

OUTDOOR ENVIRONMENT, WORKERS WELLBEING, AND PRODUCTIVITY: A LEAN CONSTRUCTION VIEW

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ABSTRACT

Worker health directly influences construction project performance by affecting productivity, reliability, and workflow continuity. Motivated by this, the present study frames environmental exposure and workload conditions as sources of variability that impact production system stability, a core principle of Lean Construction. These factors are assessed through workers' perceived well-being, in construction projects in Peru. The methodology consisted of three steps: (1) a review of Peruvian regulations to identify gaps related to comfort and well-being; (2) a survey of workers across building, infrastructure, and electromechanical projects to assess perceptions of health risks, working conditions, and productivity impacts; and (3) an analysis correlating workers' perceptions with demographic variables. The results revealed variations across regions and project types, allowing for a structured interpretation. Impacts on productivity, inactivity, and fatigue-related behaviors were found to be greater under higher temperatures. Perceptions of health risks were lowest, and well-being highest, in electromechanical projects. The findings highlight the importance of integrating comfort and well-being considerations into sectoral standards to manage environmental exposure and workload, thereby enhancing workflow reliability.

KEYWORDS

Environmental exposure, workload, job stress, workers' well-being, lean construction.

INTRODUCTION

The foundation principles of lean production are to maximize efficiency and reduce or eliminate non-value-adding activities (Koskela, 1992). Simultaneously, the construction sector struggles to meet strict time, budget, and quality goals while managing heavy workloads, long hours, and frequent task changes (Putera & Martiana, 2022; Tijani et al., 2020). This study examines the impact of environmental exposure and workload in construction workers' well-being in terms of comfort and health, and how it can be correlated with their operational efficiency and productivity stability, principles emphasized by Lean Construction. These dimensions are not fully integrated or extensively studied (Bidhendi, Poshdar, & Jelodar, 2025). To address this gap, three key factors are examined: physical environment, workload and physical effort, and stress levels. In Peru, exposure to the physical environment is intensified by long workdays, typically 10–12 hours without overtime compensation. Extreme temperatures significantly increase stress (Enshassi et al., 2015). For instance, a case study in China reported a 0.57% drop in productivity and a 0.74% rise in idle time for every 1°C increase (Li et al., 2016), while a

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survey of 102 workers in South Korea showed frequent exposure to extreme temperatures, falls, crashes, loud noise, and slips (Eom & Lee, 2020).

Regarding workload and physical effort, Abdelhamid and Everett's (2002) study illustrates the issue through workers' testimonials: "Tough; I sometimes fall asleep while driving home," "Very hard, but it is what we do for a living," and "Kills you". As for stress, the construction sector can be extremely demanding, with craft workers' stress levels comparable to those of professionals due to high workloads, pressure, and tight deadlines (Abbe et al., 2011).

In Peru, the construction industry employs 7% of the national workforce, yet existing regulations are limited and do not adequately address workers' well-being. Therefore, this study seeks to raise awareness through three objectives: (1) reviewing Peruvian construction regulations regarding Occupational Health and Safety to identify gaps and opportunities in terms of well-being management, as it represents a holistic state of health that necessitates managing both environmental exposure and workload conditions; (2) defining key control and measurement parameters to improve worker comfort; and (3) presenting correlations between workload conditions, environmental exposure, wellness and productivity stability.

LITERATURE REVIEW

REGULATORY FRAMEWORK FOR HEALTH

The Ministry of Housing, Construction, and Sanitation (Ministerio de Vivienda, Construcción y Saneamiento) has established the minimum mandatory safety regulations for civil construction activities (2006). The Peruvian Institute for Quality (INACAL) has published technical regulations intended to increase companies' competitiveness; however, their application is voluntary. The mandatory Occupational Health and Safety Regulations for the Construction Sector (DS 011-2019-TR) focus primarily on organizational aspects. They do not address the conditions required to promote wellness and comfort. Similarly, the Peruvian Technical Regulation G.050 (DS 010-2009-VIVIENDA) prescribes methods to control noise, protect respiratory health, and prevent hand injuries, but it does not consider stress, comfort, or habitability. Finally, the Peruvian Technical Standards (NTP), voluntary in application, also lack controls for working environment hazards and do not address comfort or habitability.

