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IDENTIFICATION OF AUTONOMOUS CONSTRUCTION IN MALAYSIAN CONSTRUCTION PROJECT

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Abstract: *Autonomous Construction are heralded as the primary solution to the construction industry's chronic productivity and safety issues. However, adoption rates in emerging economies remain inconsistent. This research aims to critically assess two primary dimensions within the Malaysian construction sector; the current level of its implementation among G7 contractors and the barriers impeding the transition toward autonomous workflows. Using a quantitative approach, a survey instrument was administered to 317 G7-grade contractors in Wilayah Persekutuan Kuala Lumpur. A total of 97 valid responses were collected and subjected to descriptive statistical analysis using SPSS. This allowed for the ranking of technology types currently in use and a thematic categorization of adoption barriers. The study reveals that the current level of adoption is "superficial," characterized by a heavy reliance on passive supporting technologies (e.g., drones and structural sensors) rather than active autonomous systems (e.g., robotics and 3D printing). The analysis identifies a "barrier hierarchy," where high initial capital expenditure and a critical shortage of specialized digital literacy are the most significant deterrents. Furthermore, a cultural unreadiness within the workforce suggests that the barrier is not merely financial but also organizational. By isolating the current implementation levels from the barriers, this study provides a focused diagnostic of the "digital*

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plateau" facing Malaysian G7 contractors. The findings offer a clear empirical baseline for future researchers to measure the success of Industry 4.0 initiatives in the Southeast Asian construction context.

Keywords: *Autonomous Construction, G7 Contractors, Technology Adoption, Barriers, Construction 4.0, Malaysia*

Introduction

The global construction sector is undergoing a profound paradigm shift driven by the Fourth Industrial Revolution (IR 4.0). Advanced digital ecosystems, continuous telemetry, and cyber-physical systems are increasingly replacing traditional, labor-intensive practices to resolve chronic industry challenges such as low productivity, schedule overruns, poor safety records, and skilled labor shortages (Agarwal et al., 2016). Within this landscape, Autonomous Construction—defined as the execution of construction tasks by semi-autonomous or fully autonomous heavy equipment, automated bricklaying machines, 3D concrete printers, and autonomous unmanned aerial vehicle (UAV) monitoring tools—has emerged as a foundational driver of automated on-site operations (Gharbia et al., 2020). High-income economies lead the global deployment of autonomous systems by leveraging top-down government mandates, substantial research and development investments, and mature digital connectivity standards (Juan et al., 2019). International literature heavily documents the technical feasibility, algorithmic development, and sensor accuracy of autonomous machinery, establishing that while these technologies offer transformational gains in precision and safety, their global diffusion remains constrained by severe capital costs, uncertain return on investment (ROI), and unstandardized data interoperability protocols (Almatari et al., 2024; Islam et al., 2025).
Recognizing the strategic necessity of digital maturity, the Construction Industry Development Board (CIDB) of Malaysia introduced the *Construction 4.0 Strategic Plan (2021–2025)* (Construction Industry Development Board [CIDB], 2021). The roadmap explicitly outlines 12 core emerging technologies—grouped under design modeling, smart factory automation, digital virtualization, and advanced materials—to modernize local construction workflows (CIDB, 2021). Under the "Smart Factory" cluster, Autonomous Construction is designated as a critical pillar expected to enhance output rates, mitigate occupational hazards, and reduce dependence on low-skilled foreign labor (Islam et al., 2025). Prior empirical studies in the Malaysian context provide substantial insights into the adoption dynamics of specific IR 4.0 technologies. For instance, local literature has thoroughly examined Building Information Modeling (BIM) awareness and implementation hurdles of Industrialized Building Systems (IBS) alongside basic digital site management (Lee et al., 2019). These studies consistently report that while awareness of digital transformation is growing across the Malaysian construction ecosystem, actual execution is hindered by high initial entry costs, workforce digital skill shortages, and organizational inertia (Alaloul et al., 2020; Hosseini et al., 2016).

