FIDIC ASIA PACIFIC CONFERENCE 2025 INDONESIA

NEW TECHNOLOGIES TRANSFORMING ENGINEERING AND CONSTRUCTION INDUSTRY

Investment Opportunity, Indonesia's Infrastructure Readiness to Achieve the Targeted Annual Economic Growth, Indonesia Land of Opportunities
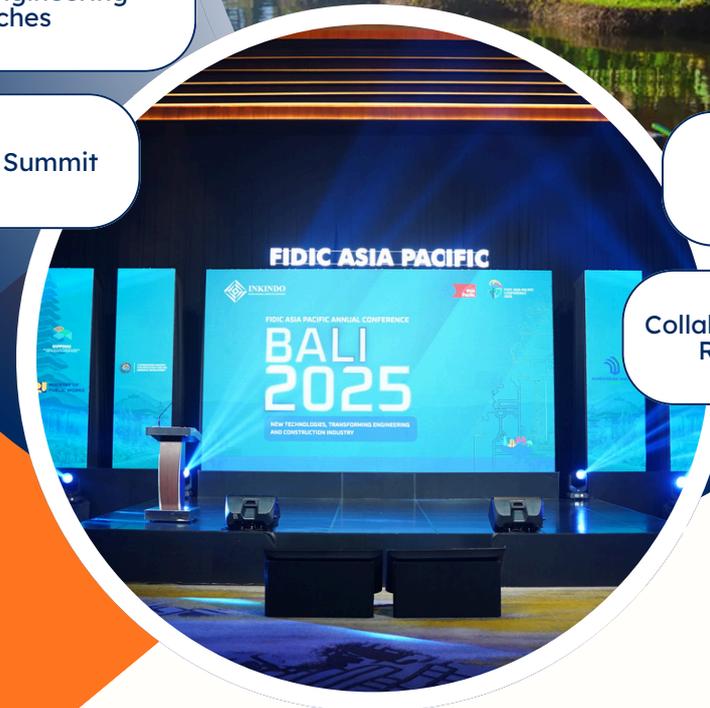
Artificial Intelligence (AI) and Construction Management

Sustainable Engineering Approaches

Young Professionals Summit

BIM and Advanced Design Practices

Collaborative Technologies and Regional Collaboration

CONFERENCE BOOK

FOREWORD

On behalf of INKINDO, the National Association of Indonesian Consultants, we are deeply honored to have successfully hosted the **FIDIC Asia Pacific 2025 Annual Conference**, held in Bali, Indonesia on August 18–20, 2025.

With the theme *"New Technologies, Transforming Engineering and Construction Industry"*, the Conference brought together Government Officers, Academicians, Professionals, and Consulting Engineers from **23 countries across the Asia Pacific region**. The fruitful discussions, insightful presentations, and vibrant exchange of knowledge have inspired us all to embrace innovation and collaboration in addressing the challenges and opportunities that new technologies bring to the engineering and construction industry.

This **Conference Book** presents a comprehensive record of the event. It includes the **Conference Summary**, the **Keynote Speeches** delivered by distinguished speakers, as well as the **articles** contributed by participants from across the region. We hope this book will serve not only as documentation, but also as a valuable reference for continuous learning, collaboration, and innovation in our field.

We sincerely appreciate the invaluable contributions of all **speakers, moderators, authors, reviewers, participants, sponsors, the Steering and Organizing Committees, and all parties whose dedication and support made this Conference possible**. May the outcomes of this gathering continue to inspire innovation, strengthen professional collaboration, and bring lasting impact to the engineering and construction practices in the Asia Pacific.

We look forward to future occasions and collaborations that will continue the spirit of this Conference.

With appreciation,

Erie Heryadi
President
The National Association of Indonesian Consultants (INKINDO)
FIDIC Asia Pacific Conference 2025 – Indonesia

EDITORIAL INFORMATION

Conference Book
FIDIC Asia Pacific Conference 2025

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Published and supported by
FIDIC Asia Pacific Conference 2025 Steering and Organizing Committee
in collaboration with INKINDO and FIDIC Asia Pacific

ACKNOWLEDGEMENT

The Editorial Team of the FIDIC Asia Pacific Conference 2025 extends its sincere appreciation to all speakers, moderators, authors, reviewers, participants, sponsors, the Steering and Organizing Committees, and all parties for their valuable contributions and dedication to the success of this conference.

Special gratitude is conveyed to INKINDO and FIDIC Asia Pacific for their continuous support in the publication and production of this conference book.

May this publication serve as a valuable reference and inspiration for future research and collaboration in the field of engineering.

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FIDIC Asia Pacific Conference 2025: New Technologies Transforming Engineering and Construction Industry

Conference Synopsis

FIDIC ASIA PACIFIC CONFERENCE 2025 - BALI, INDONESIA

The FIDIC Asia Pacific Annual Conference 2025 took place from August 18 to 20, 2025, in Bali, Indonesia. It was organized by **the National Association of Indonesian Consultants (INKINDO)** and endorsed by **FIDIC.** More than 250 delegates attended the sessions to discuss new technologies transforming the engineering and construction industry.

Held under the theme **"New Technologies Transforming the Engineering and Construction Industry"**, the conference explored the cutting-edge innovations that were reshaping the engineering consultancy sector, with a special focus on how these advancements could drive efficiency, sustainability, and resilience. In a world increasingly impacted by technological disruptions, climate change, and the challenges posed by the recent pandemic, the engineering and construction industry was seen to be evolving rapidly to remain competitive and responsible. With the rise of Artificial Intelligence (AI), Machine Learning (ML), and other digital tools, companies were presented with unprecedented opportunities to enhance collaboration, improve operational efficiency, and reduce environmental impact. As one of Asia-Pacific's fastest growing economies, Indonesia was uniquely positioned to lead the charge in these transformative shifts, bringing together industry leaders, innovators, and policymakers to foster the adoption of new technologies and practices.

The conference addressed various issues revolving around regional collaboration, such as collaborative and remote work technologies; automation and robotics for data collection, construction, operations, and maintenance; and the integration of Building Information Modelling (BIM) and advanced simulations for sustainability. Discussions also explored the many AI/ML technology advancements, while putting emphasis on their governance, ensuring these advancements were applied responsibly within the industry. As Indonesia continued to strengthen its economy and infrastructure, this event served as a vital platform for sharing insights, driving dialogue, building regional collaboration, and shaping the future of the engineering and construction sectors across the Asia-Pacific region.

Key Highlights

18 August 2025

The event commenced with participant registration, followed by a welcoming cocktail featuring food and beverages, networking opportunities, and background music.

Registration

Welcoming Cocktail

19 August 2025

The conference, held at Meru Sanur Hotel, Bali, Indonesia, kicked off its first day with the Inaugural Ceremony. The program began with an opening by the Master of Ceremony, followed by the singing of the Indonesian National Anthem (*Indonesia Raya*) and a traditional Balinese Janger dance performance.

This was followed by a series of welcome addresses and keynote speeches:
- Welcome Address by **Mr. Afiansyah Harahap**, OC Chairman
- Speech by **Mr. Erie Heryadi**, INKINDO Chairman
- Speech by **Mr. Sudhir Dhawan**, FIDIC Asia Pacific President
- Recorded Video Welcome Address by **Ms. Catherine Karakatsanis**, FIDIC President
- Welcome Address by **Mr. Prashant Kapila**, FIDIC Board Member, representing **Ms. Catherine Karakatsanis**, FIDIC President
- Keynote Speech by **Mr. Nazib Faizal**, Deputy Coordinating Minister for Equitable Regional Development, Agrarian Affairs, and Spatial Planning, representing **Mr. Agus Harimurti Yudhoyono**, Coordinating Minister for Infrastructure and Regional Development
- Keynote Speech by **Mr. Peter Frans**, Vice Chairman for Consulting Services and Studies on Downstreaming, Investment, Industry, and Environment of KADIN INDONESIA (Indonesian Chamber of Commerce and Industry), representing **Mr. Anindya Novyan Bakrie**, Chairman of KADIN INDONESIA

Opening

Singing of Indonesian Anthem (Indonesia Raya)

Opening Dance –
Janger Dance (Bali's Traditional Dance)

Welcome Address from OC Chairman –
Mr. Afiansyah Harahap

Speech from Chairman of INKINDO –
Mr. Erie Heryadi

Speech from FIDIC Asia Pacific President –
Mr. Sudhir Dhawan

Recorded Video Welcome Address from FIDIC
President – Ms. Catherine Karakatsanis

Welcome Address on behalf of FIDIC President –
Mr. Prashant Kapila

Keynote Speech –
Mr. Nazib Faizal

Keynote Speech on behalf of KADIN Chairman –
Mr. Peter Frans

Following the opening ceremony, the FIDIC Asia Pacific (FAP) Annual Awards 2025 were held online with strong participation (14 project entries and 7 emerging leader applications). Independent juries, chaired by **Mr. Yoshi Yamashita (Japan)** for infrastructure and **Ms. Meiti Kramadibrata (Indonesia)** for emerging leaders, selected the winners. The awards were presented **by Mr. Prashant Kapila, Mr. Sudhir Dhawan, and Mr. Erie Heryadi.**

Award Highlights

- Envoy of Excellence: **Mr. Zulkifli Halim & Mr. Irawan B. Koesoemo (Indonesia)**
- Emerging Leader**: Ms. Harshita Jain (India)**
- Editorial Award: **Mr. Amitabha Ghoshal (India)**
- Powerhouse Award: MA associations from **Nepal, Korea, and Pakistan**
- Outstanding Infrastructure Projects: Companies from **Japan, Pakistan, China, and India** for major transit, healthcare, energy, telecom, and road projects

The session concluded with a tea break and business matching activities.

Awards Ceremony

Tea Break & Business Matching

The main conference program comprised six thematic sessions, combining keynote presentations, technical papers, and panel discussions.

SESSION 1

Investment Opportunity, Indonesia's Infrastructure Readiness to Achieve the Targeted Annual Economic Growth, Indonesia Land of Opportunities

This session, featuring **Mr. Agus Sulaeman** (Director for Financing System and Strategy Development, Directorate General of Public Works Infrastructure Financing, Ministry of Public Works) and **Mr. Abdul Malik Sadat Idris** (Deputy for Infrastructure, Ministry of National Development Planning (PPN) / National Development Planning Agency (BAPPENAS)), moderated by **Mr. Erie Heryadi**, included keynote presentations and a moderated discussion. It emphasized Indonesia's goal of achieving 8% annual economic growth, compared to the current 5.12%. To bridge this gap, greater private sector involvement, especially through Public-Private Partnerships (PPP), is essential, with the engineering consultancy sector playing a key role. A major challenge, however, lies in improving government budget efficiency.

SESSION 2

Artificial Intelligence (AI) and Construction Management

Moderated by **Mr. Widhoon Chiamchittrong**, this session featured technical paper presentations and a moderated discussion on how AI is transforming the construction industry to improve efficiency, safety, and sustainability. **Mr. An Chao (China)** highlighted the use of Digital Twins integrating AI, IoT, and big data for water projects such as the Jenelata Dam, enabling advanced simulations, real-time monitoring, and risk management. **Mr. Bibek Singh (Nepal)** showcased drones combined with AI analysis to deliver highly accurate topographic models, reducing survey errors and supporting infrastructure planning in challenging terrains. **Mr. Ajay Pradhan (India)** discussed AI integration across the construction lifecycle through BIM, IoT, and robotics, citing case studies that achieved fewer safety

incidents and shorter schedules, while pointing to future trends such as generative AI and quantum computing.

Session 1

Session 2

SESSION 3

Sustainable Engineering Approaches

Moderated by **Ms. Meiti Kramadibrata**, this session featured technical paper presentations and a moderated discussion, highlighting the balance between economic growth and sustainability challenges such as resource scarcity and climate change. **Mr. Rajeev Supekar (Japan)** shared a Clean City–Green City model, **Mr. Chong Chew Fan (Malaysia)** presented sustainable data center design through green building certification, and **Mr. P. Dhammika (Sri Lanka)** introduced eco-friendly ceiling materials from waste Low-Density Polyethylene (LDPE) and coconut fiber. The session emphasized that green cities are the future, sustainable practices in data centers are essential, and waste can be transformed into valuable construction materials. The program continued with the Assembly General Meeting.

Session 3

FAP Assembly General Meeting

In the evening, participants attended the Gala Dinner at Taman Bhagawan, which featured traditional dance performances, dinner, networking opportunities, and photo sessions.

Gala Dinner at Taman Bhagawan

Traditional Dance
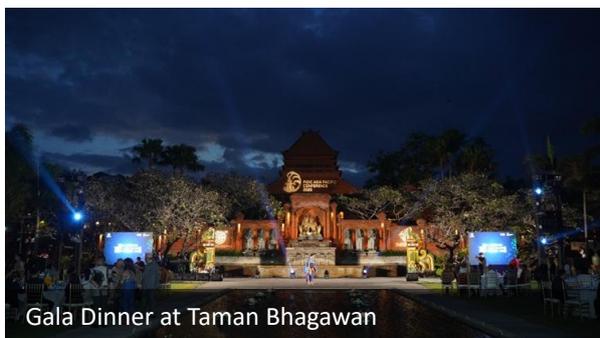
Wednesday, 20 August 2025

On the second day, the conference began with the **FACE Assembly General Meeting (AGM)**, commenced with quorum established by all seven active member associations and ACEATIL from Timor Leste as observer. **Mr. Anuar**, FACE Vice President, chaired the meeting on behalf of **Mr. Chuck Kho**, FACE President, with attendance from **Mr. Prashant Kapila**, FIDIC Board Member, and **Mr. Sudhir Dhawan**, Immediate Past FAP President. Opening remarks included a welcome by **Mr. Erie Heryadi**, INKINDO President, and **Mr. Anuar**, acknowledging all participants and expressing appreciation to INKINDO for hosting. The AGM reviewed and ratified the previous minutes, approved the proposed agenda, and received a brief report on FACE activities from 2024–2025. Key elections and appointments were conducted, including the ratification of **Mr. Anuar** as FACE President 2025–2027, election of **Mr. Erie Heryadi** as Vice President, nomination of **Mr. Zulkifli Halim** as Secretary General, and plans for the FACE Governing Board 2025–2027. The meeting also welcomed **Associacao dos Consultores de Engenharia e Arquitectura de Timor Leste (ACEATIL)** as FACE Active Member Association No. 8, discussed potential future membership from **Brunei, Cambodia, and Laos**, and concluded with a vote of thanks, closing remarks, and group photo, before participants proceeded to the second day of the FAP 2025 Bali Conference.

FACE Assembly General Meeting

FACE Assembly General Meeting

SESSION 4

Young Professionals Summit

Session 4

In parallel, the Young Professionals Summit featured a panel discussion moderated by **Mr. Abdul Haseeb Mansuri**, bringing together **Ms. Wenting Yang (China), Ms. Zulafa Azmi (Indonesia), Mr. Shekhar Nath Chapagain (Nepal), and Mr. Sheheryar Shafique (Pakistan)**. The discussion highlighted the future of engineering and construction at the intersection of sustainability, technology, human talent, and risk management, emphasizing human–machine collaboration, AI-driven construction, and predictive risk management. Speakers underscored the need to empower people, align systems, and prioritize resilience alongside innovation, concluding that the industry's future lies in human + machine, innovation + sustainability, and technology + responsibility, with young professionals recognized as the backbone of progress.

SESSION 5

BIM and Advanced Design Practices

Moderated by **Mr. Eko Bagus Delianto**, this session featured technical paper presentations and a moderated discussion highlighting the transformative role of BIM and advanced technologies in shaping the future of construction. **Mr. Hiroki Shibuya (Japan)** showcased the Mutsuzawa Wellness Town Project, where BIM, digital twins, and IoT support smart facility management and disaster resilience. **Mr. Edgardo P. Kasilag (Philippines)** demonstrated how 3D data capture and BIM enhance urban infrastructure through practical digital twin applications. **Mr. Wenting Yang (China)** discussed Virtual Power Plants as a driver for smart grid development, integrating AI and IoT for sustainable energy systems. **Ms. Sekar Mawar Oktavina (Indonesia)** presented performance-based seismic design practices applied to landmark skyscrapers in Jakarta, underscoring how advanced modeling and digital tools strengthen resilience in seismic environments.

SESSION 6

Collaborative Technologies and Regional Collaboration

Moderated by **Ms. Enni Moeliati Soetanto**, this session featured technical paper presentations and a moderated discussion on collaboration and technology in Asia-Pacific engineering and construction. **Mr. Chungwon Seo (South Korea)** highlighted smart farming as a new E&C market, **Ms. Mandakini Karki (Nepal)** emphasized improving AI readiness across member countries, **Mr. Yuheng Deng (China)** presented the AI-driven STAR model for renewable energy investment, and **Mr. Arvinder Singh Brara (India)** discussed sustainable construction and operations. The session concluded with a call to advance actionable topics, especially on FIDIC contracts, for the upcoming Sri Lanka conference.

Session 5 | Session 6

The program continued with the showcasing of the FIDIC Asia Pacific 2026 Conference – Sri Lanka, presented by **Mr. K.L.S. Sahabandu**, President of the **Association of Consulting Engineers, Sri Lanka (ACESL)**, and concluded with the closing session. The closing session featured a Symbolic Book Handover to representatives from 13 countries, a gift presentation from the **Associacao dos Consultores de Engenharia e Arquitectura de Timor Leste (ACEATIL)**, a conference summary by **Mr. Eko Bagus Delianto**, Vote of Thanks and Closing Remarks by **Mr. Zulkifli Halim**, appreciation for **Mr. Sudhir Dhawan** (President of FIDIC Asia Pacific), and ended with group photos.

Showcasing of FIDIC Asia Pacific 2026 Conference – Sri Lanka

Symbolic Book Handover to 13 Country Representatives

Gift Presentation from ACEATIL

Conference Summary – Eko Bagus Delianto

Vote of Thanks & Closing Remarks – Zulkifli Halim

Appreciation for Sudhir Dhawan

Group Photos

FIDIC Asia Pacific Conference 2025: New Technologies Transforming Engineering and Construction Industry

Keynote Speeches

Mr. Nazib Faizal
Deputy Coordinating Minister for Equitable Regional Development, Agrarian Affairs, and Spatial Planning, representing Mr. Agus Harimurti Yudhoyono, Coordinating Minister for Infrastructure and Regional Development
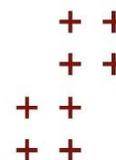
FIDIC ASIA PACIFIC CONFERENCE

New Technologies Transforming Engineering and Construction Industry

Deputy Coordinating Minister for Equitable Regional Development, Agrarian Affairs, and Spatial Planning

Bali, 19 August 2025

COORDINATING MINISTRY FOR INFRASTRUCTURE AND REGIONAL DEVELOPMENT
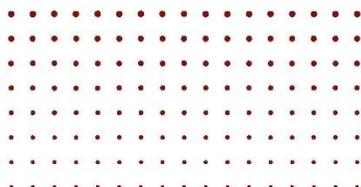
INFRASTRUCTURE: A VEHICLE FOR EQUITABLE DEVELOPMENT

More than just physical connectivity, infrastructure embodies justice, access, and national resilience.

DEPUTY COORDINATING MINISTER FOR EQUITABLE REGIONAL DEVELOPMENT, AGRARIAN AFFAIRS, AND SPATIAL PLANNING

A NEW ERA FOR INFRASTRUCTURE DEVELOPMENT

Digital Disruption
Embracing technological advancements for smarter solutions.

Climate Change
Addressing environmental challenges through sustainable practices.

Sustainable Development
Promoting long-term growth and environmental protection.

Indonesia has entered a new phase of governance under President Prabowo Subianto, guided by the 2025–2029 National Medium-Term Development Plan (RPJMN). This strategic document outlines the country's development over the next five years, with a strong focus on equitable and sustainable infrastructure.

DEPUTY COORDINATING MINISTER FOR EQUITABLE REGIONAL DEVELOPMENT, AGRARIAN AFFAIRS, AND SPATIAL PLANNING

ASTACITA: PILLARS OF NATIONAL DEVELOPMENT

The Indonesian government has designated **8 national** development priorities, known as Astacita. One of these pillars is the continued promotion of equitable and sustainable infrastructure development throughout Indonesia.

Inclusive Growth

Driving regionally balanced economic growth.

Enhanced Connectivity

Improving inter-island and inter-regional links.
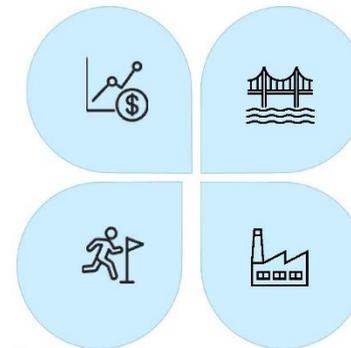
Strengthened Competitiveness

Boosting growth centers across Indonesia.

Industrial Transformation

Promoting downstream and value-added industries.
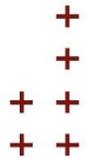
DEPUTY COORDINATING MINISTER FOR EQUITABLE REGIONAL DEVELOPMENT, AGRARIAN AFFAIRS, AND SPATIAL PLANNING

Navigating Indonesia's Unique Landscape

As the largest archipelagic country with over 17,000 islands, Indonesia's geographical diversity presents both challenges and opportunities for infrastructure development.

To address these complex challenges, the government is pursuing strategic actions to ensure sustainable, inclusive, and competitive development.

DEPUTY COORDINATING MINISTER FOR EQUITABLE REGIONAL DEVELOPMENT, AGRARIAN AFFAIRS, AND SPATIAL PLANNING

STRATEGIC ACTIONS FOR DEVELOPMENT
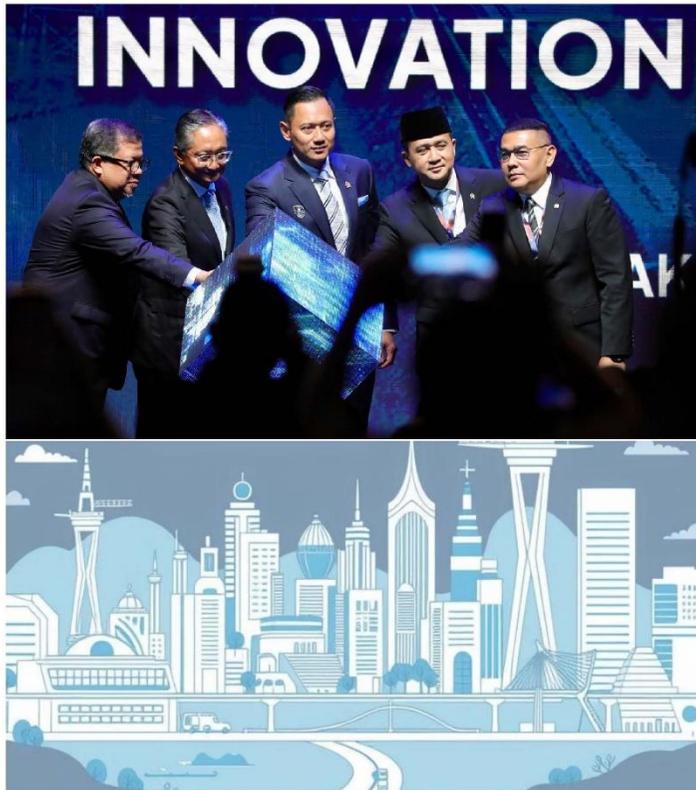
1 — **Integrated Spatial Planning**

Data-driven planning as a foundation for sustainable, inclusive, and competitive development.

2 — **Accelerating National Strategic Projects (PSNs)**

Key drivers for growth and equity across the nation.

3 — **Developing Special Economic Zones (SEZs)**

Models of transformation driven by green economy, healthcare, and tourism, like the Sanur SEZ in Bali.

4 — **Utilizing Public-Private Partnerships (PPP)**

Optimizing financing sources for large-scale projects.

5 — **Digitalizing Infrastructure**

Adopting BIM, geospatial intelligence, and AI for planning and implementation.

DEPUTY COORDINATING MINISTER FOR EQUITABLE REGIONAL DEVELOPMENT, AGRARIAN AFFAIRS, AND SPATIAL PLANNING

THE GLOBAL DEMAND FOR SMARTER SOLUTIONS

Globally, engineering and consulting practices must evolve beyond traditional methods. The world demands faster, smarter, greener, and more adaptive solutions. New technologies are vital across all phases of infrastructure projects, from planning to maintenance.
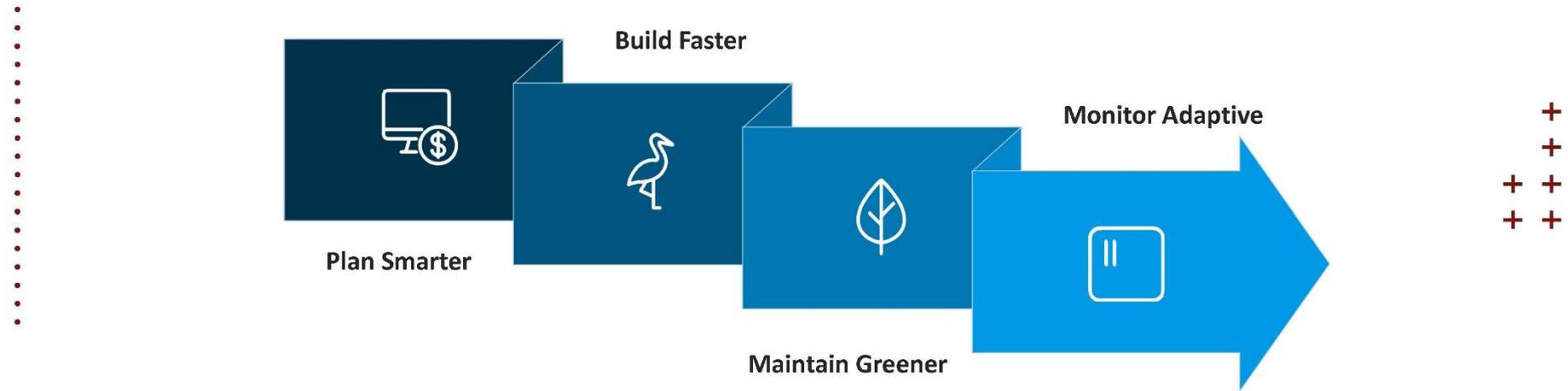
**Plan Smarter**

Build Faster

Maintain Greener

Monitor Adaptive

DEPUTY COORDINATING MINISTER FOR EQUITABLE REGIONAL DEVELOPMENT, AGRARIAN AFFAIRS, AND SPATIAL PLANNING

CRITICAL DIRECTIONS FOR INDONESIA'S CONSULTING INDUSTRY

Accurate Feasibility Studies

Analyses and findings must be based on accurate, transparent, and factual data to ensure credibility.

PPP-Ready Business Models

Feasibility study documents should include practical business models and investment frameworks for potential investors.

Spatial Planning as "Panglima"

All consultancy work must consistently position spatial planning as a guiding principle, aligning regional development with national priorities.
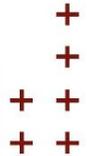
DEPUTY COORDINATING MINISTER FOR EQUITABLE REGIONAL DEVELOPMENT, AGRARIAN AFFAIRS, AND SPATIAL PLANNING

REINFORCING QUALITY AND VISION

- These strategic directions aim to reinforce the quality of consultation, ensuring Indonesia's development pathway remains both inclusive and visionary.

- Indonesia welcomes partnerships with international players and industry leaders to drive this transformation.
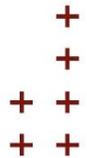
DEPUTY COORDINATING MINISTER FOR EQUITABLE REGIONAL DEVELOPMENT, AGRARIAN AFFAIRS, AND SPATIAL PLANNING

FOSTERING GLOBAL PARTNERSHIPS

Indonesia is committed to strengthening its construction and consulting ecosystem through international collaboration. We invite global partners to join us in this transformative journey.

Strengthening Capacity	Facilitating Technology Transfer	Enhancing Competitiveness
Empowering national consultants and contractors.	Promoting low-carbon innovation and knowledge exchange.	Boosting Indonesia's global standing in the industry.

DEPUTY COORDINATING MINISTER FOR EQUITABLE REGIONAL DEVELOPMENT, AGRARIAN AFFAIRS, AND SPATIAL PLANNING
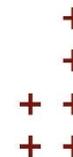
BUILDING BRIDGES OF OPPORTUNITY

Future Generations

Best Practices

New Partnerships

Professional Networks

Equitable Infrastructure

Let's ensure infrastructure serves as a bridge of opportunity for equity, access, and future generations.

DEPUTY COORDINATING MINISTER FOR EQUITABLE REGIONAL DEVELOPMENT, AGRARIAN AFFAIRS, AND SPATIAL PLANNING
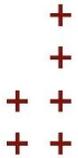
Thank you!

Deputy Coordinating Minister for
Equitable Regional Development, Agrarian Affairs, and Spatial Planning

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DEPUTY COORDINATING MINISTER FOR EQUITABLE REGIONAL DEVELOPMENT, AGRARIAN AFFAIRS, AND SPATIAL PLANNING

FIDIC Asia Pacific Conference 2025: New Technologies Transforming Engineering and Construction Industry

Keynote Speeches

Mr. Peter Frans
Vice Chairman for Consulting Services and Studies on Downstreaming, Investment, Industry, and Environment of KADIN INDONESIA (Indonesian Chamber of Commerce and Industry), representing Mr. Anindya Novyan Bakrie, Chairman of KADIN INDONESIA

KADIN Indonesia (Indonesian Chamber of Commerce and Industry) to Support the FIDIC Asia-Pacific Conference 2025

Topic: "New Technologies Transforming Engineering and Construction Industry"

Date: August 18-20, 2025

Location: Sanur Beach, Bali, Indonesia

To the honorable:

- **Dr. Agus Harimurti Yudhoyono**, Coordinating Minister for Infrastructure and Regional Development

- Leaders and delegates of FIDIC Asia-Pacific

- Chairman and board members of INKINDO

- All conference participants from 23 friendly nations

Welcome to Indonesia, welcome to Bali, a center of innovation and cultural harmony.

On behalf of the Indonesian Chamber of Commerce and Industry (KADIN), which represents **90,850 registered member** companies across various **business sectors, including private companies, cooperatives, and state-owned enterprises (BUMN)**; we welcome and **fully support the implementation of the FIDIC Asia-Pacific Conference 2025** held in Bali in August 2025. This conference is a very important strategic momentum to strengthen the **national infrastructure development ecosystem**, especially in facing the **challenges and opportunities of technological transformation and the downstreaming of the construction industry.**

KADIN Indonesia believes that this conference will be **an effective platform to strengthen the synergy between the Government of the Republic of Indonesia, FIDIC, and INKINDO.** This collaboration is very important, especially amidst national efforts to promote **inclusive and sustainable economic growth through equitable and highly competitive infrastructure development.**

The main theme of the conference: **"New Technologies Transforming Engineering and Construction Industry"** is highly **relevant to the government's current policy direction**, where **digital transformation and industrial downstreaming** are the main foundations for attracting long-term investment, increasing project efficiency, and creating **added value in the domestic supply chain**. KADIN views **the adoption of technologies such as BIM, AI, and modular construction as playing a key role** in supporting the productivity and transparency of the construction sector in Indonesia.

As a forum for the business community, **KADIN is ready to play an active role in supporting the implementation of the conference's outcomes**, particularly in strengthening the involvement of the national private sector in government priority projects. KADIN also **encourages the realization of a roadmap for strengthening the capacity of national consultants through technology transfer and equitable global partnerships**.

We hope that this conference will produce **concrete and applicable policy recommendations**, in terms of regulation, institutional, and infrastructure financing aspects. Furthermore, the **active involvement of FIDIC and INKINDO** in strategic projects such as green infrastructure, food security, public housing, and regional connectivity is an important step towards a **more innovative and inclusive construction sector transformation**.

KADIN Indonesia **appreciates the initiative of FIDIC, INKINDO, and the Government of Indonesia** in organizing this strategic forum. We are ready to be a constructive partner in encouraging **national construction sector reform through cross-sector and cross-country collaboration**. With solid cooperation, we are confident that Indonesia can emerge as a center for infrastructure investment growth in the Asia-Pacific region.

Sincerely,

Anindya Novyan Bakrie

Chairman of the Indonesian Chamber of Commerce and Industry (KADIN)

FIDIC Asia Pacific Conference 2025: New Technologies Transforming Engineering and Construction Industry

Keynote Presentations

Mr. Agus Sulaeman
Director for Financing System and Strategy Development, Directorate General of Public Works Infrastructure Financing, Ministry of Public Works

VISION OF INDONESIA EMAS 2045

Per capita income equivalent to that in high-income countries
USD 23.000 – 30.300

Eastern Indonesian Region (KTI)'s GDP Contribution
28,5%

Poverty and inequality is reduced by
0,5-0,8%

GHG Emission Intensity decreases towards net zero emission
93,5%

CHALLENGES OF NATIONAL INFRASTRUCTURE FUNDING 2025-2029

Government 7.22%
SOE 6.13%
Private Sector 86.65%

Funding Needs:
USD 2,930 Billion

Government Fund
USD 210 Billion
7.22%

State-Own Enterprises Investment
USD 180 Billion
6.13%

Private Sector Investment
USD 2,540 Billion
86.65%

Source: RPJMN 2025-2029
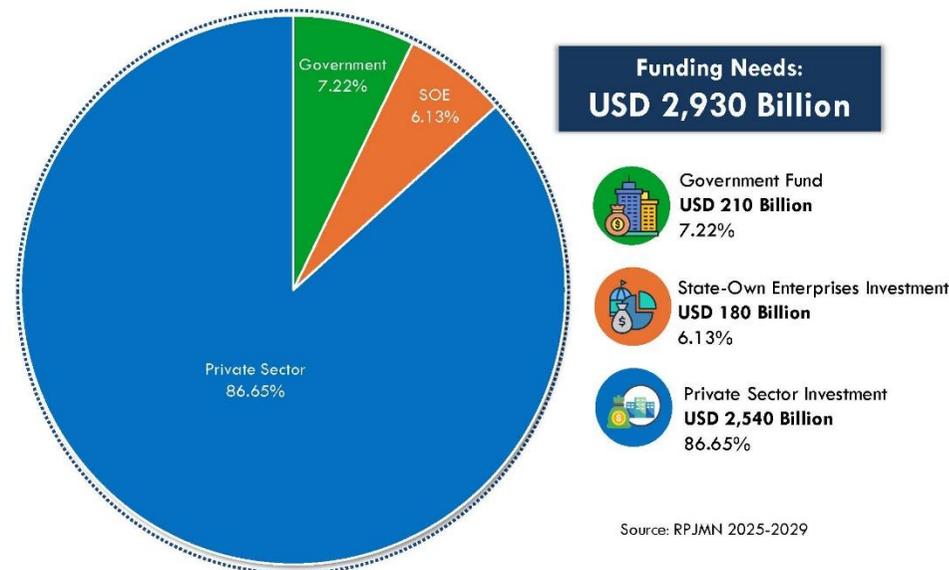
During 2025-2029, a total investment of approximately **USD 2,930 Billion** or an average of approximately **USD 590 Billion per year** is needed, which comes from government fund, investment from State-Owned Enterprises (SOE), and private/public investment.

INFRASTRUCTURE TARGETS AND FUNDING NEEDS OF THE PUBLIC WORKS SECTOR, 2025-2029

MINISTRY OF PUBLIC WORKS

INFRASTRUCTURE TARGETS 2025-2029

WATER RESOURCES

- **25** Rehabilitated Dam Units
- **63.54 m^3 / capita** Water Storage Capacity
- **180,000 ha** Irrigation Development
- **1,200,000 ha** of Irrigation Rehabilitation
- **93.79 m^3 / sec** Capacity of Managed Raw Water Infrastructure

ROAD INFRASTRUCTURE

- **98%** of National Roads in Stable Condition
- **1.7 Hours/100 km** on main Routes of the National Road Network

HUMAN SETTLEMENTS

- **43%** of Households with Access to Safe Drinking Water
- **51.36%** Urban Households with Access to Piped Drinking Water
- **30 %** Households with Safe Domestic Wastewater Access
- **38%** Waste Processed in Waste Management Facilities

Source : RPJMN 2025-2029

TOTAL BUDGET REQUIREMENTS INDICATION

IDR 1,905.3 Trillion (USD 117,18 Billion)
before the budget efficiency policy

Funding Gap
39.53 %
IDR 753,11 T
(USD 47,07 Bn)

Regional Budget
24.84%
IDR 473.28 T
(USD 29.11 Bn)

35.63%
IDR 678.91 T
(USD 41.76 Bn)

State Budget
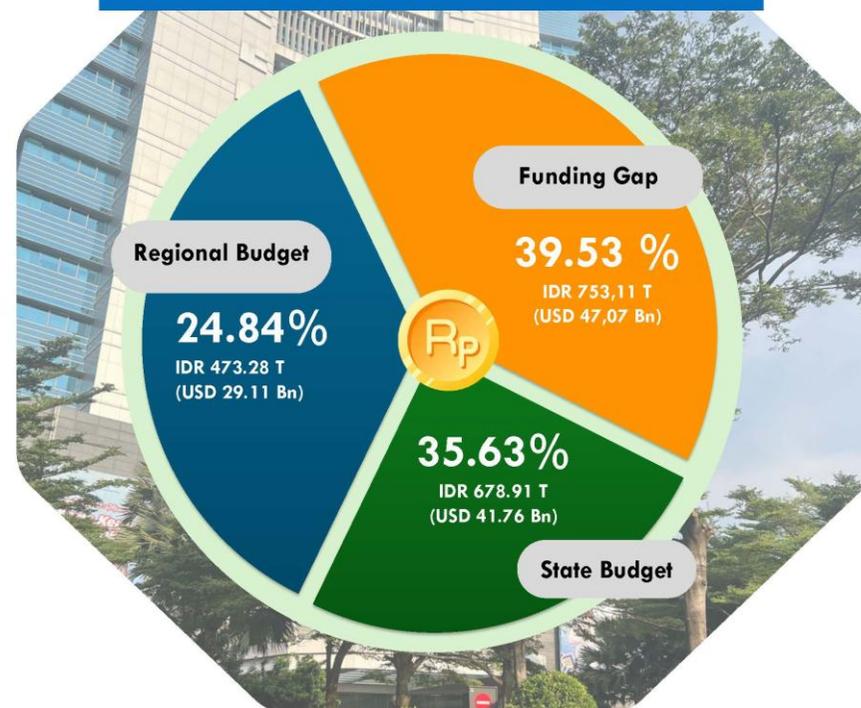
Source : Draft MPW Strategic Plan 2025–2029
I USD: IDR 16.260 (status 2 June 2025)

POTENTIAL FINANCING SCHEMES FOR PRIVATE SECTOR COLLABORATION IN INFRASTRUCTURE PROVISION

MINISTRY OF PUBLIC WORKS

1. Public-Private Partnership (PPP/KPBU)

A public facility provision scheme through collaboration between the government and the private sector to enhance infrastructure quality.

2. Public-Private Partnership (PPP/KPBU) Sharia

A form of cooperation between the government and private business entities based on Islamic Sharia principles.

3. Business to Business (B2B)

Infrastructure financing scheme that increases efficiency, encourages innovation, and creates added value in the development and management of infrastructure projects through cooperation and transactions between business entities.

4. Land Value Capture (LVC)

An infrastructure financing scheme used to monetize and leverage the increase in land value that arises as a direct result of infrastructure development in an area.

5. Assignment to State-Owned Enterprises (SOE)

A mandate given by the government to specific SOEs to carry out certain projects that are considered strategic and important for national development.

6. Limited Concession Scheme (LCS/HPT)

The optimization of State-Owned Goods (BMN) and SOE's assets to improve its operational functions in order to obtain funding for infrastructure provision financing.

