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Trends and Challenges of CAD Implementation in Robotics Development in Southeast Asia

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Abstract: In Southeast Asia, the integration of Computer-Aided Design (CAD) into robotics development has become increasingly vital in meeting the growing demand for rapid, task-specific automation. CAD plays a central role in enhancing how robotic systems are designed, simulated, and prototyped—enabling improved design precision, reduced development time, and accelerated innovation. This paper investigates the current trends in CAD applications for robotics and highlights key opportunities, including collaborative design approaches, rapid prototyping capabilities, and the convergence of digital engineering tools. Furthermore, the study discusses critical technical considerations such as software interoperability, real-time simulation integration, and the need for upskilling in CAD-related competencies. Drawing from both academic research and industrial practice across Southeast Asian countries, the findings reveal a pressing need for tighter integration between CAD platforms, robotic simulation environments, and control systems. The analysis identifies several regional challenges, including limited access to advanced CAD tools, inconsistent adoption in educational curricula, and disparities in technical training infrastructure. The paper concludes with strategic recommendations to support the growth of CAD-driven robotics in the region: bridging the digital skills gap, improving access to design technologies, promoting cross-institutional collaboration, and encouraging targeted research to adapt CAD tools to local industrial needs. These efforts are crucial for enabling Southeast Asia to capitalize on CAD's transformative potential in developing agile, affordable, and application-specific robotic solutions.

Keywords: CAD (Computer-Aided Design), Integration, Prototyping, Robotics, Simulation.

1. Introduction

Computer-Aided Design (CAD) plays a vital role in modern robotics development by enabling a precise, efficient, and iterative design process for robotic systems [1]. CAD tools integrate multidisciplinary engineering domains, allowing designers to simulate mechanical structures, analyze kinematics, and plan control systems within a unified digital environment [2]. Such integration is essential as robotics systems grow more complex to meet the evolving needs of industry and society.

The rise of Industry 4.0 and digital manufacturing further reinforces the importance of CAD, as it bridges digital design with automated production and real-time monitoring [3]. CAD supports rapid prototyping and robot customization, enabling agile manufacturing processes and intelligent automation. Furthermore, CAD has become foundational in engineering education, equipping future engineers with critical skills for the design and development of advanced robotics [4].

The demand for robotic technologies is rising due to economic growth and industrial development in Southeast Asia. Nonetheless, the implementation of CAD in robotics education and design varies significantly because of differences in infrastructure, access to training, and financial support [5]. Numerous vocational and higher education organizations are striving to incorporate CAD, yet encounter difficulties concerning curriculum content and resource accessibility [6]. The effectiveness of design and prototyping using CAD is essential for creating cost-effective and locally relevant robotic solutions in sectors like manufacturing, agriculture, and logistics [7].

Recent research has shown notable progress in CAD technologies for robotics. Nguyen Thanh Hung and Tran Van Hieu demonstrated that the integration of CAD with simulation environments enhances design precision and decreases development duration [8]. In a similar vein, Lee Sung Min and colleagues suggested a cloud-based CAD platform to facilitate collaborative robot design for distributed teams, enhancing accessibility in developing nations [9]. Chai Wun Kai and Tan Wei Lun explored methods for incorporating CAD into vocational curricula in Southeast Asia, highlighting regional content and affordable software options [6], whereas Kumar Rajesh and Singh Harpreet demonstrated how CAD facilitates interdisciplinary learning and prepares students for innovation in robotics education [4].

From an industrial viewpoint, Rahman Md. Ashrafur and Hasan Muhammad. Kamrul emphasized that CAD speeds up robot prototyping in small and medium-sized enterprises (SMEs), which are vital to ASEAN's industrial foundation [7], although issues like software compatibility and shortages of skilled labor remain. Simultaneously, Chua Wai Kit and Ong Mei Ling investigated the application of generative design algorithms in CAD to enhance robotic structures regarding weight and strength, demonstrating significant innovation potential [3].

The socio-economic aspects and policies related to CAD adoption are similarly important. Lim Wei Jie and Tan Pei Ling examined ASEAN policy frameworks, highlighting the significance of public-private partnerships and regional collaboration to tackle gaps in technology and human capital [5]. These results illustrate the intricate nature of CAD implementation in robotics, involving technical, educational, and policy-related factors.

This study aims to examine current trends in CAD adoption within robotics development in Southeast Asia. It seeks to identify key opportunities arising from CAD integration in both education and industry, evaluate critical technical and social factors influencing adoption, and uncover major challenges faced by institutions and industrial stakeholders. The findings are intended to provide a comprehensive foundation for informing policy development, shaping educational strategies, and fostering regional collaboration to accelerate CAD-driven robotics innovation across the region.