Despite these preliminary insights, existing Malaysian construction management research exhibits a critical empirical oversight: previous studies treat Construction 4.0 as a monolithic concept or aggregate non-physical software tools (e.g., BIM, cloud collaboration) with physical site automation (Alaloul et al., 2020). Consequently, current literature fails to isolate Autonomous Construction hardware as a distinct empirical construct. The specific adoption rates, operational readiness, and prioritized barrier rankings governing physical autonomous equipment—such as autonomous earthmoving machinery, robotic masonry systems, and automated layout rovers—remain unexamined in the Malaysian context (Yahya et al., 2019).

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Aggregate studies obscure the reality of physical automation, which requires vastly higher capital outlays, specialized on-site operational capabilities, and real-time physical telemetry compared to basic design software (Kozlovska et al., 2021).

To systematically address this empirical gap, this study investigates the adoption levels and prioritizes execution barriers to Autonomous Construction, focusing explicitly on Grade G7 contractors operating within Kuala Lumpur. The selection of Grade G7 contractors is strategically justified: as the highest licensing tier registered under the CIDB (entitled to undertake projects of unlimited financial value), G7 contractors possess the capital capacity, organizational scale, and risk tolerance required to absorb the high initial Capital Expenditure (CapEx) and maintenance costs of autonomous equipment (Yahya et al., 2019). Lower-tier contractors (G1–G6) face stringent financial constraints and generally lack the scale to serve as early adopters of heavy cyber-physical technology. Furthermore, Kuala Lumpur serves as the optimal geographic scope for this study. As Malaysia’s primary economic hub, Kuala Lumpur hosts the highest density of ongoing mega-infrastructure and high-rise developments, houses the headquarters of major G7 contractors, and possesses the necessary digital infrastructure (including commercial 5G coverage and low-latency IoT networks) essential for real-time autonomous telemetry.

Evaluating G7 contractors in Kuala Lumpur provides an empirical baseline to measure industry readiness against national strategic goals. By conducting a diagnostic assessment of current adoption levels and empirically ranking economic, technological, organizational, and socio-ethical barriers, this study provides actionable insights for policy frameworks, enabling CIDB, industry leaders, and academic institutions to bridge the readiness-adoption gap in Malaysia's construction sector.

Literature Review

Autonomous Construction: Conceptual Framework and Ecosystem

Autonomous Construction refers to an automated execution paradigm that integrates computer-controlled robotics, artificial intelligence (AI), multi-sensor arrays, and cyber-physical machinery to carry out building and civil engineering operations with minimal direct human intervention (CIDB, 2021; Mehrani, 2024; Zhuo & Duan, 2024). Driven by the strategic imperatives of site productivity, operational safety, and environmental sustainability, construction automation has evolved from simple mechanized tools into self-sufficient operational ecosystems (Zhuo & Duan, 2024). Modern autonomous construction systems utilize real-time telemetry, spatial computer vision, and machine-learning algorithms to perform complex tasks—including automated earthmoving, spatial surveying, structural component fabrication, and dynamic site inspection—without continuous human steering (Islam et al., 2025; Mehrani, 2024).

Reflecting this global technological shift, the international market for autonomous construction machinery was projected to expand from RM38.37 billion in 2020 to RM61.31 billion by 2025, representing a compound annual growth rate (CAGR) between 10.0% and 11.1% (Choi & Borchardt, 2022). Leading Original Equipment Manufacturers (OEMs)—such as Caterpillar, Komatsu, Volvo, Hitachi, Built Robotics, Cyngn, Royal Truck & Equipment, Case, and Deere & Company—are actively commercializing autonomous retrofits and driverless machinery to address global labor shortages while enhancing task precision and schedule reliability (Choi & Borchardt, 2022).