7. Blended Finance

A financing approach that combines funding sources from the public, private, and philanthropic sectors to support infrastructure development projects.
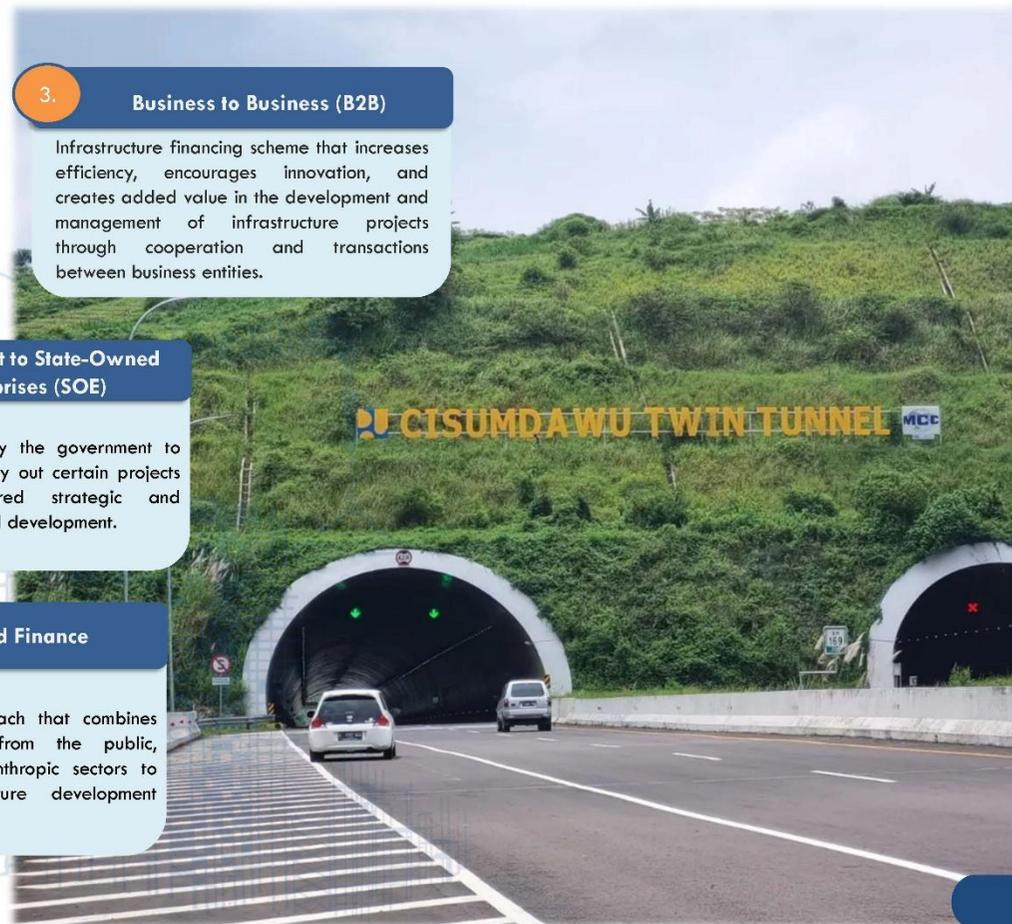
SMART INFRASTRUCTURE DEVELOPMENT IN THE PUBLIC WORKS SECTOR

Building Information Modelling (BIM)

BIM Dashboard
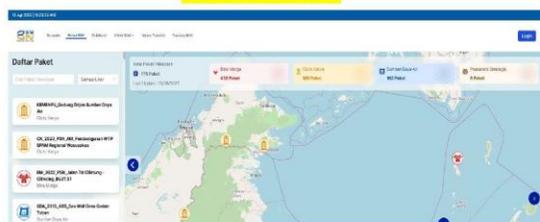
Total of 775 BIM projects have been integrated.

Implementation BIM in IKN

**The implementation of BIM is mandatory in the development of IKN
BIM 3D to BIM 5D: From Modeling to Cost Estimation**

Internet of Thing (IoT)

Smart Building – Kementerian PU

The building's technology integrates smart control systems to enhance comfort, improve energy efficiency, and harmonize human, environmental, and technological aspects.

Smart Water Management

HKP-IKN 1

Automated system for monitoring and controlling water production, distribution, and use at Sanggai-HPK 1 WTP.

Digital Twin

A virtual replica of physical assets or processes in real time, enabling simulation, monitoring, and optimization.

With Laser Scanner

Example of Digitalization of PU Office

With Oblique Photogrammetry

Source: Directorate General of Construction Development

BUILDING INFORMATION MODELLING ROADMAP

- Collection of **BIM Model Standards** for Each Dimension
- Update of **BIM IKN SOP** into MoPW BIM SOP
- Initiation of **BIM Library Development**
- Development of **BIM Dashboard**
- **Continuation of AIM Development** from As-Built Drawings and Scan-to-BIM

- Initiation of **BIM Data Integration** with **State-Owned Assets (BMN)**
- Development of **BIM Dashboard**
- Development of **BIM Library**
- **Continuation of Asset Information Model Development** form As-Built Drawings and Scan to BIM

- Final **BIM Dashboard** (**All Projects Use BIM**)
- **Continuing the Integration** of BIM Data with State-Owned Assets (BMN)

2023 **2024** **2025** **2026** **2027** **2028** **2029**

- Collection of BIM Data for the IKN (New Capital City) and National Strategic Projects (PSN)
- Development of **Asset Information Modeling from As-Built Data**
- Development of a **Standard Operating Procedure (SOP)**
- **Initiation BIM Dashboard**

- **Finalization of BIM Model Standards for Each Dimension**
- **BIM Standard Operating Procedure (SOP) for Each Infrastructure**
- Development **BIM Dashboard**
- Development **BIM Library**
- **Continuation of Asset Information Model (AIM)**

- **All Projects Must Implement BIM**
- Continuing the Integration of BIM Data with State-Owned Assets (BMN)
- Development BIM Dashboard
- Finalization BIM Library

- **All Projects have implemented BIM, and the data has been integrated with State-Owned Assets (BMN)**

SUSTAINABLE CONSTRUCTION POLICY AND STRATEGY
GREEN INFRASTRUCTURE COMMITMENT

MINISTRY OF PUBLIC WORKS

Implementation of Sustainable Development in Ministry of Public Works Infrastructure

Encouraging the Implementation of Sustainable Construction
Using eco-friendly materials and saving energy are key technical requirements for sustainable construction.

MPWH Regulation No. 9/2021 concerning Guidelines for the Implementation of Sustainable Construction.

Green and Smart Building Principles
The implementation of Smart Building Technical Standards at Green Building uses a high-performance approach by **integrating eco-friendly materials with energy and water efficiency systems,** in line with Smart Building principles.

MPWH Regulation No. 21/2021 concerning Green Building Performance Assessment, and MPWH Regulation No. 10/2023 concerning Smart Building

Mainstreaming Biodiversity Conservation
Conducting infrastructure development plans and technical regulations by considering biodiversity. Implemented in the construction of **the Elephant Crossing Tunnel on the Pekanbaru – Dumai Toll Road.**

Presidential Instruction No. 1/2023 concerning Mainstreaming Biodiversity Conservation in Sustainable Development.

Incorporating ESG Principles into PPP Projects
Ensuring that environmental protection, social responsibility, and good governance are **integrated into every PPP stage.** The pilot projects are PLTM Jenelata, Tuban-Gresik Toll Road, and SPAM Djuanda.
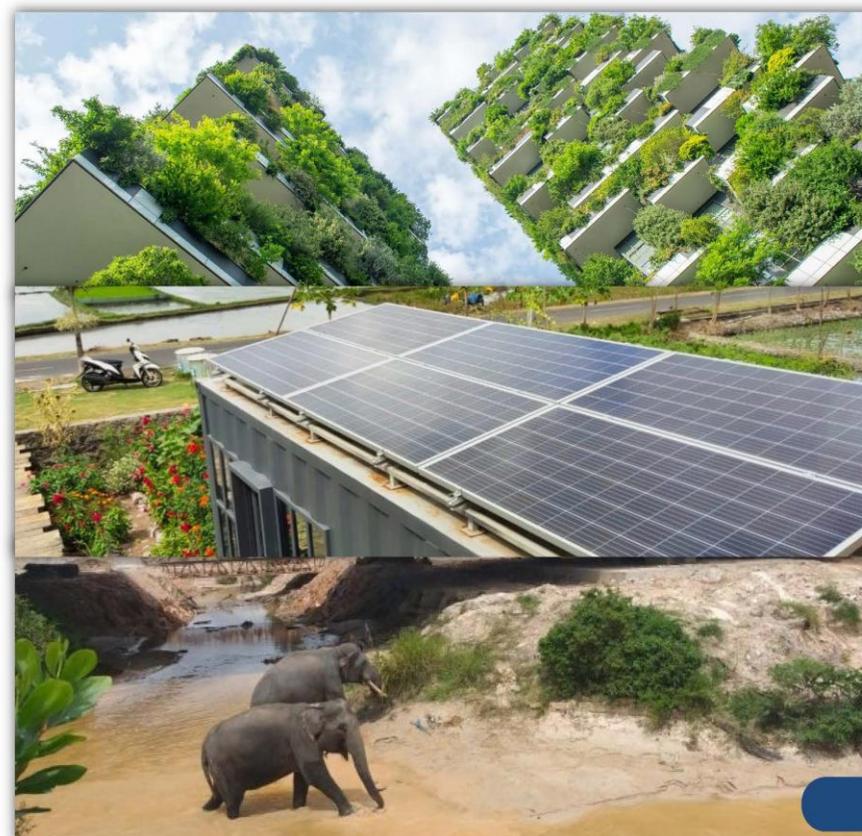
INFRASTRUCTURE DEVELOPMENT TO SUPPORT SUSTAINABLE INFRASTRUCTURE
THROUGH COLLABORATION WITH PRIVATE ENTITIES

Strengthening Coastal Defenses for Urban Resilience through the North Java Coast Giant Sea Wall Program (integrated with Toll Road)

Current Implementation:
The Giant Sea Wall Program along the North Coast of Java (Cilegon - Gresik) with an estimated cost of more than USD 62.5 billion.

Strengthening Urban Water Supply and Reducing Reliance on Groundwater

Current Implementation:
The Jatiluhur I Regional Drinking Water Supply System (SPAM) PPP Project expands access to clean water and helps reduce dependence on groundwater. This project supplies 4,750 liters of water per second to the areas of Jakarta, Bekasi Regency, Bekasi City, and Karawang Regency.

Converting Waste into Energy

Current Implementation:
The Benowo Waste-to-Energy Power Plant (PLTSa) project in Surabaya can process 1,600 tons of waste per day on a 3.7-hectare site, generating 9 megawatts (MW) of electricity through gasification, plus an additional 2 MW from landfill gas.

Utilizing Dams and Reservoirs for Renewable Energy

- Potential Tiga Dihaji Hydro Power Plant, and other potential Mini-Hydro Power Plants (PLTM) projects include Way Sekampung, Bener, and Leuwikeris.

STRENGTHENING COLLABORATION BETWEEN MINISTRY OF PUBLIC WORKS WITH FIDIC AND INKINDO
IN TRANSFORMING SUSTAINABLE CONSTRUCTION TECHNOLOGY
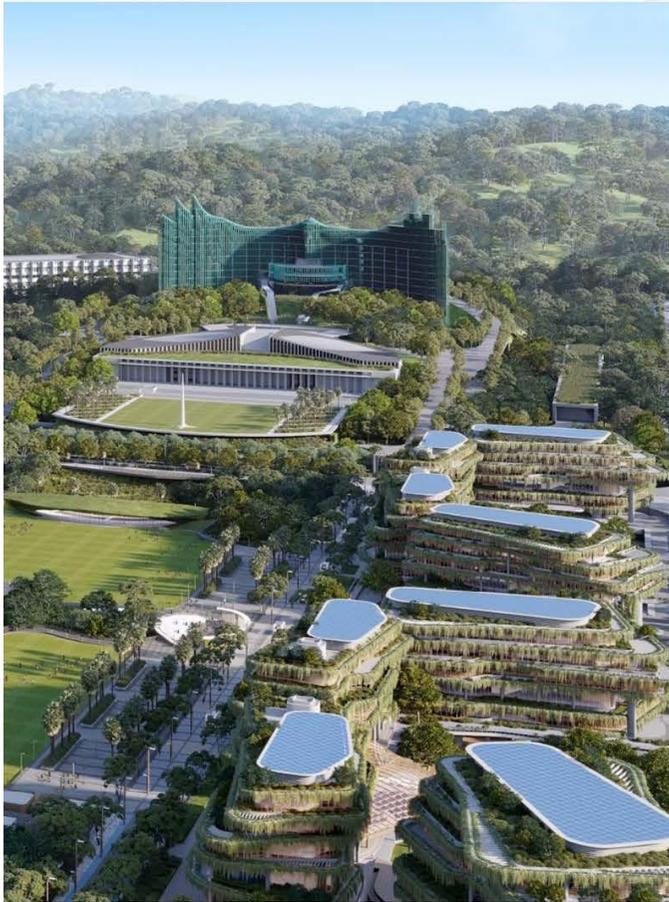
Providing certified experts and establishing building capacity training

Establishing standardized international contracts and supporting contract management to ensure Service Level Agreement (SLA) compliance and minimize project delays.

Incorporating partnerships between the government, private sector, and international entities

THANK YOU

MINISTRY OF PUBLIC WORKS
Directorate General of Public Works Infrastructure Financing

FIDIC Asia Pacific Conference 2025: New Technologies Transforming Engineering and Construction Industry

Keynote Presentations

Mr. Abdul Malik Sadat Idris

Deputy for Infrastructure, Ministry of National Development Planning (PPN) / National Development Planning Agency (BAPPENAS)

Pembangunan Infrastruktur Indonesia dalam Mencapai Pertumbuhan Ekonomi

Disampaikan dalam FIDIC Asia Pacific (FAP) Conference 2025

Abdul Malik Sadat Idris

Deputi Bidang Infrastruktur
Kementerian Perencanaan Pembangunan Nasional/
Badan Perencanaan Pembangunan Nasional (BAPPENAS)

Bali, 19 Agustus 2025

RPJPN 2025-2045
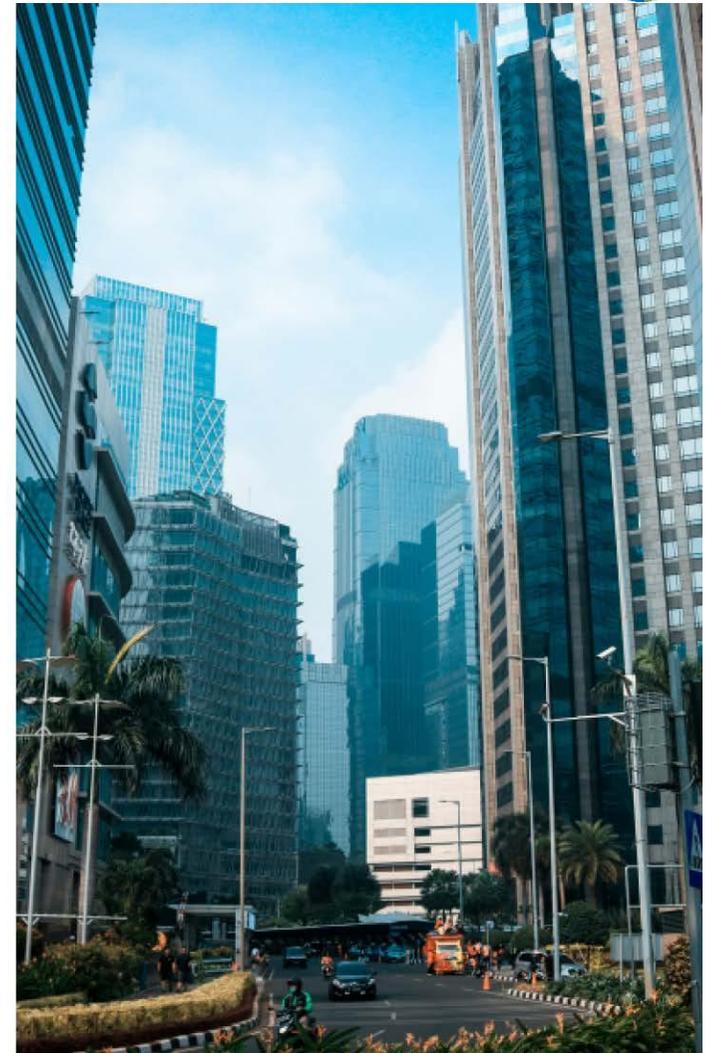# Visi Misi Indonesia Emas 2045

RPJPN 2025-2045:
Arah Kebijakan Pembangunan Infrastruktur

Kebijakan Transformasi Ekonomi

- **Perkotaan dan Perdesaan sebagai Pusat Pertumbuhan Ekonomi**
- **Penerapan Ekonomi Hijau**
- **Integrasi Ekonomi Domestik dan Global**
- **Transformasi Digital**
- **Iptek, Inovasi, dan Produktivitas Ekonomi**

Penyediaan Infrastruktur Pendukung Transformasi Ekonomi

- Efisiensi jaringan angkutan pelayaran dan penerbangan secara domestik dan terhubung secara global
- Penguatan integrasi antarmoda transportasi darat, laut, dan udara
- Mewujudkan angkutan umum massal yang berkelanjutan dan optimalisasi pemanfaatan teknologi
- Pengembangan sektor perumahan yang mendukung kegiatan dan pertumbuhan ekonomi
- Pemenuhan layanan air siap minum dan sanitasi aman serta pengelolaan sampah yang terpadu
- Peningkatan ketahanan air nasional sebagai landasan produktivitas ekonomi
- Integrasi pengembangan infrastruktur ketenagalistrikan dengan sumber Energi Baru Terbarukan
- Pembangunan interkoneksi jaringan listrik antarpulau dan internasional
- Mewujudkan produktivitas pengelolaan ketenagalistrikan
- Transformasi digital untuk mendorong percepatan pertumbuhan ekonomi

Kebijakan Transformasi Sosial

- **Kesehatan untuk Semua**
- **Perlindungan Sosial yang Adaptif**
- **Pendidikan Berkualitas yang Merata**

Penyediaan Infrastruktur Mendukung Transformasi Sosial

- Penyediaan air minum, sanitasi, persampahan, serta perumahan di kawasan permukiman yang merata
- Pemenuhan konektivitas fisik khususnya simpul transportasi dan penghubung jalan
- peningkatan kecukupan pasokan tenaga listrik dan penyediaan pembiayaan dan mekanisme penyediaan yang afirmatif
- Perluasan jangkauan dan kepastian keandalan konektivitas digital
- Memperkuat sarana dan prasarana ketahanan bencana

Kebijakan Ketahanan Sosial Budaya dan Ekologi

- **Lingkungan Hidup Berkualitas**
- **Resiliensi Terhadap Bencana dan Perubahan Iklim**
- **Berketahanan Energi, Air, dan Kemandirian Pangan**

Penyediaan Infrastruktur Pendukung Ketahanan Sosial Budaya dan Ekologi

- Penerapan pembangunan infrastruktur berbasis rendah karbon untuk mencapai penurunan emisi gas rumah kaca
- Penyediaan pengelolaan sampah dan limbah terintegrasi dari hulu ke hilir
- Penerapan jalur pembangunan yang rendah karbon melalui pengembangan transportasi berkelanjutan dan elektrifikasi transportasi
- Pembangunan infrastruktur yang memperhatikan kerawanan bencana dan perubahan iklim
- Penerapan dan pengembangan pengelolaan sumber daya air secara terpadu dan berkelanjutan

- **Konektivitas darat diwujudkan dengan penyelesaian ruas utama jalan di seluruh pulau; jalan tol Jawa dan Sumatera; jalan perbatasan; kereta api di Sulawesi, Kalimantan, dan Papua; serta transportasi perkotaan berbasis rel dan kereta cepat untuk antisipasi mega urban dan urbanisasi di Jawa.**

- Sistem transportasi antarpulau melalui transportasi laut dan udara diarahkan untuk mendukung mobilitas penduduk dan distribusi barang antarwilayah.

- Akses perekonomian di Kawasan Timur Indonesia diawali dengan pengembangan kota-kota pelabuhan dengan jalur reguler ke Kawasan Barat Indonesia dan memanfaatkan potensi jalur perdagangan internasional di wilayah tengah dan timur.

- Akses ke kawasan terpencil dan terluar disediakan melalui pembangunan pelabuhan dan bandara perintis.

- **Biaya logistik tahun 2045 turun menjadi 8 persen PDB. Stok infrastruktur meningkat menjadi 70 persen PDB pada tahun 2045.**

- Transportasi laut sebagai unsur utama konektivitas maritim dibangun melalui:

- (a) pengembangan 48 kota pelabuhan, (b) sistem pelabuhan utama tol laut dan 7 hub internasional, (c) *short sea-shipping*, dan (d) manajemen pelabuhan modern.

- **Sistem transportasi udara domestik dan internasional** dikembangkan dengan pembangunan bandara utama, **4 *Aerocity***, dan bandara perintis.

- **Konektivitas digital dan virtual** dipenuhi dengan peningkatan jaringan *broadband* hingga 100 Gbps dan literasi TIK untuk seluruh kelompok masyarakat.

- **A**kses masyarakat terhadap **prasarana dasar** dipenuhi untuk kebutuhan perumahan, air minum, sanitasi, irigasi, serta perlindungan terhadap bencana alam dan dampak perubahan iklim.

Pembangunan Infrastruktur ke depan diarahkan untuk:

- Meningkatkan Konektivitas Fisik dan Virtual
- Mendorong Pemerataan Pembangunan antar Wilayah
- Memenuhi Prasarana Dasar
- Mendukung Pembangunan Perkotaan dan Perdesaan
- Antisipasi terhadap Bencana Alam dan Perubahan Iklim, termasuk Kenaikan Muka Air Laut
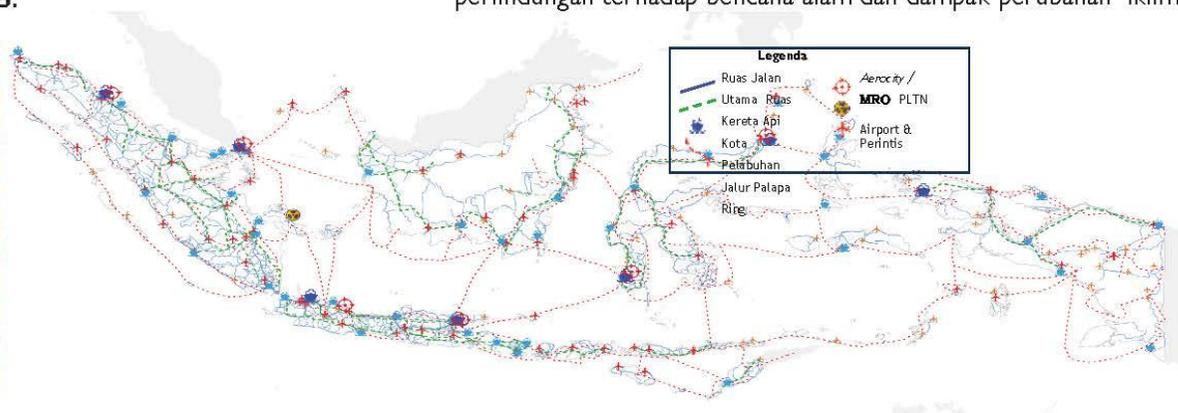
KERANGKA PIKIR DAN KEBIJAKAN RPJMN 2025 – 2029
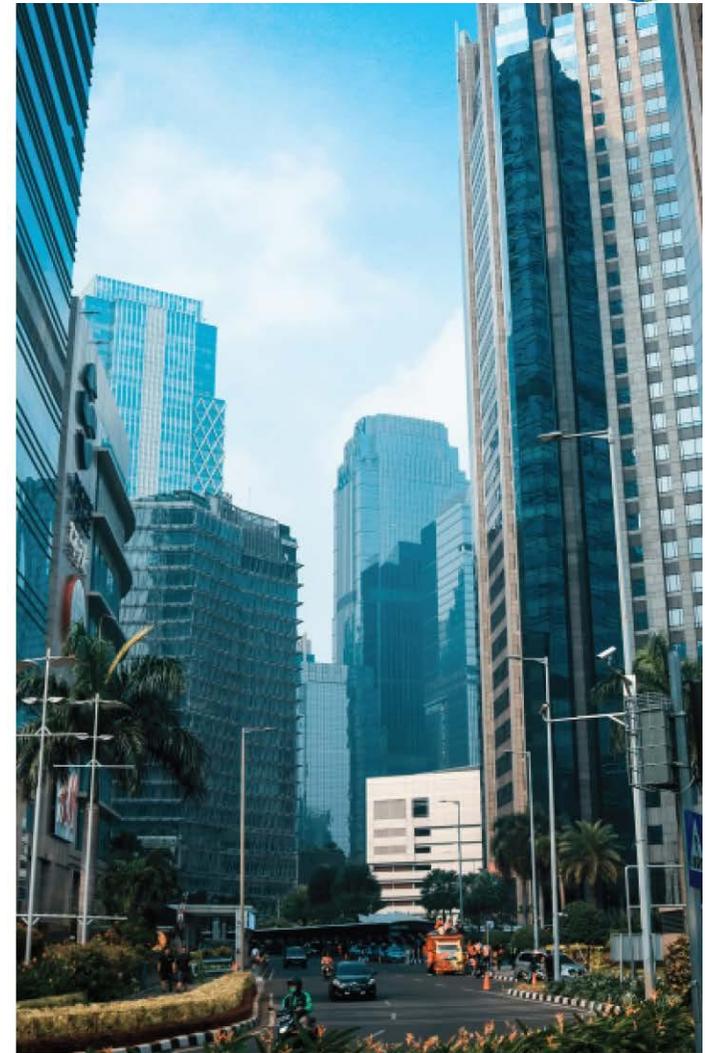
RPJMN 2025 – 2029 MENEKANKAN PADA PENURUNAN KEMISKINAN, PENINGKATAN SUMBER DAYA MANUSIA BERKUALITAS SERTA PERTUMBUHAN BERKELANJUTAN

Visi Misi Preside

RPJPN 2025–2045

Arah Pembangunan

8 Prioritas Nasional Asta Cita

Direncanakan dan dianggarkan

Strategi Kewilayahan

Menyatukan arah pembangunan nasional (pusat dan daerah)

Tata Kelola Pelaksanaan

Dikendalikan pelaksanaanya

① **Pendapatan per Kapita menuju setara Negara Maju**

✔ Pertumbuhan ekonomi menuju **8%**
✔ GNI per kapita menjadi **8.000 USD**
✔ Kontribusi PDB Maritim menjadi **9,1 %**
✔ Kontribusi PDB Manufaktur menjadi **21,9%**

Sasaran Utama Pembangunan Tahun 2029

② **Kemiskinan Menurun dan Ketimpangan Berkurang**

✔ Tingkat Kemiskinan menjadi **4,5-5,0% serta** tingkat kemiskinan ekstrem menjadi <0,5%* (di tahun kedua)
✔ Rasio gini turun menjadi **0,372-0,375**
✔ Kontribusi PDRB KTI menjadi **22,4%**

④ **Daya Saing Sumber Daya Manusia Meningkat**

✔ Indeks Modal Manusia (IMM) menjadi **0,59**

Ket:* US$ 2,15 PPP

③ **Kepemimpinan dan Pengaruh di Dunia Internasional Meningkat**

✔ *Global Power Index* menjadi **peringkat 29**

⑤ **Intensitas emisi GRK menurun menuju** *net zero emission*

✔ Penurunan intensitas emisi GRK menjadi **45,17%**
✔ Indeks kualitas lingkungan hidup menjadi **77,20**

PEMBANGUNAN INFRASTRUKTUR MENDUKUNG TRISULA PEMBANGUNAN DALAM RPJMN 2025–2029

Program Presiden

TRISULA PEMBANGUNAN

1. Pertumbuhan Tinggi Berkelanjutan
2. Penurunan Kemiskinan
3. Peningkatan Kualitas SDM

Arah Pembangunan RPJPN

STRATEGI PENGEMBANGAN WILAYAH

PENGENDALIAN

RPJMN 2025-2029 menekankan pada Pertumbuhan Berkelanjutan, Penurunan Kemiskinan dan Sumber Daya Manusia Berkualitas yang akan dilaksanakan di seluruh wilayah dan dipantau secara berkala didukung melalui keberlanjutan pengembangan infrastruktur

INFRASTRUKTUR
(SUMBER DAYA AIR, TRANSPORTASI, TEKNOLOGI INFORMASI DAN KOMUNIKASI, LISTRIK, PERUMAHAN DAN KAWASAN PERMUKIMAN)

Pembangunan infrastruktur mendukung pencapaian prioritas pembangunan

| PANGAN, AIR, DAN ENERGI | PARIWISATA & EKONOMI KREATIF | SDM, TEKNOLOGI, PENDIDIKAN & KESEHATAN | HILIRISASI DAN INDUSTRI | PERKOTAAN DAN PERDESAAN | LINGKUNGAN HIDUP |
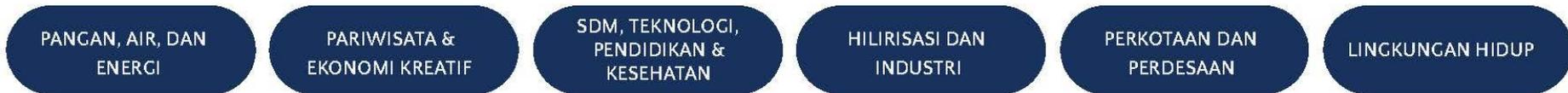
TARGET INDIKATOR INFRASTRUKTUR RPJMN 2025-2029

AIR MINUM DAN SANITASI

Meningkatnya Rumah Tangga yang terlayani Air Minum Aman — **43%** (2029)

Meningkatnya Rumah Tangga yang terlayani Akses Sanitasi Aman — **30%** (2029)

Pengentasan perilaku BABS di tempat terbuka — **0%** (2029)

PERSAMPAHAN

Timbulan Sampah Terolah di Fasilitas Pengolahan Sampah — **38% (20% terdaur ulang) (2029)**

TPA/LUR yang dioperasikan secara *sanitary landfill* / tingkat pengontrolan penuh — **11 unit (2029)**

SUMBER DAYA AIR

Kapasitas Tampungan Air — **63,54 m3/detik** (2029)

Presentase Luas Baku Sawah Fungsional Beririgasi — **62,37%** (2029)

Rasio Layanan Irigasi yang Ketersediaan Airnya Dijamin oleh Waduk — **0,43%** (2029)

Persentase Luas Kawasan Prioritas yang dilindungi dari daya rusak Air — **100%** (2029)

PERUMAHAN

Rumah Tangga Dengan Akses Hunian Layak, Terjangkau dan Berkelanjutan (%) — **74%** (2029)

Biaya Logistik — **12,5%** (2029)

Biaya Transportasi Logistik — **7,56%** (2029)

Sistem Angkutan Umum Perkotaan — **20 Kota** (2029)

Jumlah Penumpang Angkutan Umum Perkotaan — **950 Juta** (2029)

ENERGI & LISTRIK

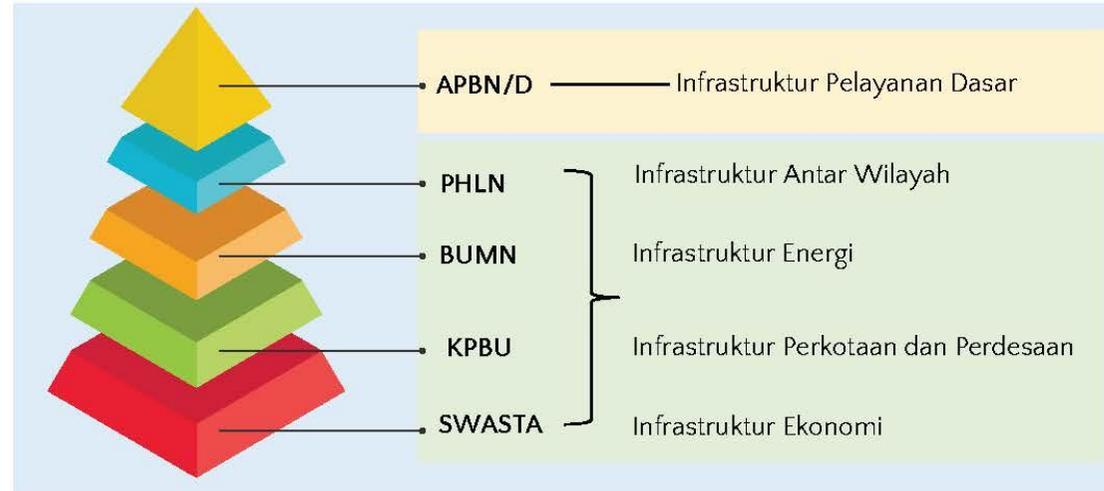Konsumsi Listrik per kapita — **1.720 kWh** (2029)

Akses gas bumi — **350.000 SR** (2029)

STRUKTUR PENDANAAN INFRASTRUKTUR INDONESIA

Kebutuhan Investasi Infrastruktur 2025–2029

Kebutuhan Investasi Rp 10.303 Triliun

- APBN Rp 2.369,7 Triliun
- APBD Rp 1.751,5 Triliun
- BUMN/D Rp 3.090,9 Triliun
- Swasta Rp 3.090,9 Triliun

Sumber Pendanaan Infrastruktur dan Arah Pemanfaatannya

- APBN/D ──────── Infrastruktur Pelayanan Dasar
- PHLN ─── Infrastruktur Antar Wilayah
- BUMN ─── Infrastruktur Energi
- KPBU ─── Infrastruktur Perkotaan dan Perdesaan
- SWASTA ─── Infrastruktur Ekonomi

Usulan target porsi sumber pembiayaan untuk RPJMN 2025-2029 diperoleh berdasarkan beberapa pertimbangan:

- **Kapasitas anggaran** yang diharapkan dalam APBN dan APBD
- Target porsi **pembiayaan BUMN** telah **diturunkan** dari perkiraan sebelumnya mengingat adanya kendala **neraca keuangan**
- Target porsi **sektor swasta** dipertahankan **lebih tinggi** mengingat **pentingnya peran Pemerintah untuk menarik investor internasional dan domestik**
- Perlu dicatat bahwa angka realisasi aktual untuk tahun 2024 belum tersedia saat ini dan oleh karena itu, angka-angka ini diasumsikan sesuai dengan target Pemerintah Indonesia untuk tahun 2024

Sumber: KIAT Team's Study, 2024

TATA KELOLA PEMBANGUNAN INFRASTRUKTUR

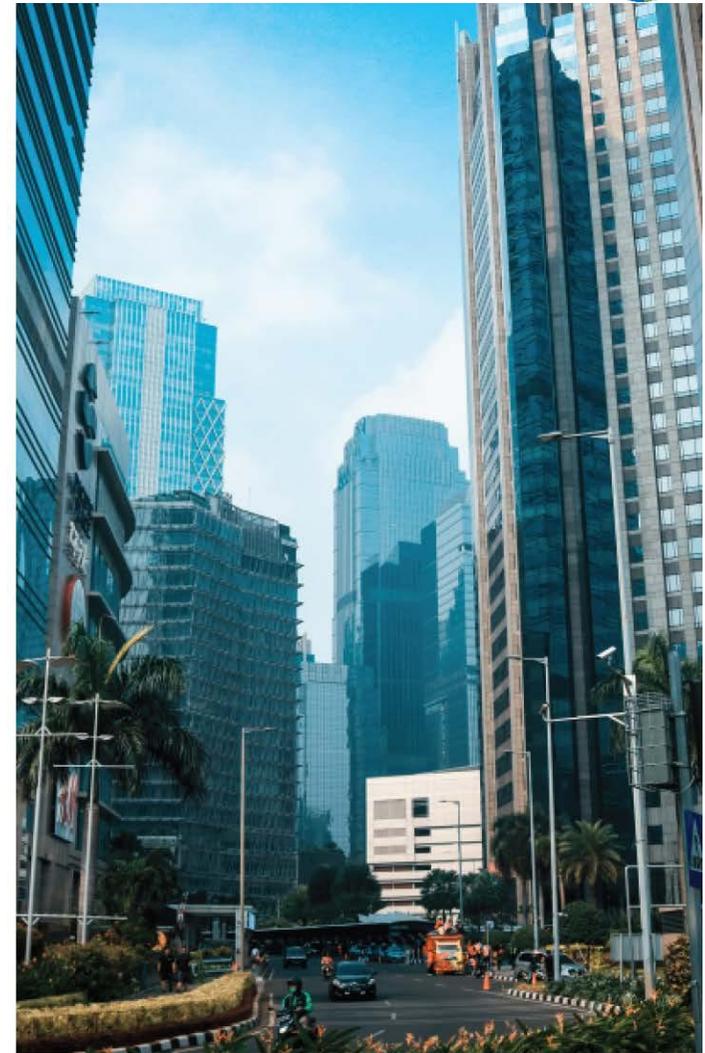| Tahapan	Fokus	Persyaratan dan Pelaku
1 Tata Cara Perencanaan	Indikasi PSN di RPJMN 2025-2029 + Pemutakhiran RKP 2025 Usulan PSN Baru: K/L, Swasta dan Pemda PSN Baru sesuai Direktif Presiden	• *Readiness Criteria* dan PMO • Bappenas, Kemenko, K/L, Pemda Kadin, dan Swasta
2 Tata Cara Penetapan	Permen PPN/Kepala Bappenas Perpres RKP yang diperbaharui setiap tahun Perpres sesuai Direktif Presiden	• *Ownership* dan Keputusan Presiden • Kemen PPN/Bappenas, Kemen Sekneg dan Kemenko
3 Tata Cara Pembiayaan dan Investasi	• APBN Rp Murni⯑ Pagu Anggaran (*at all cost*) • KPBU⯑ Kontrak Kerja+ *Cost Recovery* • Danantara⯑PMN + *Return on Investment* • Swasta⯑ Skema Insentif + *Return on Invetsment*	• *Business and Investment Plan* • Kemen PPN/Bappenas, Kemenkeu, Badan Pengelola Investasi Daya Anagata Nusantara, Kadin dan Swasta
4 Tata Kelola Pelaksanaan dan Pemantauan	APBN Rp Murni⯑ *Safeguarding* tepat sasaran KPBU⯑*Safeguarding sesuai* kontrak kerja Danantara⯑Manajemen Risiko Swasta⯑Manajemen Risiko	Sistem Informasi, Tim Teknis PMO dan Forum⯑ *Debottlenecking* • Kemen PPN/Bappenas, Kemenko, K/L, Pemda, BPI Danantara dan Swasta
5 Tata Kelola Pengendalian dan Evaluasi	APBN Rp Murni⯑ Realisasi dan Manfaat KPBU⯑Realisasi dan Manfaat Danantara⯑*Multiplier Effect* dan *Sustainbility* Swasta⯑ *Multiplier Effect* dan *Sustainibility*	Sistem Informasi, Tim Pengarah PMO dan Forum Pengambilan Keputusan • Kemen PPN/Bappenas, Kemenko, K/L, Pemda, BPI Danantara dan Swasta

Sinergitas invensi, teknologi, dan inovasi pembangunan yang unggul

Akademisi

Pemerintah

Industri

Komunitas

Media

Pemerintah
Pemerintah memiliki peran penting dalam mendorong **kebijakan** pendukung ekonomi sirkular (termasuk insentif/disinsentif & standardisasi), memprioritaskan **pendanaan** yang mendukung implementasi ekonomi hijau & sirkular, penciptaan *enabling conditions,* dan mengaktifkan kolaborasi serta kemitraan lintas sektor.

Industri/ Bisnis
Sektor swasta diharapkan lebih proaktif dalam mempercepat pencapaian SDGs melalui penerapan bisnis berkelanjutan, seperti praktik ekonomi sirkular, ESG *compliance*, investasi hijau, penerbitan Sustainability Report.