COMPARISON WITH OTHER STANDARDS AND GUIDELINES

Mining Sector

The Occupational Health and Safety Regulations in Mining (D.S. N°024-2016-EM) cover a wide range of topics, including occupational hygiene, environmental exposure, worker well-being, recreation, and assistance programs. This broader scope distinguishes mining from other construction contexts, as it incorporates not only safety control measures but also provisions that support workers' well-being and quality of life. As a result, mining projects tend to provide more structured and comprehensive conditions for managing health, safety, and well-being.

OECD and CDC

Internationally, frameworks such as the OECD Guidelines on Measuring Subjective Well-being (2013) and the CDC Worksite Health Scorecard (2024) offer comprehensive modules to assess employee wellness. These instruments highlight global opportunities to integrate well-being metrics into workplace management, establishing a benchmark for what construction environments could adopt.

OCCUPATIONAL HEALTH AND SAFETY STATISTICS

A statistical dataset from the Ministry of Labor and Employment Promotion (2016-2023) on accidents, incidents, and illnesses was reviewed. The analysis showed that work-related

accidents are the most frequent safety events. Excluding unclassified cases due to missing data, the leading causative agent of work accidents is the work environment.

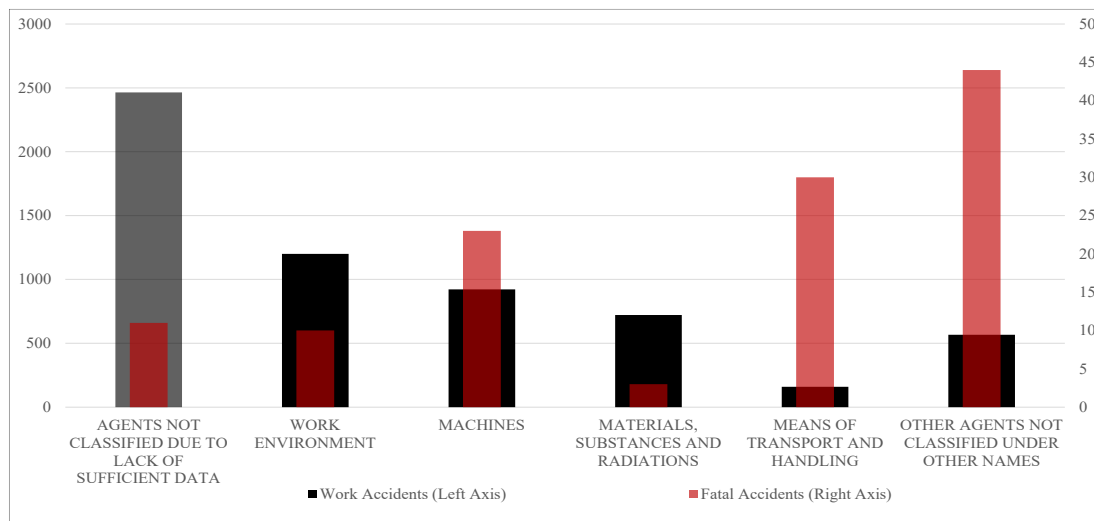


Figure 1: Causative Agents of Work and Fatal Accidents (adapted from Ministerio de Trabajo y Promoción del Empleo, 2016-2023)