2. Literature Review

2.1. CAD in Global Robotics

Computer-Aided Design (CAD) plays a foundational role in the mechanical component design of robotic systems by enabling parametric modeling and precision engineering [10]. It allows designers to create and iterate complex parts such as gear trains, linkages, and end-effectors, ensuring manufacturability and performance. For instance, Abdelmajid Ben Yahya, Santiago Ramos Garces, Nick Van Oosterwyck, Annie Cuyt, and Stijn Derammelaere present a CAD-based Bayesian optimization framework that integrates constraint handling and motion simulation for mechanism planning, showcasing CAD's capability for design automation [11].

Motion simulation within CAD environments supports dynamic analysis and control integration in robotic design. Punith Reddy Vanteddu, Gabriele Nava, Fabio Bergonti, Giuseppe L'Erario, Antonello Paolino, and Daniele Pucci demonstrate how CAD geometry directly transitions into URDF for control co-design in a jet-powered humanoid, linking physical CAD models with ROS-compatible control schemas [12]. This bridges the gap between mechanical design and control parameters by directly leveraging CAD in motion planning pipelines.

CAD also facilitates virtual testing of robotic subsystems prior to manufacturing. Arthur Niedźwiecki, Sascha Jongebloed, Yanxiang Zhan, Michaela Kümpel, Jörn Syrbe, and Michael Beetz describe a cloud-based digital twin platform where CAD-driven simulation is combined with cognitive systems, using containerization and real-time visualization via RvizWeb [13]. This approach improves early debugging and supports remote development workflows common in educational and industry collaborations.

The shift from traditional 2D drafting to advanced 3D parametric and feature-based CAD systems has transformed mechanical component modeling for robotics. Claudius Kienle, Benjamin Alt, Darko Katic, and Rainer Jäkel introduce QueryCAD, a grounded question-answering system for CAD models, enabling designers to query parts directly in natural language and integrate retrieved information into robot program synthesis [14]. This marks an important step toward interactive, information-rich CAD environments.

Cloud-based CAD platforms are driving real-time collaboration and data sharing among globally distributed robotics teams. Chengcheng Zhao, Jianping He, Zhi Yan, Chi Xu, Wenchao Xu, Hongwen Xing, Zhibo Pang, and Peng Cheng report on cloud and fog computing paradigms presented at IEEE ICCC 2024, which extend CAD functionality via distributed processing for motion simulation and joint optimization in robot fleets [15]. This distributed approach allows constrained devices to cooperate in high-compute tasks, enhancing scalability.

Digital twin technology increasingly underpins robotic system design by closely integrating CAD-generated models with rigorous dynamic simulations. Giovanni Boschetti and Teresa Sinico illustrate the use of high-fidelity robot digital twins developed via Simscape Multibody, which incorporate joint friction, transmission gears, and actuator dynamics. Their work demonstrates that CAD-based simulations achieve high dynamic accuracy, making them reliable for validating control strategies such as computed torque control [16].

CAD-enhanced digital twin methodologies also play a critical role in collaborative robot cells. Christian Cella, Marco Faroni, Andrea Zanchettin, and Paolo Rocco present a Bayesian optimization framework using a digital twin of a human–robot workspace for pre-deployment layout design. By coupling CAD models with Key Performance Indicator-based optimization, their method reduces prototyping cycles and enhances safety and efficiency in collaborative handling tasks [17].

In industrial assembly and disassembly, CAD-powered digital twins support autonomous planning. Deogratias Kibira, Guodong Shao, and Rishabh Venketesh report on leveraging digital twins to generate robotic disassembly sequences by integrating CAD models of assets into planning algorithms. This integration facilitates better path planning and collision avoidance, situating CAD as a keystone in automated industrial planning [18].

Recent advancements also integrate augmented reality (AR) with CAD-based digital twins to support no-code robotics design. Christoph Wree and Jan Hebekerl demonstrate a no-code interface that uses cloud-based CAD models and digital twin data combined with AR overlays. Their system allows non-experts to configure pick-and-place robot operations through an intuitive AR interface, democratizing robotic programming and deployment [19].

Semantic enrichment of CAD models for digital twins enhances interoperability and automation. A publication in Software and Systems Modeling presents a framework that couples CAD models with semantic lifting, embedding metadata into the model to support automation, verification, and simulation workflows. This approach improves traceability from CAD to robotics execution and enables model-driven development pipelines [20].

Recent advancements in AI-driven CAD elevate creative modeling in robotics through tool-augmented large language and vision models (VLLMs). Dimitrios Mallis, Ahmet Serdar Karadeniz, Sebastian Cavada, Danila Rukhovich, Niki Foteinopoulou, Kseniya Chernenkova, Anis Kacem, and Djamila Aouada introduce CAD-Assistant, which integrates VLLMs with FreeCAD Python APIs to autonomously interpret multimodal commands and iteratively refine CAD designs for robotics tasks [21].

The future of CAD is marked by "Intelligent CAD 2.0," featuring deeper AI integration. Qiang Zou, Yincai Wu, Zhenyu Liu, Weiwei Xu, and Shuming Gao assert that CAD is shifting from extensional (drawing-based) to intensional (intent-based) systems, where generative AI actively participates in structure proposal, constraint enforcement, and performance optimization [22].