The contemporary autonomous construction ecosystem comprises four primary technology typologies:

1. **Autonomous Vehicles and Heavy Machinery:** Integrates AI-driven driverless excavators, automated dump trucks, self-driving bulldozers, and intelligent crane systems capable of spatial path planning and payload optimization (Islam et al., 2025; Mehrani, 2024).
2. **Robotic Autonomy and Single-Task Construction Robots (STCRs):** Encompasses trade-specific robotics engineered for labor-intensive, highly repetitive operations, including automated bricklaying, plastering, tile-laying, painting, and structural condition monitoring (Gabbar, 2024; Wang, 2022).
3. **Additive Manufacturing (3D Concrete Printing):** Leverages slipform 3D printers and large-scale robotic arms linked directly to Building Information Models (BIM) to fabricate structural elements with minimal material waste (Parusheva, 2019). In Malaysia, this is demonstrated under the Construction Industry Development Board's (CIDB) Construction 4.0 initiative through a 3D-printed housing pilot project in Sarawak (Adlina, 2024; Huseien et al., 2024; CIDB, 2021).
4. **Aerial Autonomy and Spatial Monitoring:** Utilizes Unmanned Aerial Vehicles (UAVs) equipped with photogrammetry and LiDAR sensors to automate topographical mapping, progress tracking, and site safety audits (Abdullah et al., 2023; Alwashah et al., 2024).

Table 1 synthesizes these core typologies along with their specific operational site roles.

Table 1. Taxonomy and Operational Roles of Autonomous Construction Technologies.

Technology Typology	Autonomous Tool / System	Primary Operational Role	Core Citations
Autonomous Vehicles & Heavy Machinery	• Unmanned Excavators • Autonomous Dump Trucks • Self-Driving Bulldozers • Intelligent Crane Systems	Automated earthmoving, dynamic path planning, collision avoidance, heavy payload hauling, and site surveillance.	Choi & Borchardt (2022); Islam et al. (2025); Mehrani (2024)
Robotic Autonomy in Trade Operations	• Bricklaying Robots • Painting Robots • Tile-Laying Robots • Plastering Robots	Precision masonry execution, automated surface finishing, high-risk elevated work, and repetitive site assembly.	Gabbar (2024); Wang (2022)
Additive Manufacturing (3D Printing)	• Large-Scale 3D Printing Robotic Arms • Slipform 3D Concrete Printers	On-site/off-site structural element fabrication directly from BIM models, reducing formwork waste and manual labour intensity.	Adlina (2024); Huseien et al. (2024); Parusheva (2019)

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Technology Typology	Autonomous Tool / System	Primary Operational Role	Core Citations
Aerial Autonomy & Spatial Inspection	• Photogrammetry Survey Drones • Real-Time Monitoring UAVs • LiDAR Inspection Drones	Automated topographical mapping, high-resolution progress monitoring, structural health assessment, and aerial hazard audits.	Abdullah et al. (2023); Alwashah et al. (2024)

Challenges in Autonomous Construction Integration

Despite the potential of modern digital technologies to enhance efficiency and site safety, the global construction industry experiences limited adoption of autonomous systems. The key barriers to autonomous construction implementation into six thematic domains: economic feasibility, workforce readiness, operational limits, cybersecurity vulnerabilities, regulatory ambiguity, and organizational culture.

High Initial Cost and Financial Feasibility

High capital expenditure remains the primary obstacle to deploying advanced construction technologies, particularly in developing sectors such as Malaysia. The Building Contractors Association of Malaysia (MBAM, 2024) emphasized that prohibitive costs delay technology adoption, prompting requests for policy and budget interventions. Financial barriers extend beyond initial equipment acquisition to encompass infrastructure development, continuous software maintenance, specialized consulting, and employee training (Almatari et al., 2024; Alwashah et al., 2024; Hosseini et al., 2016). Unclear return on investment (ROI) metrics further discourage stakeholders from committing to long-term digital investments (Alwashah et al., 2024; Hosseini et al., 2016).

Workforce Capabilities and Human Capital Readiness

The transition toward automated and computerized procedures is constrained by an acute shortage of skilled personnel capable of operating, programming, and maintaining digital tools (Alwashah et al., 2024; Malomane et al., 2022). This expertise gap creates operational bottlenecks and slows industry growth (Osunsanmi et al., 2020). Additionally, fear of job displacement hinders adoption, particularly in developing regions where access to specialized technical training and educational resources is limited (Sherratt et al., 2020).