METHODOLOGY

This study is quantitative survey-based research of construction workers' perceptions, aiming to highlight the value of direct field investigation through workers' testimonials on health, safety, comfort, and well-being. In doing so, the Lean Construction principle of "respect for people", which promotes listening to individuals' voices and considering their concerns (Lean Construction Institute, 2025) is put into practice. Data were collected through a closed online survey (Microsoft Forms). The workers' population to be invited for the survey, followed two criteria. First, to have worked on projects from the Coast or the Highlands, as these regions are the most dynamic within the construction industry, compared with the Jungle (ComexPerú, 2021). Second, they had to have worked in at least one of these three categories: buildings, infrastructure, or electromechanical works, the latter referring to the construction or expansion of mines. These are the projects type primarily carried out in Peru (Pontificia Universidad Católica del Perú, 2017), and of these three, infrastructure and housing projects are predominant (Cámara Peruana de la Construcción, 2024). Of the 133 workers contacted, 55 responded (41%). The sample included apprentices, laborers, operators, superintendents, and professional staff (engineers and supervisors), mostly men. The findings offer a comprehensive assessment of workload conditions and environmental exposure, representing a first step toward fostering healthier environments that support workers' well-being (CDC, 2019). Although based on self-reported perceptions, these data are highly relevant because many construction standards rely heavily on theoretical principles, leaving real-world testimonials underutilized.

SURVEY SCOPE

To define the survey scope, research was conducted to identify five key areas of concern in the Peruvian construction sector, focusing on health relevance. Moreover, these areas tie into human-centric approaches that are often overlooked in traditional applications of Lean Construction principles (Bidhendi, Poshdar, & Jelodar, 2025).

- 1. Depression and stress management:** Stress and depression are critical components of mental health (National Center for Complementary and Integrative Health, 2022) and can negatively affect multiple aspects of life, including physical, emotional, and well-

being (National Institute of Mental Health, 2020, 2024). Construction projects are environments with many catalysts of mental illness due to the pressure and frustration.

2. **Musculoskeletal disorders:** NIOSH has established a clear relationship between these disorders and physical factors, particularly in cases of high or prolonged exposure typical in construction (Bernard & Putz-Anderson, 1997).
3. **Sleep and fatigue:** Construction work on site in Peru is characterized by long workdays and commute times, usually between 10-14 hours a day (42 - 58% of the day hours). Family and personal responsibilities often occur at night, leading to insufficient rest. Sleep deprivation and fatigue can lead to serious accidents.
4. **Respiratory health:** Construction significantly impacts air quality (Wieser et al., 2021). To measure this, the survey questions were guided by established environmental health frameworks (California Environmental Health & Safety, 2022) to assess workers' exposure to common site pollutants like ultrafine particles, carbon monoxide, and particulate matter (Wieser et al., 2021).
5. **Dermatological health:** Construction is usually carried out outdoors, under different climate conditions: sun, cold winds, humidity, dust, and rain, at least until the superstructure and facade are completed. Additionally, chemical products, particularly cement-based materials, are commonly handled by laborers. Since hands are a key tool used by workers, occupational contact dermatitis is highly likely to occur and accounts for more than 95% of occupational skin diseases in many countries (Timmerman, 2017).
6. **Health risk perception at projects:** This section captures workers' general perceptions of risk exposure in terms of safety and well-being throughout the construction period.

The final survey consisted of 36 questions: 10 on sample characterization, 7 on thermal/auditory comfort, 2 on stress, 1 each on musculoskeletal conditions and sleep, 5 on respiratory health, 8 on dermatological health, and 2 on final workplace perceptions.

RESULTS

The following results are structured to explain how environmental and workload conditions influence worker states and consequently, production system stability.

SECTION 1: SAMPLE CHARACTERIZATION

The 55 respondents were predominantly male (93%), primarily aged 25-45, and mostly working on coastal projects (55%) or in the mining sector (44%) under typical 10-hour workdays (see Table 1 for full demographic details)

SECTION 2: ENVIRONMENTAL CONDITIONS

Thermal comfort

A clear relationship was found between temperature, geographic region, and physical activity (see Figure 2). In coastal regions (warmer climates), workers reported slightly higher percentages of inactivity during working days. In contrast, in the highlands (colder climate), workers tended to avoid inactivity, but a greater proportion reported slower movements.