Text-to-CAD workflows are gaining traction, translating human intent to mechanical models. Systems such as CADCrafter and others map verbal or written descriptions into solid geometry, enabling designers to sketch or describe robotic linkages and receive actionable CAD models. This enables rapid iteration and lowers the barrier to entry for non-engineers, although usability studies remain in early experimental stages [23].

Image-to-CAD technologies are also emerging, aiming to reverse-engineer CAD-ready models from photographs. Early systems demonstrate that a single image can seed reconstruction of 3D part geometry, though they still grapple with occlusion and noise. This line of research promises accelerated development of robot components from real-world prototypes or legacy parts [24].

CAD increasingly integrates with digital twin and robotics operating systems (ROS), enabling seamless pipeline transitions between design, simulation, and deployment. Sorin Grigorescu and Mihai Zaha present CyberCortex.AI, an AI-powered ROS-compatible environment that draws CAD models into autonomous planning, perception, and control workflows for mobile robots [25].

CAD tools face notable challenges in usability and interoperability within robotics. Florian Maximilian Langer, Jihong Ju, Georgi Dikov, Gerhard Reitmayr, and Mohsen Ghafoorian introduce FastCAD, a real-time CAD alignment framework that retrieves and aligns CAD models to scans and videos with high accuracy [26]. Their work emphasizes the need for seamless CAD integration into vision-based systems, reducing friction when transitioning from design to real-world robotic deployment.

Synthetic CAD data is increasingly used to train deep learning models for quality inspection in assembly tasks. Xuejie Zhu, Patrik Mårtensson, Lars Hanson, Johannes Bergquist, Mattias Kristensson, Dirk Metzger, Tim Bröcker, and Hemming Lehtinen show that 2D and 3D synthetic CAD datasets significantly enhance defect detection accuracy and robustness in robotic assembly lines [27]. Their results underline CAD's crucial role in generating training data for intelligent robotic systems.

Integration of CAD with artificial vision for collaborative cobot systems is gaining momentum. Antonio A. Santos, Christian Schreurs, and Alvaro F. da Silva develop a CAD-informed vision pipeline that enables pick-and-place cobots to detect and localize parts accurately [28]. Their research illustrates how CAD models serve as ground truth geometry in vision systems, improving operational efficiency and deployment speed.

Reverse engineering from multi-view images to CAD models facilitates legacy part reconstruction for robotics. Henrik Jobczyk and Hanno Homann present DeepCAD, a multi-view image-based CAD generation system that reconstructs editable CAD models from sensor data, supporting robotic maintenance and spare-part replication [29]. This work reflects CAD's expanding role in supporting robotic autonomy via model reuse.

Text-to-CAD systems continue to advance toward fully automated design pipelines. Ruiyu Wang, Yu Yuan, Shizhao Sun, and Jiang Bian propose CADFusion, which trains language models to generate CAD parametric sequences using alternating visual feedback and sequential training stages [30]. Concurrently, Yandong Guan, Xilin Wang, Xingxi Ming, Jing Zhang, Dong Xu, and Qian Yu introduce CAD-Coder, a reinforcement-learning-enhanced LLM that outputs CadQuery scripts via chain-of-thought prompting, advancing CAD automation [31].

2.2. CAD Studies in Southeast Asia

Computer-Aided Design (CAD) adoption in Southeast Asia's technical education and manufacturing sectors gains increasing attention due to the region's rapid industrialization and digital transformation efforts. Scholars like Nurul Afiqah Mohd Zulkefli, Ahmad Hazwan Zainal Abidin, and Norazlina Abd Aziz emphasize that CAD tools serve as fundamental enablers for enhancing students' design skills and improving manufacturing efficiency in Malaysia's vocational institutes [32]. The integration of CAD into curricula aligns with national initiatives toward Industry 4.0 readiness, especially in Malaysia's education policy [32].

In Singapore, CAD adoption in higher education and industrial settings exhibits significant maturity. Research by Wei Li, Samuel Tan, and Jinghui Liu notes that Singapore Polytechnic integrates advanced CAD platforms like SolidWorks and AutoCAD into engineering diplomas, enabling students to gain industry-relevant skills. Furthermore, local manufacturers leverage CAD for rapid prototyping and precision fabrication, supporting the nation's push toward smart manufacturing [33].

Indonesia shows rapid growth in CAD integration within technical universities, though challenges remain in standardizing curriculum and software accessibility. Dwi Hartono, Rina Sari, and Bambang Nugroho identify infrastructure disparities across urban and rural campuses, which hinder consistent CAD training. Their study stresses the need for government-led initiatives to provide affordable licenses and

Vietnamese institutions increasingly adopt CAD tools to support mechanical and electrical engineering programs. Nguyen Thi Thu Ha, Le Van Minh, and Tran Quang Tuan highlight collaborations between universities and manufacturing firms that facilitate hands-on CAD training aligned with real industrial processes. This model bridges the gap between theoretical knowledge and practical application, fostering workforce readiness [35].