TANTANGAN DAN ARAH KEBIJAKAN BIDANG INFRASTRUKTUR

Tantangan Pengembangan

Tingginya Biaya Logistik terhadap PDB
(Tahun 2023: 14,1% ⬇ Target 2045: 8%)

- Transportasi Darat
- Transportasi Udara
- Transportasi Laut
- Warehouse
- Administrasi

14,1% 7%
1,2%
1,5%
3,6%

Sumber: Kajian Biaya Logistik SHL 2022

Konektivitas di Wilayah Timur Belum Memadai

Share PDB per Pulau

Rp12.000   Rp16.000

Disparitas Harga Bahan Pokok (Beras per kg)

Kemacetan Lalu Lintas di Perkotaan

Bandung (rank 8)	48%
Jakarta (rank 25)	43%
Palembang (rank 33)	41%
Medan (rank 46)	40%

*)persentase tingkat kemacetan dibanding kondisi normal kota tersebut

Konektivitas Jalan Pada Lintas Utama Pulau Belum Optimal

Waktu Tempuh (Jam/100 km)

Indonesia	2,2
Vietnam	1,5
Thailand	1
China	0,9
Malaysia	0,7

Kesenjangan Kualitas Infrastruktur Jalan Nasional dan Daerah

Rasio panjang jalan per luas wilayah (km/km2)

0,32   0,22

Wilayah Barat   Wilayah Timur

Sumber: Kementerian PUPR diolah

Masih Tingginya Tingkat Fatalitas Kecelakaan Lalu Lintas Angkutan Jalan (LLAJ)

Mahalnya Ongkos Transportasi Laut Domestik

Pilar Strategi Utama:

❑ Pembangunan, peningkatan, pemeliharaan, dan operasi **jalan nasional, pelabuhan, bandara, dan jalur kereta api**;

❑ Melanjutkan *Sustainable Urban Mobility Plan* berbasis wilayah;

❑ Menghubungkan pusat pertumbuhan dengan *hinterland* dan pasar nasional/internasional serta infrastruktur utama;

❑ Jaringan transportasi logistik yang terintegrasi dengan **kawasan industri, pusat logistik terpadu dan terhubung dengan konektivitas multimoda**;

❑ Pengembangan **SDM Transportasi Penumpang dan Logistik**

Konektivitas Transportasi Prioritas:

Pengembangan Konektivitas jalan pada Jalur Utama dan Aksesibilitas Daerah Tertinggal dan Perbatasan

Pengembangan Jaringan Pelabuhan Terpadu (internasional dan domestic) melalui Integrated Port Network & Integrated Airport Network

Pengembangan KA Penumpang Antar Kota dan Penguatan KA Angkutan Barang

Pengembangan Sistem Angkutan Umum Massal Perkotaan

Penguatan Infrastruktur Konektivitas, Layanan Backbone, Sarana Penunjang dan SDM Logistik

Pengembangan Jaringan Bandara Terpadu melalui standardisasi bandara hub primer, pengembangan bandara hub sekunder & feeder, bandara perairan, dan seaplane

Peningkatan Keselamatan Transportasi untuk mendukung konektivitas yang aman dan handal

Indikator Penting dan Kebutuhan Investasi
Sektor Konektivitas dan Infrastruktur Logistik

Indikator Pembangunan	Capaian 2020-2024	Target 2025	*Realisasi 2025
Waktu Tempuh Pada Lintas Utama Pulau	1,90	1,89	1,90
Panjang Jalan Tol beroperasi (km,kumulatif)	933	1.176	1.005
Kondisi Mantap Jalan Nasional/ Provinsi/ Kabupaten/Kota (%)	95/69/55	94/71/56/82	95/69/52/77
Tingkat Aksesibilitas Jalan Jalur Utama Daerah Tertinggal dan Perbatasan (Km/100 Km2)	2,76	2,76	2,60
Bandara Baru yang Dibangun	11	-	-
Bandara yang Ditingkatkan/Dikembangkan	115	12	6
Pelabuhan Baru yang Dibangun (lokasi)	13	-	-
Pelabuhan yang Ditingkatkan/Dikembangkan (paket)	25	28	20
Jumlah Perjalanan Kereta Api (Ribu Perjalanan)	870 (2024)	920	430
Panjang Jalur KA yang Beroperasi (km, kumulatif)	6.927	6.928	6.936
Jumlah Penumpang Angkutan Perkotaan di 10 Kota Metropolitan** (Juta Penumpang)	883,8 (2024)	850	406,5
Jumlah Lokasi Rawan Kecelakan (LRK) Ditangani	287	534	315
Peningkatan Pemenuhan SDM Transportasi yang Kompeten (Persen)	95,02 (2024)	85,50	74,21

*) Capaian Semester I Tahun 2025
**) 10 Kota Metropolitan: Jakarta, Medan, Palembang, Surabaya, Denpasar, Banjarmasin, Bandung, Semarang, Makassar, Manado

Indikasi Kebutuhan Pembiayaan/Investasi Infrastruktur Sektor Konektivitas 2025-2029

±Rp 2.050,36 T
(Pemerintah: 41%; Badan Usaha: 59%)

Sektor	Sumber Pembiayaan	
	APBN/DAK/APBD	Badan Usaha
Jalan	Indikasi APBN: Rp 357,2 T Indikasi Dukungan APBN Jalan Daerah: Rp 34,16 T (Diluar DAK)	BUMN, Swasta: Rp 420 T (Indikasi kebutuhan penuntasan Jalan Tol Trans Sumatera, Jalan Tol Trans Jawa, dan Jalan Tol Perkotaan)
Laut	APBN: Rp 67,8 T	BUMN: Rp 12 T (indikasi pengembangan dan operasional PT Pelindo)
Udara	APBN: Rp 50 T	BUMN, Swasta: Rp 20 T
Kereta Api	• APBN (DJKA): Rp 44 T • APBN/D (untuk PSO): Rp ±50 T	• KA Lahat – Tarahan: Rp ± 34 T • KA di IKN: Rp ±145 T • KA Cepat Jakarta-Surabaya:Rp ±516 T
Transportasi Perkotaan	APBN: Rp 120,9 T APBD: Rp 79 T	Rp 59,8T (BUMN/D+Swasta)
Darat, ASDP dan Road Safety	APBN: Rp 36 T DAK: Rp 2,5 T	BUMN: Rp ±2 T (Indikasi pengembangan Kawasan Merak-Bakauheni dan rencana peningkatan kapasitas dermaga pada beberapa pelabuhan penyeberangan)

Infrastruktur Keantariksaan Indonesia

MERAH PUTIH 2
Launch
Cape Canaveral, Florida
21 Februari 2024

TELKOM-3S
Launch
Guyana, Prancis
15 Februari 2017

BRISAT
Launch
Cape Canaveral, Florida
18 Juni 2016

MERAH PUTIH
(Telkom-4)
Launch
Active
Cape Canaveral, Florida
7 Agustus 2018

NUSANTARA SATU
Launch
Cape Canaveral, Florida
21 Januari 2019

SATRIA 1
Launch
Cape Canaveral, Florida
19 Juni 2023

Satellite Ground Station:
- Satria
- Provider Internet
- BRIN
- Perbankan

1. Stasiun Bumi Pantai Cermin (Indosat)
2. Stasiun Bumi Batam
3. Stasiun Bumi Agam
4. Stasiun Bumi Bogor
5. Stasiun Bumi BRhat
6. Stasiun Bumi Jatiluhur (Indosat)
7. Stasiun Bumi Cikarang
8. Stasiun Bumi Pontianak
9. Stasiun Bumi Tarakan
10. Stasiun Bumi Banjarmasin (Telkom)
11. Stasiun Bumi Banjarmasin
12. Stasiun Bumi Banyu urip (Indosat)
13. Stasiun Bumi BRIsat Tabanan Bali
14. Stasiun Bumi Pare pare
15. Stasiun Bumi Makassar
16. Stasiun Bumi Manado
17. Stasiun Bumi Ambon
18. Stasiun Bumi Manokwari
19. Stasiun Bumi Manokwari (Telkom)
20. Stasiun Bumi Biak
21. Stasiun Bumi Nabire (Telkom)
22. Stasiun Bumi Timika
23. Stasiun Bumi Jayapura
24. Stasiun Bumi Kupang
25. Observatorium Timau

Kedirgantaraan Indonesia: N219 Amfibi

CASR 23

Competitive Operating Cost
Multi Hop Capability & Quick Change Configuration
High & Hot Airfield Capability
STOL Operation
Advance & Modern Avionics
Unpaved Runway Capability
Wide Cabin (Un-pressurized)
High Payload Capacity
Fast speed in its class
High wing Configuration
Fixed Landing Gear
Twin Engine (850 SHP each)
19 Passenger

Program Pengembangan Industri Dirgantara:
Pengembangan N219 Amfibi dalam mendukung Hilirisasi, Industrialisasi dan Transformasi Digital

Tantangan

Kegiatan keantariksaan masih bergantung pada pemerintah karena keterbatasan dana dan belum ada model bisnis yang berkelanjutan.

Keterbatasan infrastruktur teknis dan ketergantungan data asing – **Kedaulatan Antariksa & Satelit** (Perang Data dan Ketahanan Siber)

Alokasi APBN 21.4 T untuk Satria-1

Pemotongan anggaran BRIN dari Rp 5.8 T ke Rp 2.07 T

PLN Kemenhan USD 300 Juta Satelit Pertahanan

KKP mengalokasikan Rp 8.9 M untuk proyek BARATA

USGS — Landsat, Sentinel, MODIS — Citra Satelit bebas biaya

Maxar Technoligies, Airbus Defence & Space — Pembelian citra satelit dari luar negeri oleh BRIN **Rp 475 M**

Kapasitas SDM terbatas dalam teknologi satelit dan roket yang berkaitan dengan **kesenjangan penguasaan teknologi kritis** (roket & propulsi)

Partisipasi industri kedirgantaraan nasional dalam rantai pasok (pasar ekspor) global **masih terbatas**, baik dari sisi produk kedirgantaraan dan komponen

Fragmentasi kelembagaan dan regulasi serta lemahnya ekosistem dirgantara dan keantariksaan

Penciptaan nilai (value creation) yang saat ini masih sangat rendah (1:6)

Belum ada skema hilirisasi dan sertifikasi produk turunan satelit

Lambannya adopsi *cloud-processing* data satelit karena pengolahan masih terpusat di pemerintah

Relatif **minimnya kolaborasi** regional ASEAN

Hambatan sosial pembangunan Bandar Antariksa Biak

Arah Kebijakan

1 Perumusan landasan kebijakan dan *roadmap* nasional yang mencakup roket, satelit, dan pesawat (N219, N245/R80), serta konsolidasi kelembagaan lintas sektor

2 Kemandirian data dan transformasi digital melalui *cloud processing*, percepatan akses, kebijakan *market creation* (≥30% data nasional), serta platform digital untuk validasi aplikasi satelit

3 Pembangunan infrastruktur hulu–hilir dan ekosistem industri meliputi desain, integrasi, pengujian satelit, bandara, aerocity park, laboratorium uji, sertifikasi internasional, serta penguatan rantai pasok dan diversifikasi produk

4 Penguatan SDM, riset, dan inovasi melalui *capacity building*, kerja sama pendidikan–industri, RD&D, *engineering office*, serta pengembangan material dan teknologi maju untuk roket, satelit, dan pesawat

5 Pendanaan dan kerja sama internasional dengan mengembangkan skema PPP, *venture capital*, *cost sharing*, serta membentuk konsorsium ASEAN, kemitraan global, dan transfer teknologi untuk mempercepat penguasaan teknologi

TANTANGAN DAN ARAH KEBIJAKAN PEMBANGUNAN INFRASTRUKTUR KETENAGALISTRIKAN

CAPAIAN KEGIATAN INFRASTRUKTUR KETENAGALISTRIKAN 2020-2024

No	Indikator	2020 Target	2020 Realisasi	2021 Target	2021 Realisasi	2022 Target	2022 Realisasi	2023 Target	2023 Realisasi	2024 Target	2024 Realisasi
1	Kebutuhan (Konsumsi) Listrik per kapita Nasional (kWh/kapita)	1.142	1.089	1.203	1.123	1.268	1.173	1.336	1.337	1.408	1.411
2	Rasio Elektrifikasi (%)	~100	99,20	~100	99,45	~100	99,63	~100	99,79	~100	99,83
3	Jumlah Produksi Tenaga Listrik (GWh)	339.082	272.420	359.946	286.256	382.696	304.331	406.325	319.332	431.281	387.296
4	Penurunan Emisi CO2 Pembangkit (Juta Ton)	4,71	8,78	4,92	10,37	5,36	13,839	5,91	15,316	6,07	16,94
5	Jumlah Pengguna Listrik (Ribu Rumah Tangga)	77.107	78.663	79.187	82.196	81.217	85.278	83.219	88.784	85.216	92.494
6	Kapasitas Terpasang Pembangkit EBT-kumulatif (GW)	10,9	10,8	11,98	11,5	13,91	12,5	14,31	13.15	19,20	14,79

K/L Pelaksana

Project Owner:
- Kementerian ESDM
- PT PLN
- Swasta (IPP)
- PT Pertamina

Lintas K/L/D:
- Kementerian Keuangan
- Kementerian Perhubungan
- Kementerian Perindustrian
- BRIN
- Pemerintah Daerah

Penjelasan Ringkas Hasil Evaluasi

- Rasio elektrifikasi meningkat menjadi 99,83% pada tahun 2024;
- Rata-rata pemenuhan kebutuhan (konsumsi) listrik menjadi 1.411 kWh/kapita tahun 2024;
- Penurunan emisi CO2 pembangkit listrik sebesar 16,94 juta ton.

ISU DAN TANTANGAN

1. **Kapasitas infrastruktur ketenagalistrikan masih terbatas** sehingga kualitas layanan ketenagalistrikan masih rendah, serta *lock-in* dan **ketergantungan terhadap penggunaan energi fosil** masih tinggi

2. ***Supply-Demand*** dan ***Spatial Mismatch*** terutama sumber daya energi terbarukan dan pusat beban/permintaan energi listrik

3. **Rendahnya produktivitas pemanfaatan dan integrasi listrik terbarukan bernilai tambah**

4. **Kebutuhan investasi yang besar dan ketergantungan terhadap pembiayaan dan teknologi dari luar negeri**

ARAH KEBIJAKAN

- Pembangunan Pembangkit Listrik.
- Pembangunan sistem penyimpanan energi.
- Pembangunan jaringan transmisi dan interkoneksi dalam dan antar pulau *(Super Grid)*.
- Pembangunan Listrik Pedesaan serta jaringan distribusi dan terisolasi.
- Pengembangan infrastruktur pendukung kendaraan listrik (SPKLU).
- Pemasangan koneksi tenaga listrik.

TANTANGAN DAN ARAH KEBIJAKAN PEMBANGUNAN INFRASTRUKTUR TRANSMISI GAS

CAPAIAN PROGRAM KEGIATAN INFRASTRUKTUR TRANSMISI GAS 2020–2024

No	Indikator Program Prioritas	Satuan	2020		2021		2022		2023		2024	
			Target	Realisasi	Target	Realisasi	Target	Realisasi	Target	Realisasi	Target	Realisasi
1	Jumlah Sambungan Rumah Jaringan Gas Kota	Kumulatif Sambungan Rumah (SR)	715.804	646.131	1.470.510	774.803	2.410.065	884.237	3.210.065	928.020	4.010.065	940.653
2	Jumlah Panjang Pipa Transmisi dan Distribusi Gas Bumi yang Difasilitasi	km	15.300	15.725	15.800	19.046	16.300	21.414	16.800	22.479	17.300	22.533

Sumber: Kementerian ESDM 2025

RENCANA PEMBANGUNAN
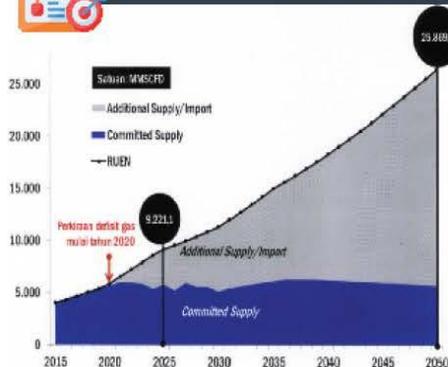
Kebutuhan dan Rencana Pasokan Gas Bumi Tahun 2015-2050

Sumber:
- Perpres Nomor 12 Tahun 2025
- Perpres Nomor 22 Tahun 2017
- PP Nomor 79 Tahun 2014

RPJMN 2025 – 2029
Mendukung pembangunan infrastruktur untuk mencapai target swasembada energi dengan indikator yakni konsumsi energi final per kapita mencapai 0.830 TOE per kapita

Kebijakan Energi Nasional
Kontribusi gas bumi dalam bauran energi primer ditetapkan paling sedikit **22%** pada tahun **2025** dan meningkat menjadi paling sedikit **24%** pada tahun **2050**

TANTANGAN/ISU

1. **Keterbatasan Infrastruktur.** Hal ini menghambat perluasan jargas ke daerah-daerah yang belum terlayani.
2. **Biaya Investasi Awal yang Tinggi.** Biaya pengembangan per sambungan rumah tangga tergolong tinggi, terutama karena tingkat konsumsi gas per rumah tangga yang masih rendah.
3. **Keekonomian Proyek**, di mana banyak badan usaha swasta merasa proyek ini berisiko tinggi dan tidak menguntungkan.

ARAH KEBIJAKAN/STRATEGI TRANSFORMASI

- Pembangunan Jaringan Gas Kota untuk Rumah Tangga (Jargas)
- Pembangunan Pipa Transmisi Gas Bumi Ruas Cirebon – Semarang (Cisem) Tahap II
- Pembangunan Pipa Transmisi Gas Bumi Ruas Dumei – Cisem (Dusem)
- Fasilitasi Pengembangan Infrastruktur Regasifikasi Gas Bumi dan Terminal LNG

ARAH KEBIJAKAN & STRATEGI PENGELOLAAN SUMBER DAYA AIR DALAM RPJMN 2025-2029

PENERAPAN PENDEKATAN FOOD, ENERGY, WATER NEXUS DALAM RANGKA MEWUJUDKAN KEMANDIRIAN BANGSA TERKAIT PEMENUHAN KEBUTUHAN AIR BERKELANJUTAN

MELALUI

PEMBANGUNAN DAN PENGELOLAAN TAMPUNGAN AIR dalam rangka peningkatan ketersediaan air

• Penyelamatan mata air kritis • Konservasi daerah tangkapan air melalui rehabilitasi hutan dan lahan • Pembangunan dan pengelolaan tampungan air untuk pemanfaatan pertanian, peternakan, air minum, dan energi terbarukan •

PENYEDIAAN PASOKAN AIR BERKELANJUTAN sebagai tumpuan pengembangan lumbung pangan dan pertumbuhan sektor produktif

• Menjaga neraca air pada tingkat Wilayah Sungai tidak dalam kondisi defisit/kritis/tertekan • Tindak lanjut pemanfaatan air baku dan irigasi dari bendungan terbangun •

PENGELOLAAN RISIKO DAYA RUSAK AIR yang berorientasi pada kesiapan dan ketahanan bencana

• Integrasi pendekatan struktural dan nonstruktural (seperti solusi berbasis alam) • Revitalisasi sungai •

PENGEMBANGAN TERPADU PESISIR UTARA JAWA sebagai upaya untuk meningkatkan ketahanan wilayah Pantura Jawa terhadap daya rusak air

• Percepatan persiapan giant sea wall sebagai bentuk pengamanan terpadu wilayah perkotaan yang terintegrasi dengan rencana pengembangan kawasan •

DIDUKUNG OLEH

PENYEMPURNAAN TATA KELOLA

• Source to sea • Smart water management • Water accounting • Perencanaan yang terpadu • Peningkatan nilai kawasan (land value capture) •

TANTANGAN PEMBANGUNAN:
Pengembangan dan Pengelolaan Jaringan Irigasi

PROYEKSI PENINGKATAN PERMINTAAN AIR

Proyeksi kebutuhan air tahunan berdasarkan sektor, 2015–2045
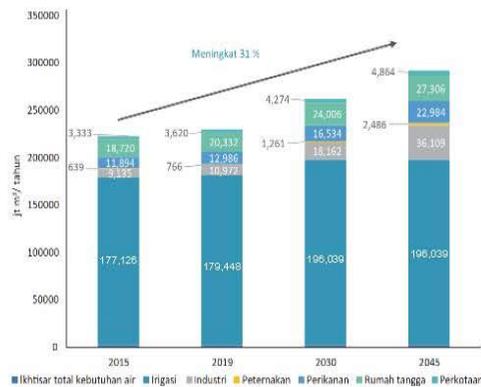
Sumber: Kajian Water Security 2019 (World Bank & Bappenas)

Permintaan air diproyeksikan meningkat 31% sebagai dampak perubahan kondisi demografi dan ekonomi.

- **Permintaan air untuk pertanian akan menghadapi persaingan dari sektor lain**

- Kebutuhan air industri meningkat 4x lipat

- Di sisi lain, kemampuan penambahan kapasitas air baku tahunan rata-rata hanya 2 m³/detik atau 63 juta m³/tahun □ sementara distribusi sampai SR sangat tergantung Pemda

Sumber: World Bank (2021)

KONDISI IRIGASI PERMUKAAN DI INDONESIA (2014)

Luas Area Irigasi Permukaan Di Indonesia

33% Pusat 2.376.521 Ha

51% Kabupaten/Kota 3.663.172 Ha

16% Provinsi 1.105.475 Ha
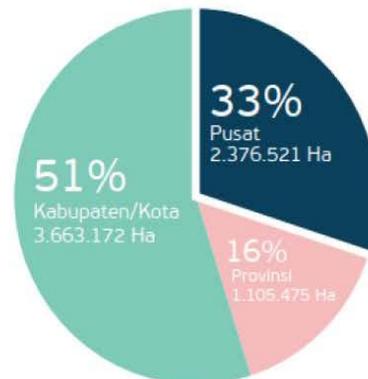
7.145.168 Ha
Baik 54% - Rusak 45%

Warna	Kondisi	Kerusakan
●	Baik	<10%
●	Rusak Ringan	10-20%
●	Rusak Sedang	20-40%
●	Rusak Besar	>40%

77,5% ◢ Pusat

48,6% ◢ Provinsi

40,9% ◢ Kabupaten/Kota

Hampir separuhnya irigasi dalam kondisi rusak

PERBANDINGAN PEMENUHAN ANGGARAN OP TA 2024 TERHADAP AKNOP INFRASTRUKTUR SUMBER DAYA AIR

BENDUNGAN	19,95%
SUNGAI	36,25%
IRIGASI	37,94%
AIR BAKU	69,16%
AIR TANAH	39,82%
PENGAMAN PANTAI	38,25%

■ DIPA ■ AKNOP
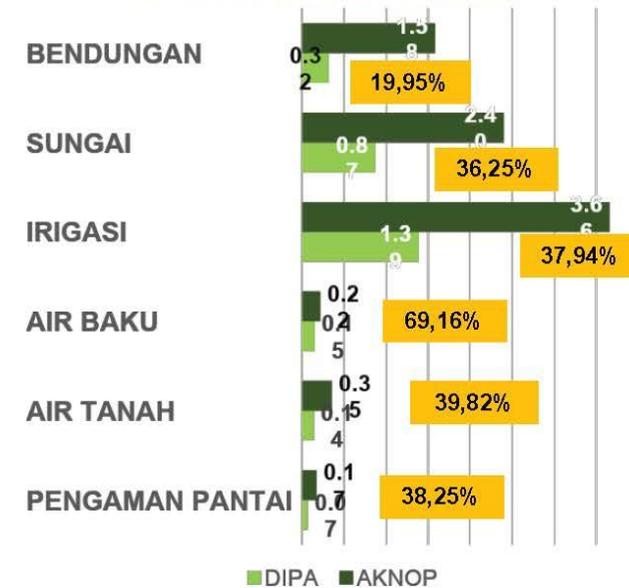
DIPA TA 2024 baru mampu memenuhi AKNOP sebesar 34,95%

TOTAL SELURUH AKNOP	Rp. 8,38 Triliun
TOTAL SELURUH DIPA OP TA 2024	Rp. 2,93 Triliun
DEVIASI	Rp. 5,45 Triliun

Indonesia merupakan salah satu negara dengan **potensi sumber daya air terbesar di dunia**, namun **kapasitas tampung air** per kapita di **Indonesia** termasuk yang **terendah di dunia**.

- **Cakupan layanan** bendungan **sangat terbatas**:

  - Hanya **16.06% area irigasi** permukaan yang dilayani bendungan

  - Hanya **23.06%** dari total **kapasitas air baku terbangun** yang berasal dari bendungan

- **Sebagian besar** layanan irigasi permukaan dan air baku **mengandalkan** debit sungai atau mata air (*free intake*):

  - **sangat rentan terhadap perubahan curah hujan**

Total renewable water resources per capita (2013)

Global Dam and Reservoir Storage Capacity

Water Storage Capacity (cubic meters/person)

	< 500
	500 - 1,000
	1,000 - 2,500
	2,500 - 5,000
	5,000 - 10,000
	10,000 - 25,000
	> 25,000
	No Data

○ circle of blue

Dam storage data from Global Reservoir and Dam Database – dates vary. Population data are 2015 estimates from the United Nations.
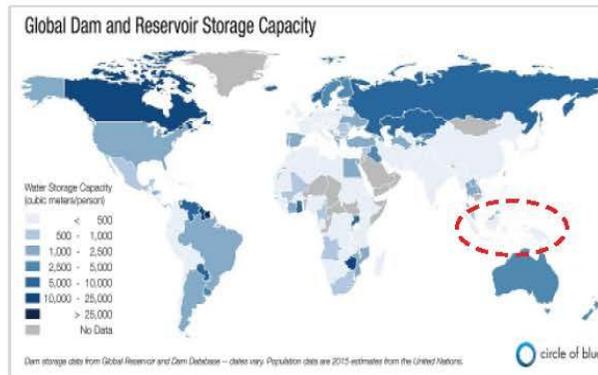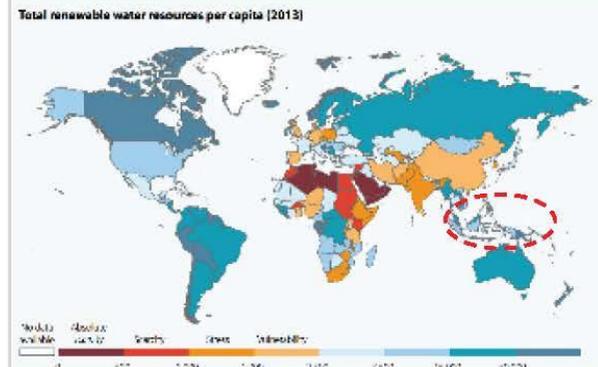
	CHINA	INDONESIA	THAILAND	ETHIOPIA
Renewable water resources (billion m³)	2,840 (Ke-5 Dunia)	2,019 (Ke-7 Dunia)	439	122
Reservoir Capacity Per Capita	564	63	1,135	273

"PEMBANGUNAN SD PEMANFAATAN BENDUNGAN BUTUH KOMITMEN JANGKA PANJANG"

- Perencanaan dan konstruksi bendungan **butuh waktu belasan bahkan sampai puluhan tahun**

BENDUNGAN	VOL (JUTA m³)	FS	KONSTRUKSI
Jatigede	1,061	1963	2006-2015
Karian	314	2006	2015-2023
Passeloreng	128	1995	2017-2021

- Penuntasan manfaat bendungan **juga membutuhkan waktu yang relatif panjang**

BENDUNGAN (TAHUN PERESMIAN)	PENUNTASAN MANFAAT		
	IRIGASI	AIR BAKU	LISTRIK
Jatigede (2015)	Modernisasi irigasi Rentang selesai tahun 2026	Tahap I selesai tahun 2019 Tahap II dalam Proses	Konstruksi (2x55 MW)
Sindangheula (2021)	Pekerjaan rehabilitasi belum dilakukan	Dalam proses penyiapan KPBU	Sudah peresmian

- Keberlanjutan pengelolaan bendungan tergantung keterlibatan dan peran banyak pihak

STAKEHOLDERS	PERAN
Kementerian PUPR	OP Bendungan
KLHK	Konservasi catchment area
KKP	pembinaan budidaya perikanan di waduk
Pemda	Pemberdayaan masyarakat, penerbitan izin

KENAIKAN RISIKO BANJIR

Tren Kejadian Banjir di Pantura 11 Tahun Terakhir

Tren kejadian banjir dalam 11 tahun terakhir **menunjukkan peningkatan.** Total kejadian mencapai 1761 kejadian, dengan jumlah korban jiwa mencapai 493 jiwa dan merendam hampir 2 juta rumah.

PENURUNAN MUKA TANAH

Penurunan permukaan tanah di Indonesia paling parah terjadi di **pesisir utara Jawa (Pantura)**, yang merupakan pusat ekonomi dengan penduduk yang padat. Penurunan muka tanah yang terjadi **1-20 cm/tahun**

KRISIS AIR BAKU DAN AIR BERSIH

STATUS AIR BAKU PULAU JAWA

POTENSI AIR

Air Permukaan : 162 miliar m3/tahun
Air Tanah : 2 miliar m3/tahun
TOTAL : 164 miliar m3/tahun

PASOKAN AIR BAKU

Permintaan Domestik : 9,21 miliar m³/tahun
Pasokan Air Tanah : 3,63 miliar m³/tahun
DEFISIT : 5,6 miliar m³/tahun

Banyak kota besar di sepanjang pantai utara Jawa memiliki cakupan sistem pasokan air (SPAM) di bawah 50%

Sumber: Andreas *et al.*, 2024

TANTANGAN DAN ARAH KEBIJAKAN PEMBANGUNAN PERUMAHAN

RPJMN 2025-2029

INDIKATOR	TARGET	CAPAIAN
Rumah tangga dengan akses hunian layak, terjangkau dan berkelanjutan*	74% (2029)	65,25% (2024)

Indikator keterjangkauan dan keberlanjutan masih dalam proses pengembangan

Sumber: Olah Data Susenas, BPS

Key strategies:
1. Integrasi antar sektor perumahan, air minum, air limbah, dan persampahan
2. Integrasi sektor perumahan dan kawasan permukiman dengan sektor lainnya (contoh: konektivitas, transportasi publik)

TANTANGAN/ISU

Rusunawa Pasar Rumput

DAK Tematik Pengentasan Permukiman Kumuh Terpadu

Target nasional 2026 sebesar 68,66% untuk mencapai target 2026 perlu dilakukan intervensi penyediaan perumahan baik di perkotaan maupun perdesaan. Target 2026 di perkotaan sebesar 68,69% dan di perdesaan sebesar 67,54%.

- Program perumahan belum dapat diakses secara luas oleh masyarakat berpenghasilan tidak tetap dan bagi yang membangun rumah secara swadaya, seperti FLPP yang baru menjangkau masyarakat berpenghasilan formal;
- Program yang belum tepat sasaran, seperti hunian subsidi yang dibeli namun tidak dihuni;
- Tata kelola program perumahan yang belum optimal seperti kelembagaan dan pengelolaan aset, perencanaan berbasis data, keterpaduan program, pembagian peran kewenangan, penerapan

ARAH KEBIJAKAN/STRATEGI TRANSFORMASI

PERKOTAAN

- Penyediaan hunian tapak dan vertikal yang didukung fasiltiasi kemudahan pembiayaan perumahan
- Penyediaan hunian vertikal dengan pembiayaan alternatif
- Optimalisasi lahan melalui konsolidasi tanah dan pengembangan TOD
- Penanganan kumuh secara terpadu

PERDESAAN

- Pembangunan hunian baru, termasuk perumahan berkelompok
- Peningkatan kualitas hunian
- Stimulan pembiayaan dan bantuan konsultasi teknis
- Skema kemudahan pembiayaan secara bertahap (KPR mikro dan KPR swadaya)
- Penanganan permukiman kumuh dengan Pemda yang memegang *leading role*

PENGUATAN EKOSISTEM PERUMAHAN DAN PERBAIKAN TATA KELOLA

- Penegakkan aspek tata ruang dan keandalan bangunan yang berketahanan bencana dan iklim
- Kemudahan perizinan
- Perlindungan konsumen
- Peningkatan kepastian bermukim
- Pengembangan pendanaan alternatif
- Penegakkan kebijakan hunian berimbang
- Insentif fiskal dengan kondisi tertentu

OPTIMALISASI PERAN SETIAP PEMANGKU KEPENTINGAN

Mendukung penyelenggaraan perumahan seperti pelaksana dan pengelola program pemerintah terkait perumahan, pengelola dana Tapera dan FLPP, serta berperan dalam membangun dan mengembangkan pasar pembiayaan sekunder perumahan.

TANTANGAN DAN ARAH KEBIJAKAN PEMBANGUNAN INFRASTRUKTUR AIR MINUM

RPJMN 2025-2029

INDIKATOR	TARGET	CAPAIAN
Meningkatnya Rumah Tangga yang terlayani Air Minum Aman	42% (2029)	20,49%* (2023)
Meningkatnya Rumah Tangga yang Terlayani Akses Air Minum Jaringan Perpipaan	40,2% (2029)	30,12%** (2024)
Meningkatnya Akses Rumah Tangga Perkotaan terhadap Air Siap Minum Perpipaan	51,36% (2029)	39%*** (2025)

*)sumber: SKAM-RT Kemenkes, **) sumber: Kementerian PU,
***) baseline RPJPN 2025-2045

TANTANGAN/ISU

79,51% Rumah Tangga Mengakses Air Minum yang Tidak Aman
(termasuk 75,87% tercemar E. Coli)

Akses perpipaan memiliki tingkat aman tertinggi, namun baru 30,12% rumah tangga yang memiliki aksesnya

- 64% Rumah Tangga menggunakan air tanah sebagai sumber utama air minum │ Land Subsidence (Jakarta dan Semarang 2-10 cm/tahun): banjir, intrusi air laut
- Pengelolaan aset air baku, IPA, dan distribusi yang belum efisien │ 34,6% BUMD Air Minum berkinerja tidak sehat dan hanya 3 BUMD Air Minum yang berkinerja sehat berkelanjutan, rata-rata NRW 33,9%
- Belum efektifnya pengaturan sektor air minum terutama dalam penetapan tarif │ tarif di 226 kab/kota tidak menutupi biaya O&M

Sumber Data: Susenas (2024) dan Data Kumuh Kementerian PUPR (2024)

ARAH KEBIJAKAN/STRATEGI TRANSFORMASI

PEMBENTUKAN BADAN REGULATOR
- Regulasi lingkup pengaturan air baku, air minum, dan air limbah.
- Fungsi pengawasan kinerja
- Rekomendasi tarif air baku, air minum, dan air limbah
- Pada tahap awal berupa badan pengatur dibawah Kementerian PU .

PENGELOLAAN ASET TERPADU
- Pengeleloaan aset terpadu/intake, transmisi, IPA, jaringan distribusi hingga SR air minum/air limbah --> dapat berupa holding BUMN/BUMD+ Investasi swasta
- Regionalisasi layanan wilayah metropolitan

OPTIMALISASI PENDANAAN
- Pemanfaatan sumber-sumber alternatif termasuk investasi swasta
- blended financing
- performance-based funding

TANTANGAN DAN ARAH KEBIJAKAN PEMBANGUNAN INFRASTRUKTUR SANITASI (AIR LIMBAH DOMESTIK)

RPJMN 2025-2029

INDIKATOR	TARGET	CAPAIAN
Meningkatnya Rumah Tangga yang terlayani Akses Sanitasi Aman	30% (2029)	10,25% (2024)
Mengentaskan perilaku BABS di tempat terbuka	0% (2029)	3,2% (2024)
Jumlah Kab/Kota yang memiliki Instalasi Pengolahan Lumpur Tinja (IPLT)	514 (2029)	203* (2024)

Sumber: Susenas KOR BPS; *Data Kementerian PU

TANTANGAN/ISU

Hanya 1 dari 10 Rumah Tangga (10,25%) di Indonesia yang terlayani akses sanitasi aman (BPS, Susenas KOR)

Layanan sanitasi masih rendah dan tertinggal dibanding negara lain **Urutan ke-9 di ASEAN, tertinggal dari Malaysia, Thailand dan Kamboja**. Akibatnya, **53% sungai di Indonesia tercemar berat**. Pada 3 DAS besar, 53-84% bagian DAS tercemar Air Limbah Domestik

83 IPLT belum/tidak beroperasi dan sebagian besar dalam keadaan rusak, sementara terdapat **16 IPLT memerlukan peningkatan kapasitas.**

Tata kelola kelembagaan dan pembiayaan belum terbangun **Hanya 25% Kab/Kota yang memiliki operator** air limbah domestik, dan 6 PDAM yang mengintegrasikan layanan sanitasi dengan air minum

Isu pembiayaan dan baru 15 Kab/Kota yang mengimpelementasikan tarif/retribusi (tarif ini maksudnya apa)

Alokasi APBD yang rendah dan tarif

ARAH KEBIJAKAN/STRATEGI TRANSFORMASI

PENGUATAN REGULASI DAN BADAN REGULATOR

- Penguatan kerangka regulasi untuk mengatur tata kelola dan standar layanan air limbah
- Penguatan fungsi regulator air (air baku, air minum, air limbah) di tingkat pusat

PENGELOLAAN TERPADU DENGAN SEKTOR AIR

- Pengeleloaan aset dan yang terpadu/ intake dengan Air Baku dan Air Minum --> dapat berupa holding BUMN/BUMD+ Investasi swasta
- Integrasi pelayanan, utamanya dalam penarikan tarif/retribusi

PENERAPAN PRINSIP CITIWIDE INCLUSIVE SANITATION (CWIS)

- Setiap Kabupaten/Kota memiliki minimal 1 IPLT
- Termasuk implementasi Layanan Lumpur Tinja Terjadwal (L2T2)

PENDAMPINGAN PPSP

- Program Peningkatan Kapasitas Pemda bertujuan untuk menggaet komitmen Kepala Daerah dan Uji Coba Model Layanan

TANTANGAN DAN ARAH KEBIJAKAN PEMBANGUNAN INFRASTRUKTUR PERSAMPAHAN

RPJMN 2025-2029

INDIKATOR	TARGET	BASELINE
Timbulan sampah terolah di fasilitas pengolahan sampah (%)	38 (20 terdaur ulang) (2029)	15 (13 terdaur ulang) (2022)
TPA/LUR yang dioperasikan secara sanitary landfill / tingkat pengontrolan penuh (unit)	11 (2029)	0 (2024)
Rumah tangga dengan layanan pengumpulan sampah (%)[a]	85% (2029)	35,01%* (2022)

Keterangan:

[a]) Target yang dimandatkan pada SEB RPJPN-RPJPD
Sumber: *) Susenas MKP BPS, 2022

TANTANGAN/ISU

- Pengoperasian TPA dengan metode *open dumping* masih sebesar **40,09%** secara nasional
- **39,14%** sampah terbuang ke lingkungan melalui pembakaran, illegal dumping atau bocor ke badan air
- Belum adanya pemisahan fungsi regulator-operator pada **399 kab/kota**
- Alokasi APBD untuk pengelolaan sampah memiliki rata-rata hanya **0,7-0,85%** di setiap daerah
- Persentase pengumpulan **retribusi sampah hanya sebesar 40-45%**
- **Hanya 11 kab/kota** yang sudah memiliki Rencana Induk Sistem Pengelolaan Sampah
- Skema terbentuk/berkelanjutan: KPBU/kerja sama PSEL, dan TPST masih terkendala
- **93,2% rumah tangga belum** melakukan pemilahan
- Belum berkembangnya **inovasi bauran pendanaan** dan optimalisasi **retribusi daerah**

ARAH KEBIJAKAN/STRATEGI TRANSFORMASI

Pemisahan Peran Reguator dan Operator
- Regulator diperkuat dalam hal pengawasan dan tarif
- Operator, perlu pengelolaan aset yang hulu hilir (operator pelayanan pengumpulan terpadu dengan operator TPST)––> layanan menyeluruh (dilakukan oleh satu badan usaha (pengelolaan aset terpadu hulu hilir)

Skema Pembiayaan/Model Bisnis dari Sumber APBN/APBD/dan Investasi swasta
- PSEL Revisi Perpres 35 tahun 2025 (sedang dilakukan)
- Perlu disusun regulasi untuk teknologi lainnya, misal RDF (melalui pengaturan yang melingkupi biaya logistik, offtaker, tipping fee)

Partisipasi Masyarakat
Penyadartahuan dan pemicuan perubahan perilaku masyarakat untuk pengurangan dan pemilahan sampah di sumber serta peningkatan permintaan dan partisipasi serta kemauan untuk membayar retribusi.