Auditory health

Approximately 75% of the surveyed workers did not report major impacts on their auditory health. The main sources of noise were construction equipment and power tools used for hardened concrete. Most of the perceived noise originated either from workers' own tools or from those operated by coworkers within the same crew.

Table 1: Sample characterization results

	Occupation							Totals (N=55)	
	Apprentice	Journeyman	Foreman	Equipment Operator	Site Supv.	Field Engineer	Project Engineer	N	%
Women		1				3		4	7%
Men	3	15	12	7	5	3	6	51	93%
Age Range									
a. [25–30]	2	3				5	3	13	24%
b. [31–35]	1	1	2	1		1	2	8	15%
c. [36–40]		6	1	2			1	10	18%
d. [41–45]		1	4	3	1			9	16%
e. [46–50]		3	1		1			5	9%
f. [51–55]		1	2		1			4	7%
g. [56–60]		1	2	1	1			5	9%
h. >60					1			1	2%
Project Type									
High-rise Buildings	2	2	2		1	1	4	12	22%
Low-rise Buildings			1	1		1	1	4	7%
Infrastructure		3	2		2	3	1	11	20%
Mining	1	10	6	5	2			24	44%
Other		1	1	1		1		4	7%
Demographical Region									
Coast	3	8	7	5	2	2	3	30	55%
Mix Coast/Highlands		4	2		2	3	2	13	24%
Highlands		4	3	2	1	1	1	12	21%
Workday Length									
>10 hours/day			3	3	1	2	1	10	18%
10 hours/day	2	9	7	4	3	1	2	28	51%
8 hours/day	1	7	2		1	3	3	17	31%

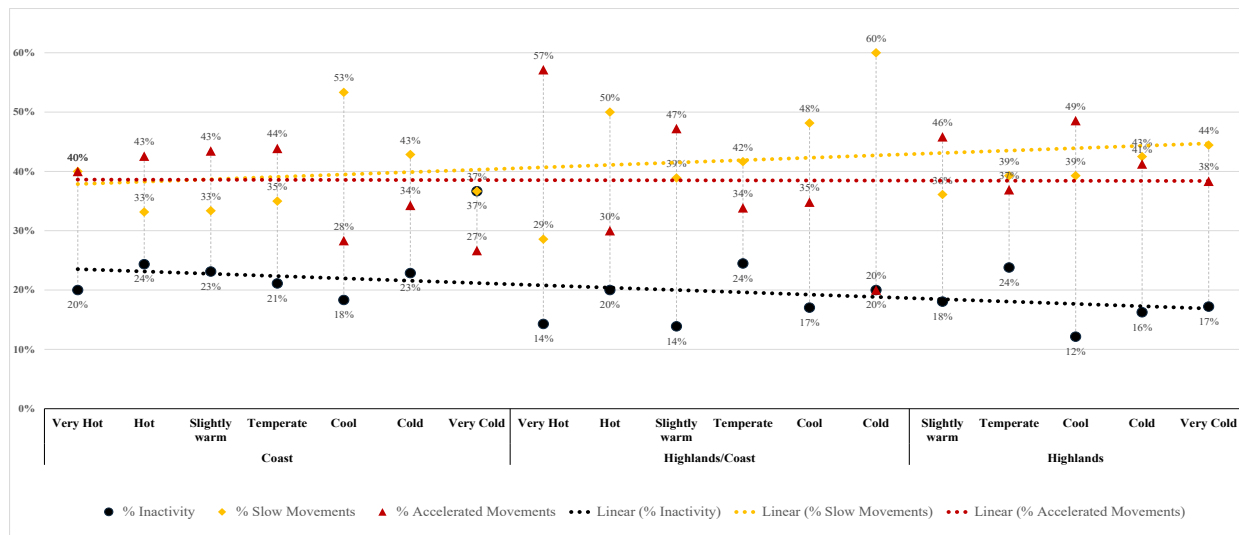


Figure 2: Type of workday physical activity by geographic region and temperature perception