A cross-country comparative study by Siti Nurhaliza Osman, Chong Wei Ying, and Hoang Van Dung reveals disparities in CAD software adoption rates between Singapore, Malaysia, Indonesia, and Vietnam. Singapore leads with over 80% adoption in engineering programs, while Indonesia and Vietnam lag below 50%, attributed mainly to funding constraints and lack of faculty expertise [36].

Despite growing adoption, a significant theory-practice gap persists in CAD education at secondary and vocational levels. Ahmad Fauzi, Nurul Huda, and Tran Minh Long discuss that while curricula include CAD fundamentals, limited access to up-to-date software and hardware prevents effective hands-on learning. The mismatch affects student preparedness for higher education and industry demands [37].

The ASEAN Manufacturing Industry Survey by Lim Chee Heng, Maria Lourdes Garcia, and Tran Van Anh underscores the uneven implementation of CAD in small and medium-sized enterprises (SMEs). The survey reports that only 30% of SMEs in Malaysia and Indonesia use CAD regularly, citing cost, technical skills shortages, and resistance to change as main barriers. This limits competitiveness in the regional and global markets [38].

Research by Thuy Nguyen, Pham Quang Vinh, and Le Thi Mai emphasizes that Vietnamese vocational training centers increasingly adopt cloud-based CAD platforms to overcome hardware limitations. Cloud CAD tools enable students to access advanced software remotely, facilitating consistent practice and collaboration, which positively impacts skill acquisition despite infrastructure challenges [39].

In Malaysia, government initiatives such as the National Industry 4.0 Policy (Industry4WRD) provide subsidies and training programs to increase CAD adoption in small manufacturers. Chong Wei Fong, Ahmad Faizal Abdul Karim, and Nur Syafiqah Mazlan evaluate the policy's effectiveness, noting increased CAD integration but highlighting the need for continuous technical support to sustain adoption [40].

Indonesia's manufacturing industry faces bottlenecks due to limited skilled CAD professionals. Putri Lestari, Arif Kurniawan, and Dedi Setiawan identify this skills gap as a critical barrier, advocating for enhanced collaboration between universities and industry to align CAD education with evolving industrial needs [41].

A study by Lim Hui Ying, Nguyen Van Anh, and Mohd Azmi Hassan highlights the role of international partnerships in elevating CAD education quality in ASEAN. Collaborative programs with foreign universities provide curriculum updates, faculty training, and exposure to the latest CAD technologies, which benefit students and educators alike [42].

The adoption of CAD in Indonesian vocational high schools (SMK) faces curriculum rigidity and lack of qualified instructors, according to Andi Saputra, Rini Melati, and Sri Hartini. Their research suggests curriculum reforms and professional development programs are essential to close the gap between theoretical knowledge and practical CAD skills at the secondary education level [43].

In Singapore's manufacturing sector, the integration of CAD with computer numerical control (CNC) machines streamlines production workflows. Jonathan Tan, Mei Ling Lim, and Rajesh Kumar analyze how CAD-CNC coupling enhances precision and reduces lead times, supporting Singapore's advanced manufacturing strategy [44].

A study by Siti Aisyah, Nguyen Thi Thanh, and Anwar Malik explores the gender gap in CAD education across ASEAN, noting female students' underrepresentation in engineering courses. They propose targeted mentorship and inclusive curriculum design to boost female participation and retention in CAD-related fields [45].

Vietnam's SMEs face challenges in CAD adoption due to licensing costs and limited technical support. Tran Minh Tuan, Le Hoang Anh, and Pham Quang Huy investigate open-source CAD software as cost-effective alternatives, showing promising results in increasing CAD accessibility for small manufacturers [46].

In Malaysia, the role of CAD in product lifecycle management (PLM) is expanding, with firms adopting integrated CAD-PLM solutions for improved collaboration. Farah Nur Azizah, Ahmad Rosli, and Zulkifli Mohamed discuss the positive impact on design iteration speed and cross-functional team communication [47].

The ASEAN Education Ministers' Council emphasizes digital skills development, including CAD proficiency, as critical for future workforce competitiveness. Nurul Hidayah, Lim Wei Ching, and Riza Fauzi recommend regional policy harmonization to standardize CAD training frameworks across ASEAN member states, facilitating labor mobility and industrial synergy [48].

3. Methodology

3.1. Research Method

This study uses a descriptive qualitative approach based on literature studies and secondary data analysis. This approach was chosen to provide a comprehensive understanding of the implementation of Computer-Aided Design (CAD) technology in the development of robotics in the Southeast Asia region, both from the technical, educational, and policy aspects.