Operational Constraints and System Adoption

The fragmented, project-based structure of the construction sector complicates the deployment of standardized autonomous technologies across variable site environments (Lattanzi & Miller, 2021). Conservative industry norms, tight budgets, software interoperability issues, and inadequate site network infrastructure restrict widespread integration (Almatari et al., 2024; Juma & Shaalan, 2020; Sookhak et al., 2019). Furthermore, Small and Medium Enterprises (SMEs) face financial exposure due to the high cost of autonomous machinery and difficulty in projecting safety and productivity ROI (Adhikari & Vadlamudi, 2025; Lattanzi & Miller, 2021; Ma, 2024; Pan et al., 2021).

Cybersecurity Vulnerabilities and Data Governance

Interconnected autonomous systems—including sensor networks, GPS, and cloud platforms—expose construction projects to cyber threats, including data breaches, system hijacking, and unauthorized intrusions (Alaloul et al., 2020; Duan et al., 2025; Liang et al., 2023). Sensor-targeted attacks such as GPS spoofing or LiDAR data manipulation risk operational errors, site accidents, and equipment damage (Hussain, 2022; Taha, 2024). Furthermore, fragmented site data and "black-box" decision-making in Artificial Intelligence (AI) models undermine system transparency and user trust (Sarsam & Hassan, 2025; Yap, 2025).

Regulatory Frameworks and Legal Ambiguity

Existing safety codes, building regulations, and zoning laws assume human-operated workflows, presenting compliance barriers for driverless vehicles and robotic equipment (Fan, 2022; Lattanzi & Miller, 2021; Woodhead et al., 2018). Legal liability allocation in the event of autonomous equipment failures or site accidents remains unresolved among manufacturers, software developers, site managers, and owners (Duan et al., 2025; Wang et al., 2022; Yap, 2025). Non-uniform regulations across regions increase compliance overheads and impede geographic scaling (Lattanzi & Miller, 2021).

Organizational Culture, Digital Leadership, and Upskilling

Cultural resistance to change and a preference for traditional methods present persistent barriers to digital transformation (Ghosh et al., 2020; Pan et al., 2021). Overcoming these barriers requires active leadership, clear digital strategy, and the implementation of Common Data Environments (CDEs) to foster collaboration (Chee, 2025; Firanescu, 2024; Olakunle, 2024). Structured upskilling programs focusing on Building Information Modelling (BIM), AI/ML, and robotics taxonomy are necessary to mitigate fear of automation and close the technical skills gap (Chee, 2025; Fernando, 2023; Yap, 2025).

Critical Synthesis and Comparative Analysis of Integration Barriers

Despite the demonstrated performance benefits of autonomous construction, global adoption remains gradual (Juan et al., 2019). Existing literature broadly groups implementation hurdles into six thematic domains: economic feasibility, workforce capabilities, operational and infrastructural constraints, cybersecurity risks, regulatory or legal ambiguity, and organizational culture. However, a critical synthesis reveals that these barriers do not operate uniformly across national economies, technology types, or firm scales.

Cross-National Dynamics: Developed vs. Emerging Economies

A comparative review reveals distinct contextual barrier hierarchies between developed and developing construction markets:

- Universal Barriers: High initial Capital Expenditure (CapEx), software interoperability issues, and legal ambiguities concerning accident liability persist across both high-income and developing economies (Juan et al., 2019; Kozlovska et al., 2021).
- Emerging Market Primacy (e.g., Malaysia, India): Adoption is dominated by immediate financial limitations, lack of government fiscal subsidies, and the structural reliance on low-cost foreign labor (Alaloul et al., 2020; Almatari et al., 2024). In these regions, abundant manual labor lowers the economic motivation to transition toward high-CapEx machinery.
- Developed Market Primacy (e.g., Japan, Singapore, UK): Where severe labor shortages and aging populations force automation, financial barriers are secondary. Instead, adoption is primarily constrained by strict regulatory frameworks (such as airspace permits for UAVs), legal liability allocation, and rigid legacy operating procedures (Juan et al., 2019; Woodhead et al., 2018).