INDIKATOR PENTING DAN KEBUTUHAN INVESTASI
SEKTOR PERUMAHAN DAN INFRASTRUKTUR KAWASAN PERMUKIMAN
2025–2029

Indikator Pembangunan	Capaian 2020-2024	Target 2025	Realisasi 2025
Rumah Tangga dengan Akses Hunian yang Layak	65,25% (2024)	67%	**
Rumah Tangga dengan Akses Air Minum Aman	20,49% (2023)	33%	**
Rumah Tangga dengan Akses Air Minum Jaringan Perpipaan	30,12% (2024)	31%	**
Akses Rumah Tangga Perkotaan terhadap Air Siap Minum Perpipaan	24,00% (2020)	39,2	**
Rumah Tangga dengan Akses Sanitasi Aman	10,25 (2024)	12,5%	**
Rumah Tangga yang mempraktikkan BABS di Tempat Terbuka	3,2% (2024)	2,5%	**
Jumlah Kabupaten/Kota yang memiliki Instalasi Pengolahan Lumpur Tinja (IPLT)	196	218	207***
Timbulan sampah terolah di fasilitas pengolahan sampah	15% (13% terdaur ulang) (2022)	24% (16% terdaur ulang)	**
TPA/LUR yang dioperasikan secara sanitary landfill / tingkat pengontrolan penuh	0 unit (baseline)	0 unit	**

**) Dihitung tahunan
***) Prognosis s.d Triwulan I tahun 2025

Indikasi Kebutuhan Pembiayaan/Investasi Sektor Perumahan dan Infrastruktur Kawasan Permukiman

±Rp 1394,83 T
(Pemerintah: 753,33%; Non Pemerintah: 641,5%)

Sektor	Sumber dan Kebutuhan Pembiayaan 2025-2029	
	APBN/DAK/APBD	Non APBN/APBD
Perumahan	Belanja K/L:Rp 60 T Subsidi: Rp 140 T	Rp 514 T
Air Minum	APBN: Rp 67 T DAK: Rp 28 T APBD: Rp 17,63 T	BUMD: Rp 38 T Swasta: Rp 24 T ZISWAF dan CSR: Rp 1,5 T Masyarakat: Rp 2,4 T
Sanitasi (Air Limbah Domestik(	• APBN: Rp 75 T • DAK: 38,7 T • APBD (termasuk operasionalisasi): Rp ±79,8 T	• Swasta: Rp ±10-15 T • Kontribusi Masyarakat: Rp 30-40 T
Pengelolaan Persampahan	APBN: Rp 65 T DAK: Rp 2,2 T APBD: Rp 180 T (termasuk Capex dan Opex)	Lainnya: Rp 6,6 T (masyarakat dan dunia usaha) (termasuk Capex dan Opex)

INFRASTRUKTUR BERKELANJUTAN

Isu dan Persoalan

1. **Kurangnya integrasi prinsip-prinsip keberlanjutan** dalam perencanaan dan pelaksanaan proyek infrastruktur
2. Sebagian besar **infrastruktur rentan terhadap perubahan iklim**
3. **Akses** terhadap **pembiayaan inovatif berwawasan lingkungan masih terbatas**
4. Pembangunan **infrastruktur** yang **tidak mempertimbangkan aspek keadilan sosial**
5. Pendekatan **pembangunan infrastruktur yang ekstraktif dan tidak efisien** mempercepat eksploitasi sumber daya alam
6. **Kurangnya regulasi komprehensif dan lemahnya penegakan hukum** menghambat kepatuhan proyek infrastruktur terhadap standar lingkungan dan sosial
7. **Transformasi infrastruktur** berkelanjutan bergantung pada **teknologi canggih untuk efisiensi dan mitigasi dampak lingkungan**

Arah Kebijakan

1. Perkuat aturan dan pengawasan lingkungan serta **beri sanksi tegas terhadap pelanggaran**
2. **Mewajibkan prinsip lingkungan, sosial, dan iklim** dalam perencanaan dan desain proyek
3. **Larangan pembangunan di habitat kritis tanpa mitigasi**, seperti jalur satwa liar
4. **Mendorong green bonds, insentif fiskal, dan kemitraan publik-swasta** ramah lingkungan
5. Menerapkan **standar infrastruktur tahan bencana** dan **dukung solusi berbasis alam**

Strategi Penyelesaian

Integrasi Prinsip Lingkungan dalam Perencanaan Awal

Pengembangan Infrastruktur Hijau (Green Infrastructure)

Penguatan Regulasi dan Penegakan Hukum

Pendanaan Berkelanjutan dan Inovatif

Teknologi untuk Pemantauan dan Evaluasi

Contoh pembangunan *sustainable infrastructure*

Terowongan gajah di Tol Pekanbaru-Dumai

Jalan Tol Semarang – Demak terintegrasi dengan tanggul pantai

Positioning Stakeholder
Pembangunan Infrastruktur

Pemerintah

Perencana (Konsultan/ Ahli)

Pengawas (Konsultan Supervisi)

Pemberi Dana (Pemerintah, Bank, Investor)

Dokumen Perencanaan

Anggaran Pembiayaan

Kontraktor

Sub Kontraktor

Tenaga Kerja/Ahli

Pelaksanaan Fisik

Masyarakat
(Pengguna & Penerima Manfaat)

Pengawas Lapangan
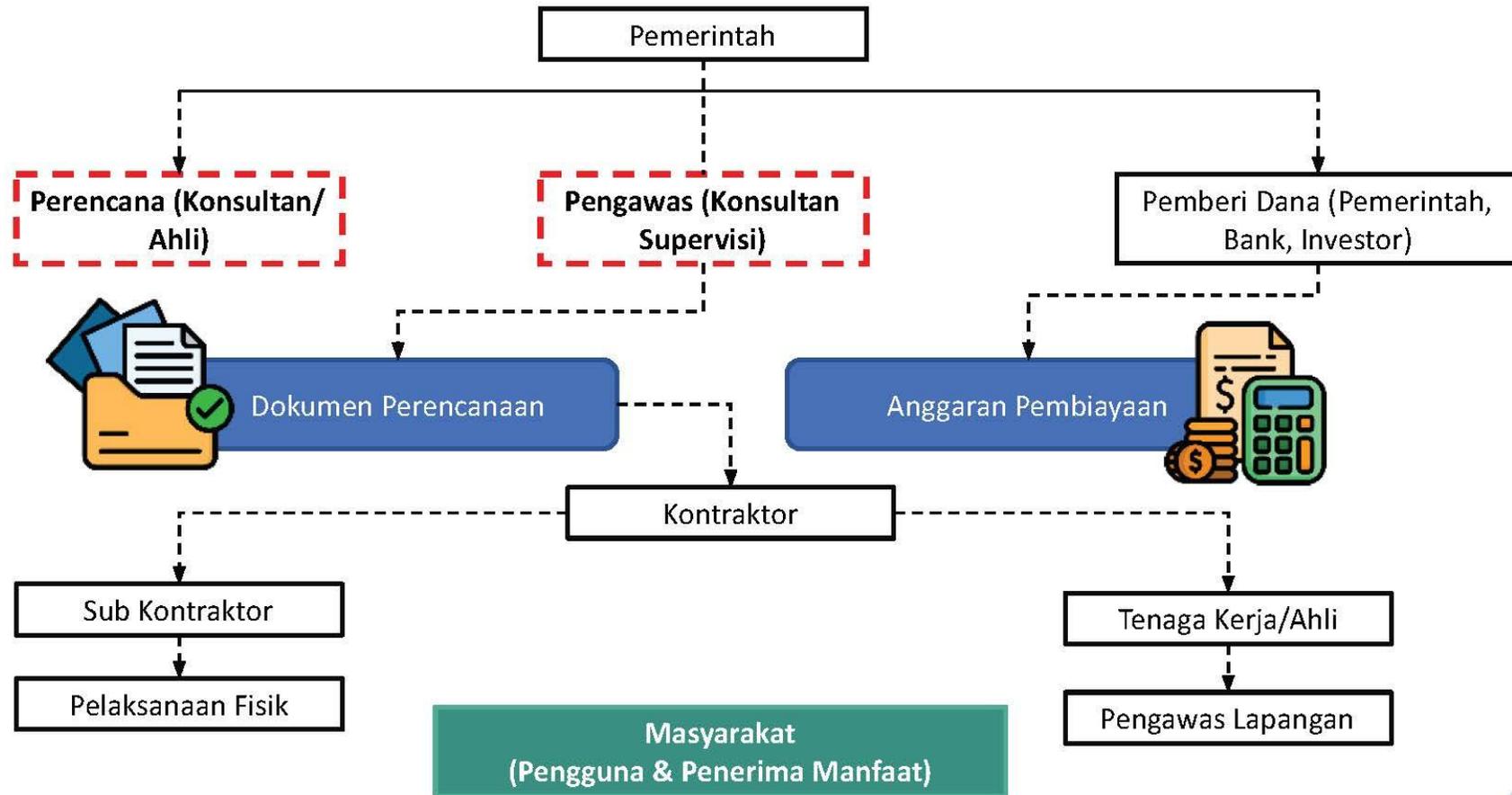
Sumber: berbagai sumber, diolah.

Peningkatan Profesionalisme dan kompetensi	Mendukung reformasi dan Regulasi jasa Konstruksi	Kemandirian dan Daya Saing Konsultan Nasional

❑ Meningkatkan kualitas tenaga ahli dan profesional melalui pelatihan, sertifikasi, dan standarisasi kompetensi.

❑ mengikuti perkembangan teknologi dan metode kerja baru (misalnya BIM, digitalisasi proyek).

❑ Menjaga etika profesi dan integritas dalam pelaksanaan tugas konsultansi.

❑ Menjadi mitra strategis dalam implementasi regulasi jasa konstruksi, seperti UU No. 2 Tahun 2017 dan peraturan turunannya.

❑ Memberi masukan dalam penyusunan kebijakan pemerintah terkait jasa konsultansi konstruksi.

❑ Menyosialisasikan regulasi baru kepada stakeholder.

❑ INKINDO memperkuat kapasitas konsultan nasional agar tidak kalah bersaing dengan konsultan asing, khususnya dalam proyek-proyek strategis nasional dan internasional.

❑ INKINDO mendorong konsultan anggotanya untuk berkolaborasi dan membentuk konsorsium agar bisa mengerjakan proyek besar dan kompleks.

KONSULTAN SANGAT MENENTUKAN KUALITAS INFRASTRUKTUR

INKINDO
IKATAN NASIONAL KONSULTAN INDONESIA

FIDIC
International Federation of Consulting Engineers
The Global Voice of Consulting Engineers

REKOMENDASI PENINGKATAN PERAN INKINDO DALAM MENYIAPKAN JASA KONSULTAN YANG MEMPUNYAI KOMPETENSI DALAM BIDANG INFRASTRUKTUR

Sektor Konektivitas dan Infrastruktur Logistik

Meningkatkan Profesionalisme dan kompetensi

- Meningkatkan kualitas tenaga ahli dan profesional melalui pelatihan, sertifikasi, dan standarisasi kompetensi
- Mengikuti perkembangan teknologi dan metode kerja baru (misalnya BI dan digitalisasi proyek)
- Menjaga etika profesi dan integritas dalam pelaksanaan tugas konsultansi
- Mengerjakan tugas dengan basis bukti dan ilmu pengetahuan

Meningkatkan Kemandirian dan Daya Saing Konsultan Nasional

- Memperkuat kapasitas konsultan nasional agar tidak kalah bersaing dengan konsultan asing, khususnya dalam proyek strategis nasional dan internasional
- Mendorong konsultan anggotanya untuk berkolaborasi dan membentuk konsorsium agar dapat berkontribusi dalam proyek besar dan kompleks

- **Masterplan dan dokumen sejenisnya** pada sektor konektivitas dan infrastruktur logistik yang lebih baik
- **Kesiapan proyek** sektor konektivitas dan infrastruktur logistik yang lebih baik dan dapat diandalkan
- **Penyiapan proyek** atau kumpulan proyek yang dapat menarik investasi swasta khususnya di sektor konektivitas dan infrastruktur logistik

Sektor Sumber Daya Air

- **Meningkatkan Kompetensi dan Spesialisasi**
  Melalui program sertifikasi internasional dan pelatihan khusus di bidang sumber daya air
- **Mengadopsi Standar Global**
  Mengarusutamakan standar FIDIC dan praktik terbaik internasional dalam desain, manajemen risiko, serta tata kelola proyek.
- **Mendorong Kolaborasi Internasional**
  Memperkuat peran konsultan nasional di proyek pembiayaan internasional.
- **Memperkuat Digitalisasi dan Inovasi**
  Memanfaatkan teknologi digital (BIM, GIS, pemodelan hidrologi) serta membangun platform nasional database tenaga ahli dan praktik terbaik.

Sektor Transmisi, Ketenagalistrikan, Kedirgantaraan, dan Antariksa

Transmisi Gas
- Penyelesaian dan perluasan proyek pipa transmisi strategis
- Integrasi jaringan transmisi dengan jargas kota
- Pengembangan infrastruktur penunjang transmisi gas seperti fasilitas regasifikasi, LNG terminal, *metering station*, dan *booster station* untuk mendukung suplai gas

Ketenagalistrikan:
- Pelatihan dan sertifikasi teknis ketenagalistrikan
- Peningkatan kerjasama dengan pemerintah, PT PLN, dan institusi pendidikan/penelitian
- Peningkatan kompetensi non-teknis konsultan (*feasibility study*, pembiayaan, AMDAL, dan *digital tools*)
- Advokasi keterlibatan konsultan domestik dalam proyek ketenagalistrikan

Kedirgantaraan dan Antariksa:
- Keterlibatan aktif dalam penyusunan kajian strategis dan *roadmap* nasional
- Partisipasi dalam perancangan skema pendanaan inovatif
- Berperan sebagai fasilitator kemitraan internasional dan transfer teknologi
- Penguatan kapasitas industri nasional dan ekosistem keantariksaan
- Pendampingan teknis lintas sektor pemanfaatan citra penginderaan jauh
- Konsultasi sosial dan *stakeholder engagement*

Sektor Perumahan dan Infrastruktur Kawasan Permukiman

- Meningkatkan pemahaman konsep THIS (Tematik, Holistik, Integratif, dan Spasial) dalam perencanaan pembangunan infrastruktur
- Meningkatkan pemahaman substantif lingkup perumahan dan infrsatruktur kawasan permukiman
- Mendorong keterlibatan aktif dalam kajian strategis dan inovasi untuk mendukung ketercapaian sasaran pembangunan nasional

" TERIMA KASIH
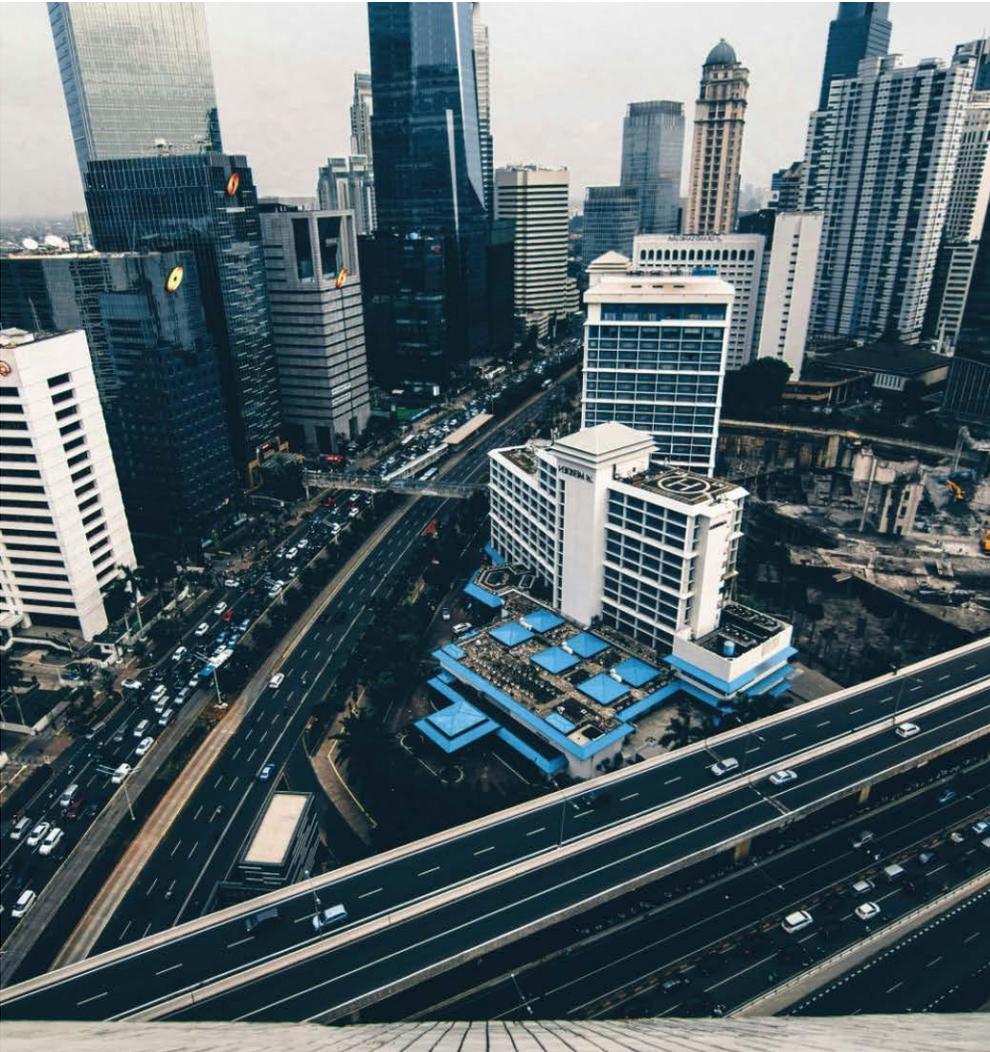
" LAMPIRAN

Tingginya Biaya Logistik terhadap PDB
(Tahun 2023: 14,1% ⮕ Target Tahun 2045: 8%)

Legenda:
- Transportasi Darat
- Transportasi Udara
- Transportasi Laut
- Warehouse
- Administration

14,1% 7%
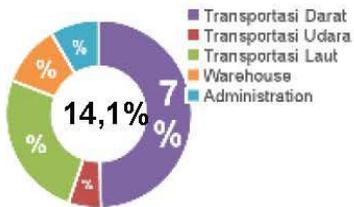
Sumber: Kajian Biaya Logistik SIRI, 2022

Biaya Logistik terhadap PDB Tahun 2023

100% — Sorong — 30% — Surabaya

Sumber: Kajian Bappenas, 2019

Rata-Rata Muatan Datang dan Muatan Balik Angkutan Laut di Kawasan Timur

80% biaya logistik disumbang oleh **sektor transportasi** (mayoritas oleh transportasi darat dan transportasi laut)

❑ Ongkos transportasi darat mahal antara lain karena:
  - Kerusakan jalan (28% jaringan jalan mengalami kerusakan berat, 77% diantaranya merupakan jalan daerah)
  - Kemacetan lalu lintas di perkotaan dan rendahnya pangsa kereta api logistik (<1%) terutama untuk jarak tempuh 750-1.500 km

❑ Ongkos transportasi laut mahal, disebabkan:
  - Skala ekonomi rendah (muatan sedikit dan ukuran kapal kecil)
  - Rendahnya muatan balik dari Kawasan Timur (30%) karena terbatasnya kawasan ekonomi dan hub domestik di Timur serta belum terbentuknya konsolidasi rute pelayaran secara

Kemacetan Lalu Lintas di Perkotaan

- Bandung (rank 8) | 48%
- Jakarta (rank 25) | 43%
- Palembang (rank 33) | 41%
- Medan (rank 46) | 40%

*)persentase tingkat kemacetan dibanding kondisi normal kota tersebut

Peringkat Kemacetan Kota-Kota di Indonesia (ranking di dunia) (Sumber: TomTom, 2025)

- Private vehicles
- Public transport
- Shared mobility
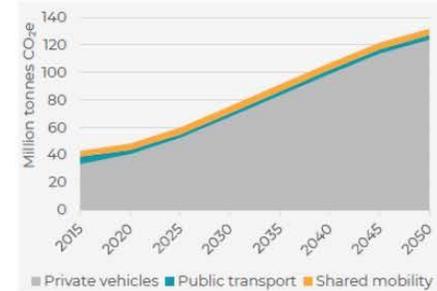
Proyeksi Emisi Gas Rumah Kaca (Sumber World Bank)

❑ Wilayah Metropolitan menyumbang 45% PDB Nasional, namun terdapat isu kemacetan
  - Metropolitan Bandung menjadi **Wilayah Metropolitan termacet** di ASEAN tahun 2024

❑ Kemacetan menyebabkan inefisiensi urbanisasi
  - **1% urbanisasi** hanya menghasilkan peningkatan **1,4% PDB per kapita** (China **3%**, Negara-Negara Asia Timur & Pasifik **2,7%**)

❑ Kerugian ekonomi akibat kemacetan di Jabodetabek **± Rp 65 T** pada tahun 2023

❑ Utilisasi Layanan angkutan umum massal di Wilayah Metropolitan masih terbatas
  - **Pangsa angkutan umum** di Jakarta, Bandung, Surabaya dan kota besar lainnya masih **<20%** (Kuala Lumpur dan Bangkok **20%-50%**, Singapura dan Tokyo **>50%**)

❑ Total Emisi kendaraan pribadi diprediksi meningkat **2,7 kali** pada 2050
❑ Keterbatasan pembangunan angkutan umum massal disebabkan belum adanya

Konektivitas Jalan pada Lintas Utama Pulau Belum Optimal

- **Perbandingan Waktu Tempuh pada Lintas Utama Antar Negara di Asia Tenggara**
  Koridor lintas utama di sejumlah negara tetangga umumnya dilayani oleh jalan bebas hambatan

- **Waktu Tempuh pada Lintas Utama di setiap Pulau di Indonesia**

  - Koridor Trans Pulau di Sumatera, Sulawesi, dan Bali di atas rata-rata nasional ⌐ penyelesaian rencana pembangunan jalan tol masih rendah.
  - Jalan tol di Jawa dan Kalimantan di bawah rata-rata nasional
    - Sebagian besar rencana pembangunan jalan tol di Jawa dapat terpenuhi,
    - Koridor Balikpapan-Samarinda dengan trafik tinggi telah dilayani oleh jalan tol Balikpapan–Samarinda

- **Pembangunan Jalan Tol di Indonesia Belum Optimal**

  - Investasi sektor swasta dalam jalan tol masih sedikit (sebagian besar pembiayaan masih bertumpu pada APBN)
  - Belum optimalnya pemanfaatan jalan tol terbangun
  - Kepadatan Jalan Tol di Indonesia (6,75), jauh lebih rendah daripada sebagian besar negara tetangga (Vietnam: 23,22 dan Malaysia: 63,75) (dalam Km/1 Juta Jiwa)
  - Pembiayaan dan proses pembebasan lahan salah satu kendala utama dalam pembangunan jalan tol

Waktu Tempuh (Jam/100 km)
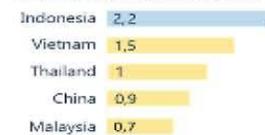
Indonesia	2,2
Vietnam	1,5
Thailand	1
China	0,9
Malaysia	0,7

Waktu Tempuh (Jam/100 km)

Nasional	2,20
Bali	2,58
Sulawesi	2,34
Kalimantan	2,11
Sumatera	2,26
Jawa	1,88
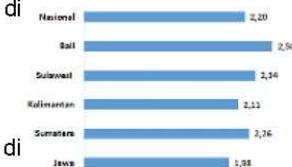
Masih Tingginya Tingkat Fatalitas Kecelakaan Lalu Lintas Angkutan Jalan (LLAJ)

Jumlah Fatalitas Kecelakaan LLAJ

Sebaran Daerah Rawan Kecelakaan

Sumber: POLRI, Kemenhub, PUPR (2024)

- Tingginya jumlah korban meninggal dunia akibat kecelakaan LLAJ rata-rata per tahun mencapai ±27 ribu jiwa (setara 3-4 orang meninggal per jam)

- Meningkatnya jumlah Daerah Rawan Kecelakaan

  - Pada tahun 2023, terdapat 786 titik Daerah Rawan Kecelakaan (DRK) dengan jumlah fatalitas mencapai 2.762 korban jiwa

- 40-50% kendaraan barang di Jalan Lintas Utama Pulau Jawa dan Sumatera tergolong *Over Dimension Over Loading* (ODOL), yang berdampak terhadap:

  - Penurunan kualitas jalan (secara ideal umur rencana jalan 10 tahun turun menjadi 3 tahun) pemborosan keuangan negara Rp.43,45 T/10 tahun

  - 17% dari 116.000 kasus kecelakaan LLAJ tahun 2023 disebabkan oleh kendaraan ODOL

Konektivitas di Wilayah Timur Belum Memadai

❑ Indeks konektivitas* di Wilayah Timur (Papua, Maluku, Nusra) rata-rata 0,36 (jauh di bawah Pulau Jawa 0,79)

Rata-rata kunjungan kapal di Pelabuhan Utama Wilayah Timur 400–700 kapal/tahun (sedangkan di Wilayah Barat mencapai 5.000–15.000 kapal/tahun)

❑ Layanan transportasi barang bersubsidi (PSO dan perintis) moda laut, udara dan darat belum berdampak signifikan terhadap penurunan disparitas harga antara Wilayah Timur dan Wilayah Barat maupun antara pusat pertumbuhan dan kawasan hinterland.

❑ Kecelakaan penerbangan lebih sering terjadi di Wilayah Timur (terdapat lebih dari 200 *Airstrip* di Papua yang belum memenuhi standar keselamatan)

* Indeks konektivitas dihitung melalui akumulasi indeks Kinerja Angkutan Jalan dan Angkutan Sungai, Danau & Penyeberangan (ASDP)

Share PDB per Pulau

Disparitas Harga Bahan Pokok (Beras per kg)

Gambaran Kondisi Airstrip di Wilayah Papua

☐ **Kesenjangan Kualitas Infrastruktur Jalan Nasional dan Daerah**
☐ **Ketimpangan Jaringan Jalan di Wilayah Timur dan Barat**

❑ Total panjang Jalan Daerah (452.440 Km) mencapai 91% dari seluruh jaringan jalan di Indonesia. Tahun 2024, tingkat kemantapan Jalan Nasional mencapai 94%. Sedangkan Jalan Provinsi 71% dan Jalan Kabupaten/Kota hanya 58%.

❑ Isu tata kelola penyelenggaraan jalan daerah: Laju penurunan kualitas infrastruktur Jalan Daerah 3-5% per tahun lebih tinggi dibandingkan dengan Jalan Nasional sebesar 2,7% per tahun

❑ Kapasitas fiskal Pemerintah Daerah masih terbatas untuk menjaga kualitas Jalan Daerah secara berkesinambungan (APBD+DAK belum mencukupi untuk memelihara seluruh jaringan Jalan Daerah ⊢ kebutuhan Rp 1.000 T dalam 5 tahun sementara alokasi 2020-2024 Rp 385 T)

❑ Ketersediaan infrastruktur jalan di Wilayah Timur lebih rendah dibandingkan Wilayah Barat ⊢ Masih terdapat *missing link* jalan di daerah 3TP (contoh: Papua, Kalimantan, dan pulau 3T)

Peta Kapasitas Fiskal Daerah Tahun 2023
Sumber : diolah dari PMK84/2023)

Rasio panjang jalan per luas wilayah (km/km2)

Wilayah Barat 0,32 — Wilayah Timur 0,22
Sumber: KemenPUPR 2020, diolah
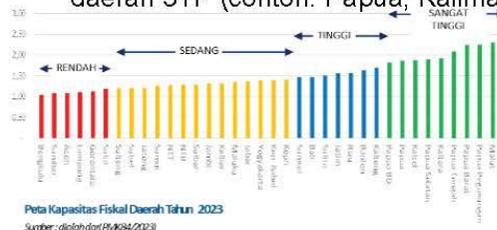
RENCANA INDUK JARINGAN PIPA TRANSMISI DAN DISTRIBUSI GAS NASIONAL (KEPMEN ESDM 173/2024)

Legend:

- Existing Transmission Pipeline
- On-going Transmission Pipeline Devt.
- **Planned Transmission Pipeline**
- Existing Distribution Pipeline
- On-going Distribution Pipeline Devt.
- Existing Private-owned
- Existing Upstream Pipeline

- Existing LNG Plant
- On-going LNG Plant Devt.
- Existing FSRU/FRU LNG
- On-going FSRU/FRU LNG
- Existing CNG Facility
- On-going CNG Facility

- Existing LNG Regasf. Plant
- On-going LNG Regasf. Plant
- **Planned LNG Regasf. Plant (PT PLN/State Electricity Company)**

- Area Jaringan Distribusi Gas Bumi yang Direncanakan
- Jaringan Pipa Gas Bumi Rumah Tangga Eksisting - APBN
- Jaringan Pipa Gas Bumi Househoald Eksisting - Non-Anggaran Negara
- Jaringan Pipa Gas Bumi Rumah Tangga yang Sedang Berjalan - Non APBN
- **Jaringan Pipa Gas Bumi Rumah Tangga yang Direncanakan - Pembiayaan KPBU**

PENYUSUNAN *PROJECT DEVELOPMENT FACILITY* (PDF)

PERMASALAHAN PENGEMBANGAN PROYEK

Permasalahan: Proyek berpotensi mundur dari target yang ditetapkan karena kurangnya perencanaan yang matang dalam persiapan dan pelaksanaan proyek.

1 Rendahnya minat investor, baik swasta maupun pemberi pinjaman, untuk membiayai proyek.

2 Identifikasi risiko dan koordinasi antar sektor masih rendah, misalnya keterkaitan antar proyek dalam satu kawasan.

3 Kesalahan dalam memilih pengembang proyek karena kurang berpengalaman.

PROJECT DEVELOPMENT FACILITY (PDF)

Project Development Facility **(PDF)** adalah sebuah mekanisme yang dilakukan untuk mempersiapkan proyek agar lebih matang.

Tujuan PDF:

1 Meningkatkan kualitas perencanaan proyek sehingga lebih menarik bagi investor.

2 Melakukan mitigasi risiko dengan perspektif proyek yang lebih luas, khususnya keterkaitan proyek dalam suatu kawasan dengan berbagai sektor infrastruktur.

3 Melakukan percepatan persiapan proyek.

PERAN KEMENTERIAN PPN/BAPPENAS

1 Penyusunan proyek strategis dalam dokumen perencanaan untuk mendapatkan beberapa fasilitasi, seperti kemudahan perizinan dan tata ruang.

2 Dukungan fasilitasi skema pembiayaan, baik berupa bunga rendah melalui pinjaman pemerintah, KPBU, maupun penggabungan berbagai instrumen pembiayaan *(blended finance)*.

3 Fasilitasi koordinasi dengan berbagai *stake holder* terkait seperti Pemerintah Pusat dan Daerah, Mitra Pembangunan Nasional dan Internasional, dll.

4 Penyusunan mitigasi risiko pembangunan nasional.

Sumber: Studi JICA 2025, diolah

FIDIC Asia Pacific Conference 2025: New Technologies Transforming Engineering and Construction Industry

Conference Papers

Analysis and Development Prospects of Digital Twin and AI in Reshaping the Whole Process of Water Conservancy Projects

An Chao, China

An Chao holds a master's degree in Hydraulic Structure and over 19 years of experience in water resources and hydropower engineering design; currently serving as the Chief Engineer of oversea institute at Yellow River Engineering Consulting Co., Ltd. (YREC).

He has strong expertise in professional knowledge and digital transformation application & organization; and well-versed in water resources & hydropower industry development trends and standards, both domestically and internationally; skilled in leveraging digital technologies, including digital twin and artificial intelligence, to enhance engineering design and project management in water resources and hydropower projects; extensive frontline experience in production and operations, effectively integrating specialties such as hydraulic structures, hydrology, geology, construction, cost, and economic evaluation with digital transformation, having significantly enhanced the efficiency of hydraulic design and project management through the application of interdisciplinary expertise; receiving numerous provincial science and technology awards.

Under the global wave of artificial intelligence, the practice of the whole engineering process faces unprecedented opportunities and challenges. This paper conducts an in-depth analysis of how digital twin and AI are reshaping the whole engineering practice, projects future developments, and proposes corresponding strategies.

Construction Goals

By leveraging technologies such as big data, the Internet of Things (IoT), and artificial intelligence (AI), we aim to build a Digital Twin of the Jenelata Project. This system will support core engineering applications such as:

a. Construction management
b. Structural safety monitoring
c. Rainfall and flood management Irrigation and water supply
d. Sediment transport and deposition
e. Reservoir area management

Through digital mapping of all elements and the entire operation process of the physical project, combined with intelligent simulation and predictive modeling, the system will enable real-time synchronized simulation with the physical dam, virtual-physical interaction, and iterative optimization.

This initiative will significantly enhance the digitalization, networking, and intelligence of dam construction and operation management, establishing a model benchmark for water infrastructure informatization in Indonesia.

Construction Management Approach

Based on the characteristics of the Jenelata Project, the implementation strategy for construction management is formulated around the specific management needs during the construction phase.

Smart Construction Site

The first key task in construction management is the control of the "5M1E" factors on the construction site: Man, Machine, Material, Method, Environment. This is achieved by building a comprehensive, all-element, all-time monitoring and sensing system, which includes the deployment of various sensors, wireless mesh networks, and other smart devices throughout the site.

The goal is to realize integrated information management for personnel, equipment, materials, methods, and environmental conditions, thereby improving overall management efficiency.

The video demonstrates a smart site management platform from a recently launched mega water conservancy project in China. It visually showcases how each element on-site is effectively monitored and managed.

On the left side of the platform interface, you can see modules for personnel management, vehicles and equipment, environmental monitoring, and video surveillance.

The system includes a notification tool (bell icon) to display all warnings and alarms.

a. Personnel Management

On the right side, the platform shows the personnel register. Selecting any individual reveals details such as name, contact information, worker type, and job role. The system also tracks their attendance records and safety training status.

The platform supports real-time positioning and trajectory tracking. Clicking on the "locate" function highlights the individual's current position within the digital twin model.

A detailed personnel dashboard display:
·   Total personnel on-site that day
·   Real-time headcount inside tunnels
·   Entry and exit statistics over time
·   A personnel status board also monitors key personnel in real time.

b. Vehicle Management

Similar to personnel, selecting any vehicle displays its real-time location and operational status. This ensures efficient tracking and scheduling of machinery and transport vehicles.

c. Environmental Monitoring

This module integrates:
- **Atmospheric conditions**
- **Toxic/harmful gases inside tunnels**
- **Hydrological data**
- **Ventilation fan operations**

Selecting a monitoring point automatically shifts the scene to its location and shows detailed readings such as:
- **Temperature, humidity, noise, wind speed**
- **PM2.5, PM10**
- **Historical trends and charts**

For toxic gases, data like hydrogen sulfide, methane, and carbon monoxide levels are shown alongside information on personnel present in that tunnel section.

Smart ventilation systems provide unified control over all fans, including real-time operation status, oxygen levels, and harmful gas concentrations, ensuring a safe construction environment.

d. Video Surveillance

All construction site cameras are integrated into the platform and organized by location.

Clicking any camera gives remote real-time video feeds, allowing instant visual inspection of on-site activities.

Project Management

For the management of construction projects, the goal is to achieve virtual mapping of all project elements, synchronized progression throughout the entire process, and comprehensive and precise control.

By utilizing visualization tools such as BIM (Building Information Modeling) and GIS (Geographic Information Systems), combined with five independently developed key supporting technologies, the system realizes digital-physical mapping, correlation, coordination, and efficient information exchange across multiple business areas including quality, schedule, safety, investment, and environment.

This approach comprehensively reflects the project's construction status in the past, present, and future, driving refined project control and enabling scientific scheduling and decision-making.

a. Project Management — Safety

Safety management is primarily based on six safety management mechanisms. Leveraging the geospatial positioning capabilities of BIM and GIS, the system centers on safety risk control, hazard identification, hazard inventory, and controlled status management. Using a comprehensive engineering safety analysis model, it establishes a dynamic safety warning and control system covering "before, during, and after" stages.

This system provides early warnings for construction safety risks, automatically generates safety response instructions, and presents real-time safety status, enabling closed-loop safety management and precise decision-making.

(1) Hazard Search
In the upper left corner, all hazard sources are listed, with 78 major hazards identified. Clicking on any hazard reveals details including the work project, hazard name, possible consequences, risk level, and risk status.

(2) Risk Identification
A four-color safety risk map is created, categorizing risks into major, significant, general, and low. The red areas represent major risk zones, currently numbering five.

(3) Early Warning
The system aggregates intelligent warnings from personnel alerts, AI alerts, gas exceedances, and environmental monitoring, pushing notifications to responsible personnel.

(4) Prevention
A hazard investigation and remediation system covering construction, supervision, and local companies is established. It includes measure checklists, hazard inspections, graded controls, and risk announcements. There are currently 56 identified issues in the system, all of which have been fully rectified. Users can view detailed information and on-site images for each inspection and remediation.

(5) Response

Includes comprehensive emergency plans, special plans, on-site responses, emergency supplies, and emergency teams. Detailed information is accessible by clicking.

(6) Responsibility

Ensures accountability for personnel safety, including monitoring the number and frequency of pre- job education and training sessions.

b. Project Management — Schedule

Schedule management is based on the BIM model's division of the project, allowing real-time planning and management of key nodes and routes at the overall line level, contract section level, and work area level. Applications include:

a. Real-time schedule preparation
b. Comparison and simulation of planned vs. actual progress
c. Deviation trend analysis
d. Monitoring of critical nodes and routes

The system visually and dynamically presents the project's progress status, analyzes and forecasts risks of delay at key construction milestones, guides the formulation of corrective schedule measures, and issues acceleration orders.

The video shows detailed schedule implementation information segmented by contract sections, locations, and types, supporting construction process simulation.

In the upper left corner, the system separately manages schedule control for excavation and support works. Clicking on any workface shows detailed information and comparative data.

In the lower left corner, daily progress data for excavation and support are displayed. Clicking these reveals details on construction intensity and workface progress, including comparisons between planned and actual data. Users can also click to simulate or view current segment construction simulations.

c. Project Management --- Quality

Safety management is primarily based on six safety management mechanisms. Leveraging the geospatial positioning capabilities of BIM and GIS, the system centers on safety risk control, hazard identification, hazard inventory, and controlled status management. Using a comprehensive engineering safety analysis model, it establishes a dynamic safety warning and control system covering "before, during, and after" stages.

This system provides early warnings for construction safety risks, automatically generates safety response instructions, and presents real-time safety status, enabling closed-loop safety management and precise decision-making.

(1) Quality management uses unit projects as the smallest granularity for control. By leveraging BIM modeling technology, the virtual 3D model is mapped to physical unit projects, enabling full coverage of quality control before, during, and after construction, as well as comprehensive quality tracing and management across unit, division, and sub-project levels to promptly eliminate quality risks.

(2) In the video, the left side shows the project's hierarchical division, managing the entire project by unit, division, and individual units step-by-step. Clicking any unit allows viewing its quality evaluations, inspections, and test data in detail.

(3) Quality tracing begins by reviewing the current unit's evaluation, showing relevant construction units, supervision units, affiliated units and divisions, timing, and evaluation grades. It integrates digital and electronic evaluations, evaluation images, and process documentation. Users can also access construction images, design attributes, and all design drawings.

(4) The system has developed an over-excavation and under-excavation analysis feature. It dynamically analyzes excavation quality across the entire project by collecting and scanning actual excavation data on-site for each segment and comparing it with the design excavation data. The results are visualized in motion to show over- and under-excavation, with red indicating large deviations between actual and design measurements.

d. Project Management — Investment

(1) Focusing on investment control as the core and contract management as the main thread, the system integrates BIM models to perform monthly, quarterly, and annual statistics, analysis, and monitoring across dimensions such as contract sections and progress stages.

(2) It visually presents the overall project investment status, compares investment target values with actual values, and tracks the investment execution path. The system issues early warnings for cost overrun risks, enabling both precise static control and dynamic real-time management of investments.

(3) All contract and agreement information—including signing, review, risk, and payment—is fully traceable and managed. This data is linked with actual project progress and quality evaluations to ensure that measurement and payment are conducted under conditions meeting quality and schedule requirements.

e. Full-Process Concrete Control — Full-Process Simulation

(1) Using a detailed BIM model coupled with construction methods, the system simulates key and complex construction processes, integrating the construction schedule to conduct independent simulations of each subsystem and combined simulations of system groups throughout the entire construction process. This enables precise optimization of construction resource allocation.

(2) The video showcases the full-process simulation of the Guxian Dam project, which began construction last year. This project is a roller-compacted concrete gravity dam with a pouring volume exceeding 18 million cubic meters.

(3) By simulating the entire construction sequence, combined with actual resource allocation, the system models on-site operations to proactively avoid potential construction issues. It also links construction progress plans and resource plans to optimize the construction schedule.

f. Full-Process Concrete Control — Intelligent Temperature Control

(1) To ensure the quality of large-volume concrete pouring and prevent dam cracking, the key control focus is on concrete temperature management. Real-time temperature data is collected through on-site sensors tracking each concrete batch from the mixer outlet, transport, storage, to pouring. Temperature sensors and water pipes embedded inside the dam enable full-process temperature monitoring and control of the concrete mass.

(2) The video shows the control interface for a 230-meter dam. Based on the dam's detailed BIM model divided into storage compartments, the system monitors the temperature of each batch throughout the pouring process—from mixer outlet to storage. It analyzes and predicts temperature trends and dynamically adjusts cooling of the concrete mix, transport covering, water temperature for cooling pipes, and spraying volume on the compartment surface.

(3) These measures ensure the internal temperature, predicted temperature, and target temperature converge, guiding anti-cracking cooling and insulation measures for the concrete.

Focusing on the entire process of large-volume concrete pouring, beyond temperature control, the system comprehensively applies data-driven decision technologies—such as full-space, full-element, and full-process data sensing, mining, correlation, and traceability—across various operational scenarios including concrete preparation, transportation, leveling, vibration, pouring, curing, and quality inspection. This enables complete data traceability, real-time analysis, and intelligent management and control of each concrete batch throughout the entire process.

Operation and Management Approach

Based on the physical Jenelata project in Indonesia, the focus is on building information infrastructure, the digital twin platform, and business applications, supplemented by cybersecurity systems and support systems to construct a robust "three horizontal and two vertical" overall architecture for the Jenelata digital twin.

The information infrastructure includes monitoring and sensing, communication networks, and information foundation environments. The digital twin platform consists of the data foundation, model library, knowledge base, and twin engine. Business applications cover engineering safety, rainstorm management, irrigation and water supply, sediment erosion and deposition, and reservoir management.

The following sections will briefly break down these components.

a. Twin Scene

Drawing on the construction experience of Xiaolangdi and Wanjiazhai projects, the Jenelata reservoir and surrounding areas utilize satellite, drone, LiDAR point clouds, underwater topography, and other methods to integrate multi-source (airborne, satellite, terrestrial), multi-scale (multi-level watershed), and multi-dimensional (time and space) data.

This fusion creates a high-fidelity digital twin scene, providing the foundational "computing data" for the digital twin platform.

By means of integration, extension, customization, and consolidation, functions such as model management, scene configuration, and simulation are developed to enable collaborative and efficient computation of various models.

This provides high-fidelity, intelligent digital twin simulation support with full time-space, full process, and full-element coverage for key business areas like engineering safety, rainstorm management, and irrigation water supply.

It offers simulations of water level changes, lighting variations, dynamic discharge, and others.

b. **Rainstorm Management – Monitoring and Sensing**

The first component is the rainfall radar. It is tentatively planned to deploy one set of rainfall radar within the Jenelata watershed area, achieving real-time rainfall monitoring and early warning within a 75 km radius.

This will provide rainfall forecast support for reservoir dispatching and rainstorm management. Currently, there are 7 rainfall stations near Jenelata. Additional rainfall and water level stations will be installed within the project watershed area.

By integrating rainfall stations, rainfall radar, meteorological satellites, and other methods, a comprehensive "sky-space-ground" meteorological monitoring network will be established.

c. **Rainfall and Flood Management Models**

The rainfall and flood management models include rainfall forecasting, flood evolution, and hydrodynamics.

The video shows a distributed flood forecasting model. It is a distributed hydrological model that tightly couples multiple hydrological processes such as rainfall integration, natural surface runoff generation, and river channel hydrodynamics.