Data sources include:
1) Scientific journal articles related to CAD, robotics, and engineering education,
2) Industry reports and white papers from the manufacturing and technology sectors,
3) Policy documents from government agencies and educational organizations,
4) Case studies from educational institutions and industries in ASEAN countries.

The data collection period is focused on the period 2020 to 2025, reflecting the current dynamics in the industry 4.0 era and the development of manufacturing digitalization in the region.

3.2. Analysis Technique

The data was analyzed using thematic analysis methods, to identify key patterns and themes relevant to the research objectives. The results of the analysis are categorized into four main domains that are in line with the focus of the study, namely:
1) Trends in CAD implementation in robotics,
2) Opportunities arising from CAD integration in education and industry sectors,
3) Technical and social considerations influencing CAD adoption,
4) Institutional, policy, and technological limitations and barriers.

In addition, a cross-ASEAN country comparison is also conducted to explore variations in:
1) National policies related to engineering education and innovation,
2) Level of access and readiness of CAD technology,
3) Practices of CAD implementation in vocational curricula and local industries.

This analysis aims to identify gaps and potential for regional collaboration, and provide a basis for policy recommendations and strategies to strengthen CAD integration in robotics design in Southeast Asia.

4. Findings and Discussion

4.1. Trends

The study shows that CAD adoption in Southeast Asia is shifting towards cloud-based and open-source solutions. This makes it easier for educational institutions with limited funds to continue to access the latest technology. In addition, there is an increasing trend of CAD integration with robotic simulation environments, such as the use of SolidWorks with ROS (Robot Operating System) in learning and developing robot prototypes.

Collaboration between industry and educational institutions is also growing in the form of project-based learning, allowing university and vocational high school students to work on real robotic design projects with local companies.

Table 1. CAD Implementation Trends in ASEAN Robotics Education and Industry (2020–2025)

Key Trend	Brief Description
Cloud & Open-Source CAD	Increased use of FreeCAD, Onshape, and Autodesk Fusion 360 Cloud in educational setups.
Simulation Integration	Integration of SolidWorks, Blender, and ROS for robotic motion and control simulation.
Industry-Education Collaboration	Joint internship and training programs focused on project-based robotic design.

1) Cloud & Open-Source CAD

The use of cloud-based and open-source CAD solutions such as FreeCAD, Onshape, and Autodesk Fusion 360 Cloud is increasing in the education environment in ASEAN. This is driven by several key factors: first, the accessibility of much lower costs compared to fully licensed commercial software, making it easier for institutions with limited funds to provide CAD facilities for students and scholars. Second, cloud platforms allow flexible access from various devices and locations, greatly supporting distance learning and cross-institutional team collaboration. However, challenges arise related to the stability of internet connections which still vary in some regions, as well as the need for training for teachers to be able to optimally utilize the features of these platforms. Overall, this trend shows a paradigm shift from expensive locally licensed software to solutions that are more inclusive and adaptive to the needs of modern education.

2) Simulation Integration

The integration of CAD with simulation using software such as SolidWorks, Blender, and Robot Operating System (ROS) marks a significant advancement in the development of robotics in ASEAN. Through this simulation, students and practitioners can virtually model the movement and control of robots before building physical prototypes, significantly reducing development costs and time. SolidWorks provides detailed mechanical design features, Blender supports visualization and animation, while ROS allows real-time simulation of robot control and programming. This approach strengthens cross-disciplinary skills such as mechanics, programming, and control systems, which are essential for future robotic innovation. However, mastering these simulation technologies requires intensive training, as well as adequate computer infrastructure, which is still a barrier in some institutions with limited resources.

3) Industry-Education Collaboration

Collaboration between industry and educational institutions through joint internship programs and project-based training has become an effective model for strengthening human resource capacity in the field of robotics. By involving students in real robot design projects with local companies, they gain practical experience that is relevant to industry needs. This also opens up opportunities for faster technology transfer and innovation, as well as building professional networks that can support their future careers. This approach narrows the gap between academic theory and industrial practice, which is often a criticism of formal curricula. However, the success of this collaboration depends on the alignment of goals between educational institutions and companies, as well as adequate regulatory and funding support from the government and related parties.

Figure 1 shows the adoption rate of cloud-based CAD in several ASEAN countries, namely Indonesia, Malaysia, Thailand, Vietnam, the Philippines, and Singapore. This percentage shows the proportion of educational institutions and industries in each country that have implemented cloud-based CAD during the period 2020 to 2025.

- Singapore ranks highest with around 85% of institutions using cloud-based CAD. This reflects the readiness of very advanced technology, strong digital infrastructure, and support from government and education sector policies that support the rapid adoption of modern technology.

- Malaysia and Indonesia are in the middle position with percentages of around 70% and 60%, respectively. Both countries have shown significant progress in integrating cloud-based CAD, supported by efforts to improve infrastructure and training in the education sector and collaboration with industry.
- Vietnam and Thailand have adoption rates of around 55% and 50%, indicating progress but with certain challenges such as limited technological infrastructure, lack of training, and funding constraints that still need to be overcome to increase the penetration of this technology.
- The Philippines is in the lowest position with a percentage of around 45%, indicating that the use of cloud-based CAD is still relatively limited. Factors such as inequality in internet access, especially in remote areas, and limited skilled human resources, are major obstacles in the country.