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Contradictions and Theoretical Tensions in Current Literature

The academic discourse surrounding construction automation contains several unresolved empirical tensions:

- The Capital Cost vs. Lifetime Value Paradox: Financial management studies argue that high initial CapEx is an insurmountable hurdle for main contractors (Almatari et al., 2024; MBAM, 2024). Conversely, engineering studies prove that autonomous equipment generates rapid lifetime net-positive Returns on Investment (ROI) by eliminating material rework, accelerating completion times, and reducing occupational injury liabilities (Islam et al., 2025).
- The Employment Disruption Controversy: Socio-technical scholars highlight widespread workforce resistance driven by fear of job displacement among manual laborers (Lee et al., 2019; Sherratt et al., 2020). In contrast, organizational literature argues that automation does not destroy jobs but shifts workforce profiles toward higher-skilled, safer supervisory roles, such as remote fleet managers and system programmers (Mehrani, 2024).

Specific Barrier Differentiation: Drones vs. Single-Task Robots vs. Heavy Machinery

Prior research often aggregates "autonomous technologies" into a single category, obscuring operational differences across hardware typologies:

- Unmanned Aerial Vehicles (Drones): Exhibit low capital entry costs, making procurement accessible (Abdullah et al., 2023). However, their integration is restricted by regulatory and legal constraints, including civil aviation spatial restrictions, data privacy mandates, and strict line-of-sight operating rules.
- Single-Task Construction Robots (STCRs): Trade robotics (e.g., bricklaying or tiling) carry moderate capital costs but are heavily constrained by unstructured site environments and task versatility limitations. Variable physical conditions, uneven ground, and lack of multi-task adaptability hinder real-world performance (Gabbar, 2024; Wang, 2022).
- Autonomous Heavy Machinery: Heavy cyber-physical machinery (e.g., automated excavators, autonomous dump trucks) faces severe financial, infrastructural, and risk barriers. They require massive CapEx, dedicated ultra-low-latency network infrastructure (5G/IoT), and carry significant liability exposure in the event of site collisions or equipment failure (Islam et al., 2025; Kozlovska et al., 2021).

Firm Scale Dynamics: Grade G7 Contractors vs. Small and Medium Enterprises (SMEs)

Contractor classification fundamentally shapes technology adoption capabilities:

- Small and Medium Enterprises (SMEs / Grade G1–G6 Contractors): Suffer from severe capital scarcity, razor-thin profit margins, and lack dedicated R&D resources (Pan et al., 2021). For SMEs, autonomous technology investments represent an existential financial risk (Adhikari & Vadlamudi, 2025; Ma, 2024).
- Grade G7 Contractors: As top-tier licensed contractors under CIDB managing projects of unlimited financial value, G7 firms possess the capital capacity, balance sheets, and project scale required to absorb high initial CapEx (CIDB, 2021; Jaafar et al., 2024). However, G7 contractors face unique organizational and operational barriers, including corporate bureaucracy, multi-tiered subcontractor coordination friction, high switching costs when overriding legacy workflows, and organizational inertia across large

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management structures (Ahmad Sekak et al., 2022; Alaloul et al., 2020; Hosseini et al., 2016).

Methodology

Research Design

This study employed a quantitative research design to assess the current state of autonomous construction implementation in Kuala Lumpur and identify its barriers. The approach allowed for systematic collection and statistical analysis of data from a large sample of construction professionals.

Population and Sampling

The target population comprised G7 contractors registered with the Construction Industry Development Board (CIDB) Malaysia and operating in Kuala Lumpur. These contractors represent the highest registration grade and are typically engaged in large-scale construction projects. According to CIDB website, there are approximately 1,814 G7 contractors in Kuala Lumpur.

By referring to Krejci and Morgan's formula (1970), a sample size of 317 companies was determined. A simple random sampling technique was used to select respondents, ensuring that each firm had an equal chance of participation, thus improving the generalizability of the findings.

Data Collection

Primary data was collected through a structured questionnaire distributed electronically via email and *WhatsApp* medium to the selected G7 contractors. Before the questionnaire is being distributed to the selected respondent, the questionnaire must go through research ethics committee from the respective institutional and got consent. The questionnaire was developed based on an extensive literature review and contained two key sections

- Section A: Level of autonomous construction implementation (Yes/No -Dichotomous)
- Section B: Challenges in autonomous construction (Likert scale)

For section B, respondents rated their agreement with various statements using a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree).