Based on parallel computing, it achieves real-time calculation, analysis, and decision-making through a cycle of "data – computation – optimization – iteration."

d. **Rainfall and Flood Management**

Fully drawing on the experience of Xiaolangdi and Wanjiazhai, a "Four Forecast" flood management system is constructed.

First, forecasting: Using the established rainfall radar, rain gauges, and water level stations, combined with the inflow forecasting model to perform rolling calculations of inflow processes for the next 3-5 days, achieving rainfall and reservoir inflow forecasts.

(1)   Early Warning
Based on the forecasting results, early warnings are issued for future rainfall, coverage area, and spatial distribution of precipitation in the Jenebelang River basin. Warnings are also given for inflow and outflow discharge, reservoir levels exceeding characteristic thresholds, and water level fluctuations surpassing safety limits.

(2)   Simulation and Rehearsal
Using flood scheduling, evolution models, and simulation engines, simulations and rehearsals are conducted for scenarios such as reservoir area flooding and downstream river flood progression during heavy rainfall events. Based on the rehearsal results, the reservoir flood control scheduling plan is optimized. The video analyzes and simulates flooding in the basin following heavy rain.

(3)   Contingency Plan
Based on the rehearsal results, the knowledge base is utilized to formulate scientific scheduling plans to support command and decision-making.

e.   **Engineering Safety**

One of the core requirements of operation management.

The Jenarata Dam is a composite dam consisting of concrete face rockfill sections on the left and right banks and a central gravity dam. Drawing on experiences from projects like Xiaolangdi and Wanjiazhai, flexible inclinometers and piezometers are installed on the dam. Finite element analysis is used to assess the dam's stress and deformation conditions. Simulations of seepage and deformation monitor the dam's safety status in real-time. The video demonstrates stress and deformation monitoring of the dam under heavy rainfall conditions in the watershed.

By installing monitoring facilities to track dam safety, operational status, fault information, diagnostics, maintenance predictions, emergency alerts, and risk warnings are transmitted in real- time to the managers.

f.   **Irrigation and Water Supply**

Based on the project's functions and irrigation water supply needs, develop application modules including water volume scheduling, engineering measurement and control, project management, and water fee collection. Achieve key functions such as water resource supply and demand forecasting and analysis for the irrigation area, precise water volume scheduling, and automatic gate control.

g.   **Sediment Erosion and Deposition**

The operation of the Jenarata Reservoir requires regular monitoring of the underwater topography in the reservoir area to visually reflect sediment accumulation and changes in reservoir capacity.

Using sediment models to simulate and analyze sediment deposition in the reservoir, timely scheduling and operation of the sediment discharge bottom outlets are carried out to maintain the reservoir's long-term effective capacity. The video demonstrates the effect of sediment erosion and deposition pattern analysis.

h. Reservoir Area Management

By equipping inspection terminals and QR codes on buildings, routine manual inspections are made more convenient. Additionally, using drone inspection systems, unmanned boats, and other equipment enables automated patrols of the project and surrounding areas, with automatic identification of common hazards such as cracks, riverbank erosion, and landslides.

(1) Reservoir Area Management
An intelligent recognition model library is built to identify typical targets such as floating debris, illegal intrusions, and unauthorized activities, achieving over 85% accuracy in recognizing specific targets and behaviors.

The real-time localization method for drone inspection images is based on the key technology of matching video frames with the inspection area's DOM (Digital Orthophoto Map) of near-ground objects, enabling meter-level accuracy in spatial positioning of pixels on the inspection video frames. The system centrally displays information from video surveillance, drones, and manual inspections, combined with intelligent recognition algorithms to identify, verify, and supervise issues such as shoreline management, water surface management, reservoir flooding, and landslides or collapses in the reservoir area.

(2) The video demonstrates the matrix management functionality of the Sanmenxia Reservoir in China.
It integrates accumulated operational business management data such as safety assessments, scheduling, maintenance, monitoring inspections, and patrol management, while also combining monitoring information from power generation, engineering safety, rainfall and water conditions, and video surveillance.

(3) The "Four Alls" include:
a. Comprehensive supervision coverage
b. Mastering all elements
c. Around-the-clock control
d. Full lifecycle management

(4) The "Four Systems (Governance)" include:
a. Improved institutional frameworks
b. Sound mechanisms
c. Strengthened rule of law
d. Implemented responsibility systems

(5) The "Four Preventions" modules, based on digital twin technology, establish systems for:
a. Rainfall and flood scheduling
b. Engineering safety
c. Sediment deposition and erosion
d. Reservoir area management

(6) The "Four Managements" include:
a. Timely hazard removal
b. Regular inspections

c. Enhanced maintenance
d. Safety assurance
i. Construction of the Dispatch Center

After implementing intelligent business systems, it is also necessary to establish a comprehensive operations dispatch center. This includes a consultation center, large display screens, centralized control center, and data center. These facilities provide an integrated environment for decision-making and consultation to support business management in areas such as engineering safety, rain and flood management, irrigation and water supply, sediment deposition and erosion, and reservoir area management.

Outlook

Through the construction of the digital twin Jenelata, digital mapping, intelligent simulation, and forward-looking previews are carried out on all elements of the project and the entire operation process, achieving synchronous simulation operation and virtual-real interaction with the physical project. Effectively improve the digitalization of project management, intelligent operation, and intelligent decision-making.

Starting from the digital twin Jenelata project as a pilot, it will be extended to the entire basin in the future to comprehensively improve the intelligent level of basin management and protection.

A Methodological Framework for Integrating Drones and AI for Efficient Topographic Surveying and Spatial Analysis: Case Studies of Nepal

Bibek Singh, Nepal (Corresponding Author)

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Manisha Kushwaha, Nepal

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ABSTRACT

Traditional surveying methods in infrastructure and urban planning projects often prove to be time-consuming, costly, and limited in detail. Engineers and planners increasingly seek comprehensive and accurate representations of project sites not just isolated points, but complete surface models that reflect real ground conditions. Drone-based surveys and point cloud generation offer a faster and more detailed alternative, enabling three-dimensional modeling of terrain and built environments. When combined with artificial intelligence (AI), these datasets support advanced spatial analysis and automation.

This paper presents a methodological framework for integrating drone- based data collection with AI-powered analysis. The process consists of two main phases: 1) precise and efficient data acquisition using drones equipped with Post-Processed Kinematic (PPK) GNSS systems, and 2) AI-based classification and analysis for mapping and decision- making.

Flight plans and strategically placed Ground Control Points (GCPs) are used to generate point clouds and contours with vertical accuracy of up to 5 cm. These point clouds are filtered and segmented into categories such as ground, vegetation, and structures, facilitating the creation of accurate terrain models and contour maps. Supervised AI models, including U-Net and random forest classifiers, are then employed to identify features like roads, houses, trees, and water bodies.

The framework has been applied and tested in various real-world projects, including highway design projects, urban planning initiatives collectively covering over 500 square kilometers. These applications have enhanced the ability of design teams to visualize, plan, and make informed decisions, thereby improving project outcomes.

Keywords: *UAV photogrammetry, PPK/RTK, Ground Control Points, LiDAR, U-Net segmentation, building extraction, road detection, cost– accuracy analysis, Nepal case study*

INTRODUCTION

High-quality surveying is fundamental to the success of infrastructure and construction projects. Accurate geospatial data underpins every stage from design through execution, and errors in surveying can propagate into costly problems. A detailed study of 139 completed projects reported that design-stage positional mistakes consumed 6.85 % of the contract value directly and a further 7.36 % indirectly an aggregate loss approaching one-seventh of total budgets.[1] Investing in precise, reliable surveys therefore represents an economic imperative rather than a discretionary cost.

The challenge is especially acute in countries such as Nepal, where mountainous topography and limited transport infrastructure constrain the deployment of conventional survey crews. Rough terrain covers nearly three-quarters of the country, and less than 43 % of rural residents live within 2 km of an all-season road.[2] Reaching remote sites often requires multi-day treks or helicopter lifts, inflating

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[1] M. Thibault, "Contractors lost $1.8 trillion globally in 2020 due to bad data, new report says," Construction Dive, Sep. 22, 2021. https://www.constructiondive.com/news/contractors-lost-18-trillion- globally-in-2020-due-to-bad-data-new-report/606939/

[2] S. A. Shrestha, "Access to the North-South Roads and Farm Profits in Rural Nepal," Univ. Michigan Working Paper, 2012.

survey budgets and encouraging reliance on sparse or outdated base maps factors that later manifest as re-work, claims, and safety concerns. These factors create a pressing need for more efficient, cost-effective surveying methods that can operate in remote, steep terrain. In Nepal and similar developing countries, the goal is to obtain the accuracy needed for design and construction, but with manageable cost and logistics.

Recent technological advances in surveying offer promising avenues to meet these needs. Over the past two decades, the field has evolved from labor-intensive traditional tools toward high-resolution digital mapping. Modern techniques such as photogrammetry and laser scanning can capture millions of points to create 3D point clouds and detailed topographic models. UAVs equipped with RTK or PPK GNSS can efficiently survey inaccessible terrain, providing centimeter level geotagging accuracy in real time.[3] Structure-from-Motion algorithms, for example, enable reconstructing terrain geometry from overlapping images, producing dense point clouds, digital surface models, and orthomosaics.[4] This proliferation of rich survey data has been paired with advances in data processing notably, artificial intelligence (AI) and deep learning to automatically interpret and extract features from complex datasets. In remote sensing and mapping, deep convolutional neural networks now routinely outperform traditional manual or rule-based methods in both efficiency and accuracy.[5] For instance, researchers have demonstrated that modern CNN architectures can learn to recognize and segment features in aerial imagery with high precision. Models such as U‑Net and Mask R-CNN, originally developed for image segmentation tasks, have been applied to orthophotos and LiDAR data to automatically identify buildings, roads, vegetation and other semantic classes.[6] The ability to derive intelligible GIS layers (e.g., maps of structures or land cover) directly from survey data is a game-changer for mapping and planning. At the same time, unmanned aerial vehicles (UAVs or drones) have emerged as versatile survey platforms.

In summary, the convergence of drone-based mapping and AI-driven data analysis represents a powerful new paradigm for surveying. It offers the potential to dramatically accelerate data collection in challenging environments like Nepal's mountains, while maintaining – or even improving the accuracy and detail of the survey results.

Against this backdrop, the present research evaluates four practical drone-survey configurations in Nepal: (i) DJI Phantom 4 Pro V2 without ground control points (GCPs), (ii) the same platform but with Ground Control Points (GCPs), (iii) Wingtra One Gen II without GCPs, and (iv) Wingtra One Gen II with GCPs. Independent GNSS checkpoints provide an objective assessment of horizontal and vertical accuracy, while crew-hour accounting quantifies the economic cost of GCP deployment in rugged terrain. The resulting orthomosaics are subsequently processed with a U-Net-based semantic-segmentation model to extract building, road and vegetation layers automatically. By linking

[3] S. C. Westoby, J. Brasington, N. F. Glasser, M. J. Hambrey, and J.
M. Reynolds, "'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications," Geomorphology, vol. 179, pp. 300–314, 2012, doi: 10.1016/j.geomorph.2012.08.021.
[4] S. C. Westoby, J. Brasington, N. F. Glasser, M. J. Hambrey, and J.
M. Reynolds, "'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications,"
[5] S. Minaee, Y. Y. Boykov, F. Porikli, A. J. Plaza, N. Kehtarnavaz, and D. Terzopoulos, "Image segmentation using deep learning: A survey," IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 44, no. 7, pp. 3523–3542, 2022, doi: 10.1109/TPAMI.2021.3059968.
[6] S. Minaee, Y. Y. Boykov, F. Porikli, A. J. Plaza, N. Kehtarnavaz, and D. Terzopoulos, "Image segmentation using deep learning: A survey,"

rigorously validated survey data with AI-driven feature extraction, the study offers a decision framework for selecting an acquisition strategy that balances accuracy and cost, demonstrating how nations such as Nepal can obtain survey-grade, information-rich spatial data quickly and affordably.

LITERATURE REVIEW

Accurate drone-based surveys rely heavily on the georeferencing technique used. Studies consistently demonstrate that integrating ground control points (GCPs), real-time kinematic (RTK), or post-processed kinematic (PPK) positioning systems significantly enhances the spatial accuracy of photogrammetric outputs. Niu et al. showed that RTK enabled UAVs achieved sub-decimeter horizontal accuracy without dense GCP deployment. Similarly, Zhao et al. compared UAV surveys using GCP-only and PPK-assisted setups and found that PPK achieved superior vertical accuracy even with minimal ground control.[7]

The arrangement and quantity of GCPs further influence mapping precision. Studies by Forlani et al. suggest that well-distributed GCPs (corners + center) significantly outperform clustered formations, particularly for large-area mapping.[8] Li et al. emphasize that integrating sparse GCPs with onboard PPK provides a cost-effective balance between accuracy and field effort. In parallel, research on dense point cloud classification highlights its role in improving the interpretability of UAV derived 3D data.[9] Semantic segmentation of point clouds aids in distinguishing terrain, buildings, and vegetation an essential step for robust geospatial analysis.[10]

For post-survey analysis, various deep learning models have been applied to orthomosaics for feature extraction. Architectures like FCN, DeepLabv3+, and Mask R-CNN have been used to identify structures and land cover, but recent studies identify U-Net as particularly well- suited for segmentation of aerial imagery due to its encoder-decoder structure and spatial precision. Tan et al. demonstrated that a Res- U-Net model outperformed other architectures for building and road extraction in hilly regions.[11] However, a clear methodological framework linking drone selection, GCP configuration, AI model training parameters, and cost-benefit trade-offs remains underexplored. This research aims to address that gap.

Semantic segmentation of aerial imagery is now foundational for urban planning and infrastructure mapping, with deep learning methods, especially convolutional encoder decoder networks, largely

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[7] S. C. Westoby, J. Brasington, N. F. Glasser, M. J. Hambrey, and J. M. Reynolds, "'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications; Zhao, H. (2024). Impacts of GCP distributions on UAV-PPK photogrammetry at Sermeq Avannarleq Glacier, Greenland. Remote Sensing, 16(21), Article 3934

[8] Forlani, G., Dall'Asta, E., Diotri, F., Cella, U. M. d., Roncella, R., & Santise, M. (2018). Quality assessment of DSMs produced from UAV flights georeferenced with on-board RTK positioning. Remote Sensing, 10(2), 311. https://doi.org/10.3390/rs10020311

[9] M. Li, Q. Zhang, and H. Sun, "Georeferencing optimization in UAV photogrammetry using hybrid GCP-PPK strategy," Sensors, vol. 22, no. 12, Art. 4445, 2022.

[10] M. Schwind et al., "Semantic classification of photogrammetric point clouds for topographic mapping," ISPRS Int. J. Geo-Inf., vol. 8, no. 11, Art. 492, 2019.

[11] C. Tan et al., "Building extraction from unmanned aerial vehicle data in a landslide-affected scattered mountainous area based on Res- Unet," Sustainability, vol. 16, no. 22, Art. 9791, 2024.

replacing classical techniques that required manual tuning and struggled in complex scenes.[12] Among these, U-Net stands out for its ability to preserve spatial detail through skip connections, making it a reliable baseline in remote sensing tasks; variants (e.g., U-Net++ or attention-enhanced U-Nets) can improve accuracy at added complexity, yet the original architecture remains competitive for its simplicity and efficiency, which is why we adopt it as the core of our segmentation pipeline.[13]

For feature-specific tasks like building and road extraction, supplementing RGB orthomosaics with auxiliary cues (e.g., elevation models, vegetation indices, or boundary aware loss formulations) has been shown to substantially boost performance elevating building detection precision/recall and refining footprint boundaries.[14] Road segmentation poses added challenges due to narrow, linear geometry and occlusions; efforts to capture multi-scale context and long-range dependencies (e.g., transformer-based branches or hybrid YOLO-style architectures) demonstrate meaningful gains over vanilla U-Net, particularly on small or irregular paths, while still often building on U-Net–like foundations to balance accuracy and computational cost.[15]

Evaluation in the literature consistently emphasizes overlap-based metrics especially Intersection over Union (IoU), along with precision, recall, and F1-score to account for class imbalance and spatial fidelity; techniques such as weighted losses help mitigate background dominance and ensure strong performance even when target classes occupy limited area.[16] This consensus validates using standard U-Net with modern training refinements as a robust backbone, providing a clear benchmark (IoU, F1, accuracy) for comparing our drone imagery segmentation results.

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[12] S. Minaee et al., "Image Segmentation Using Deep Learning: A Survey," IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 44, pp. 3523–3542, 2021, doi: 10.1109/TPAMI.2021.3059968. https://doi.org/10.1109/TPAMI.2021.3059968; Y. Liu et al., "A Road Extraction Method Based on Region Growing and Mathematical Morphology from Remote Sensing Images," Journal of Computer and Communications, vol. 6, pp. 91–97, 2018, doi: 10.4236/jcc.2018.611008.

[13] O. Ronneberger, P. Fischer, and T. Brox, "U-Net: Convolutional Networks for Biomedical Image Segmentation," in Proc. Medical Image Computing and Computer-Assisted Intervention – MICCAI 2015, Springer, 2015, pp. 234–241, doi: 10.1007/978-3-319-24574-4_28.; S. Minaee et al., "Image Segmentation Using Deep Learning: A Survey,"

[14] S. Minaee et al., "Image Segmentation Using Deep Learning: A Survey,"; W. Boonpook, Y. Tan, and B. Xu, "Deep Learning-Based Multi- Feature Semantic Segmentation in Building Extraction from Images of UAV Photogrammetry," International Journal of Remote Sensing, vol. 42, pp. 1–19, 2021, doi: 10.1080/01431161.2020.1788742.

[15] Y. Liu et al., "A Road Extraction Method Based on Region Growing and Mathematical Morphology from Remote Sensing Images; O. Ronneberger, P. Fischer, and T. Brox, "U-Net: Convolutional Networks for Biomedical Image Segmentation,"

[16] P. Singh, A. B. M. Shawkat Ali, R. A. Naqvi, and M. U. G. Khan, "A Comparative Study of Deep Semantic Segmentation and Traditional Machine Learning Algorithms for Road Extraction from Aerial Images,"; B. Xiang et al. (assuming multiple authors), "Semantic segmentation of UAV-based urban aerial imagery using U-Net encoder–decoder architecture," https://d-nb.info/1278557814/34
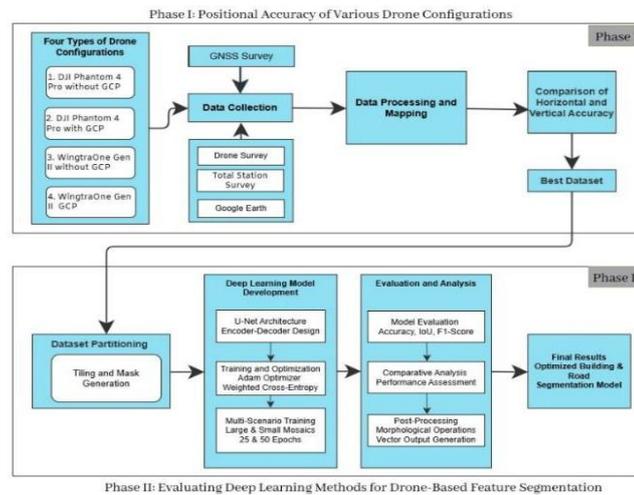
METHODOLOGY

Figure 1. Methodology, Phase 1- Evaluation of GNSS-Aided Positional Accuracy in Multiple Drone Configuration. Phase 2- Evaluating Deep Learning Methods for Drone-Based Feature Segmentation

As illustrated in Figure 1, the research follows a two-phase methodology. In Phase I, four UAV–GCP configurations—DJI Phantom 4 Pro and Wingtra One Gen II, each with and without GCPs— are evaluated through GNSS-supported data collection, mapping, and comparison of horizontal and vertical accuracies to identify the most accurate setup. Phase II uses this optimal dataset in a U-Net–based segmentation workflow, where imagery is tiled, masks are generated, and the model is trained and optimized. Performance is assessed using accuracy, IoU, and F1-score, followed by post-processing to produce final building and road mapping output to identify the optimum strategy to train U-Net models.

3.1 Phase 1- Evaluation of GNSS-Aided Positional Accuracy in Multiple Drone Configuration

Figure 2. UAV survey configurations tested in Phase I: (a) DJI Phantom 4 Pro with and without ground control points (GCPs) and (b) WingtraOne Gen II with and without GCPs, conducted at multiple locations for positional accuracy assessment against standard GNSS survey benchmarks.

Phase I focuses on evaluating the positional accuracy of different UAV GCP configurations to determine the most effective setup for high precision mapping. As shown in Figure 2, the tests covered four configurations: (a) DJI Phantom 4 Pro with and without GCPs, and (b) WingtraOne Gen II with and without GCPs. Surveys were conducted at multiple locations to capture diverse terrain and operational conditions. For each configuration, aerial data was collected, processed into orthomosaics, and compared with results from a standard GNSS survey to assess horizontal and vertical positional accuracy. This comparison allowed for a clear assessment of the influence of both platform choice and GCP deployment on mapping precision.

3.1.1 Case 1: DJI Phantom 4 Pro Without GCP

In this configuration, a DJI Phantom 4 Pro drone was deployed to capture aerial imagery without the use of Ground Control Points (GCPs). Horizontal accuracy assessment was performed using data obtained from Google Earth and Differential GNSS (DGPS/GNSS). Flight paths were designed with sufficient overlap, and image capture was automated through mission planning software. After image acquisition, the data was processed using photogrammetry tools to generate a Digital Surface Model (DSM) and orthomosaic. For vertical accuracy evaluation, Total Station (TS) survey data was used to generate a Digital Elevation Model (DEM), which was then compared against the drone-derived DSM. The absence of GCPs led to a reliance on onboard GNSS data, which introduced georeferencing errors.
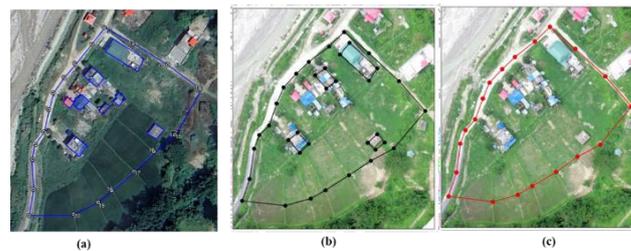
Figure 2. (a) Google Earth Points, (b) DGPS Points and (c) Orthomosaic Points
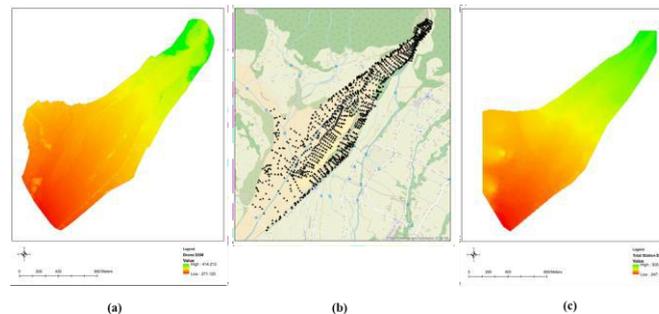
Figure 3. (a) Drone DSM, (b) Total Station Survey Points and (c) Total Station DEM

3.1.2 Case 2: DJI Phantom 4 Pro With GCP

For this case, the DJI Phantom 4 Pro was used in combination with established Ground Control Points. GCPs were identified and surveyed using DGPS/GNSS equipment to provide highly accurate ground references. The position of GCP used was such that for every one square kilometer about 21 GCPs and 4 checkpoints were used ((5 rows and 5 columns) in equal distance. For horizontal accuracy, Google Earth was used for base referencing and alignment visualization. Aerial images were processed with photogrammetric software where GCP coordinates were manually input during the image alignment process to enhance georeferencing. This approach improved the horizontal accuracy significantly.

Vertical accuracy was evaluated by comparing the drone-derived DSM with a DEM created using Total Station data, ensuring detailed assessment in both elevation and planimetry.
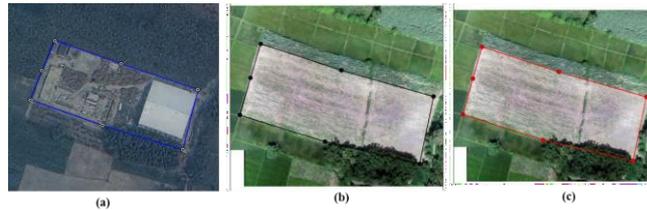
Figure 4. (a) Google Earth Points, (b) DGPS Points and (c) Orthomosaic Points
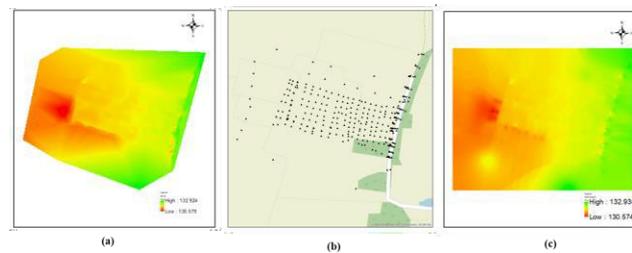
Figure 5. (a) Drone DSM (b) Total Station Survey Points and (c) Total Station DEM

3.1.3 Case 3: WingtraOne Gen II Without GCP

In this setup, the WingtraOne Gen II drone was used for aerial data collection without deploying GCPs. Horizontal accuracy was assessed using high-precision onboard GNSS data in conjunction with visual references from Google Earth and positional validation via GNSS survey points. WingtraOne's Post-Processed Kinematic (PPK) capabilities provided better accuracy, even without GCPs. For vertical accuracy, the drone-derived DSM was compared against a DEM generated from DGPS (GNSS) elevation data. Although GCPs were not used, the integration of PPK GNSS and DGPS based DEM helped reduce potential vertical and horizontal inaccuracies.
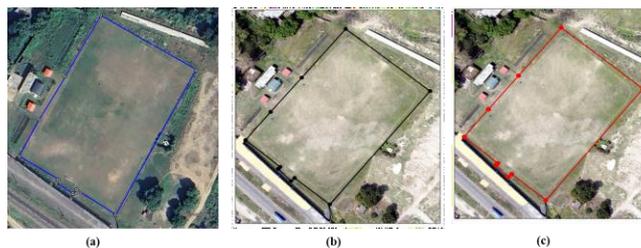
Figure 6: Comparison of Horizontal Position between (a) Google Earth Points,
(b) DGPS Points and (c) Orthomosaic Points
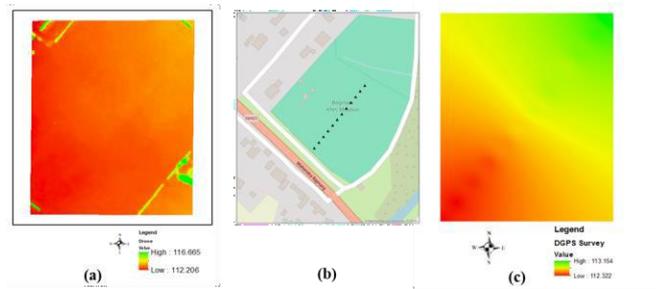
Figure 7: (a) Drone DSM, (b) DGPS/GNSS Survey Points and (c) DGPSGNSS DEM

3.1.4   Case 4: WingtraOne Gen II With GCP

This configuration utilized the WingtraOne Gen II drone along with Ground Control Points to ensure high geospatial accuracy. GCPs were marked and measured using DGPS equipment prior to the flight. Google Earth imagery assisted in verifying spatial alignment and context. The photogrammetric processing of aerial imagery was enhanced with precise GCP integration, significantly improving horizontal geolocation accuracy. For vertical accuracy assessment, the drone-derived DSM was compared with a DEM developed from DGPS (GNSS) elevation readings.
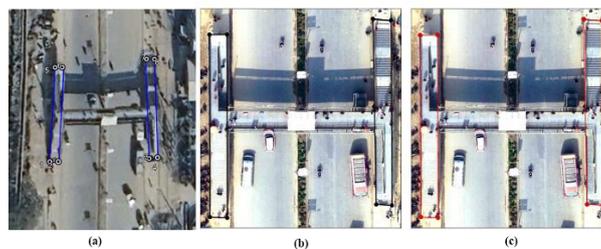
Figure 8: (a) Google Earth Points, (b) DGPS Points and (c) Orthomosaic Points
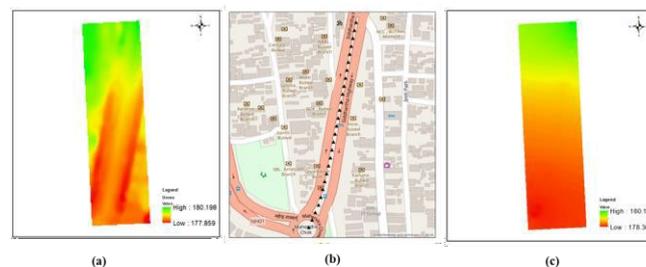
Figure 9: (a) Drone DSM (b) DGPS/GNSS Survey Points and (c) DGPS/GNSS DEM

3.2   Phase 2- Evaluating Deep Learning Methods for Drone- Based Feature Segmentation

This study introduces a comprehensive and systematic approach combining drone-based remote sensing with advanced deep learning techniques to enhance topographic surveying and spatial analysis. The methodology encompasses three sequential phases: dataset preparation, deep learning model development and training, and rigorous evaluation and validation of the developed models. The core focus is the automated detection and segmentation of buildings and roads from high-resolution drone imagery.

3.2.1 Dataset Preparation

To support robust AI-based feature extraction, a custom Python-based data processing pipeline was developed to automate and streamline dataset preparation. The pipeline began with intelligent data handling, including automated ingestion, validation, and quality assurance of input orthomosaics. Annotated features were then classified using keyword based rules into thematic categories (e.g., buildings, roads, vegetation). Next, the orthomosaics were tiled into standardized 1024×1024 pixel blocks, with irrelevant or featureless tiles discarded

to optimize training efficiency. Each retained tile was paired with a precisely aligned multi-class segmentation mask. For model training, the dataset was split into 80% training and 20% validation sets through random stratification, ensuring balanced class distribution and reproducibility via fixed random seeds.

3.2.2 Deep Learning Model Sample Predictions:

The U-Net architecture was employed for semantic segmentation due to its suitability for pixel-wise classification. The model comprised an encoder path for extracting hierarchical spatial features, a bottleneck layer for semantic abstraction, and a decoder path with skip connections to restore spatial detail. Training was performed using a batch size of 7 and a learning rate of 2×10^{-4}, optimized via the Adam optimizer. Class imbalance was addressed using weighted cross- entropy loss, while overfitting was mitigated through early stopping. GPU acceleration, mixed-precision training, and batch normalization were also used to enhance performance. Four training scenarios were tested: two mosaic sizes 21337×19663 pixels (1.56 GB) and 14509×10095 pixels (380 MB) each trained for 25 and 50 epochs to evaluate model generalization across different dataset scales.
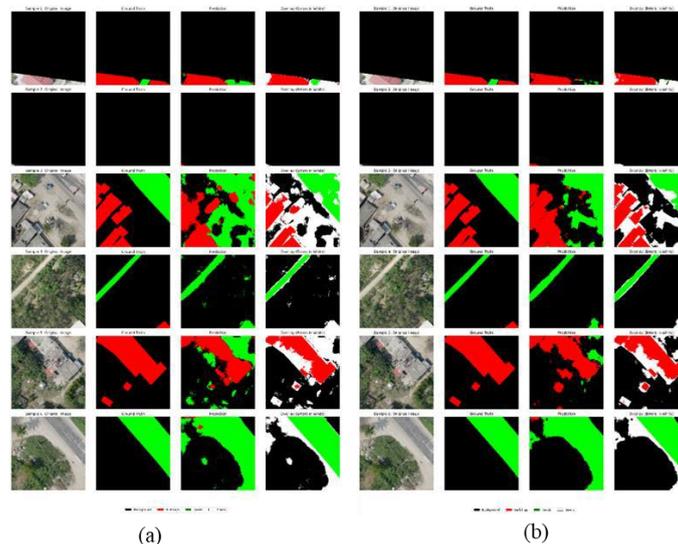
Figure 10: (a) Bigger Mosaic 25 epoch and (b) Bigger Mosaic 50 epoch

Figures 11 and 12 illustrate the methodological approach for evaluating segmentation performance using different input tile sizes and training durations. For each configuration, the original drone imagery was divided into mosaics larger tiles for Figure 11 and smaller tiles for Figure 12 and processed through a U-Net-based deep learning pipeline. The model was trained separately for 25 and 50 epochs, with outputs compared side by side to assess the effect of training length. Each row shows the original

image patch alongside predicted masks for buildings (red) and roads (green), enabling a visual inspection of feature extraction quality. This methodology allows for controlled comparison of how mosaic granularity and training duration influence feature boundary clarity, class separation, and noise reduction. By structuring the experiment in this way, it isolates two key variables tile size and training epochs providing insight into their relative impact on

segmentation performance across diverse urban and peri-urban contexts
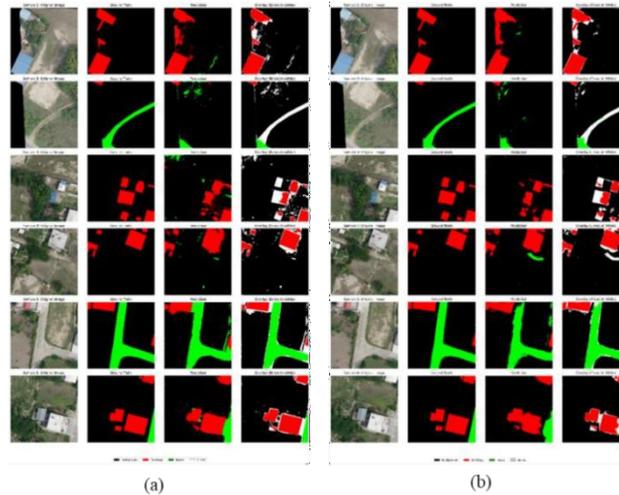
Figure 11: Smaller Mosaic 25 epoch and (b) Smaller Mosaic 50 epoch

RESULTS AND DISCUSSIONS

The comparison of horizontal and vertical accuracy among the four drone configurations revealed distinct differences influenced primarily by the type of drone then the use of Ground Control Points (GCPs).

4.1   Comparison of horizontal accuracy

The horizontal positional accuracy assessment across four survey sites (Table 1) demonstrates that UAV-derived orthomosaics consistently outperform Google Earth imagery when referenced against DGPS control points. For all configurations, the RMSE values obtained from UAV data are significantly lower than those from Google Earth, indicating the superior geospatial fidelity of drone-based surveys. For example, at Site 1, the DJI Phantom 4 Pro without GCPs achieved a horizontal RMSE of 2.58307 m, compared to 4.58123 m for Google Earth, representing a ~44% improvement.

Table 1: RMSE for horizontal positional accuracy

Configurations and Sites	Horizontal RMSE Drone with DGPS (Meter)	Horizontal RMSE DGPS with Google Earth (Meter)
DJI Phantom 4 Pro Without GCP (Site 1)	2.58307	4.58123
DJI Phantom 4 Pro With GCP (Site 2)	0.78895	4.26048
WingtraOne Gen II Without GCP (Site 3)	0.63411	5.16672
WingtraOne Gen II With GCP (Site 4)	0.05457	7.95813

The analysis further reveals that both drone platform capability and GCP integration substantially influence positional accuracy. Incorporating GCPs markedly reduces RMSE for the same drone

model: the DJI Phantom 4 Pro improves from 2.58307 m without GCPs (Site 1) to 0.78895 m with GCPs (Site 2), a reduction of nearly 70%. Similarly, the Wingtra One Gen II shows a decrease from 0.63411 m without GCPs (Site 3) to an exceptional 0.05457 m with GCPs (Site 4). These findings align with prior studies that highlight the synergistic effect of advanced UAV sensor suites and optimal ground control distribution in achieving sub-decimeter-level accuracies.

Importantly, variations in Google Earth RMSE across sites (ranging from 4.26048 m to 7.95813 m) are independent of UAV performance, as they depend solely on the inherent spatial accuracy of the Google Earth basemap for that location. Nonetheless, the results confirm that even the least accurate UAV configuration (DJI Phantom 4 Pro without GCPs) still provides superior accuracy compared to Google Earth, underscoring the value of UAV mapping for precise spatial application.
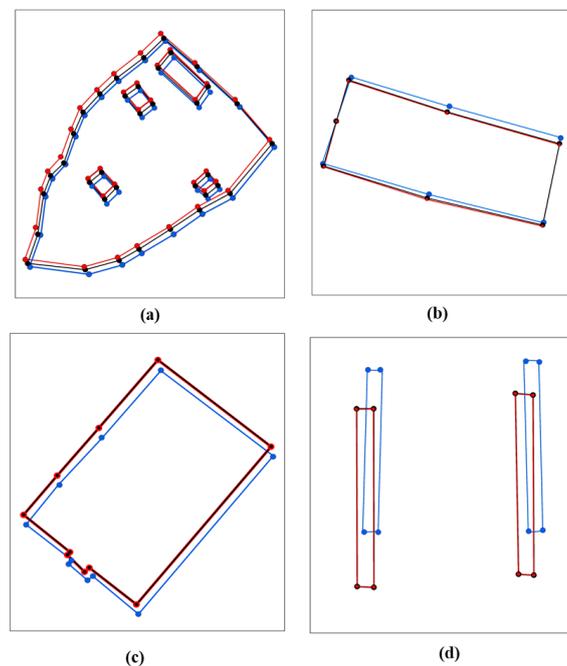
Figure 12: Horizontal Positional (x,y) Plotting of four configurations of Drone Cases, Blue color represents Google Earth, Red Color represents Orthomosaics from Drones and Black color represents DGPS/GNSS. (a) DJI Drone Without GCP, (b) DJI Drone with GCP, (c) WingtraOne Gen II without GCP and (d) WingtraOne Gen II with GCP

4.2 Comparison of vertical accuracy

Table 2: RMSE for vertical positional accuracy

Configurations	Vertical RMSE Drone with Total Station (Meter)	Vertical RMSE Drone with GNSS (Meter)
DJI Phantom 4 Pro Without GCP	24.84264	-
DJI Phantom 4 Pro With GCP	0.04058	-
WingtraOne Gen II Without GCP	-	0.06104
WingtraOne Gen II With GCP	-	0.01724

The vertical positional accuracy results in Table 2 highlight the influence of Ground Control Points (GCPs) and onboard positioning capabilities on UAV outputs. For the DJI Phantom 4 Pro, comparison with Total Station data shows a vertical RMSE of 24.84264 m without GCPs, reduced dramatically to 0.04058 m (~4 cm) with GCPs, confirming their necessity for survey-grade accuracy in consumer- grade UAVs.

For the WingtraOne Gen II, evaluated against GNSS survey data, the vertical RMSE was 0.06104 m (~6 cm) without GCPs, improving to 0.01724 m (~1.7 cm) with GCPs. This indicates that while survey grade UAVs with PPK deliver high accuracy independently, GCPs still enhance precision for sub-centimeter requirements.

Overall, GCP integration yields a larger improvement for the DJI Phantom 4 Pro than for the WingtraOne, underscoring the interplay between hardware capabilities and ground control. Even with advanced platforms, GCP supported workflows remain the most reliable method for achieving the highest vertical accuracy in engineering and geospatial applications.
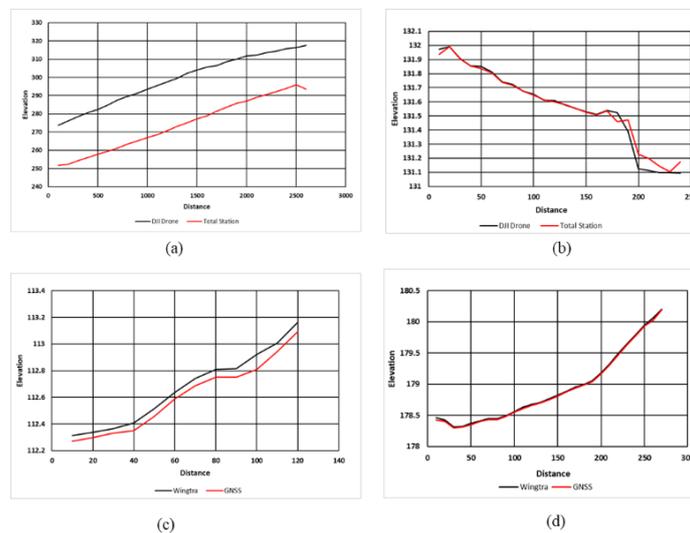
Figure 13: L-Profile of four cases for Vertical positional accuracy. (a) DJI Drone without GCP with Total Station, (b) DJI Drone with GCP with total Station, (c) WingtraOne Gen II without GCP with GNSS and (d) WingtraOne Gen II with GCP with GNSS

Figure 14 presents L-profile comparisons illustrating how each UAV configuration aligns with reference elevation data. The DJI Phantom 4 Pro without GCPs (a) shows a clear vertical offset from the Total Station profile, while adding GCPs (b) results in near perfect alignment. For the WingtraOne Gen II, even without GCPs (c) the profile closely follows the GNSS reference, and with GCPs (d) it achieves almost complete overlap. These profiles visually demonstrate that while advanced PPK-equipped systems inherently deliver high vertical accuracy, GCP integration remains crucial for consumer-grade UAVs and still offers refinement benefits for survey-grade platforms.

