systems in construction projects. Longitudinal studies and larger datasets may also provide deeper insights into how robotics adoption evolves within the construction industry.

7. Declaration of generative AI and AI-assisted technologies

In preparing this manuscript, AI-assisted technologies such as Grammarly were used to support the structuring of the text and improve clarity, readability, and presentation. All outputs generated with the assistance of these technologies were carefully reviewed and edited by the authors, who take full responsibility for the content of the manuscript.

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