Data Analysis

Data were analysed using descriptive statistics to identify trends and patterns in autonomous construction implementation and challenges in autonomous construction

Finding and Discussion

There was a total of 317 surveys that were distributed to the companies who work as contractors, and 97 of them were collected, resulting in a response rate of 30% percent. Malnik (2023) and Wu(2022) has stated that above 30% is considered as a good response rate for email survey. An adaption of SPSS is used to perform an analysis on the 97 answers that were gathered by all of the respondents from the surveys.

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Level of Implementation of Autonomous Construction in the Construction Industry

This study evaluates the implementation status of autonomous construction methods among contractors by analysing four core domains: autonomous machinery, construction robotics, 3D printing, and drones. Dichotomous responses are interpreted through the comparative ratio of affirmative adoption or familiarity rates against negative responses.

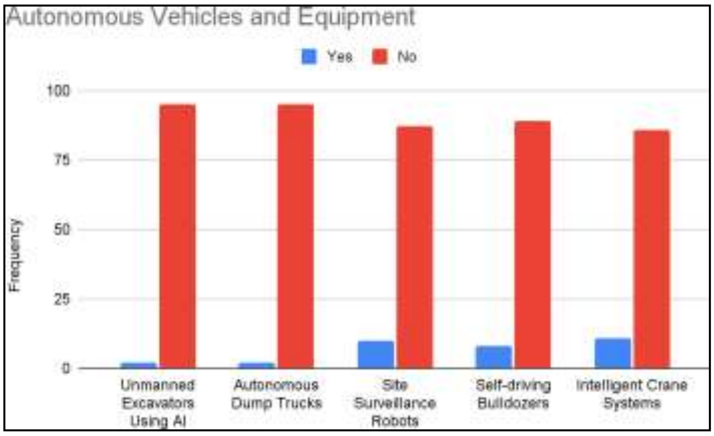

Figure 1: Autonomous Vehicles and Equipment

Based on the figure 1, empirical findings indicate that the industry-wide adoption of autonomous vehicles and equipment among construction contractors remains exceedingly limited. Specifically, utilization rates for unmanned AI excavators and autonomous dump trucks are each restricted to 2.1% of respondents, whereas self-driving bulldozers and site surveillance robots account for 8.2% and 10.3%, respectively. Furthermore, intelligent crane systems exhibit an adoption rate of 11.3%. Collectively, these results demonstrate a pronounced lack of widespread deployment and market penetration of autonomous machinery across contemporary construction projects.

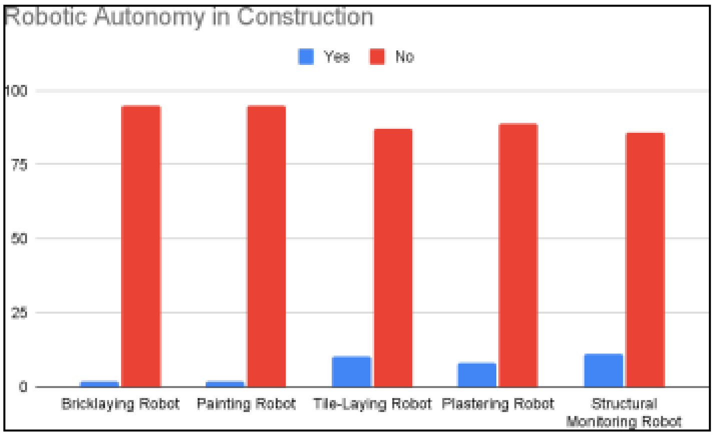

Figure 2: Robotic Autonomy in Construction

The data reveal a similarly restricted deployment of robotic autonomy within the surveyed contracting firms. Utilization rates for task-specific construction robots remain negligible, with bricklaying and painting robots each utilized by merely 4.1% of respondents. Similarly, tile-laying, plastering, and structural monitoring robots account for adoption rates of 5.2%, 6.2%, and 8.2%, respectively, with non-adoption rates exceeding 91% across all categories. In

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aggregate, these findings confirm that the integration of robotic autonomy into standard construction workflows is currently minimal.