SECTION 3: STRESS AND DEPRESSION MANAGEMENT

The first set of questions assessed participants' ability to make decisions that support their well-being at work. On average, 65% of those working more than 10 hours per day reported an ability to manage stress. This rate dropped by 10% among those working 8-hour days. By occupation, only 45% of white-collar staff reported positive responses, 17% less than blue-collar workers. Regarding company's role in supporting wellness, 70% of the white-collar workers in mining projects reported good support, compared with 45% in buildings and infrastructure. Blue-collar responses were more varied but still slightly higher for those whose latest project was in mining.

SECTION 4: PHYSICAL AND MUSCULOSKELETAL WELL-BEING

Blue-collar workers reported a much stronger perceived link between overexertion and repetitive motions and musculoskeletal issues (67%) compared with white-collar staff (33%). Regarding the company's role in planning appropriate workloads, perceptions were generally positive, with 72% agreeing that workloads were adequately managed, and 86% affirming compliance with awareness campaigns. When asked about health insurance coverage, 100% of office staff believed they were covered, versus only 60–70% of field staff and workers.

SECTION 5: SLEEP AND FATIGUE

On average, 80% of the participants reported that their companies complied with awareness campaigns, implemented strategies to address sleep and fatigue issues, and provided policies and resources to help manage them.

SECTION 6: RESPIRATORY HEALTH

Seventy-three percent of participants stated that they did not perceive new or increased respiratory problems as a result of exposure to the construction site. In contrast, 51% considered the construction site a contaminated environment and reported frequent respiratory discomfort while working. The most reported contaminants were dust from paved and unpaved roads (29%), concrete dust from cutting and finishing activities (24%), exhaust gases from fuel-powered construction equipment (18%), particles generated by welding and metal cutting (18%), and wood chips present in the environment (11%). (See Table 2)

Table 2: Perception of respiratory health discomfort among construction workers

My daily perception is	Laborer	Foreman	Site Sup.	Equip. Oper.	Other	Field Eng.	Project Eng.	N	%
I don't feel any discomfort	0	-	1	-	1	-	2	4	7%
I experience discomfort sometimes	6	4	4	2	-	4	1	21	38%
I almost always experience discomfort	-	-	-	-	2	-	-	2	4%
My workplace environment is very contaminated	8	7	-	5	3	3	2	28	51%
I perceived that my discomfort was caused by:									
Genetic condition	-	-	-	-	-	-	-	3	6%
Increased due to my job	-	-	-	-	-	-	-	10	18%
I have no discomfort.	-	-	-	-	-	-	-	42	76%
About the company:									
Provides the necessary PPE	-	-	-	-	-	-	-	47	85%
Sometimes, they don't have the proper PPE	-	-	-	-	-	-	-	6	11%
They completely lack PPE	-	-	-	-	-	-	-	1	2%
There is not enough PPE stock	-	-	-	-	-	-	-	1	2%
I perceive the air pollution source to be:									
Dust raised from paved and/or unpaved roads	-	-	-	-	-	-	-	31	29%
Concrete dust	-	-	-	-	-	-	-	26	24%
Equipment with fuel engines	-	-	-	-	-	-	-	19	18%
Particles from welding or cutting metals	-	-	-	-	-	-	-	19	18%
Wood chips	-	-	-	-	-	-	-	11	11%

SECTION 7: DERMATOLOGY HEALTH

Almost 90% of the participants reported not having skin health issues in the last 12 months. However, 77% perceived latent risks to exposed skin due to the aggressiveness of the jobsite (47%) and contact with hazardous materials (11%). Regarding weather conditions of major concern, the most frequent responses were extreme heat (55%) and prolonged cold (20%).