4.3   *GCP Placement for DJI phantom 4 pro V2 (Non PPK/RTK) and Wingtra (PPK) drone*
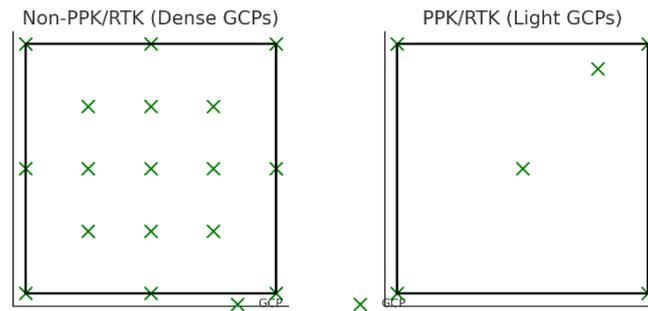
Figure 15. GCP configurations for a 1 km² survey block: (left) non-PPK/RTK dense layout with 17–20 control points; (right) PPK/RTK light layout with 4–6 control points.

The comparative layouts in Figure 15 show the differing GCP needs for non-PPK/RTK and PPK/RTK workflows over a 1 km² survey block. In the non-PPK/RTK case (DJI Phantom 4 Pro v2), a dense network of 17–20 GCPs was used, including corners, mid-edges, interior grid points, and terrain extremes. This configuration strengthened block geometry, reduced distortions such as doming, and delivered accuracies near the theoretical limit of twice the GSD. Our results showed clear accuracy gains over sparser layouts, with interior GCPs especially improving vertical precision.

In contrast, the PPK/RTK configuration achieved similar centimetre- level accuracy with only 4–6 GCPs, typically at the corners, block centre, and one terrain extreme. On board dual-frequency GNSS provided precise camera positions, greatly reducing the need for dense control. This minimal setup maintained 2–3 cm horizontal and 3–5 cm vertical accuracy while cutting GCP survey effort, showing that PPK/RTK workflows can match dense-control results with far fewer ground points.

4.4   *Segmentation Performance Comparison of U-Net Across Mosaic Sizes and Training Epoch*
Table 3 and Figure 16 present the comparative performance of U-Net segmentation models trained under different mosaic sizes and epoch settings. The evaluation considered Overall Accuracy, Mean IoU, and class-specific IoUs for building and road extraction. For the large mosaic scenario, increasing training epochs from 25 to 50 improved Overall Accuracy from 87.43% to 90.83% and Mean IoU from 65.41% to 72.35%, with notable gains in road IoU (48.00% to 63.32%). The smaller mosaic consistently outperformed the large mosaic in all metrics, achieving the highest performance at 50 epochs with 94.09% Overall Accuracy, 79.10% Mean IoU, 73.98% building IoU, and 70.31% road IoU. This highlights the sensitivity of segmentation performance to both input mosaic size and training duration. The results also indicate that smaller mosaics enable the model to learn finer spatial details, particularly for narrow features like roads.

Table 3: comparative performance of segmentation models

Cases	Epochs	Overall Accuracy (%)	Mean IoU (%)	Building IoU (%)	Road IoU (%)
Large Mosaic	25	87.43	65.41	62.43	48.00
Large Mosaic	50	90.83	72.35	64.43	63.32
Smaller Mosaic	25	92.18	73.49	68.22	61.27
Smaller Mosaic	50	94.09	79.10	73.98	70.31

Figure 16 visually corroborates these results, showing higher bar values for the smaller mosaic configurations, particularly at 50 epochs, indicating better model generalization and class separation. These findings suggest that finer mosaic tiling provides richer spatial detail for the U-Net, enabling more accurate feature extraction, while increased epochs allow the network to better converge, especially for the more complex road class.

Overall, smaller mosaics combined with extended training deliver superior segmentation performance across all evaluation metrics the smaller mosaic configuration consistently outperformed the larger mosaic across all evaluation metrics, with the best results achieved at 50 epochs. This improvement can be attributed to the increased number of training samples generated from smaller patches, allowing the U-Net model to observe more localized variations and fine-grained spatial details in buildings and roads. The reduced input size also ensured efficient GPU utilization and supported more effective convergence. However, it is important to note that smaller mosaics inherently reduce the broader spatial context available to the network, which may affect the classification of features requiring long-range continuity. While this limitation did not significantly impact performance in our case likely due to the strong local patterns of the target classes future applications involving large-scale contextual features should balance patch size to preserve both local detail and global structure.
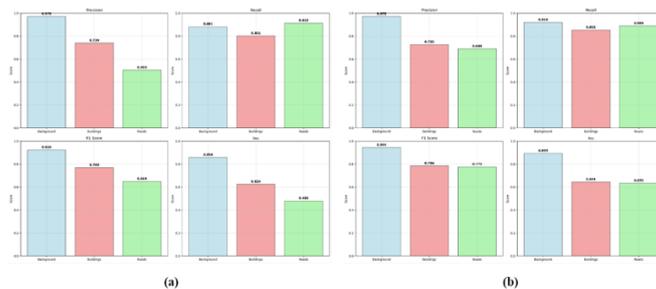
Figure 16: (a) Bigger Mosaic 25 epoch and (b) Bigger Mosaic 50 epoch
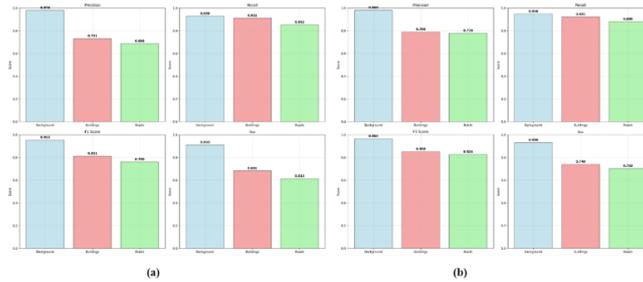
Figure 14: (a) Smaller Mosaic 25 epoch and (b) Smaller Mosaic 50 epoch

CONCLUSION

Our results indicate that survey configuration choice should be guided by project objectives, budget, and required accuracy thresholds. For applications requiring only moderate horizontal accuracy (better than freely available sources like Google Earth) and where vertical precision is not critical, the low-cost DJI Phantom 4 Pro v2 without GCP offers a viable option, albeit with limited vertical accuracy. When precise elevation data is required, especially for engineering-grade design and volume calculations, incorporating a dense GCP network with the Phantom 4 Pro v2 dramatically improves both horizontal (0.79 m) and vertical (4 cm) accuracy, offering a cost-effective alternative for smaller projects.

Table 4: Cost and Accuracy Comparison for Different Drone–GCP Configurations over 1 km² Survey Area

Configuration	Estimated Cost for 1 km² (NPR)	Time	Horizontal RMSE (m)	Vertical RMSE (m)
DJI Phantom 4 Pro v2 – Without GCP	30,000 (Very Low)	1 day	2.58307	24.84264
DJI Phantom 4 Pro v2 – With GCP	80,000 (Medium)	1 day (Parallel Team)	0.78895	0.04058
WingtraOne Gen II – Without GCP	200,000 (High)	1 Hour	0.63411	0.06104
WingtraOne Gen II – With GCP	300,000 (Very High)	1 Hour (Parallel Team)	0.05457	0.01724

In high-accuracy, large-scale surveys where field time is limited, the WingtraOne Gen II without GCP achieves sub-meter horizontal and ~6 cm vertical accuracy due to onboard PPK capabilities, reducing reliance on dense GCP networks. For the most demanding applications such as cadastral mapping,

deformation monitoring, or precision engineering combining WingtraOne Gen II with strategically placed GCPs yields centimetre-level accuracy in both horizontal and vertical components, albeit at the highest operational cost. This comparison demonstrates that optimal drone and GCP configurations should be matched to the specific accuracy and cost constraints of each project.

Table 5: Comparative Performance of Our Model vs Existing Studies

Model / Study	Building IoU (%)	Building F1 (%)	Road IoU (%)	Road F1 (%)	Mean IoU (%)
Our Model (U-Net)	73.98	85.04	70.31	82.57	79.10
Khan et al. [17]	91.00*	—	—	—	91.00*
Farajzadeh et al. [18]	—	94.00	—	—	—
YOLO-U [19]	—	—	83.00	90.00+	—
Majidizadeh et al. [20]	—	—	—	—	75.10

Table 5 compares the performance of our U-Net model with existing studies for building and road extraction. Our model, trained jointly for both classes, achieved a mean IoU of 79.10%, with 73.98% building IoU and 70.31% road IoU demonstrating balanced performance across feature types. In contrast, studies such as Khan et al. and Farajzadeh et al. reported higher building IoUs (91.00% and 94.00%, respectively) but were trained exclusively for building extraction, while YOLO-U achieved strong results for roads (83.00% IoU, 90%+ F1) through class-specific training. Majidizadeh et al., similar to our multi-class setup, attained a lower mean IoU of 75.10%. This highlights that while single-class models can optimize accuracy for one feature type, our approach offers robust, simultaneous detection of multiple classes.

Future Work and Enhancement Opportunities

This study demonstrated how UAV platform selection, GCP strategy, and AI-based segmentation can be integrated into a unified methodology for efficient topographic surveying and spatial analysis. Building on these results, several avenues exist for advancing both data acquisition and analytical capabilities. On the acquisition side, further experiments could compare additional UAV categories such as LiDAR- equipped multirotor systems, multispectral fixed-wing platforms, and VTOL hybrids to evaluate their performance in varied terrains and under different GCP densities. Such comparisons would help quantify trade-offs between platform cost, coverage efficiency, and achievable accuracy, especially in environments with vegetation cover or limited line-of-sight for GNSS. Testing beyond the four configurations used in this study would also support the development of a decision matrix linking drone type, sensor payload, GCP requirements, and project- specific accuracy targets.

On the AI side, extending the U-Net segmentation framework to incorporate multi-modal datasets combining RGB orthomosaics with LiDAR-derived DSMs, GNSS point grids, or multispectral indices could improve class separability and robustness, particularly for narrow or visually ambiguous features such as unpaved roads or rooftop edges. Architectural enhancements such as hybrid CNN Transformer networks, attention mechanisms, or boundary aware loss functions could boost building and road IoUs beyond current levels. Additionally, adopting model compression and edge deployment techniques

would enable near real-time inference directly on UAVs during flight, supporting time-critical missions such as disaster assessment or

construction monitoring. Integrating temporal change detection into the workflow could further expand applications to urban growth monitoring, deformation tracking, and infrastructure lifecycle assessment.

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Revolutionizing Construction Management: The Impact of AI Adoption and Advanced Digital Tools in the Built Environment

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ABSTRACT

The construction industry is undergoing a profound transformation driven by the integration of Artificial Intelligence (AI) and advanced digital tools. These technologies enhance project management, cost control, safety, and sustainability across the entire building lifecycle. This paper explores the role of AI-powered solutions, including Building Information Modeling (BIM), drones, automation, and predictive analytics in reshaping traditional construction workflows. Real- world case studies highlight the tangible benefits of these technologies in terms of efficiency, cost savings, and risk mitigation. The paper also discusses future trends, including generative design, AI-driven compliance, and quantum computing for project optimization.

INTRODUCTION

The advent of digital technologies, especially Artificial Intelligence (AI), has brought about significant changes in the construction sector. Previously characterized by labor-intensive and highly fragmented processes, the industry is now embracing digitization to enhance efficiency and competitiveness. AI enables construction managers to harness data for better forecasting, streamline collaboration, and make real-time decisions. The adoption curve is rising due to reduced hardware costs, more accessible cloud infrastructure, and scalable platforms.

Construction management involves planning, coordinating, and overseeing projects to ensure they meet client requirements. AI and digital tools are revolutionizing traditional practices by automating tasks, improving decision-making, and enabling real-time monitoring. These technologies are no longer futuristic—they are essential in today's construction landscape.

ROLE OF AI IN CONSTRUCTION MANAGEMENT

AI applications span the project lifecycle: from real-time project monitoring and intelligent resource allocation to predictive cost estimation and safety management. AI automates inspections, enhances site monitoring, and supports decision-making with data-driven insights.

Figure 1: AI Applications Across the Construction Lifecycle

ADVANCED TOOLS AND TECHNOLOGIES

Technologies enabling AI integration include BIM for digital modeling, drones for aerial surveys, AR/VR for immersive design experiences, IoT for real-time data collection, robotics for repetitive tasks, and cloud platforms for collaborative project management.

BENEFITS OF AI INTEGRATION

AI enhances productivity, reduces costs, and improves safety. It enables proactive risk management, supports sustainable construction, and brings innovation to design and planning. The combination of efficiency and foresight improves project delivery and profitability.
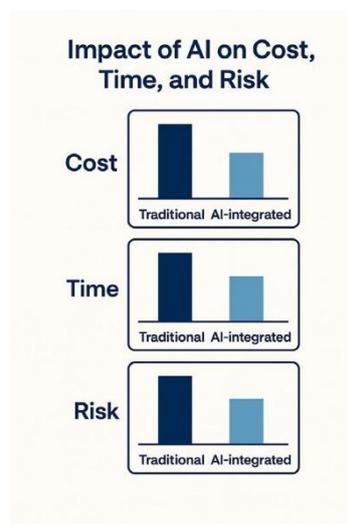
Figure 2: Impact of AI on Cost, Time, and Risk

CASE STUDIES AND INDUSTRY EXAMPLES

Other notable examples include Buildots, which uses helmet-mounted cameras and AI algorithms to compare planned versus actual progress, enabling automatic detection of delays. Similarly, nPlan applies machine learning to historical construction schedules to predict risks and offer mitigation strategies. These platforms represent a shift from reactive to predictive project management.

Examples include OpenSpace for automated site documentation, SAM100 for bricklaying, and predictive maintenance in transit systems. These showcase how AI boosts accuracy, saves time, and lowers operational risks.

Skanska deployed Smartvid.io's AI-based computer vision for safety monitoring, which flagged unsafe behavior like missing PPE. This led to a 20% reduction in safety incidents (Smartvid.io, 2024).

Mortenson Construction used ALICE Technologies to simulate and optimize construction sequencing for a wind farm project. The AI reduced the schedule by 17% and improved resource allocation (ALICE Technologies, 2024).

Larsen & Toubro applied AI and IoT for structural health monitoring in metro rail infrastructure, enabling predictive maintenance and extending asset life (L&T Smart World, 2024).

China State Construction combined drones with AI image analysis for high-rise façade inspections, improving inspection speed by 60% and reducing manual effort (Construction Dive, 2023).

Obayashi Corporation implemented robotic systems guided by BIM for tunnel rebar and concrete tasks. This minimized labor in confined zones and improved precision (Obayashi Corp, 2023).

Laing O'Rourke utilized AI for labor forecasting across multiple sites, using weather and site data to reduce idle time and boost scheduling efficiency (Laing O'Rourke, 2023).

DPR Construction used StructionSite to compare real-time site photos with BIM models, enabling immediate detection of deviations and reducing rework (StructionSite, 2024).

Bouygues Construction adopted generative design tools to optimize temporary scaffolding layouts, reducing material use by 25% and improving logistics (Autodesk Generative Design, 2023).

FUTURE DIRECTIONS

Emerging trends include AI-IoT integration for smart sites, generative AI for design, blockchain for contracts, and quantum computing for complex project optimization. These technologies promise to redefine construction methodologies.
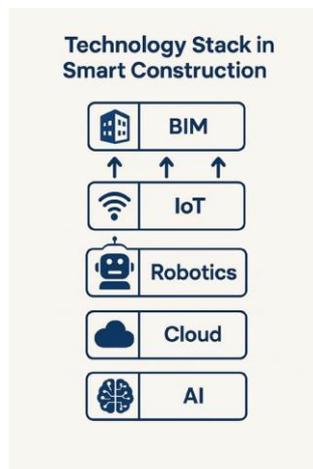
Figure 3: Technology Stack in Smart Construction

AI ACROSS THE BUILDING LIFECYCLE

In preconstruction, AI aids in feasibility studies and regulatory compliance checks. During construction, computer vision systems track progress and flag inconsistencies. Post-construction, AI supports facilities management through predictive analytics and lifecycle tracking of infrastructure. The feedback loop between design, construction, and operations is being shortened and enriched with AI-powered insights.

From feasibility analysis and design optimization to real-time construction monitoring and asset management, AI supports every phase of the construction lifecycle. It ensures smarter planning, efficient execution, and sustainable operation.

IMPLEMENTATION CHALLENGES IN AI ADOPTION FOR CONSTRUCTION

Despite the clear potential of AI in construction management, the path to widespread adoption is fraught with practical challenges. These issues span technological, organizational, cultural, and economic domains.

Low digital maturity, fragmented data systems, cultural resistance, high implementation costs, lack of regulatory frameworks, and cybersecurity concerns are the key challenges hindering AI adoption in construction. Addressing these barriers systematically is key to realizing the full value of AI- driven transformation.

RECOMMENDATIONS FOR POLICY MAKERS AND INDUSTRY LEADERS

Policy makers and industry leaders should develop national AI roadmaps, offer R&D incentives, mandate digital delivery for major public projects, establish innovation hubs through academia-industry collaboration, promote open data standards, support workforce upskilling programs, and create regulatory frameworks for ethical and secure AI adoption in construction.

CONCLUSION

AI and digital tools are transforming construction management. Their strategic adoption leads to enhanced project performance, increased sustainability, and long-term resilience in the built environment.

AI and advanced digital tools are not just enhancing construction management—they are redefining it. From design and planning to execution and operations, AI enables smarter decision-making, real-time collaboration, and predictive control across the entire project lifecycle. These technologies improve cost efficiency, safety, and sustainability, offering tangible value to both developers and end users.

However, to realize their full potential, the industry must address critical implementation challenges such as digital maturity gaps, data integration, cultural resistance, cost barriers, and the need for ethical frameworks. Strategic collaboration among policy makers, industry leaders, and technology providers is essential to create supportive ecosystems that drive innovation, foster trust in AI-driven processes, and ensure inclusive digital transformation.

The future of construction lies in intelligent, connected, and resilient systems—powered by AI and guided by a shared vision for smarter, sustainable infrastructure.

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Advancing Project Delivery in Indonesia: A BIM-Based Integrated Project Delivery System (IPDS) Model to Improve Construction Performance

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ABSTRACT

The construction sector is vital to Indonesia's economy, but continues to face low performance and inefficiencies, especially in building complex projects. This study investigates the shortcomings of existing Project Delivery Systems (PDS) and proposes a BIM-based Integrated Project Delivery System (IPDS) tailored to the Indonesian context. Using a mixed-methods approach, the research evaluates nine critical PDS elements linked to contract practices and project performance. Surveys and literature analysis reveal how stakeholders—owners, contractors, and consultants—perceive both conventional and BIM-enabled delivery models. Findings show that BIM-based IPDS significantly enhances project efficiency and collaboration. However, challenges remain, such as underutilized Common Data Environments (CDEs) and a lack of regulatory support in preconstruction planning. Legal frameworks, skilled professionals, and stakeholder synergy emerge as key success factors. This study offers a novel framework mapping PDS components to performance outcomes and provides practical recommendations for improving procurement systems in Indonesia. It sets the foundation for future research on optimizing project delivery through digital integration and collaborative contracting.

Keywords: *Project Delivery System (PDS), Integrated Project Delivery System (IPDS), Building Information Modelling (BIM), project performance, building construction*

INTRODUCTION

The construction industry has consistently contributed significantly to Indonesia's gross domestic product (GDP) over the past decade, matching the contribution of other key economic sectors.[17] Nonetheless, it continues to confront several challenges, primarily related to poor performance and inefficiency in building projects, especially those managed by local firms. These issues affect the country's global competitiveness in the construction industry.[18]

Additionally, the use of conventional PDS and procurement regulations that hinder efficiency exacerbates this issue. 2 3 Siregar et al. further identified that the conventional PDS model creates various issues at every project phase, from feasibility studies (FS) and design/engineering (D/E) to procurement, pre-construction, and construction. Error! Bookmark not defined. Their research revealed that most issues arise during the design and construction phases, particularly in interactions between contractors and designers (see Figure 1). This situation highlights that the use of conventional PDS significantly contributes to the poor performance of construction projects.

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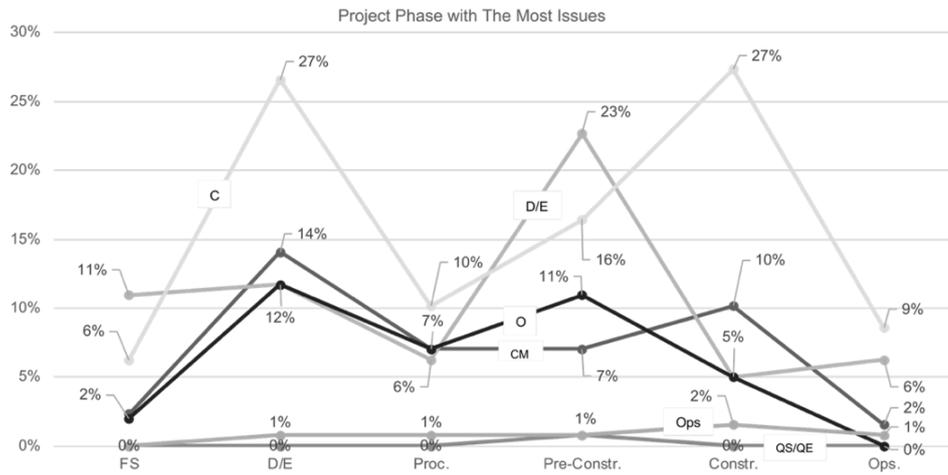
Figure 1. Project phases experiencing the most issues according to project stakeholders.Error! Bookmark not defined.

In response to these challenges, several studies emphasize the need to transform the PDS into an Integrated Project Delivery System (IPDS). This change promotes better collaboration, communication, and efficiency among owners, designers, and contractors.[19] Creating an IPDS relies on supporting tools such as Building Information Modeling (BIM) and the Common Data Environment (CDE), which serve as platforms for integration. BIM functions not just as a digital tool but also as a system that impacts project culture, workflows, and information management.[20]

The adoption of CDE in Indonesia has faced challenges due to technological constraints, limited expertise, and weak cross-disciplinary collaboration.[21] Harjono et al highlighted that effective communication between contractors and owners is essential for the success of IPD-based projects. 10 However, there is still limited research on how BIM-based IPDS affects project performance in Indonesia, particularly in projects involving all stakeholders. This study compares the implementation of IPDS-BIM and conventional PDS through questionnaires and observations, utilizing the nine PDS aspects (X) to assess their influence on nine project performance aspects (Y).[22]

METHODS

This study mapped the development of PDS in Indonesia through an online survey employing the snowball sampling technique, but with a larger sample of 320 respondents to capture a broader range

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[21] Bernstein Phillip, G., and H. Pittman Jon. "Barriers to the Adoption of Building Information Modeling in the Building Industry." Autodesk Building Solutions Whitepaper. (2005).; Ku, Kihong, and Mojtaba Taiebat. "BIM experiences and expectations: the constructors' perspective." International Journal of Construction Education and Research 7, no. 3 (2011): 175-197.

[22] Siregar, Larasati, and Indraprastha, "Project Delivery Systems and Project Performance: A Causal Relationship Analysis of Indonesian Stakeholders."

of project experiences.[23] The reliability of responses was validated using Cronbach's alpha, following Andrieux et al., to ensure consistency and linearity.[24] Performance comparisons focused on two state-owned building projects that adhere to Minister of Public Works and Public Housing Regulation No. 22/PRT/M/2018, which mandates the use of Building Information Modeling (BIM) for buildings exceeding 2,000 m².

Over 70 weeks, issues from the meeting minutes were collected as open-ended raw data and analyzed qualitatively through directed and summative content analysis.[25] Each issue was coded as a binary variable (1–0) for quantitative interpretation and grouping against latent variables (x and y), following the methods of Holsti and Kondracki et al.[26]

a. Variables

This study modifies the model by Siregar et al., which treats nine PDS aspects as independent variables (X) and nine project performance aspects as dependent variables (Y).[27] A Principal Component Analysis (PCA) was performed, following Hair et al. (2010), to reduce data dimensionality (n = 320) and account for changes in latent variables. The PCA results update the original model by identifying four latent variables within the PDS aspects and three within project performance aspects, as illustrated in Table 1. Additionally, multivariate regression analysis was conducted to examine the effect (β) of the latent PDS variables on project performance.

Table 1. Latent Variables Related to PDS Aspects – Project Performance

	Aspects of PDS Measurable Variables		Latent	Latent	Project Performance Aspects	Measurable Variables	
x^9	Project Closeout					Quality	$y2$
x^4	Organization	x^1	Management	$y1$	Quality	Safety	$y4$
x^5	Documentation					Stakeholder Satisfaction	$y6$
x^7	Project Management					Time	$y3$
x^1	Project Scope					Functionality	$y7$
x^6	Obligation and Responsibilities	x^2	Legal and Technical			User Satisfaction	$y5$
x^3	Project Phase			$y2$	Satisfaction	Value and profit	$y9$
x^2	Execution Methode	x^3	Execution Methode			Environment Performance	$y8$
x^8	Rewards	x^4	Rewards	$y3$	Cost	Cost	$y1$

[23] Siregar, Larasati, and Indraprastha, "Project Delivery Systems and Project Performance: A Causal Relationship Analysis of Indonesian Stakeholders."

[24] Andrieux, Pierre, Stephanie Leonard, Vanessa Simmering, Marcia Simmering, and Christie Fuller. "How cognitive biases influence problematic research methods practices." Electronic Journal of Business Research Methods 22, no. 1 (2024): 01-12.

[25] Hsieh, Hsiu-Fang, and Sarah E. Shannon. "Three approaches to qualitative content analysis." Qualitative health research 15, no. 9 (2005): 1277-1288.; Mayring, Philipp. "Qualitative content analysis: A step-by-step guide." (2021): 1-100.; Potter, W. James, and Deborah Levine‐Donnerstein. "Rethinking validity and reliability in content analysis." (1999): 258-284.

[26] Holsti, Ole R. "Content analysis for the social sciences and humanities." Reading. MA: Addison-Wesley (content analysis) (1969).; Kondracki, Nancy L., Nancy S. Wellman, and Daniel R. Amundson. "Content analysis: Review of methods and their applications in nutrition education." Journal of nutrition education and behavior 34, no. 4 (2002): 224- 230.

[27] Siregar, Larasati, and Indraprastha, "Project Delivery Systems and Project Performance: A Causal Relationship Analysis of Indonesian Stakeholders."

ANALYSIS AND DISCUSSION

b. PDS Conditions in Indonesia

Research shows that in Indonesia, the Design-Bid-Build (DBB) method is predominant at 44%, while the IPDS makes up only 19% (see Figure 2). However, IPDS is usually implemented through separate contracts, which limits its integration mainly to Building Information Modeling (BIM) for technical coordination. This method falls short of realizing the collaborative goals of IPD, which involve engaging all stakeholders from the start.[28] These results highlight the necessity for contractual reforms and a cultural change in work practices to develop a truly collaborative IPDS in Indonesia.
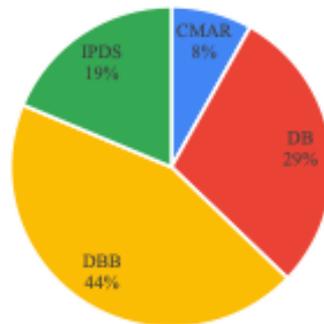
Figure 2. Distribution of PDS across Indonesia

Mapping issues across various PDS highlights significant increases in the design/engineering (D/E) and construction (C) phases (Figure 3). These phases emerge as critical milestones that need targeted focus.[29] The widespread use of separate contracts in projects claiming to implement the IPDS in Indonesia limits early stakeholder engagement, resulting in coordination mainly during the execution stage. As AIA4 points out, this leads to design conflicts, scope modifications, and construction inefficiencies. Therefore, managerial and contractual reforms are essential, including early stakeholder involvement, enhanced cross-disciplinary coordination, and contract restructuring to foster deeper collaboration and improve IPDS effectiveness in Indonesia.
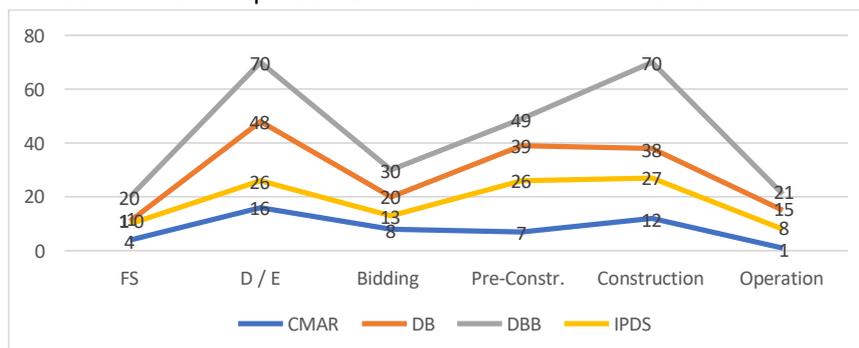
Figure 3. Issue Distribution – Project Phase
Source: Research Data

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[28] AIA and AIA, *Integrated Project Delivery*: A Guide.

[29] Project Management Institute. "A Guide to the Project Management Body of Knowledge (PMBOK® Guide)–Seventh Edition and The Standard for Project Management." Project Management Institute, (2021).; Kerzner, Harold. Project management: a systems approach to planning, scheduling, and controlling. John Wiley & Sons, (2025).

The feasibility study (FS) and pre-construction phases are essential for developing a comprehensive project plan that involves all stakeholders in technical, administrative, and legal aspects (Turner, 2014).[30] In Indonesia, despite the growing importance of pre-construction, this phase lacks formal recognition in the existing literature or regulations, including clear definitions of its role and duration.[31] This absence of a formal framework hampers the legitimacy and effectiveness of pre-construction as a bridge between planning and execution, increasing the risks of delays and cost overruns in subsequent phases.[32] Therefore, updating the regulatory and technical guidelines to explicitly define the objectives, scope, and duration of the pre-construction phase and to mandate early stakeholder involvement is necessary. Such an update is expected to enhance the pre-construction sector's ability to reduce fragmentation, improve planning quality, and support more effective PDS implementation in Indonesia.

c. Conventional PDS Project

Based on the project observation results, a total of 380 problem items were identified. Content analysis included coding with latent variables (x) and (y). The findings show that the majority of issues pertain to Legal & Technical Aspects, comprising 54%, followed by Management Aspects at 39%, Execution Method Aspects at 6%, and Reward Aspects at only 1% of the total problems (see Figure 4a).
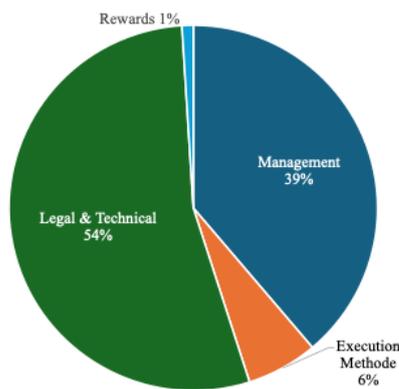
Figure 4a. Distribution of PDS Aspect Issues
Source: Research Data
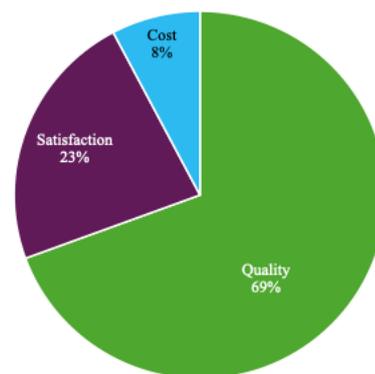
Figure 4b. Distribution of Performance Issue Aspects
Source: Research Data

These issues significantly impact project performance, particularly in the Satisfaction Aspect (60%), followed by Quality (32%), and Cost (8%) (see Figure 4b). A multivariate regression analysis between the PDS variables (X) and project performance (Y) yields a model, as shown in Figure 5, providing a quantitative view of how each aspect affects project performance.

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[30] Turner, J. Rodney. The handbook of project-based management. Vol. 92. New York, NY: McGraw-Hill Education. (2014).

[31] Kementerian Pekerjaan Umum dan Perumahan Rakyat, Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat Nomor 22/PRT/M/2018 tentang Pembangunan Bangunan Gedung Negara. .

[32] Project Management Institute. "A Guide to the Project Management Body of Knowledge (PMBOK® Guide)– Seventh Edition and The Standard for Project Management." Project Management Institute, (2021).; Olawale, Yakubu, and Ming Sun. "Construction project control in the UK: Current practice, existing problems and recommendations for future improvement." International journal of project management 33, no. 3 (2015): 623-637.
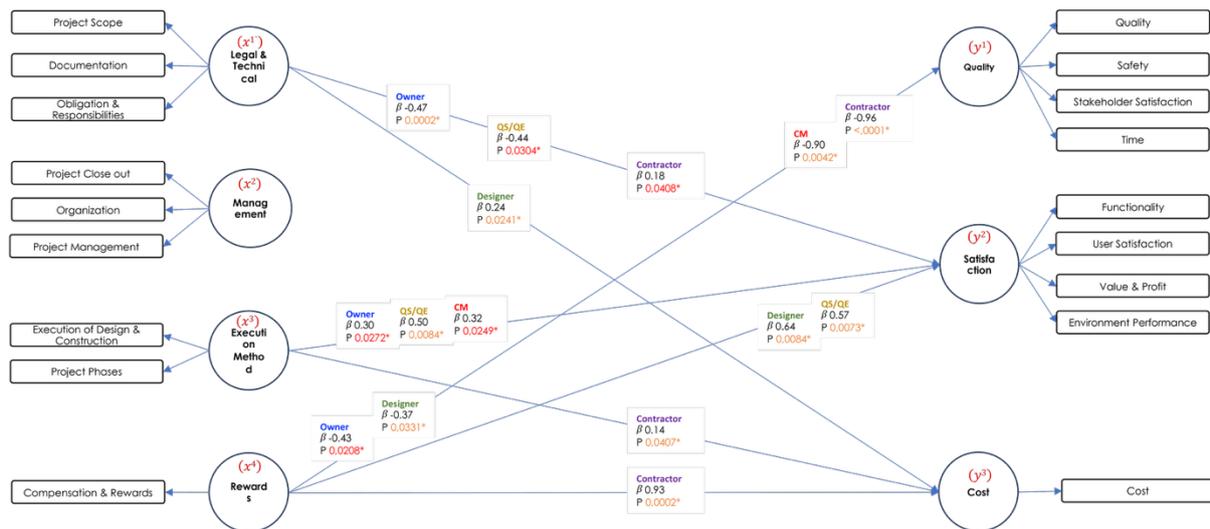
Figure 5. Conventional PDS Regression Model: PDS Aspect – Project Performance

The results show that objects with a conventional PDS experience the greatest regression, with a ß of -0.96 and a p-value below 0.0001*, indicating a highly significant effect at less than 0.01%. This impact is observed between reward factors influencing quality performance. Contractors exhibit ambivalence towards the reward system; although it effectively enhances cost efficiency, it tends to reduce quality. This finding supports the work of those who examined value engineering practices in DBB projects. 22

Interestingly, in projects using conventional PDS, the strongest regression was ß = -0.96; p < 0.0001* (*Significant at the < 0.01% level) between the Reward Aspect and Quality performance. This indicates that while the reward system effectively encourages cost efficiency, it can also reduce work quality. These findings are consistent regarding the adverse effects of value engineering practices on Design-Bid-Build (DBB) projects.[33] Therefore, improving the reward system to better balance cost incentives with quality assurance is crucial for enhancing overall project success.

These findings verify that DBB systems, due to their sequential and segmented process, inherently encounter difficulties in balancing cost, quality, and satisfaction.[34] The distinct separation between design and construction phases often impedes effective communication and coordination, resulting in unavoidable trade-offs. This highlights the limitations of DBB in promoting collaboration and integration compared to PDS alternatives, such as IPDS, which emphasize early stakeholder engagement and a partnership-focused approach.[35]
Furthermore, the highlighted legal weaknesses and the minimal recognition of particular stakeholders' roles reveal a gap in the application of relational contracting principles.[36] This approach emphasizes

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[33] Love, Peter ED, and Zahir Irani. "A project management quality cost information system for the construction industry." Information & management 40, no. 7 (2003): 649-661.

[34] Walker, Derek, and Keith Hampson. "Enterprise networks, partnering and alliancing." Procurement Strategies 30 (2003).

[35] Kent, David C., and Burcin Becerik-Gerber. "Understanding construction industry experience and attitudes toward integrated project delivery." Journal of construction engineering and management 136, no. 8 (2010): 815-825.

[36] Macneil, Ian R. "The new social contract: An inquiry into modern contractual relations." Ethics 93, no. 1 (1982).; Motiar Rahman, M., and Mohan M. Kumaraswamy. "Assembling integrated project teams for joint risk management." Construction Management and economics 23, no. 4 (2005): 365-375.

the importance of clear contracts, along with adaptable relationships and incentives that promote teamwork. Therefore, these findings indicate the possibility of implementing relational contracting ideas within DBB systems or moving towards a more integrated PDS approach to improve project outcomes sustainably.

d. IPDS Project

The object identified 818 issues related to analog data (see Figure 6a) and 104 issues concerning CDE (see Figure 6b). Similar to conventional projects, technical and legal factors were the dominant variables in both research areas. This suggests that legal and technical considerations are essential in affecting project outcomes. Even in projects involving BIM-CDE, these legal and technical aspects remained the main influences on performance.

Figure 6a. Analog Distribution: PDS Aspects Source: Research Data
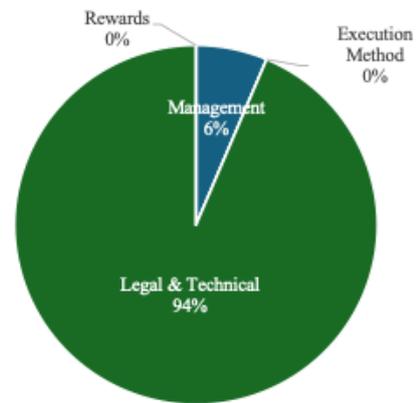
Figure 6b. CDE Distribution: PDS Aspects Source: Research Data

This situation highlights that the clarity of contracts, technical standards, and regulatory mechanisms for collaboration remains insufficient, resulting in persistent structural challenges despite the implementation of BIM-CDE technology. Consequently, it is crucial to improve contractual regulations and develop technical standards that facilitate collaboration, ensuring BIM-CDE's full potential in project management is realized.
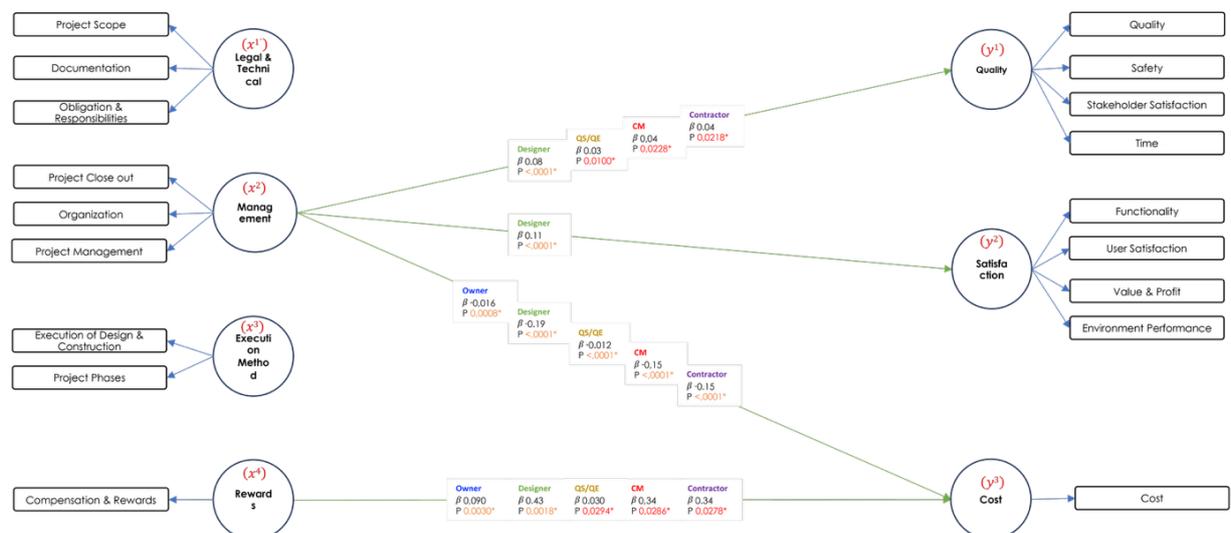
Figure 7. IPDS Regression Model: Aspects of PDS – Project Performance

Multivariate regression analysis (Figure 7) indicates that, in the IPD-BIM project, the reward aspect has a significant impact on cost performance (β = 0.43), particularly influencing designers and engineers. The current incentive system encourages cost-effective behavior but lacks sufficient quality control, which risks compromising work quality in the pursuit of savings. Consequently, it is crucial to develop a reward system that balances efficiency incentives with robust quality oversight, in line with the principles of relational contracting.[37]

Furthermore, a significant shift in roles was observed in the IPD-BIM project, where management became crucial for improving quality and satisfaction. This emphasizes management's focus on cross-disciplinary collaboration and early decision-making. [38] This change minimized the typical fragmentation in BIM projects. It positioned management as a key factor for success, highlighting the need to strengthen project management skills and adopt a more integrated approach. Notably, execution methods and legal-technical factors appeared to have had little impact on the results, suggesting a shift away from strict control toward a more trust-based, flexible approach. The emphasis on stakeholder collaboration within the IPD framework confirms that an integrated system can reduce fragmentation in BIM projects and reinforce management's role as a primary driver of success.