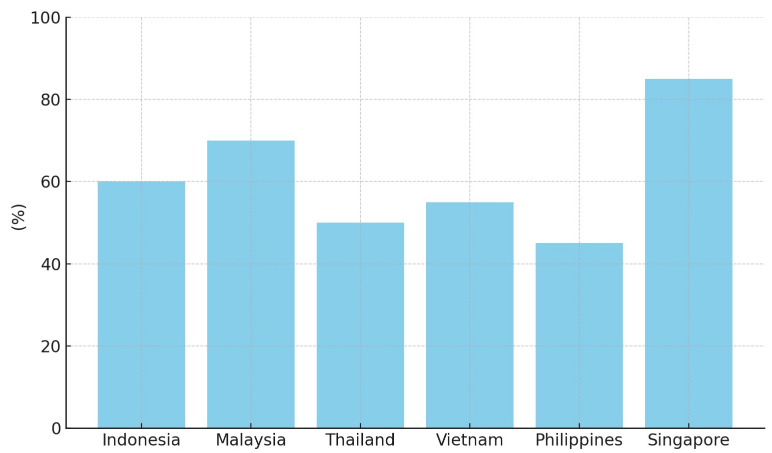

Figure 1. Percentage of ASEAN Institutions Using Cloud-Based CAD (2020–2025)

Figure 1 indicates a disparity in the adoption rate of cloud-based CAD in ASEAN, which is greatly influenced by the readiness of technology infrastructure, education policies, and human resource capacity in each country. Singapore is an example of a country with the best readiness, while the Philippines needs to strengthen infrastructure and training support to accelerate the use of cloud-based CAD technology. Regional efforts and cross-country collaboration can help close this gap so that the integration of CAD in education and the robotics industry in ASEAN can be more equitable and effective.

4.2. Opportunities

It was found that CAD provides great opportunities in developing local robots at low cost, especially when combined with 3D printing technology. Many engineering institutions have started implementing CAD-based curricula at the vocational high school and polytechnic levels, which creates ready-to-use human resources in the manufacturing and automation sectors.

Table 2. Key Opportunities for CAD Integration in Education and Industry

Opportunity	Explanation
Low-Cost Local Robots	Utilization of CAD and 3D printing to reduce development costs.
Curriculum Integration in Vocational/ Polytechnic Schools	CAD applied in mechanical design and robotics subjects.
Regional Research Collaboration	Collaborative robotic design projects among ASEAN universities.

1) Low-Cost Local Robots

Huge Opportunity for Technology Democratization: By utilizing CAD (Computer-Aided Design) and 3D printing technology, robot production costs can be reduced significantly lower than traditional manufacturing methods that require heavy equipment or mass manufacturing processes.

- Sustainable Local Innovation: The development of low-cost local robots encourages innovation that is tailored to specific regional needs, such as agricultural robots in the ASEAN region that can be produced and customized locally without relying on expensive component imports.
- Increased Accessibility for Small and Medium Industries: Small and medium industries (SMEs) or technology startups in the region can utilize CAD and 3D printing for rapid prototyping and production of robots without large capital investments. This opens up new entrepreneurial opportunities and increases regional competitiveness.
- Technical and Material Challenges: However, attention needs to be paid to the quality of 3D printing materials and CAD capabilities so that robots remain reliable and durable. The development of a supportive local material ecosystem is also important.

2) Curriculum Integration in Vocational/ Polytechnic Schools

Strengthening Vocational Education for Industry 4.0: Integration of CAD into the curriculum of vocational schools and polytechnics is very strategic to equip students with modern design skills that are much needed in the era of digitalization of manufacturing and robotics.

- Link and Match with the Industrial World: With CAD knowledge, graduates have ready-to-use competencies for the robotics and manufacturing industry, thereby reducing the skills gap between education and labor market needs.
- Increasing Local Interest and Capacity: Students who are familiar with digital design and prototyping technology are more creative and innovative in developing locally relevant robotic solutions.
- Need for Teacher Training and Infrastructure: Successful implementation depends on the readiness of competent teaching staff and the availability of adequate CAD and prototyping laboratory facilities. This also requires investment from the government or private sector.

3) Regional Research Collaboration

- Strengthening Regional Research and Innovation Capacity: Research collaboration among ASEAN universities in robotic design can accelerate the development of robotic technology that is relevant to regional challenges and needs.
- Complementary Expertise and Resources: Each country or institution has different strengths—from human resources, technology, to application focus—this collaboration allows for effective knowledge transfer and resource sharing.
- Establishment of a Regional Innovation Ecosystem: Through joint projects, a mutually supportive robotic innovation ecosystem can be created, strengthening research networks, and opening up international funding opportunities.
- Barriers to Coordination and Standardization: Despite its great potential, cross-country collaboration faces regulatory challenges, differences in education policies, language, and technology that need to be overcome with good project management and institutional support.