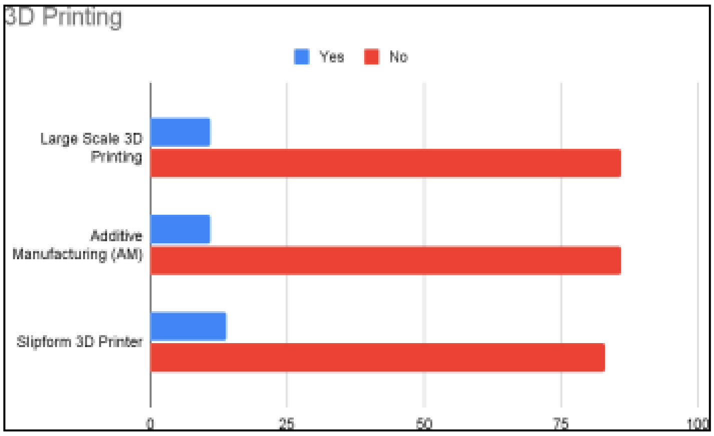

Figure 3: 3D Printing

3D printing technology adoption among the construction industry respondents surveyed was low, as demonstrated by only 11 respondents (11.3%) reporting the use of large-scale 3D printing and 86 respondents (88.7%) reporting non-usage. The same pattern holds for additive manufacturing (AM), where 11 respondents (11.3%) used it, and 86 respondents (88.7%) did not. However, use of a slipform 3D printer was reported by 14 respondents (14.4%), while 83 respondents (85.6%) did not use this type of printer. Therefore, the results suggest that the current use of 3D printing solutions in the construction industry remains minimal.

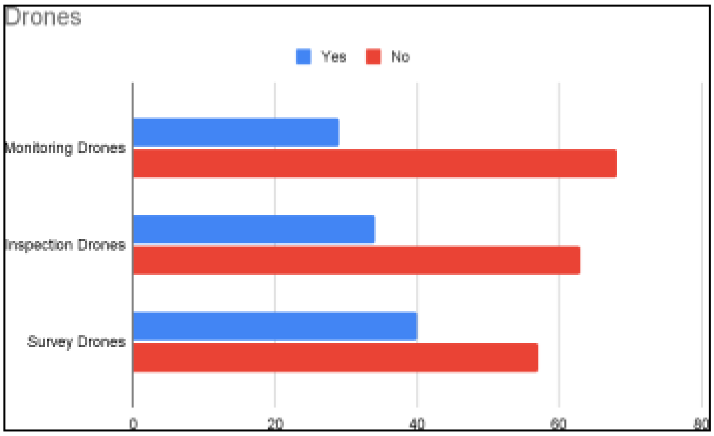

Figure 4: Drones

Drones are likewise under-utilized, with an average percentage and frequency analysis revealing a very low level of adoption among the surveyed professionals. The 29 respondents (29.9%) reported using drones for monitoring purposes, whereas 68 respondents (70.1%) indicated not using it. The same pattern was observed across the other drone categories, where 34 respondents (35.1%) reported using drones for inspection purposes, and 63 respondents (64.9%) did not use it. Then, 40 respondents (41.2%) reported using drones for surveying, while 57 respondents (58.8%) did not. Consequently, based on the available evidence, drones are not widely utilized in the construction profession.

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Discussion on level of implementation of autonomous construction in Malaysia
Empirical evaluation of autonomous technology adoption among G7 contractors in Kuala Lumpur reveals a nascent, pragmatic integration model characterized by a preference for supportive over labor-replacing innovations (Almatari, 2021; Nik Yahya et al., 2020). Higher acceptance rates were observed for non-disruptive technologies—such as UAVs for surveying, intelligent crane systems, and task-specific robots (e.g., tile-laying, structure-monitoring)—which offer immediate efficiency and safety gains without overhauling traditional workflows (Halder, 2023; Zhou et al., 2024). Conversely, fully autonomous systems, heavy equipment (e.g., unmanned excavators), and large-scale 3D printing exhibit minimal deployment due to substantial capital costs, steep IT infrastructure requirements, regulatory hurdles, and persistent operational rigidity (Islam et al., 2025; Ling et al., 2020; Melenbrink et al., 2020). Collectively, these findings indicate that while Malaysian contractors receptively integrate workflow-enhancing tools, the broader industry remains in the early stages of systemic process automation.