The multivariate x-k-y relationship model (see Figure 8) illustrates that the integrative nature of the PDS significantly influences process integration (IP), responsibility integration (ITG), and decision-making integration (IPK). Notably, IPK has a strong negative effect on owners' performance satisfaction, with a β of -0.736 and a p-value of 0.0226*, indicating significance at the 2.26% level. Excessive integration burdens may lead to role stress for owners, which in turn decreases their satisfaction. This suggests that integration does not always yield a straightforward positive outcome; instead, its effectiveness depends on maintaining a proper balance of roles and authority sharing.[39] Therefore, integration efforts should aim to foster a more equitable distribution of responsibilities (ITG), maximizing the benefits of collaboration while avoiding overloading owners.

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[37] Motiar Rahman, M., and Mohan M. Kumaraswamy. "Assembling integrated project teams for joint risk management." Construction Management and economics 23, no. 4 (2005): 365-375.

[38] Kent, David C., and Burcin Becerik-Gerber. "Understanding construction industry experience and attitudes toward integrated project delivery."

[39] Thomsen, Chuck, Joel Darrington, Dennis Dunne, and Will Lichtig. "Managing integrated project delivery." Construction Management Association of America (CMAA), McLean, VA 105 (2009).
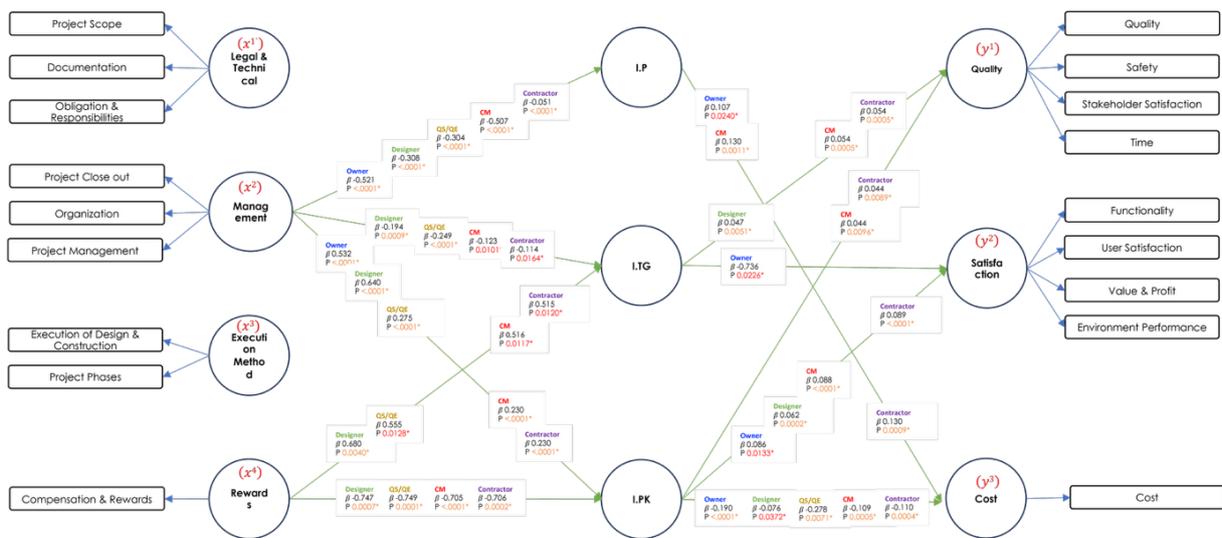
Figure 8. Regression Model: PDS Aspects – IPDS Project Performance, influenced by PDS Characteristics

Furthermore, the minimal influence of legal issues and implementation strategies in IPD-BIM projects points to a shift from procedural oversight towards better coordination and work relationships, which aligns with the relational contracting approach.25 Although coordination has improved, differences in stakeholder perspectives still exist, indicating that collaborative systems alone do not automatically resolve conflicts of interest. Clearly defined roles and structured work relationships are crucial for achieving sustainable project outcomes in IPD. Thus, a collaborative IPD model can only succeed when it is supported by effective work relationships and shared accountability, offering empirical evidence for the importance of balanced, collaborative design within IPD literature.

CONCLUSION

The analysis reveals that BIM-based IPD has a reliable impact on project outcomes, with managerial and reward factors being the most influential, while procedural elements play a smaller role. This suggests a shift toward management practices based on trust, collaboration, and relational contracting. The success of IPD relies on the integration of a cohesive system, stakeholder participation, and balanced management of integration to avoid negative effects on parties such as designers, QS/QE, and owners. These findings confirm that BIM-CDE significantly fosters an integrated and collaborative project structure, although challenges in responsibility sharing and joint decision-making still require refinement. The study also indicates that BIM-based IPDS projects perform better than traditional PDS, due to improved processes, responsibilities, decision-making, and CDE support that enhance coordination. Although currently semi-structured in Indonesia—with separate contracts and limited CDE use—this collaborative approach improves quality, cost efficiency, and stakeholder satisfaction. To maximize collaboration, it is essential to optimize CDE use and restructure roles and contracts. These measures will also facilitate the development of a 'technology-based relational integration' project management model, more suitable for the Indonesian context.

"Clean City - Green City": Sustainable replicable model

Rajeev Supekar, Japan

Regional Director (South Asia) - Chodai Co. Ltd. Tokyo, Japan. With Infrastructure, Renewable Energy, Power, Water sector consulting experience. With 3 decades of living in Japan, he aims to spread the Clean City-Green City movement to the rapidly developing Asian countries, seeking regional cooperation, appropriate finance, youth involvement and deploying AI.

URBANIZATION & CHALLENGES

As South Asia and South-East Asia region continues to foster economic growth combined with increase in population, the steady urbanization is giving birth to several new, upcoming planned cities. In the meanwhile, Tier1 and Tier 2 cities continue to expand laterally as well as vertically. One of the common problem faced by these new cities and expanding cities in urbanization process is waste management. Waste generation is going to increase with increase in population over next few decades[40]. Several plans exist on paper and in preliminary implementation but the ground reality is majority of waste leads to uncontrolled discharge, land-filling. Ignoring increasing waste quantity and using conventional land filling as unsustainable solution has reached its peak level beyond which, it poses danger to sprawling population in vicinity, causing health-hazard. A few modern plants to treat waste are in place but face intermittent or low capacity operation, worse, there are cases of closure, due to mis-operation.

Severity of Issue: Whole situation is alarming and even United Nations have urged growing economies to address this on urgent basis.[41] If this advise is ignored, vast population may face sub-standard living, un- clean environment, defying dignity.

Urban Planners, city governing councils (known by various names as municipality, Municipal corporation, District Collector Office, State or Federal Ministry body etc.), combined with developers and builders have social responsibility to address this situation, noting that the infrastructure they plan and build is already proven at some other geographic location and replication in sustainable "clean city, green city" is plausible.

Figure 9: Projected global municipal solid waste destinations in 2030, 2040 and 2050 compared with 2020.
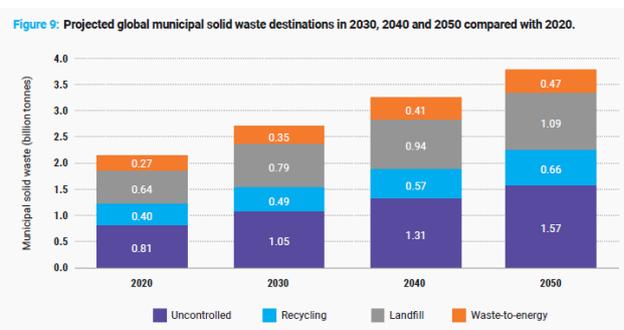
The graph on left shows the Waste classification based on its destination. It is obvious that Waste meant for Uncontrolled discharge and landfill has potential to shift as much possible to proper utilization i.e. Energy projects.

Research and pilot scale operation in several research institutions, national and private alike have given new hopes of sustainable recycling of waste, scale-up/scale-down operation as well as power generation and

reusable material, extraction of metals. All these established and upcoming technologies need a consolidation for rapid implementation coupled with funds availability.

Japan model: Inbound tourists and expatriate staying in Japan are amazed in a way small towns-mid-tier-cities. Large cities are kept spotlessly green and clean with high efficiency. Some of them generate electricity and help sustain the environment. Recycling the waste scientifically by right classification

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[40] UN Mandate- SDG 11: https://globalgoals.org/goals/11-sustainable-cities-and-communities/
[41] UN Mandate- SDG 11: https://globalgoals.org/goals/11-sustainable-cities-and-communities/

at root level must be given its due credit. Individuals and groups have summarised sustainable Clean Cities as a mission and a wider regional cooperation for this social cause. Planning, execution and continuous improvement is key to success of this model. This paper offers way to keep cities clean and illustrate several technologies to foster this enterprise.

GREEN CITY BASIS

One of the first work in planning for new development is allocation of land for garden, playground and tree plantation in the facilities. Gardens and tree plantation take preference. Techniques adapted in most cases is different from ordinary afforestation in that it is a distinctive technique in which tree species and different types of saplings that are locally indigenous are grown and planted close together (mixed and dense planting) in arrangements closely resembling natural forests. This method has been employed to regenerate forests in many different places. It is said that it normally takes several years to regenerate a forest; however, the Miyawaki method can regenerate a forest within 10 to 20 years. After three years from planting, basically, it will become unnecessary to take care of the forest. Besides most of the tree species selected in this method are broad-leaved evergreen trees with deep and tap roots that do not easily fall down, creating a strong disaster-prevention forest protecting the environment around it from typhoons, earthquakes, tsunamis and such natural disasters. Trees absorb Carbon Dioxide (CO_2) in the atmosphere and fix it onto cell walls, etc. reducing the GHG effect. Green city trees depending on its type mainly are as under

Sr.	Type	Tree / Plant name
1	Tall trees	Sakura (Cherry), Camphor, Zelkova, Ginkgo, Cedar, Hinoki are often used as street trees.
2	Shrubs and hedges	Evergreen and deciduous shrubs such as Geidai, Japanese Maples, Wisteria, Styrax, and Peonies., Satsuki azalea, Hirado azalea etc.
3	Garden and landscape	Fraxinus serrata, kousa dogwood, Plum blossom, Sawara, Koya Maki, Asunaro Thujopsis dolabrata trees are also popular.

Sakura or Cherry trees that bloom during onset of spring are more popular among many localities and at some places, there are hundreds of trees that give a beautiful landscape during early spring. Visitors not only local but also overseas come in thousands to see the nature's miracle and gives boost to local business.

Several upcoming areas aim to plant exotic trees that are seen in western countries and not suiting local climate. Traditional useful trees are best for plantation and local botanists should be consulted to preserve traditions rather than going for expensive exotic unsuitable planting that need periodic care.

CLEAN CITY BASIS

The success of the plan is education and discipline to all strata of society, residents where waste is generated. It is well-planned to inform and make all residents/ occupants when they move in to

dwelling and by periodic updates on social media circles.[42] Please refer to the pamphlets distributed to incoming residents and displayed prominently in public boards.[43] Linking civic sense with some incentive to the community will ensure segregation at root level.

Solid Waste Treatment Plant capacity: Collection into common treatment facility plot as designated by local civic body for long term nominal lease and for facilitating the treatment is key to the project. As the cities expand and the treatment facility also need to keep pace with time, a suitable margin, spare land adjoining the facility will be helpful. For a city with population ranging 100,000 onward, a small tipping to pick up garbage is a big incentive in the Financial Model, showing improved ROI. As for treatment capacity, most cities begin with 10-50 ton/day solid waste treatment and eventually reach 300 – 500 tons per day over a decade or two as they keep expanding. Planning of such project has to bear in mind that steadily increasing standards of life and modern life-style produces more garbage and therein more challenges. Building up for a marginal higher capacity and allocating space for expansion is prudent*6)

*8 Environment Ministry of Japan: Solid Waste Management and Recycling Technology
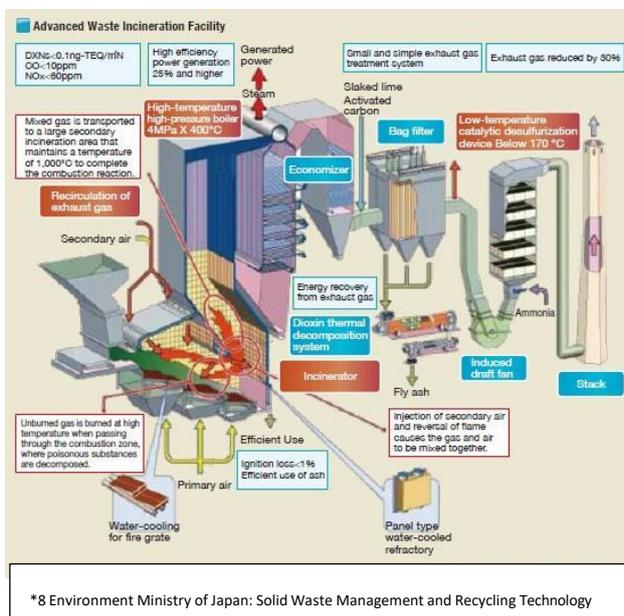
Waste measurement and classification helps in proper planning of waste treatment center. For example, as per web page information (*10), within May 2025, Tokyo 23 wards Solid waste facilities collected and treated Burnable Waste equal to 1.56 Million Ton, non-burnable waste of 23,300 ton whereas oversize waste was 67,300 ton thereby yielding average waste generation of around 700 grams per day per person. The composition of waste and its calorific value vary based on the season, population. For example, agricultural harvesting, seasonal fruits increase proportion of organic waste in the solid waste.

Undoubtedly, the most troublesome waste to handle is plastic and its derivatives. Every passing year, increasing volume of plastic and their derivatives treatment is causing concern amongst the environmentalists. As plastics give rise to dioxins if burnt at normal temperature and causes potential harm to human health and environment, high temperature pyrolysis is practiced. In the sketch is shown a treatment process as being marketed by a Japanese major company in this field. Whereas most of the burnable waste is "consumed" in this way, the heat generated is used to generate steam that is fed to STG to generate power. Though the burnable waste has some heat value, it is not sufficient to reach necessary pyrolysis temperature hence the supplementary fuel like coke or oil/ gas are used. Local bodies like Tokyo Metropolitan Government (TMG) have a policy for zero

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[42] Smart city communication via social media: analysing residents' visitors' engagement - S Molinilloa University of Malaga, Spain

[43] How to Sort and Dispose Household Garbage; Waste Management in Japan https://www.geihokukouiki.jp/contents/pdf/gomi-dashikata-gaikoku/001-english.pdf

emission along-with halving GHG and limiting temperature rise to 1.5 C. and these end objectives do not go follow same direction.[44]

TECHNOLOGIES BASKET

When properly treated, the Waste Treatment Facility is a source of following products and services depending on the composition and technology.

1.   Manure / fertilizer for farming & agriculture
2.   Recyclable plastics
3.   Compressed Bio Gas (CBG), Bio-diesel
4.   Small scale Waste-To-Energy power generation plant
5.   MBT process pallets

Each of the above are described in brief below.

Breakdown of plastic waste

Shape		Use and Contents	Type of Resin	
Bottles and tubes	Beverage bottles	Soft drinks	Juice, cola, drinking water, tea, alcoholic beverages	PET	
		Lactic acid beverage	Yogurt, milk	Polystyrene, PET, polyethylene	
	Food and condiment bottles		Tempura and salad oil, soy sauce, sauce mirin (sweet sake used as seasoning)	PET, polyethylene, polypropylene	
	Condiment tubes		Mayonnaise, ketchup, dressings, wasabi and mustard paste	Composite materials	
	Bottles and tubes for daily necessities		Toiletries, gardening supplies, car supplies, liquid detergent, fabric softener, toothpaste, cosmetics, hair shampoo, hair conditioner, bleach and body shampoo	PET, composite materials, polyethylene, polypropylene	
Packs and cups	Food packs (EPS and non-EPS packs)		Margarine, tofu, nattou (fermented soybeans), fruit, vegetables, processed foods, prepared foods, packed lunches	EPS	Polystyrene
				Non-EPS	Polystyrene, polypropylene, PET
	Food cups (EPS and non-EPS packs)		Miso (soybean paste), tamago-dofu (steamed egg custard), miso soup, yogurt, ramen, yakisoba (fried noodle), jelly, custard pudding, deserts food cups	EPS	Polystyrene
				Non-EPS	Polystyrene, polypropylene, PET, polyethylene, composite materials
	Cup and pack lids			Polystyrene, PET, polypropylene, polyethylene, composite materials	
Trays and blister packs	EPS and non-EPS trays		Meat, fish, sashimi (slices of raw fish), sliced ham, vegetables, processed foods	EPS	Polystyrene
				Non-EPS	Polystyrene, polypropylene, PET
	Blister packs		Drugs (tablets), processed meat and fish products, roast ham, bacon, curry roux, household tools, toothbrushes, cosmetics	Polyethylene, polypropylene, PET, polystyrene, PVC resin	
	Egg boxes			PET, polystyrene	
Bags	Large, medium and plain bags		Rice, gardening bags, fish, fruit, confectionery, frozen foods, ramen, vacuum-packed foods, pickles, food boiled in soy, miso, bread, dried fish, cleaning	Polyethylene, polypropylene, PET, composite materials	
	Carrier bags			Polyethylene	
	Rubbish bags			Polyethylene	
	Small bags		Quail's eggs, ginger, pickles, condiments, ramen stock, wagashi (Japanese confectionery), candy, wafers, chocolate	Polypropylene, polyethylene, composite materials, PET	
Caps and stoppers			Beverages, foods, daily necessities, other plastic bottles	Polypropylene, polyethylene	
Wrapping, packaging and labelling film	Wrapping film			Polyvinyl chloride resin, PVC resin, polyethylene	
	Packaging film		Tofu, curry roux, plastic food decorations, wagashi, chees, frozen foods, cod roe, sausages, frozen noodles	Polypropylene, polyethylene, composite materials	
	Labels		Bottles, caps	Polystyrene, polyethylene, PET, polypropylene	
Boxes and cases			Detergent boxes lids, foods, underwear, powder compacts, lotion cases, dehumidifiers, deodorizers	Polypropylene, polystyrene, polyethylene, PVC resin	
Protects and fixing			Urethane sponge, foam products, nets, air caps	Polystyrene, polyethylene	
Others			Baskets, handles, multi-packs, sieves, replanting pots	Polyethylene, PET, polypropylene, PVC resin, polystyrene	

Note : The types of resin indicated in the table are those mainly used.

a.   Manure/ fertilizer for agriculture:

Organic and compostable waste such as food, agricultural waste are excellent source for composting and producing manure by anaerobic bacteria. It is said that one-third of the world's food is wasted, which accounts for 8% of the world's greenhouse gas emissions. Composting is nature's way of recycling. Any organic matter, be any plant or animal dies and decomposes properly by composting, nutrient-rich material is produced as manure in form of granules. This can be used in gardening, horticulture, and farming to support plant growth. A domestic, household version of composting plant is now being marketed under different brands. It ranges from as low as 10 kg per day and the compost is ready in a day and needs a sachet of "breed" material for start-up with a low- power electric supply.[45]

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[44] Tokyo Metropolitan Government – Zero Emission Tokyo Strategy
[45] Renewable and sustainable solution for the treatment of organic waste: https://harprenewables.com/:

b. Recyclable Plastics:

One of the most amazing invention of human kind, used extensively in daily life is a miserable when its waste is not treated properly. Plastics are mainly highly polymerized compounds consisting of carbon and hydrogen, made from substances, accounting to 3% of total crude oil consumption.[46] As per analysis of plastic waste, the PET bottles constitute 14%, packing + packaging around 69% and others are 17%.[47]

Three forms of recycling of plastics is popular depending on its constituents.

Category (in Japan)	Method of recycling		ISO 15270
Material recycling	Recycling to make · Plastic raw materials · Plastic products		Mechanical recycling
Chemical recycling	Monomerization		Feedstock recycling
	Blast furnace reducing agent		
	Coke oven chemical feedstock recycling		
	Gasification Liquefaction	Chemical feedstock	
		Fuel	Energy Recovery
Thermal recycling	Cement kiln Waste power generation RPF(*1), RDF(*2)		

A. **Recycling: In order to make raw material for plastic products, thus reducing plastic raw material intake.**
B. **Chemical Recycling: A grade of plastics are proven to undergo a Controls generation of dioxins by incineration.**
C. **Thermal recycling: Reshaped as Refuse Derived Fuel (RDF), rather Refuse Plastic Fuel (RPF), it can e used as alternate fuel source in plants like Cement production as fuel, where the energy is recovered.**

c. Compressed Bio Gas (CBG), Bio-diesel:

The organic matter in solid waste can be degraded by anaerobic bacteria to produce bio-gas and bio-diesel. The biogas generation process consists of four subsequent chemical and biochemical reactions i.e. Hydrolysis reaction, Acidogenesis reaction, Acetogenesis reaction and Methanogenesis reaction in a compact plant.

Hydrolysis is reaction that decomposes organic molecule such as carbohydrates, proteins and fats present in solid waste into glucose, amino acids and fatty acids, respectively. Acidogenesis converts those generated small organic molecules to volatile organic acids with help from bacteria. During the Acetogenesis process, bacteria in the acetic group digests volatile organic acids and releases acetic acid. Lastly, anaerobic bacteria in the methanogenic producing bacteria group will complete the Methanogenesis process by converting acetic acid to methane gas and other gases like Carbon Dioxide and Hydrogen Sulfide. Corrosive and poisonous constituents like this needs to be eliminated before Methane is compressed to 250 Bar and shipped. The Hydrogen Sulfide removal from the produced Bio-Gas is separated by either of the Water Scrubbing, Activated Carbon adsorption, Biological fixation etc. Likewise, Carbon Dioxide suppresses calorific value of Methane. So its removal either by Pressure Swing Adsorption (PSA), Membrane Separation or by Water Scrubbing. Each of such process has its own advantage/ disadvantage and costs (OPEX and CAPEX) apart from losses of Methane gas. For example, PSA process operates automatically but need adsorbing material like activated carbon or

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[46] Solid Waste Management and Recycling Technology of Japan － Ministry of Environment, Japan

[47] Plastic Waste Management Institute: Plastic Recycling Handbook

zeolites. After a cycle of useful service the catalyst bed is regenerated by a sequential decrease in pressure before the column reloading again. With low OPEX, moderate CAPEX, this process main disadvantage is loss of Methane to around 20%, thus making this process a difficult proposition. One of the process gaining traction in this area is membrane separation, for which the gas drying is a necessary condition.

d. Waste-To-Energy small scale power generation plant:

Distinctive separation of Burnable and non-burnable waste, among other categories is the key to Waste-to-Energy plants, operating almost in all prefectures in Japan. The Ministry of the Environment Japan, compiled results of a nationwide survey on municipal waste (garbage and sewage) generation and disposal status for fiscal year 2022, following information is available for the number of Waste Incineration facilities.

- **Total waste generation was 41.67 million tons with a per capita per day rate of 901 grams.**
- **Final disposal volume decreased 4.2% year-on-year. Recycling rates increased.**
- **The number of waste incineration facilities decreased (from 1,070 to 1,056).**
- **The number of waste incineration facilities with power generation facilities accounted for 36.6% of the total, up from 36.0% last year.**
- **Total electricity generation at waste incineration facilities increased (10,153 GWh, equivalent to the annual electricity consumption of approximately 2.38 million households).**
- **Residue, Final disposal volume: 3.64 million tons (4.2% decrease)**
- **Direct landfill rate: 0.9% (1.0% in the previous fiscal year)**
- **Total recycled waste: 8.33 million tons (8.4 million tons in the previous fiscal year) [0.9% decrease]**
- **Overall Recycling rate: 20.0% (19.6% in the previous fiscal year)**
- **Treatment capacity: 176,202 tons/day (177,001 tons/day in the previous fiscal year)**
- **Avg. Treatment capacity /facility: 167 tons/day (165 tons/day in the previous fiscal year)**
- **Number of facilities that use waste heat: 738 (742 in the previous fiscal year)**
- **Number of facilities with power generation facilities: 387 (36.6% of the total)**
- **Total power generation capacity: 2,079 MW (2,079 MW in the previous fiscal year) [-]**[48]

Parallel fuel firing along-with solid waste burning makes these facilities rely on fossil fuels however they fulfil the objective of eliminating the burnable waste altogether.

Though it is possible to generate electric power (range is 1 MW to 5 MW per plant), this is certainly not economical. Transportation of waste material from city area to the plant site, Capital cost for this size of Waste –To-Energy plant and Operation+ Maintenance cost for such plant is hardly justified in real economics purely from the point of view of power generation revenue. These plants help keep the cities clean, reducing the waste to ash and is a solution where the land-filling sites are not available or resisted by local due to dense population. Many of such waste incineration facilities are located right in the city but do not cause issues like odour, smoke, particulate matter due to strict adherence to environment guidelines. (https://www.union.tokyo23-seisou.lg.jp/kojo/index.html) In Japan, a

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[48] Ministry of Environment, Japan: https://www.env.go.jp/press/110813.html

strong legal framework exists from 1960s to ensure clean environment and action against defaulting facilities.

e. Mechanical Biological Treatment (MBT) Fuel pallets (Also known as Tunnel RDF)

Due to issues discussed in above 4 remain unresolved, a comparatively new technology, developed in Europe and practiced in Japan is becoming popular. Also known as "Tunnel Compost Method", the outline is instead of burning, this waste (mixed waste) can be recycled. Thus Waste containing a mixture of food waste, plastic, and paper which been difficult to recycle due to its odour and moisture content, the tunnel composting method ferments and dries this mixed waste, making it recyclable. This method reduces the burden on waste producers and promotes resource recovery. This is a streamlined recycling method that utilizes microorganisms, with waste as their feedstock and breeding.

As for the equipment, in a sealed concrete fermentation tank called a Bio-tunnel, a system automatically controls (temperature, pressure, air volume, etc.) the aerobic environment to ensure that fermentation remain active, ensuring efficient and reliable conditions for fermentation. The heat generated by microbial fermentation is enough to dry the waste.

This waste treatment method, developed in Europe, effectively utilizes mechanical (mechanical) techniques such as crushers to reduce the solids to uniform size, producing larger surface area to induce biological fermentation. After its successful trial at Kagawa prefecture, it is expected to become more widespread in Japan in the coming years.[49] One of the most attractive feature of this method is its low operation cost due to simple equipment. CAPEX , initial costs are lower than other waste treatment methods and fewer personnel are required for operation, keeping running costs low. As process has lesser moving parts like no agitation within the bio-tunnel, there is no need for switching devices. By keeping spare fans and motors in inventory, quick response to breakdown is possible.

All above technologies/ methods are well established and proven on medium scale plant capacity.[50] The compost fuels, also called compressed Reduced Derived Fuel (RDF) can be stored and shipped to a larger power generation /incineration plant as fuel thereby reducing the overall fossil fuel requirement. In the long term, it shall help reduce emission of GHSs significantly. Shift from several small capacity Waste-To-Energy plant to decentralized MBT process may happen gradually. Kaizen, steady improvement of the adapted process is a part of overall shift in every living aspect.

REPLICATION OF CLEAN CITY MODEL

As per public perception and overseas visitors opinion, Japan ranks far above globally in the "Clean city-Green city" category. The key to this success is the establishment of facilities that treat waste efficiently due to root level separation. A mutually cooperative approach fostering the regional collaboration can be adapted with major Japanese cities. Most of the cities are active in global collaboration and can be reached through G-To-G contacts or by approaching local embassy / consulates.

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[49] Eco Master Composting Technology: https://biotunnel.net/

[50] Solid Waste Management and Recycling Technology of Japan －Ministry of Environment, Japan

FIDIC FRAMEWORK OF CONTRACTS

While executing these projects, specially Silver Book (EPC/ Turnkey projects) and Gold Book (Design, Build and Operate DBO Projects) contracting framework can lead to successful implementation.[51] FIDIC is well known and practiced among consultants with several reference cases. Application to such upcoming Waste Treatment projects will benefit cities and urbanization, on the broader front the entire region.

Scaling up and proper operation ensures long term benefits to the residents living in the surroundings to reap benefits of urbanization. Japan as well as public-private companies in South Asia, South-East Asia have requisite knowledge and experience to lead the movement to achieve end objective.

BUSINESS ANGLE

It helps a lot when such facilities that remove waste and keep cities clean are self-sustainable and yield a small profit to the investors. When deployed in conjunction with PPP model and (overseas cooperation + domestic investment), these projects generate high civic sense where the fruits of healthy, clean environment will facilitate civilized living.

With land at nominal rent/ lease for long term and utilities (water, power etc. supply) from Utility company and garbage collection, routing arranged by from the local government with main investment coming from private players including CSR funds, this enterprise has potential to become an engine of commercial activity in each upcoming town. Generating employment and keeping environment clean to give users a fulfilment of urban life, the "Clean-City Green-City" model is ideal for developing economies.

The Basic Concept of JCM
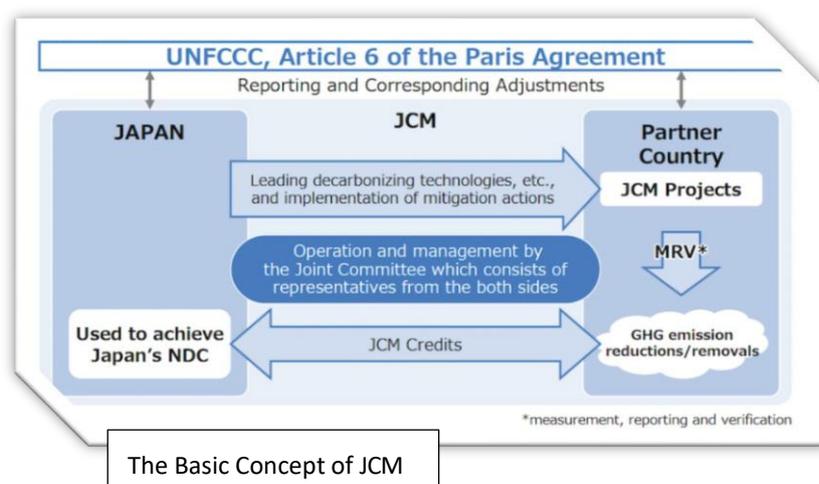
The investment in such solid waste management projects by the city corporation, depending on the capacity and packages, it may vary from 5 to 50 Million US$. [52] Such investment will in turn activate the local economy during the construction and operation phase. Besides generating the local employment and establishment of new businesses, the effects of such projects i.e. clean environment and hygiene will go long way in enriching experience to the residents. Depending on off-taker for tipping fee, products, be in manure, power or RDF pallets (revenue part) and the land lease, utility provision, expenses for manpower during construction/ operation (expense part), the project structure may take a form of Public Private Partnership (PPP), enabling preferential treatment from the financing institutes. Enough financing options are available under ADB, JICA and

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[51] FIDIC: https://fidic.org/book-subjects/ppp FIDIC Silver Book (EPC/Turnkey Contract) and the FIDIC Gold Book (Design-Build-Operate) for large projects

[52] JCM Japan Credit Mechanism (https://www.jcm.go.jp/ – The Basic Concept

such infrastructure financing world bodies. One of the most attractive funding for such facilities could be Joint Credit Mechanism (JCM).[53] JCM facilitates diffusion of leading decarbonizing technologies, products, systems, services, and infrastructure as well as implementation of mitigation actions, and contributes to sustainable development between host / partner country and Japan. The mechanism evaluates suitable contributions from Japan either to reduce GHG emission or remove in a justifiable, quantitative manner. Thus both host country and Japan can use them to achieve their respective NDC, fulfilling the UNFCCC objectives.

USE OF SOCIAL MEDIA TO PROPAGATE CLEAN CITY CAMPAIGN

Bringing "change" from current uncontrolled waste disposal to its orderly treatment needs radical shift in thinking and acts. Currently, every individual has access to social media platforms (FB, LI, Instagram, Twitter etc.) and tries to maintain cleaner, better image in virtual world[54]. It is imperative for the developing city/ town to have its own presence, acknowledge the community for cleanliness of their locality. For example, Indore, a town in central India has won several consecutive awards for the "Clean city" and has effectively used social media for local residents.[55]

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[53] JCM Japan Credit Mechanism (https://www.jcm.go.jp/ – The Basic Concept
[54] Smart city communication via social media: analysing residents' visitors' engagement - S Molinilloa University of Malaga, Spain
[55] Indore wins clean city award 7 times (https://imcindore.mp.gov.in/our-achievement

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*2: UN Mandate- SDG 11: https://globalgoals.org/goals/11-sustainable-cities-and-communities/

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*4: Smart city communication via social media: analysing residents' visitors' engagement - S Molinilloa University of Malaga, Spain

*5 How to Sort and Dispose Household Garbage; Waste Management in Japan https://www.geihokukouiki.jp/contents/pdf/gomi-dashikata-gaikoku/001-english.pdf

*6   Global   snapshot   of   Waste   Management: World   Bank   Report (https://datatopics.worldbank.org/what-a- waste/trends_in_solid_waste_management.html)

*7: Solid Waste Management and Recycling Technology of Japan－Ministry of Environment, Japan

*9: Plastic Waste Management Institute: Plastic Recycling Handbook

*10: https://www.union.tokyo23-seisou.lg.jp/somu/koho/toke/nakami/index.html

*11 Manure from Domestic waste by Queensland Australia: https://www.detsi.qld.gov.au/our-department/news-media/down-to-earth/how-to-compost-effectively

*12   Renewable   and   sustainable   solution   for   the   treatment   of   organic   waste: https://harprenewables.com/:

*13 Tokyo Metropolitan Government – Zero Emission Tokyo Strategy

*14 Eco Master Composting Technology: https://biotunnel.net/

*15 Indore wins clean city award 7 times (https://imcindore.mp.gov.in/our-achievement)

*16 JCM Japan Credit Mechanism (https://www.jcm.go.jp/) – The Basic Concept

*17 White Paper on "Compressed Bio Gas (CBG) - The Fuel of the Future"

Annexures:

1.   https://www.union.tokyo23-seisou.lg.jp/kokusai/documents/ap.pdf   :   International collaboration of Tokyo Solid Waste Treatment Plants with Indonesia etc.

2.   Waste and Recycling Collection mechanism (Following page)

Every resident in Koto ward of Tokyo receives following Chirashi when they move in.

Greening the Cloud: Sustainable Design and Construction of Data Centre in Malaysia Through Green Building Certification

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INTRODUCTION

The digital revolution has ushered in an era where data has become the cornerstone of modern economies. From cloud computing to artificial intelligence, the proliferation of digital technologies has resulted in an exponential growth in data processing needs, fuelling an unprecedented surge in data centre development globally. In Malaysia, this growth is particularly evident. The country is rapidly establishing itself as a key data centre hub in Southeast Asia, driven by favourable geopolitical positioning, competitive electricity tariffs, abundant land availability, and a commitment to becoming a digital economy powerhouse.

However, the expansion of data centres brings with it significant sustainability challenges. These facilities are among the most resource-intensive building types, consuming vast amounts of electricity and water to maintain uninterrupted operation and optimal thermal conditions. According to recent data, Malaysian data centres collectively consumed 434.5 megawatts as of the end of 2024, representing approximately 2.2% of the Peninsular's total electricity demand. Moreover, projections indicate that electricity demand from this sector could soar to 5 gigawatts by 2035 — nearly 40% of Peninsular Malaysia's current power capacity. On the waterfront, a single 100 MW facility can consume over 4 million litres daily, underscoring the immense pressure on local water resources.

In parallel, the carbon footprint of data centres remains a pressing concern. With Malaysia's power grid still significantly reliant on fossil fuels, the high energy demand of data centres translates into considerable greenhouse gas emissions. This directly conflicts with the national vision articulated in the National Energy Transition Roadmap (NETR), which outlines Malaysia's ambition to reach net-zero emissions by 2050 and achieve a 70% share of renewable energy in its electricity mix.

To address these challenges, the Malaysian government and professional bodies have introduced a suite of policies and frameworks aimed at promoting sustainable data centre development. The Malaysian Investment Development Authority (MIDA) has rolled out guidelines that integrate sustainability considerations into the design and operation of data centres, mandating the adoption of key performance metrics such as Power Usage Effectiveness (PUE), Water Usage Effectiveness (WUE), and Carbon Usage Effectiveness (CUE), in line with ISO 30134 standards. Simultaneously, MIDA's Digital Ecosystem Acceleration (DESAC) scheme provides significant tax incentives to encourage green investment in digital infrastructure.

Against this policy backdrop, green building certification emerges as a critical tool to institutionalise sustainable design and operational practices in the data centre industry. In this context, the Green Building Index (GBI) — Malaysia's national green rating tool — plays a transformative role. Formed in 2009 by the Association of Consulting Engineers Malaysia (ACEM) and the Malaysian Institute of Architects (PAM), the GBI has evolved to include a dedicated Data Centre Tool, specifically tailored to address the environmental challenges and operational peculiarities of data centres in tropical climates.

THE SUSTAINABILITY CHALLENGE IN MALAYSIAN DATA CENTRES

The rising demand for cloud computing, AI processing, and digital storage has positioned data centres as a backbone of Malaysia's digital economy. However, this growth comes at a significant environmental cost. In the context of Malaysia's hot and humid climate, data centres require substantial energy for cooling and continuous operation, as well as large volumes of water to support their thermal management systems. The sustainability challenge is, therefore, both urgent and multifaceted.

a. High Energy Consumption and Carbon Footprint

Energy is the single largest operating cost for data centres and the most prominent source of their environmental impact. Malaysian data centres, particularly hyperscale facilities, draw vast amounts of electricity primarily from a grid still dominated by fossil fuels. As of December 2024, 19 data centres in Malaysia were reported to consume 434.5 megawatts of electricity — representing approximately 2.2% of Peninsular Malaysia's total power consumption. As digital infrastructure continues to scale up, projections suggest that data centre energy demand could reach 5 gigawatts by 2035, equivalent to 40% of the region's current power generation capacity.

This trajectory raises serious concerns about national carbon emissions. With much of Malaysia's electricity generated from coal and natural gas, the carbon intensity of data centre operations remains high. In response, the National Energy Transition Roadmap (NETR) has outlined Malaysia's commitment to achieve net-zero emissions by 2050 and to expand the share of renewable energy in its electricity mix to 70% by the same year. However, the pace of renewable energy deployment and grid decarbonisation remains a critical bottleneck.

Power Usage Effectiveness (PUE), defined as the ratio of total facility energy consumption to the energy used by IT equipment, serves as a key metric in measuring energy efficiency. In temperate countries, PUE values as low as 1.1 are achievable due to the availability of free cooling. In contrast, Malaysia's climate leads to significantly higher PUE values, often ranging between 1.6 and 2.0 or higher. Achieving lower PUE in such an environment requires the deployment of high-efficiency cooling systems, airflow containment, energy-efficient IT equipment, and advanced energy monitoring — all of which demand upfront capital investment and technical expertise.

b. Water Usage and Resource Stress

Data centres are not only energy intensive but also extremely water-intensive, particularly those relying on evaporative cooling or water-cooled chiller systems. It is estimated that a single 100 MW data centre could consume up to 4.16 million litres of water per day — equivalent to the daily water requirement of a small city. The water footprint of data centres, while often overlooked, has become a growing concern in Malaysia, where periods of drought and uneven water distribution already affect certain regions.

Water Usage Effectiveness (WUE), measured in litres per kilowatt-hour of IT energy use, is emerging as a vital sustainability metric alongside PUE. Achieving low WUE values necessitates strategies such as the use of air-cooled systems, recycled or reclaimed water, high cooling tower cycles of concentration (COC), rainwater harvesting, and the adoption of water-efficient equipment.

Concerns about water sustainability have been echoed by national agencies. The National Water Services Commission (SPAN) have highlighted the unsustainable consumption of potable water by

data centres, urging for stricter regulation and better integration of water resource planning into data centre design. Moreover, increasing scrutiny from environmental authorities and the public underscores the urgency of embedding water conservation strategies into every stage of a data centre's lifecycle.

c. Environmental, Social and Governance (ESG) Pressures

Beyond regulatory compliance, data centre operators now face increasing pressure from investors, clients, and global hyperscalers to demonstrate robust Environmental, Social and Governance (ESG) credentials. Sustainability performance has become a key differentiator in site selection, especially for multinational corporations seeking to align their global operations with climate targets and ESG reporting requirements.