These three opportunities are interrelated and form a sustainable robotic development ecosystem in the ASEAN region. The use of CAD and 3D printing technology for low-cost robots is the foundation for innovation that can be supported by strengthening vocational education and regional research collaboration. To realize this potential to the maximum, attention is needed to the development of human resources, infrastructure, and policies that support cross-country cooperation.

4.3. Considerations

The implementation of CAD in robotics education and industry must consider the capacity of human resources, such as teachers and lecturers who do not all have adequate training. In addition, the selection of CAD platforms (between commercial ones such as SolidWorks and open-source ones such as FreeCAD) must be adjusted to the funding capabilities of the institution.

The condition of technology infrastructure and software licensing varies greatly between ASEAN countries, which affects the effectiveness of CAD use.

Table 3. Key Considerations in CAD Adoption

Consideration	Impact
Teacher/Lecturer Training	Limited CAD proficiency; ongoing training is needed
Platform Choice	Trade-off between full-featured (commercial) vs. low-cost (open-source)
Infrastructure & Licensing	Availability of hardware and network affects integration effectiveness

1) Teacher/Lecturer Training

- Key to Successful CAD Curriculum Implementation: Teachers and lecturers who teach CAD and robotics must have high competency in order to teach concepts and practices well. Their limited abilities are the main obstacle in CAD integration in vocational and polytechnic education.
- Direct Impact on Learning Quality: If teachers are not familiar or not proficient with CAD software and modern design techniques, the material delivered will be less effective and will not meet current industry standards. This can hinder students' ability to master the necessary skills.
- Need for Continuous Training: CAD technology continues to develop with new features and tools, so training must be continuous (continuous professional development). In addition to technical training, pedagogy for using digital technology also needs to be developed.
- Solutions and Support: The government, educational institutions, and industry need to collaborate to provide training programs, workshops, certification, and mentoring support so that teachers can always be updated.

2) Platform Choice

- Cost vs. Features Dilemma: Commercial CAD platforms such as AutoCAD, SolidWorks, or Fusion 360 have extensive features, strong technical support, and industry standards, but licensing and subscription costs are prohibitively high for educational institutions in developing countries.
- Open-Source Alternatives with Limitations: Open-source software (e.g., FreeCAD, LibreCAD) offers low-cost or free solutions, but often has limited features, stability, or lack of official support, which can limit the quality of learning or practical applications.
- Impact on Learning and Research: Platform choice affects the quality of learning, students' ability to adapt to industry, and the institution's ability to conduct innovative research.
- Hybrid Strategy and License Negotiation: Institutions can adopt a combination strategy of using open-source software for basic learning and obtaining educational licenses for commercial software for advanced learning. The educational license negotiation approach is also important to reduce costs.

3) Infrastructure & Licensing

- Adequate Infrastructure Needs: CAD requires powerful hardware—for example, computers with high specifications for 3D rendering and simulation. If the computer infrastructure in vocational schools and polytechnics is inadequate, the learning process will be disrupted.
- Network Access and Cloud Computing: Many modern CAD software utilize cloud services that require a stable and fast internet connection. Network limitations can limit access to software and data, especially in remote areas.

- Software Licenses and Legality: The use of licensed software must comply with legal and licensing regulations, otherwise it can cause legal problems and access disruptions. Proper license management also affects the effectiveness of software use in institutions.
- Impact on Integration and Scalability: The availability of appropriate infrastructure and licenses allows CAD to be integrated into the curriculum smoothly and allows for learning to scale to many students at once. Conversely, these limitations are major obstacles to the development of CAD programs.
- Stakeholder Role: Government, educational institutions, and software providers must work together in infrastructure investment and affordable licensing for sustainable CAD technology implementation.

These three considerations are interrelated and greatly determine the success of CAD implementation in vocational and polytechnic education. Adequate teaching staff competency, selection of the right software platform with consideration of cost and features, and availability of sufficient hardware and network infrastructure are the main pillars for effective CAD integration and positive impact on the quality of education and regional robotics innovation.

4.4. Constraints

The study found several major barriers to CAD implementation, especially high licensing and hardware costs, and limited technical skills among students and educators. In addition, the lack of a national curriculum that regulates CAD-robotics is an obstacle to standardizing learning.

Another obstacle is uneven access to the internet and hardware, especially in rural and underdeveloped areas, causing a digital divide between regions.

Table 4. Barriers to CAD Implementation in Southeast Asia

Barrier	Explanation
High Costs	Software licenses and advanced hardware are difficult for institutions to afford.
Limited Skills	Many students and educators lack adequate CAD proficiency.
Non-Standardized National Curriculum	No centralized guidelines for integrating CAD in robotics.
Uneven Internet & Device Access	Remote areas struggle to participate in cloud-based CAD learning.