Challenges of Autonomous Construction Used in Construction Projects

Table 2: Challenges of Autonomous Construction Used In Construction Projects

	Decsriptions	Mean	Perception Level	Rank
A	Limited Adoption Of Autonomous Technologies	4.59	High	1
B	Lack Of Knowledge	4.56	High	2
C	Lack Of Digital Culture And Training	4.55	High	3
D	High Initial Cost	4.53	High	4
E	Security Issues	4.42	High	5
F	Government And Regulatory Barriers	4.41	High	6
G	Unreadiness Employees	4.40	High	7

An evaluation of mean score rankings demonstrates ubiquitous agreement among respondents that multiple structural, financial, and organizational barriers impede the integration of autonomous technologies, with all evaluated variables registering high mean values .The primary impediment identified was the limited existing adoption baseline (,Rank 1), corroborating the core findings of Objective 1 regarding low operational deployment. This reflects an industry-wide conservatism and risk-averse behavior wherein contractors privilege legacy construction paradigms over unproven innovations (Almatari, 2021; Nik Yahya et al., 2020). Deficits in digital knowledge (Rank 2) and organizational digital culture and training (Rank 3) emerged as key secondary constraints. As noted by Wang et al. (2022) and Nasir et al. (2023), pervasive digital illiteracy regarding artificial intelligence and robotics fosters institutional reluctance, inhibiting the shift from conventional manual operations to data-centric automated decision-making. Extensive capital expenditure requirements (Rank 4) present further economic friction; high setup costs extend beyond initial equipment acquisition to encompass maintenance overhead, staff upskilling, and prerequisite IT infrastructure (Alwashah et al., 2024; CIDB, 2023; Hosseini et al., 2016; Nasir et al., 2023). Furthermore,

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cybersecurity vulnerabilities (Rank 5) and regulatory ambiguity (Rank 6) constitute systemic headwinds. Incomplete legislative frameworks and unquantified security risks create strategic uncertainty, constraining long-term capital commitment (Aghimien, 2023; Sarsam & Hassan, 2025).Finally, while employee unreadiness recorded the lowest relative mean (Rank 7), its magnitude still indicates strong respondent consensus. This human-centric barrier reflects workforce anxiety surrounding job displacement and task redefinition, underscoring the necessity of structured organizational reskilling and change management frameworks to mitigate technological resistance (Osunsanmi et al., 2018).

Conclusion and Recommendations

The findings demonstrate that autonomous construction technology adoption among Malaysian G7 contractors remains nascent and risk averse. Integration is largely confined to supportive, non-disruptive innovations—such as surveillance UAVs, inspection drones, and structural monitoring systems—while fully autonomous vehicles, construction robotics, and large-scale 3D printing exhibit minimal deployment. Malaysian contractors prioritize low-risk assistive technologies that enhance site visibility and safety without altering core operational workflows, a pragmatic trajectory mirroring the adoption phases observed in developed nations. This reflects a broader industry conservatism and reluctance toward high-risk technological shifts.

Crucially, the study establishes that adoption barriers transcend technical constraints, encompassing multifaceted financial, organizational, regulatory, and human resource challenges:

- **Financial & Capital Constraints:** High upfront expenditures for equipment procurement, system integration, continuous maintenance, and prerequisite infrastructure create severe economic risk, discouraging early investment.
- **Organizational & Human Capital Deficits:** Inadequate digital literacy and organizational culture foster persistent workforce reluctance. Without structured change management, transparent communication, and dedicated reskilling frameworks, employee fears surrounding role displacement and functional changes drive acute institutional resistance.
- **Regulatory & Systemic Obstacles:** Vague legal guidelines and unstandardized regulatory frameworks introduce long-term compliance uncertainties, further constraining capital allocation.

Overall, transitioning the Malaysian construction sector from basic assistive tools to systemic autonomous implementation requires an integrated strategy that pairs capital assistance and clear regulatory frameworks with structured organizational change management.

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