SECTION 8: FINAL PERCEPTION ASSESSMENT

The final assessment revealed that 58% of the participants rated the workplace as “good” regarding health and wellness, 27% rated it as “excellent,” 9% considered it “deficient,” and 6% expressed indifference. In terms of perceived health risk exposure, 77% considered that risks exist but are controllable through joint efforts between workers and employers. Eighteen percent believed that risks are primarily managed by the employer, whereas only 5% indicated that health risks are not manageable by either the employer or the workers.

ANALYSIS AND FINDINGS

From a Lean Construction perspective, workers’ well-being perception, in terms of comfort, health, and safety risk, is an indicator of underlying conditions that shape production system stability. The findings show that environmental exposure and workload cause variability in workers’ well-being, consequently, they need to be managed to protect productivity outcomes.

MAJOR RISK FACTORS FOR HEALTH

Table 3 shows the selection of the most significant risk agents for health and well-being, perceived by the sample. These answers come from Sections 2, 4, 6, and 7. Two of them are related to work design, and two are related to environmental conditions; both require attention to mitigate sources of instability in production performance.

Table 3: Perceived major risk factors for health and well-being

Risk categories	Main perceived factors
Noise sources	Construction machinery, Concrete and demolition equipment
Air quality pollutants	Dust raised from paved and/or unpaved roads, Concrete dust
More aggressive climates	Climate of strong solar radiation, Prolonged cold weather
Physically tiring tasks	Constant repetitive movements and/or overexertion

HEALTH IMPACT LEVEL ASSESSMENT

The results presented in Sections 2, 4, 6, and 7 were evaluated using a weighted scale from 0 for no health impacts to 1 for highest impact on workers’ health. These scores were factored with the response frequencies to obtain a normalized value of perceived health impact (see Table 4). Analysed by region and project type, the following patterns emerged:

- Compared to building and infrastructure projects, workers in mining-related construction projects reported higher awareness of health, safety, and well-being. This increased awareness could help mitigate the variability caused by the environment and workload, which may result in lower production instability.
- Across all project types and regions, skin health was the least affected.

Physical and musculoskeletal health was the most impacted. Because manual labor drives Peruvian construction, unmanaged physical strain introduces hidden performance variability.

Mitigating this strain is therefore a core Lean strategy to sustain continuous workflow.

PRODUCTIVITY IMPACT

Assessing responses from the Thermal Comfort section and applying a reduction factor of 75% for working time related to resting or inactivity hours, a reduction factor of 25% related to slow movements and no impacts for accelerated motion activity on an overall working day, an average productivity decrease of 26% was observed across the different types of projects. An analysis of the same results by demographic region revealed that inactivity hours were slightly greater in the coastal region, whereas the frequency of slow movements was slightly greater in the highlands (see Table 5). This analysis reinforces the positive correlation between productivity and safety synthesized by Usmen and Vilnitis (2015). It also reflects variability and instability in the production system, caused by the environmental exposure: productivity declines when workers' health is affected or when they perceive a hazardous environment.

Table 4: Perception of health impacts by region and project type (normalized)

Health Aspect	Region	Buildings	Infrastructure	Mining
Respiratory health	Coast	0.59	0.75	0.66
	Coast/Highland	1.00	0.58	0.50
	Highland	0.67	0.63	0.68
Auditory health	Coast	0.27	0.08	0.32
	Coast/Highland	0.25	0.04	0.08
	Highland	0.25	0.13	0.29
Dermatological health	Coast	0.00	0.00	0.18
	Coast/Highland	0.00	0.00	0.00
	Highland	0.00	0.00	0.00
Musculoskeletal health	Coast	0.19	0.37	0.36
	Coast/Highland	0.10	0.25	0.27
	Highland	0.20	0.35	0.36