1) High Costs

- Significant Financial Barriers: Commercial CAD software licenses and hardware capable of running demanding applications such as 3D CAD and robotics simulations generally require high investment costs. Many educational institutions, especially in developing countries or remote areas, do not have sufficient budgets to purchase and maintain these devices.
- Impact on Education Quality: Funding constraints result in the use of limited versions of software or open-source software with limited features that may not meet industry standards, thereby reducing the quality of learning and graduate readiness.
- Maintenance and Upgrade Constraints: In addition to the initial purchase, costs for license upgrades, hardware updates, and technical support are also ongoing burdens that are difficult to meet.
- Role of Policy and Subsidies: Governments and donors need to come forward with subsidy programs, negotiate educational licenses, or provide shared infrastructure to reduce costs and expand access.

2) Limited Skills

- Limiting Competency Gap: Lack of basic and advanced CAD skills among students and educators causes CAD implementation to be less than optimal. This can be caused by lack of formal training, practical experience, or inadequate curriculum.

- Impact on Productivity and Creativity: If students and educators do not master CAD well, they will have difficulty in completing design tasks, hindering innovation, and reducing competitiveness in the labor market and technology research.
- Need for Intensive Training Programs: Skill development should be a primary focus by providing courses, workshops, online tutorials, and mentoring to improve CAD literacy levels.
- Potential Use of Blended Learning Methods: Combining face-to-face and digital learning can help reach more participants with effective methods.

3) Non-Standardized National Curriculum

- Fragmentation of Education and Curriculum: Without clear national standards, educational institutions develop CAD programs individually with variations in quality and scope of materials. This causes a mismatch in graduate competencies between institutions.
- Barriers to Accreditation and Competency Recognition: Non-uniform standards make it difficult to assess student performance and recognize learning outcomes at the national and international levels.
- Difficulties in Integrating Technology and Curriculum: Institutions will have difficulty adapting to the latest CAD technology and industry practices if there is no clear guidance and systematic support from the ministry of education or standards body.
- Need for Regulation and Multi-Stakeholder Cooperation: The development of an integrated curriculum involves government, academia, industry, and professional associations to meet market needs and technological developments.

4) Uneven Internet & Device Access

- Digital Infrastructure Inequality: Stable internet access and adequate computing devices are key prerequisites for modern CAD learning, especially cloud-based learning. Remote or less developed areas often experience limited access to this.
- Impact on Educational Inclusion: Unequal access creates a gap in learning opportunities between students in large cities and remote areas, which impacts the quality of education and career opportunities.
- Barriers to Implementing New Technologies: Cloud CAD and collaborative platforms are becoming increasingly popular, but users in areas with poor access are unable to take full advantage of these technologies.
- Applicable Solutions: Government investment in digital infrastructure, development of well-equipped learning centers in remote areas, and adaptation of offline or lightweight application-based learning materials can help address this issue.

These barriers reinforce each other and create complex challenges for developing CAD and robotics education in developing regions. Effective solutions require a multi-dimensional approach: government financial and policy support, intensive training for teachers and students, standardization of national curricula, and the development of a uniform digital infrastructure. Without comprehensively addressing these factors, the potential for robotics and CAD technology development in the region will be limited.

5. Conclusion

This research emphasizes the changing and developing function of Computer-Aided Design (CAD) in robotics training and sectors throughout Southeast Asia from 2020 to 2025. The rise of open-source and cloud-based CAD platforms has greatly expanded access to sophisticated design tools for resource-limited institutions. Furthermore, the combination of CAD with robotic simulation platforms such as ROS, along with the increase in collaboration between industry and education via project-based learning, is speeding up skill enhancement and innovation in robotic systems. Opportunities are particularly evident in affordable local robot development, enabled by the integration of CAD and 3D printing technologies. The growing incorporation of CAD into vocational and polytechnic programs throughout ASEAN is creating a stream of workforce-prepared graduates in mechatronics and automation. Regional collaboration, particularly via ASEAN University Network (AUN) efforts, is enhancing joint research on robotic prototyping.

Various technical, institutional, and infrastructural factors persist. The differences in software availability, internet access, and teacher expertise among ASEAN nations create considerable obstacles. The lack of a unified national CAD-robotics curriculum obstructs uniform application and evaluation. These limitations need to be tackled with focused policies, capacity-enhancement initiatives, and investment in digital infrastructure.

Future studies ought to concentrate on assessing the enduring effects of CAD-integrated programs on the employability of graduates and the innovation produced. Research comparing educational outcomes of commercial versus open-source CAD platforms would also be beneficial. Moreover, investigations ought to examine approaches for standardizing curricula at both national and regional levels, particularly in underserved and rural areas. Investigating AI-assisted CAD tools and their capability to aid beginner users in robot design might also create new opportunities in educational and industrial contexts

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