Table 5: Impact on workers' productivity due to outdoor environment, by region

Region	Idle movement	Normal movement	Accelerated movement	Weighted Productivity Reduction Factor
Coast	0.25	0.36	0.40	0.73
Coast/Highland	0.19	0.44	0.36	0.74
Highland	0.18	0.40	0.42	0.77

ASSESSMENT OF GENERAL WELL-BEING

Section 3 on stress and depression management included questions about workers' well-being and mood in the workplace. Responses were weighted to calculate an average score: 'Never' = 0, 'Sometimes' = 0.5, 'Often' = 0.75, and 'Always' = 1. Selecting 'Never' indicated a lack of resources to manage stress, discomfort in the workplace, and limited company support, whereas

‘Always’ reflected available resources, a positive environment, and active employer involvement. The results shown in Table 6, classified by project type and geographical region, reflect that well-being perception was lowest in infrastructure projects suggesting a higher risk of production instability related to poor working conditions.

From a Lean Construction perspective, environmental and workload-related conditions can be understood as sources of variability that disrupt workflow continuity and reduce production reliability. Worker behaviors such as inactivity and reduced movement speed reflect fluctuations in task execution, affecting flow and system stability. Therefore, managing these factors should be considered a Lean strategy to improve production performance.

Table 6: Well-being level of construction workers

Well-being dimension	Region	Buildings	Infrastructure	Mining
Adequate workload and positive environment	Coast	0.63	0.79	0.69
	Coast/Highland	0.66	0.68	0.81
	Highland	0.78	0.59	0.82
Attention to anxiety and/or depression	Coast	0.20	0.23	0.30
	Coast/Highland	0.44	0.15	0.44
	Highland	0.24	0.29	0.33

MANAGERIAL IMPLICATIONS AND WORK SYSTEM DESIGN

To translate these findings into practice, construction managers should integrate environmental and health indicators into their daily management routines. Based on the survey results, the following practical guidelines are recommended:

- **Work system design for weather:** Since the data shows a 26% productivity reduction factor linked to temperature extremes, managers should adjust daily crew rotations and task sequencing during peak exposure hours. This aligns with Lean principles of reducing variability at the task execution level (Koskela, 2000).
- **Continuous monitoring of well-being:** Musculoskeletal strain and fatigue should be treated as leading indicators of workflow disruption. Managers can incorporate quick, structured well-being check-ins. This practice not only monitors hidden variability but actively exercises the Lean pillar of "Respect for People" (Howell & Macomber, 2003).
- **Standardizing site conditions:** Building and infrastructure projects should adopt the structured wellness approaches observed in the mining sector, such as standardizing hydration stations, shaded rest areas, and clear workload pacing, to stabilize production.

CONCLUSION

This study analyzed perceptions from 55 construction workers in Peru regarding health, safety, and well-being on active construction sites. Workers identified machinery noise, dust exposure, extreme temperatures, and repetitive motions as the most significant risks. Compared to building and infrastructure projects, those in mining reported notably better well-being, likely due to more comprehensive sectoral safety and health regulations. Regional differences were evident: coastal projects showed more inactivity due to heat, whereas highland projects showed reduced pace due to cold, with an average productivity loss of 26%. Despite these challenges, most workers rated their well-being positively and believed risks were manageable. Overall, this study demonstrates that environmental and workload-related conditions act as hidden

sources of variability within construction production systems. Integrating worker comfort and well-being into project planning is not merely a regulatory compliance issue; it is a fundamental execution of the Lean pillar of 'Respect for People,' and creates safer workplaces that contribute by improving production stability, reducing inefficiencies, and enabling reliable workflows.

LIMITATIONS

This study is limited by its relatively small sample size (55 construction workers), which may affect the representativeness of the findings and reflects constraints related to workers' digital literacy in Peru. Additionally, the results are based on self-reported perceptions, as no on-site measurements were conducted due to the remote nature of the study.

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