Global technology companies such as Google, Microsoft, and Amazon have already pledged carbon neutrality or net-zero operations within specific timeframes, and their Malaysian facilities are expected to conform to these global benchmarks. As such, the integration of sustainable design principles and performance-based certifications like the Green Building Index (GBI) has become essential not only for environmental reasons, but also for business competitiveness and long-term viability.

d. Regulatory and Policy Alignment

The Malaysian government has responded to these challenges with a coordinated suite of initiatives:

- **National Energy Transition Roadmap (NETR):** Targets 45% emissions reduction by 2030 and net-zero emissions by 2050.
- **MIDA Guidelines for Sustainable Data Centres:** Encourages the integration of metrics such as PUE, WUE, and CUE; aligned with ISO 30134.
- **Digital Ecosystem Acceleration Scheme (DESAC):** Offers 100% tax allowance for sustainable capital expenditure, valid until 2027.
- **Corporate Renewable Energy Supply Scheme (CRESS):** Facilitates direct procurement of renewable energy from independent producers.

These policy tools are designed to nudge the industry toward greener infrastructure by incentivising sustainability while reinforcing compliance with international standards.

GREEN BUILDING INDEX (GBI) DATA CENTRE TOOL – AN OVERVIEW

In response to the pressing environmental challenges posed by the data centre industry, Malaysia has developed a tailored green certification framework that addresses both local conditions and operational realities. The Green Building Index (GBI) Data Centre Tool represents a pioneering effort to integrate sustainability into the design, construction, and operation of data centres in a tropical, rapidly developing economy.

e. Evolution of GBI and the Data Centre Tool

The Green Building Index (GBI) was jointly established in 2009 by the Association of Consulting Engineers Malaysia (ACEM) and the Malaysian Institute of Architects (PAM). Initially focused on commercial and residential buildings, the index evolved over the years to accommodate various specialised building typologies. Recognising the unique energy and operational demands of data centres, GBI introduced its first dedicated Data Centre Tool in 2012.

The tool underwent a comprehensive revision in 2025 (Version 2.0), reflecting advances in technology, increased awareness of embodied carbon, and alignment with national sustainability targets under the National Energy Transition Roadmap (NETR). This updated tool provides a robust, performance-based framework to help data centre developers and operators embed sustainability principles into every phase of the project lifecycle.

f.   Structure and Categories

The GBI Data Centre Tool evaluates projects based on six core sustainability categories, with a maximum score of 100 points:

No.	Category	Max Points	Weightage
1	Energy Efficiency (EE)	38	38%
2	Indoor Environmental Quality (EQ)	8	8%
3	Sustainable Site Planning & Management (SM)	9	9%
4	Material and Resources (MR)	19	19%
5	Water Efficiency (WE)	19	19%
6	Innovations (IN)	7	7%
	Total	100	100%

Each category comprises multiple sub-criteria, many of which are specifically designed for data centre applications. These include energy intensity thresholds (e.g., PUE), water use metrics (e.g., WUE), and innovative low-carbon design strategies.

g.   Key Metrics and Emphasis

At the core of the GBI Data Centre Tool is its focus on performance metrics that directly affect environmental impact and operational efficiency:

• **Power Usage Effectiveness (PUE):** Encourages efficient energy use by tracking the ratio of total energy consumption to IT equipment energy. Points are awarded based on actual operational data, with higher points for achieving lower PUE values.

• **Water Usage Effectiveness (WUE):** A relatively novel addition to many green tools, WUE in the GBI framework promotes efficient cooling water usage and discourages reliance on potable water supplies.

• **Carbon Emissions and Offset (CEr/REF):** The tool awards additional points for facilities that procure renewable energy or offset a significant portion of their carbon emissions.

• **Embodied Carbon and Circularity (MR1, MR2):** The GBI Data Centre Tool goes beyond operational energy to address lifecycle emissions. Points are awarded for using low-carbon construction materials, modular systems, and circular economy practices such as design for disassembly.

h.   Tailored for Malaysian Context

What sets the GBI Data Centre Tool apart from global certifications like LEED or Green Mark is its contextual sensitivity. Developed in Malaysia, the tool directly aligns with national policies and standards, including:

• **MS 1525:2019** – Code of Practice on Energy Efficiency and Renewable Energy for Non-Residential Buildings

- **ISO/IEC 30134-2/8/9** – For PUE, CUE, and WUE calculations
- **NETR and MIDA Guidelines** – Ensuring policy coherence and investment readiness

Moreover, the tool takes into account Malaysia's hot-humid climate by promoting adaptive design strategies such as:

- Use of high chilled water supply temperatures (e.g., 19°C)
- High-efficiency cooling towers and EC fans
- Liquid cooling and airflow containment to reduce thermal losses

i. Benchmarking Against Global Standards

While tools like LEED and Green Mark for Data Centres are internationally recognised, they often require localisation or rely heavily on North American or temperate climate assumptions. A comparative analysis reveals the GBI tool's strengths in the Malaysian context:

Criteria	GBI Data Centre Tool	LEED v4/5	Green Mark (SG)
Tailored for Malaysian climate	✓	X	✓
PUE & WUE metrics (Design + Actual)	✓	X	✓
Embodied carbon and circularity	✓	Limited	Too easy
Alignment with NETR and MS 1525	✓	X	X
Carbon offset & green fuels	✓	✓	X
Pocket forest & urban heat island	✓	✓	X
E-waste management	✓	X	X

This comparison highlights GBI's integrated, holistic approach, which combines operational metrics with broader sustainability concerns such as biodiversity, waste management, and innovation.

j. Emphasis on Performance Verification

One of the most powerful aspects of the GBI Data Centre Tool is its insistence on real-world performance validation. Rather than relying solely on design intent, the tool mandates the submission of post-occupancy energy and water usage data, verified through submeters and building management systems (BMS). Enhanced commissioning, ongoing monitoring, and transparent documentation are required to support claims made during the certification process.

This results-based approach enhances credibility and provides data centre operators with actionable insights into how their facilities perform under live conditions.

DESIGN STRATEGIES FOR SUSTAINABLE DATA CENTRES

Designing a sustainable data centre demands a comprehensive integration of energy, water, and material efficiency considerations—right from the planning stage through to operation. In Malaysia, this is particularly challenging due to its tropical climate, high humidity, and a power grid still reliant on fossil fuels. However, by leveraging the Green Building Index (GBI) Data Centre Tool and applying state-of-the-art engineering strategies, it is possible to achieve significant reductions in resource use and carbon emissions. This section presents key design strategies aligned with the GBI framework.

k. Energy Efficiency: Reducing PUE in a Hot Climate

Energy Efficiency (EE) accounts for the largest portion of GBI points (38%) and is considered the most critical pillar of sustainable data centre design.

a)   High-Efficiency Cooling Systems

Cooling constitutes a major share of total data centre energy consumption. In Malaysia, where ambient temperatures are consistently high, it becomes essential to design systems that minimise cooling load while maintaining server reliability.

Key strategies include:

- Hot and cold aisle containment: Prevents air mixing and improves thermal control.
- Increased supply air temperature: Supplying air at 26°C instead of traditional 20–22°C reduces chiller workload.
- Efficient chillers with high COP (>10): These reduce energy per unit of cooling.
- Free cooling (where feasible) and liquid cooling technologies (direct-to-chip, immersion): Especially relevant for high-density computing loads.
- Computational Fluid Dynamics (CFD) simulation : Optimises airflow and detects hotspots in design phase.

b)   Efficient Electrical Systems

Data centres also lose energy through electrical conversion and distribution. Design strategies include:

- High-efficiency Uninterruptible Power Supply (UPS) systems
- Low-loss transformers and Power Distribution Units (PDUs)
- Modular systems that scale with IT load to avoid part-load inefficiencies
- Sophisticated Energy Management Systems (EMS) for real-time monitoring

c)   IT Load Optimisation

Improving the efficiency of IT hardware itself is vital. Strategies include:

- Server virtualisation and consolidation: Ratios of 10:1 or higher significantly reduce the number of physical machines.
- Decommissioning zombie servers: Servers that consume power but provide no output.
- Procurement of energy-efficient servers rated under schemes such as ENERGY STAR or SERT.

Together, these measures can lower PUE from a baseline of 2.0 to below 1.5—even under Malaysian climate constraints.

l. Water Efficiency: Achieving Low WUE

Water Efficiency (WE) in the GBI tool contributes up to 19 points and is particularly relevant in view of Malaysia's growing concerns over potable water scarcity.

a)   Air-Cooled vs Water-Cooled Systems

While water-cooled chillers offer higher energy efficiency, they consume more water. In water-stressed areas, air-cooled chillers or hybrid systems may offer better environmental performance overall.

b)   Rainwater Harvesting and Reuse

GBI awards points for rainwater harvesting systems that achieve ≥15% reduction in potable water usage, or ≥1 m³/year per m² of building footprint. Collected rainwater can be used for:

- Cooling tower make-up
- Irrigation
- General maintenance

c)   Water Recycling and Alternative Sources

- Greywater reuse and reverse osmosis backwash recovery can help reduce dependence on municipal supplies.
- Cooling tower optimisation: By increasing the Cycles of Concentration (COC) to 8–10, less water is lost via blowdown.
- Leak detection systems and submetering: Essential for accountability and performance optimisation.

WUE targets of <1.8 L/kWh are achievable through these measures, with world-class facilities reaching values <1.5.

m. Low-Carbon Materials and Circular Construction

Materials and Resources (MR) account for 19% of the GBI tool and address both embodied carbon and circularity.

a)   Embodied Carbon Reduction

Construction materials such as cement, steel, and glass are major contributors to embodied emissions. GBI encourages:

- Use of low-carbon materials verified by Environmental Product Declarations (EPDs)
- Prefabricated and modular systems to reduce waste and enhance build efficiency
- Products with >25% reduction in embodied carbon compared to CIDB baseline values

b)   Circular Economy Practices

GBI awards up to 4 points for projects where ≥60% of total material cost is from circular sources, including:

- Recycled content
- Bio-based or rapidly renewable materials (e.g., bamboo, timber)
- Reuse of formwork or building components
- Materials designed for disassembly, repairability, and extended lifespan

These approaches not only reduce environmental impact but can also accelerate construction timelines and reduce cost overrun risks.

n. Indoor Environmental Quality and Human-Centric Design

While data centres are machine-intensive, they also house personnel and support staff. GBI allocates 8 points for Indoor Environmental Quality (EQ), which focuses on:

- Fresh air provision and tobacco smoke control

- Real-time monitoring of air quality parameters (temperature, humidity, CO_2, PM2.5)
- Advanced air filtration (MERV-13 or higher) and infectious aerosol management
- Thermal comfort and lighting quality in control rooms and occupied spaces
- Biophilic design elements, such as indoor greenery and natural light access

Though often overlooked, these features contribute to occupant health, satisfaction, and operational resilience, especially during emergencies.

o. Sustainable Site and Construction Practices

Sustainable site management (SM) contributes 9 points and supports long-term resilience through:

- Brownfield redevelopment and avoidance of ecologically sensitive areas
- Stormwater management using infiltration and filtration systems
- Pocket forests and vegetated open spaces
- Support for sustainable commuting (e.g., cycling facilities, EV chargers) During construction,

GBI also encourages:

- Erosion and sedimentation control
- Construction waste recycling targets (≥75%)
- Worker welfare and proper amenities on-site

p. Innovation and Localisation

The GBI tool rewards innovative design approaches and solutions that go beyond conventional standards. Examples include:

- Use of hydrogen fuel cells or biofuel for backup power instead of diesel
- Integration of building management systems (BMS) with AI-driven analytics
- On-site renewable energy generation or procurement under schemes like CRESS

Innovation points also encourage the adoption of new standards such as ISO 30134 series for performance benchmarking.

In summary, the GBI framework provides both a roadmap and a set of measurable criteria for implementing high-impact sustainable design in Malaysian data centres. When properly executed, these strategies can significantly reduce operational costs, carbon emissions, and environmental risks—while enhancing resilience, investor confidence, and compliance with national and global sustainability standards.

DISCUSSION: CHALLENGES, OPPORTUNITIES, AND THE ROLE OF ENGINEERS

The transition toward sustainable data centre development in Malaysia presents a unique mix of technical, economic, and institutional challenges. However, it also opens a spectrum of opportunities—both for infrastructure resilience and national environmental performance. This section discusses the real-world obstacles to adopting green data centre strategies, emerging opportunities within the sector, and the pivotal role engineers play in bridging ambition with execution.

q. Implementation Challenges

Despite the comprehensive structure of the GBI Data Centre Tool and the array of government incentives available, several barriers hinder the widespread adoption of sustainable practices.

a) High Capital Costs

Green technologies such as high-efficiency chillers, advanced submetering, hydrogen-compatible generators, and water reuse systems typically entail higher upfront costs. While they offer long-term savings and tax advantages, the initial capital outlay remains a deterrent, especially for smaller developers or projects without hyperscale backing. Furthermore, the payback period may be longer in environments where electricity and water tariffs are relatively low.

b) Technical Complexity

Designing for optimal PUE, WUE, and CUE involves integrated planning across architecture, mechanical and electrical systems, and IT infrastructure. This requires expertise in dynamic energy simulation, airflow CFD modelling, ISO performance metrics, and commissioning—skills that may not be widely available in the local industry. Many developers still rely on traditional MEP approaches that do not prioritise system-wide performance or cross-disciplinary collaboration.

c) Operational Verification Gaps

GBI and MIDA guidelines emphasise post-occupancy performance monitoring. However, in many projects, actual performance deviates from design-stage predictions due to:

• Improper commissioning
• Inadequate BMS calibration
• Lack of training for facility managers
• Absence of continuous verification protocols

Ensuring consistent performance over the life of a data centre remains a critical gap in sustainability assurance.

d) Policy and Grid Limitations

Although Malaysia is progressing toward a renewable energy future, the current grid mix remains carbon-intensive, and opportunities for direct solar or hydro PPAs are still limited by regulatory complexity. This affects the ability of operators to source green energy, which is a crucial lever in reducing carbon intensity (CUE).

r. Opportunities for Industry Transformation

In contrast to these challenges, the digital infrastructure sector is also presented with several transformative opportunities that favour green development.

a) Competitive Advantage and Brand Value

Sustainability performance is increasingly valued by hyperscale tenants, cloud service providers, and enterprise clients. Demonstrating compliance with GBI and ISO 30134 standards enhances ESG credibility, supports investor confidence, and aligns with global procurement expectations.

b) Operational Cost Savings

Energy and water efficiency measures can produce significant operational savings over time. For instance, reducing PUE from 2.0 to 1.5 in a 10 MW data centre can save millions of ringgit annually in electricity costs. Similarly, effective water reuse systems can shield operators from rising water tariffs and supply volatility.

c) Tax Incentives and ROI Enhancement

The DESAC scheme, through its 100% Investment Tax Allowance, allows developers to offset capital investment with tax savings, thereby improving internal rate of return (IRR). Projects that target higher GBI scores are more likely to secure these incentives, creating a direct link between sustainability performance and financial viability.

d) Technological Innovation

Data centres offer a testbed for cutting-edge sustainable technologies, including:

- Liquid immersion cooling
- AI-driven facility control
- Smart grid integration with battery energy storage
- Modular prefabricated construction

These innovations not only lower environmental impact but also increase operational flexibility and scalability.

s. The Role of Engineers and Consultants

Engineering professionals, especially consulting engineers, play a critical enabling role in driving the greening of data centres. Their responsibilities extend across the entire lifecycle of the project, from feasibility and concept design to construction, commissioning, and ongoing performance monitoring.

Key roles include:

- Integrative Design Leadership: Engineers must bridge silos between civil, MEP, IT, and environmental disciplines to ensure that all systems are optimised for PUE, WUE, and CUE simultaneously.

- Modelling and Analysis: Utilising tools like CFD simulation, energy modelling (BEIT, IESVE, etc.), and Life Cycle Assessment (LCA), engineers can support data-driven decision-making early in the design phase.

- Standards Compliance: Engineers interpret and apply the GBI tool, MS 1525, and ISO 30134 series to ensure regulatory and performance compliance.

- Performance Commissioning: Acting as Commissioning Specialists (CxS), engineers verify that operational results align with the intended design and that building systems are fine-tuned post-occupancy.

- Training and Handover: Engineers are responsible for educating operations teams on the use of BMS, EMS, and other systems that ensure long-term sustainability outcomes.

Ultimately, the shift toward green data centres cannot be realised through design specifications alone. It requires a cultural and professional shift—led by engineers who champion holistic, lifecycle-oriented thinking and are equipped with both technical tools and sustainability literacy.

In conclusion, while challenges such as cost, technical capacity, and grid emissions remain, the potential benefits of greening Malaysia's data centres—both environmental and economic—are substantial. With a strong framework in place, a growing ecosystem of incentives, and increasing pressure for ESG alignment, the momentum for sustainable data centre design is undeniable. Engineers stand at the centre of this transition, uniquely positioned to turn sustainable ambition into operational reality.

CONCLUSION AND FUTURE OUTLOOK

Malaysia stands at a pivotal moment in its digital transformation journey. As data centres continue to proliferate in support of cloud computing, artificial intelligence, and the broader digital economy, their environmental footprint must be managed with urgency and foresight. Without proactive measures, the sector risks becoming a major source of greenhouse gas emissions, water stress, and unsustainable material use—outcomes that are incompatible with Malaysia's climate goals and global environmental commitments.

This paper has examined the sustainability challenges faced by data centres in Malaysia and the potential solutions offered by adopting green building certification—specifically, the Green Building Index (GBI) Data Centre Tool. The revised 2025 version of the tool offers a comprehensive and contextually appropriate framework that aligns with national priorities under the National Energy Transition Roadmap (NETR), MIDA's development guidelines, and fiscal instruments such as the DESAC scheme.

The GBI Data Centre Tool distinguishes itself through its integrated approach, combining metrics such as Power Usage Effectiveness (PUE), Water Usage Effectiveness (WUE), and Carbon Usage Effectiveness (CUE) with broader sustainability considerations including material circularity, embodied carbon, indoor environmental quality, site resilience, and innovation. Its emphasis on actual performance verification—rather than solely design intentions—adds rigour to sustainability claims and ensures long-term accountability.

The hypothetical case study presented in this paper illustrates the practical application of the tool, demonstrating how a data centre can be designed to meet ambitious PUE and WUE targets, leverage rainwater harvesting and green energy, reduce embodied carbon, and achieve GBI Platinum certification. Importantly, the case underscores the value of early-stage planning, cross-disciplinary collaboration, and data-driven design in achieving high sustainability performance.

Nevertheless, challenges persist. High upfront costs, limited technical expertise, and barriers to renewable energy access continue to slow down the pace of sustainable transformation in the industry. Many facilities are still being built without proper performance metrics or without consideration for the long-term operational impact of their design choices. These gaps must be addressed urgently.

To accelerate the greening of Malaysia's digital infrastructure, the following strategic recommendations are proposed:

a)   **Mandate Sustainability Metrics for New Data Centres**

As part of environmental approval and planning processes, all new data centres should be required to submit projected PUE, WUE, and CUE values in compliance with ISO 30134 standards.

Integration with national carbon accounting frameworks would allow for sectoral benchmarking and regulatory oversight.

b)   Expand Incentive Structures

While the DESAC scheme is a strong start, further enhancements—such as fast-track approvals for GBI-certified projects, grant funding for energy modelling or metering, and incentives for retrofitting existing facilities—could encourage more developers to commit to green design.

c)   Build Technical Capacity Across the Supply Chain

Professional development programmes focused on sustainable MEP design, commissioning, and operational analytics are critical. Universities, industry associations, and government agencies must collaborate to expand the talent pool of engineers and designers equipped to deliver green data centres.

d)   Promote Innovation and Localisation

Malaysia can become a hub for tropical data centre innovation by investing in research on liquid cooling, AI-driven energy optimisation, and prefabricated modular systems tailored for the region's climate and resource constraints. Incorporating these innovations into national standards would strengthen Malaysia's leadership in the field.

e)   Champion the Role of Consulting Engineers

Consulting engineers must play a proactive role—not only in technical delivery but also in advocating for sustainable procurement, client education, and cross-disciplinary coordination. Their leadership is essential in realising the full potential of tools like GBI and ensuring that green design is not a checklist, but a continuous improvement process.

LOOKING AHEAD

The global momentum towards decarbonisation and digitalisation is converging rapidly. Countries that align their infrastructure growth with environmental responsibility will be better positioned to attract global investment, foster innovation, and ensure long-term resilience. Malaysia has taken important steps in this direction, but the journey is far from complete.

By institutionalising green building certification, supporting holistic design practices, and mobilising the engineering community, Malaysia can ensure that its data centre boom becomes a model of sustainable development—one that powers the digital economy without compromising environmental integrity.

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Sustainable Construction and Operation Technologies

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Consultants Pvt. Ltd which has four Divisions, HRD. Projects, Environmental and IT Services and has successfully steered its growth as its Chairman and Managing Director since 1979. Apart from providing effective consultation to a number of companies worldwide on specific organizational, Environmental and motivational issues, he has organized and conducted various management and self-improvement workshops with great success. Due to his in-depth knowledge on various aspects of Environment management, technology, industrial development & management, Mantec has grown over the years as a leading multi-disciplinary consultancy organization in India & abroad.

INTRODUCTION

Sustainable construction and operation technologies encompass a wide range of strategies and techniques aimed at minimizing the environmental impact of buildings throughout their lifecycle. These technologies focus on reducing energy consumption, water usage and waste generation, while promoting the use of renewable and recycled materials.

OBJECTIVE

Building construction whether Residential, Commercial or Industrial generates significant impacts on the Environment. The objective is to see how the Impacts on the Environment can be reduced and mitigated to reduce the Carbon footprint and minimize Impacts on Climate Change.

KEY CONSTRUCTION TECHNOLOGIES TO REDUCE ENVIRONMENTAL IMPACTS:

a. **Renewable Energy Integration**

Solar Panels, Wind Turbines and geothermal systems can be integrated into building design to generate on site energy, reducing reliance on fossil fuels.

Solar panels can be and should be installed on Residential Rooftops, Commercial spaces and office building Rooftops and the Electricity Generated can be easily sold to the concerned electricity providers to reduce electricity bills.

The Author has installed solar panels on his house rooftop and on the rooftops of his office buildings resulting in considerable reduction in electricity bills while helping to reduce pollution by reducing electricity required from fossil fuels like Coal, Crude Oil etc.

The payback period for investment in installing solar is less than 3 years and it makes good economic and environment source for more and more individuals to benefit financially while installing solar panels on rooftops and other available spaces while helping to reduce air Pollution.

b. Smart Materials

Electro chromic glass, which can adjust its light and solar heat transmission and bio-based materials with low environmental impact are becoming increasingly popular.

c. 3D Printing

This technology allows for on-site construction with minimal waste and can be used to create complex and customized building components.

d. Passive Design

Maximizing natural light and ventilation through building orientation, window placement and landscaping can significantly reduce energy consumption.

e. Water Efficiency

Rainwater harvesting, greywater recycling and low flow fixtures help conserve water resources.

f. Sustainable Resource Sourcing

Prioritizing locally sourced recycled and sustainably harvested materials minimizes transportation emissions and supports local economies.

g. Insulation

High performance insulation materials and techniques such as insulated concrete forms (ICFs) minimize heat transfer and reduce energy demand for heating and cooling.

h. Green Roofs

Vegetated roofs provide insulation, reduce storm water runoff and enhance biodiversity.

i. Cool Roofs

The Cool Roof initiative and encouragement from UNEP to use high Solar Reflectance Index (SRI) of 102 has been successfully tried in India. This led to temperature reduction of 5 to 8°C inside the buildings during peak summer months.

j. Low VOC Materials

Using materials with low volatile organic compound (VOC) emissions improves indoor air quality.

KEY OPERATION TECHNOLOGIES TO REDUCE ENVIRONMENTAL IMPACTS:

a. Building Management Systems (BMS)

BMS enables centralized control and monitoring of building systems like HVAC, lighting and water, optimizing energy and resources use.

b. Internet of Things (IoT) Sensors

IoT sensors can collect data on occupancy, energy consumption and environmental conditions, enabling data driven decisions for improved efficiency.

c. Predictive Maintenance

Analyzing data from sensors can predict potential equipment failures, allowing for proactive maintenance and preventing energy waste.

d. Waste Management

Implementing comprehensive waste management strategies, including recycling and composting programs, minimizes landfill waste.

e. Digital Twins

Digital representations of buildings can be used to simulate performance, optimize operations and facilitate deconstruction and materials reuse at the end of a building's site.

DIGITALIZATION & SUSTAINABLE INFRASTRUCTURE

Organizations in different regions and industries are addressing decarbonization and resource efficiency at different rates and in different ways. But in all cases, digitalization is key to effective infrastructure transformation, and there is an urgent need for increased investment in digital solutions that improve both sustainability and business performance.

KEY ASPECTS ARE AS FOLLOWS:

a. Advances in digitalization enables more sustainable infrastructure – enormous potential remains

Digital technologies have significant or massive potential to advance the decarbonization of infrastructure operations. This highlights the growing recognition that digital solutions are essential to reducing carbon footprints.

b. Organizations are mature or advanced in data driven operations

Many organizations rate themselves as mature or advanced in data driven management of systems, resources or infrastructure. Many organizations remain in the early stages of their digitalization journeys, but those further ahead have already shown digital technologies will be central to future productivity, business resilience and sustainability.

c. Organizations rate AI as the most impactful technology area for decarbonization and resource efficiency

Once organizations have built a solid digital foundation, they can begin to use various technologies to improve decarbonization and resource efficiency efforts. Organizations expect AI with its ability and vast datasets to optimize operations to have the biggest positive impact over the next three years. For this to happen, quickly more will need to be done to improve the energy efficiency of AI.

d. Data gaps pose a major challenge to decarbonization efforts

Many organizations say they have little to none of the data they need in areas that are key to improving decarbonization and resource efficiency: 44% lack emissions data, 44% lack decentralized

energy resources data, and 30% lack energy consumption data. These gaps are a critical obstacle to establishing more sustainable operations.

e. Five leading advantages of digital business platforms

Organizations highlighted five factors as the top benefits of adopting digital business platforms as follows;

a) **Scalability**
b) **Time and cost efficiency**
c) **Faster implementation**
d) **Reliability**
e) **Interoperability.**

BENEFITS OF SUSTAINABLE CONSTRUCTION AND OPERATIONS

1.   Reduced Environmental Impact

Lowering greenhouse gas emissions, conserving natural resources and minimizing pollution.

2.   Improved Indoor Environmental Quality

Better air quality, thermal comfort and natural lighting contribute to occupant health and well being.

3.   Cost Savings

Reduced energy and water consumption can lead to significant long term cost savings.

4.   Increased Property Value

Buildings with green certifications and sustainable features often command higher market values.

5.   Positive Public Image

Adopting sustainable practices can enhance a company's or organizations reputation and brand image.

CONCLUSION:

By proper use of Sustainable Construction and Operation technologies, considerable reduction in impacts on the Environment are possible to reduce Global Warming which is high priority to safeguard the health and well-being of the present and future generations.

FUTURE DIRECTIONS:

Use of AI for better construction design to build in Sustainability will grow in future. Success stories of Sustainable Construction and Operation in countries like India need to be duplicated with adaptation in other Asia Pacific countries through Regional Collaboration and Cooperation.

Eco-Friendly Composite Ceiling Material from Low -Density Polyethylene and Coconut Fibre

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Ms. Madawala's research based on sustainable construction materials, with a particular focus on enhancing the performance and durability of composites for practical applications. Her work emphasizes the importance of post-processing treatments to improve these materials for real-world use. She has conducted extensive studies on developing eco-friendly and cost-effective material using waste polyethylene and natural fiber. The primary objectives of her research include addressing the limitations of conventional materials, evaluating the mechanical properties and production feasibility of the proposed materials, and promoting the use of recycled and natural resources in construction.

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materials such as concrete waste and both natural and artificial fibres, contributing to innovative and eco-friendly building solutions.

ABSTRACT

Ceilings in buildings play a crucial role in both functionality and aesthetics. It offers several solutions for covering structural and non-structural components, enhancing acoustics, and optimizing light intensity. However, conventional ceiling materials pose challenges such as sagging, discoloration, and vulnerability to environmental factors. Further, the estimated annual global production of plastic is millions of tons, hence the magnitude of the environmental challenge posed by plastic waste. The continuing presence of plastics in the environment for extended periods is a critical concern, necessitating their recycling and reuse. This study proposes to develop a composite ceiling material using waste LDPE and coconut fibre (coir) to address these challenges and requirements. The study describes the production process using the hand lay-up method that guarantees the required thickness and mechanical properties in compliance with applicable criteria for the composite ceiling panels. The composite materials were compacted using a hot-press equipment at a constant temperature and pressure. Experiments were conducted to investigate these composite sheets' deflection, water absorption, and swelling properties. Composite panels with dimensions of 400 mm × 400 mm with different thicknesses were tested for deflection, and the results showed that the 5 mm thickness was the most suitable option for ceiling panels. The composite with 30% coir fibre and 70% LDPE exhibits optimal characteristics, with minimal deflection. Moreover, applying a waterproofing agent shows potential swelling due to moisture and water absorption, enhancing durability. Future studies should explore embodied energy, biodegradability, and life cycle costing for a comprehensive assessment and further optimization of the composite material.

Keywords: Low-density polyethylene, Coconut fibre, Composite material, Ceiling material.

INTRODUCTION

Global plastic production, estimated at approximately 400 million tons annually, has generated substantial plastic waste[1]. The absence of proper recycling facilities in many developing nations like Sri Lanka, Bangladesh, Pakistan, and Brazil has resulted in the undervaluation of these materials, leading to uncontrolled disposal that severely impacts the local communities, causing environmental and public health concerns. Poor waste management practices in developing nations exacerbated this issue, emphasizing the urgent need for ecologically responsible and economically viable approaches[2]. As a result, waste management is a persistent global issue, particularly regarding plastic and polyethylene waste. The persistent environmental concerns associated with plastic waste have prompted efforts to reduce the use and enhance recycling rates[3].

Coconut fibre is one of the natural fibres that is abundantly available, resulting from harvesting the coconut seed. This fibre, recognized for its durability and hardness, is an appealing natural material for industrial applications due to its resistance to acoustic damage, microbial/fungal degradation, and being non-toxic and flame-resistant. Coconut fibre beats other natural fibres, demonstrating superior resistance to moisture, heat, and saltwater exposure [4]. Its chemical composition comprises cellulose, hemicellulose, lignin, and pectin, with average ranges reported as 32-50% cellulose, 0.15- 15% hemicellulose, 30-46% lignin, and roughly 3-4% pectin. These compositions make Coconut fibre a promising material for diverse industrial uses [5], [6]. Coconut fibre possesses key characteristics crucial for its varied applications. Its density of 1.15 g/cm³ and diameter ranging from 100 to 450 micrometres demonstrate suitability for various uses and purposes. Additionally, Coconut fibre

exhibits a Young's modulus of 4 to 6 GPa, tensile strength between 131 and 175 MPa, and a 15.40% elongation at break, providing insights into its mechanical properties. Coconut fibre, especially as a reinforcement in composite materials, contributes to increasing toughness with a high strain on failure (20%–40%). Despite not being extremely strong or stiff (234 MPa strength, 4.6 GPa stiffness), Coconut fibre proves thermally stable up to 200 degrees Celsius, aligning with typical manufacturing temperatures [7], [8], [9].

Introducing innovative construction materials from waste materials offers a sustainable solution to this challenge, aligning with circular economy principles, reducing waste, conserving resources, enhancing material properties, lowering carbon footprints, and creating economic opportunities [10].

Various studies explore the development of polyethylene-based ceiling materials such as recycled low-density polyethylene and waste breadfruit coat, high-density polyethylene and polyethylene terephthalate plastic wastes, corncob, sawdust, carbonized breadfruit coat, paper, starch composite, and palm kernel shell. One study incorporates breadfruit seed coat and recycled low-density polyethylene to create a ceiling board with low thermal conductivity and resistance to moisture. Another study focused on recycled high-density polyethylene and polyethylene terephthalate for ceiling tiles, demonstrating sustainability and good properties [11], [12]. A research project investigates Doum fibre-reinforced low-density polyethylene composites, highlighting their mechanical strength, thermal characteristics, and environmental benefits. Additionally, a study on coconut fibre and low-density polyethylene composition guides hot press procedures for composite materials. This emphasizes the potential of these materials for diverse applications, offering strength, lightweight nature, durability, and environmental sustainability.

The study by Dharmaratne et. al (2021) played a crucial role in informing these research procedures. Their comprehensive investigation on the optimal composition of coconut fibre and low-density polyethylene (LDPE) revealed a weight ratio of 3:7, which is the most effective for achieving optimum flexural strength. The study also highlighted key parameters for the hot press process, including a 4 MPa pressure, a temperature of 140 degrees Celsius, and a 6-minute manufacturing duration. These perceptions significantly influenced our material formulation strategy and guided the methodical development of our composite materials. Our research seeks to fill this gap by evaluating the properties and feasibility of LDPE waste as a potential material for ceiling board production [13].

Composite materials can be categorized based on the type of matrix, which is the continuous phase that holds the reinforcement in place, and the type of reinforcement, which provides the material's specific properties. The choice of matrix and reinforcement greatly influences the overall performance and characteristics of the composite material [14].

In the present world, composite materials are used for engineering applications due to several advantages such as light weight, low density, low production cost, resistance to chemical reactions,easy manufacturing, flexibility to design according to the requirement, and more durability, etc. The composite materials are used as construction materials, mechanical systems, aerospace structures, automobile items, electrical equipment, pipes, infrastructure, and textiles [15], [16], [17]. However, a specific investigation into using waste low-density polyethylene to produce a ceiling material is yet to be explored.

The ceilings are essential in defining the appearance of quality and overall value of residential and commercial structures in architectural design and construction. The selection of appropriate ceiling materials is a crucial factor, capable of enhancing both the physical and functional attributes. Hence,

there is an imperative for a structural material that embodies unwavering durability and reliability. This supplementary architectural layer, commonly referred to as a drop ceiling or suspended ceiling, not only enhances the aesthetics of a space but significantly influences the quality of life experienced within.

Ceiling provides few practical advantages such as adding space for air-conditioning ducting, increases air conditioner functionality, and lowers electricity use, increases acoustic quality by absorbing all external noises, keeps the space much colder by trapping any excess heat in the room, hiding electrical wires, pipes, and ducts, and increasing light reflection and deflection avoids the need for additional illumination. However, existing ceiling materials suffer from various drawbacks, such as a shorter lifespan, higher maintenance requirements, deflection, and instability during their life. To overcome these drawbacks, there is a pressing need to enhance durability, reduce maintenance requirements, and the cost of manufacturing and materials, in addition to improving the physical and mechanical properties of ceiling materials.

Hence, the current research addresses a significant gap in sustainable construction material requirements, in the context of ceiling materials. Further, the polymer composites are dominant globally, but developments involving natural fibre and recycled waste that can serve as sustainable alternatives to ceiling materials are notably absent. Therefore, this study explores the feasibility of developing a composite material that can be used as a ceiling material using waste as raw material.

AIM AND OBJECTIVES

The primary objective of this research project is to prepare a ceiling panel utilizing a composite material of low-density polyethylene reinforced with Coconut fibre, aiming to meet optimal thickness requirements that satisfy established serviceability conditions. The optimum thickness for the composite ceiling panel is evaluated through a deflection test.

MATERIALS AND METHODS

Waste low-density polyethylene and coir fiber were selected to prepare the composite material. The waste polyethylene bags and sheets were collected from Rapid Creation Industries (Pvt) Ltd, Panagoda, Western Province, Sri Lanka. The coconut fibre was collected from a trusted supplier that delivers high-quality materials. Generally, the raw coir fibre are 125 – 150 mm long, and the tensile strength varies between 94-159 MPa, Young's modulus is between 1.2-1.8 GPa, and Elongation at breaking point is 15-35 %. The coconut fibre were customized to a uniform length of 3 cm to ensure better mechanical properties for the final product [13]. Preparing composite materials for this research involved a comprehensive process to enhance the suitability of waste low-density polyethylene and coconut fibre. In the initial stage, the LDPE underwent a thorough cleaning procedure, eliminating any impurities that might compromise its integrity. Subsequently, the cleaned LDPE was subjected to a shredding process using the advanced shredder machine. This step was crucial in breaking the LDPE into smaller, more manageable pieces, facilitating its effective integration into the composite material. The coconut fibre also underwent a cleaning and drying procedure to remove dust and moisture that could impact its performance in the composite. Figure 1 shows the selected raw materials.

Figure 1: Raw Materials (Coconut fibre and LDPE)

THE MANUFACTURING PROCESS OF COMPOSITE

The composition for the composite material, determined at 3:7 (Coconut fibre to Waste Low-Density Polyethylene), was chosen based on insights from prior research, specifically aligning with optimal flexural properties identified in previous studies [13]. However, three mix proportions were carried out as shown in Table 1, with six composites created for each proportion. The coir fibre and waste LDPE composite was mixed manually to achieve a homogeneous distribution of coconut fibre and low-density polyethylene. Well-mixed raw materials were laid on a steel mould with internal dimensions of 400 mm x 400 mm and a thickness of 3 mm, 4 mm and 5 mm by the hand-layup method. These distinct thicknesses were specifically chosen to determine the most suitable thickness for the ceiling panel.

Table 1: Mix Proportions

Mix Code	Coir length (mm)	Mix proportion (by weight)
		Coir : LDPE
MC 01	30	2:8
MC 02	30	3:7
MC 03	30	4:6

The manufacturing process of composite material involves a series of steps to ensure the production of high-quality panels. First, the mould and steel plates were placed in the hot press equipment and preheated before placing the mixed raw materials on the mould. The temperature set for the process was 140°C in the hot press machine. After a 3-minute duration, the moulds were carefully taken out, and a fine mist of silicon emulsion was uniformly sprayed on the moulds, which helps to effectively de-mould the composite without sticking to the mould surfaces. By forming a barrier between the mixture and the mould surfaces, the silicon emulsion contributes to the prevention of undesired adhesion, and helps to maintain the integrity of the composite material during the de-moulding process. Figure 2 illustrates a few steps of the preparation process of the composite.

After completing the 6-minute hot pressing phase, the mould was carefully removed from the hot press and placed in a cooler to provide a uniform cooling process and environment, which is operated with a simple water flow mechanism. Gradually reducing the mould's temperature to room temperature was an essential aspect of the cooling phase. Once the mould reached room temperature, it was carefully removed from the cooler, and the resulting composite panel was

removed from the mould. This step required precision to prevent any deformation of the composite panel.

Figure 2: Steps of composite preparation

DETERMINATION OF DEFLECTION

After preparing the samples, they were laid on a wooden frame as shown in Figure 3, simulating the ceiling arrangement to measure the deflection. Generally, ceilings do not bear any loads other than their weight. Therefore, the sample deflection was determined by its own weight. The deflection was measured periodically at the center of the samples. The three replicates were used in each thickness to determine the deflection. Initially, the dial gauge was adjusted to zero at the top of the wooden frame. The wooden frame was levelled on the horizontal before taking each reading.

A precision dial gauge with an accuracy of 0.01 mm was used for the testing. The dial gauge readings were taken once a week over six months, capturing the dynamic behaviour of the panels. The deflections were calculated based on the measured values. The arrangement for deflection measurements is shown in Figure 3.

Figure 3: Arrangement of sample for deflection measurements

DETERMINATION OF SWELLING

After deciding on the suitable thickness of the composite for the ceiling material, another set of samples was prepared to measure the swelling effect. The swelling was measured as the deviation of the thickness of the sample along the four edges. The thickness was measured continuously for 30 days under the different exposure conditions, which were selected to simulate the basic conditions that a ceiling can be exposed to during its life, as shown in Table 2.

Table 2: Conditions used for Swelling Check

Sample Code	Condition
SC 01	In an indoor environment without applying the waterproofing
SC 02	In an indoor environment with applying the waterproofing

SC 03	In an outdoor environment without applying the waterproofing
SC 04	In an outdoor environment with applying the waterproofing

DETERMINATION OF WATER ABSORPTION

The next set of samples, in a five-millimeter-thick composite, was used to measure the water absorption. The percentage of water absorption was determined under different environmental conditions, as shown in Table 3. The water absorption was carried out according to the ASTM D570 Standard test method for water absorption of plastics.

Table 3: Conditions used for water absorption test

Sample Code	Condition
WA 01	Samples without waterproofing
WA 02	Four edges were sealed by waterproofing material, and both surfaces of the samples were exposed to water without waterproofing
WA 03	The whole sample was sealed with waterproofing on all four edges and both surfaces.

RESULTS AND DISCUSSION

SELECTING A SUITABLE MIX PROPORTION

Samples were prepared for the three types of mix proportions listed in Table 2. The sample with a 2:8 (Coir: LDPE) ratio was overly flexible and easily fractured during handling, indicating a lack of reinforcing material. The sample with a mix proportion of 4:6 (Coir: LDPE) did not have a smooth finish, and the surface was perforated, indicating insufficient binding of matrix material (LDPE) to seal the reinforcing material (coir) and form a proper composite. As a result, a 3:7 (Coir: LDPE) ratio was chosen to create the composite for the ceiling material meeting [13] investigations.

DEFLECTION OF COMPOSITE

The average dial gauge readings of the three replicates were converted to deflection values. The variation of deflection of the center point of the sample in different thickness over sixteen weeks' time period is shown in Figure 4. The deflection of the panel decreases with the increase in the panel thickness. This is because the thicker panels has high bending capacity, hence shows the lesser deformations.

According to the International Building Code 2006, the serviceability requirements stipulate the allowable deflection for structural elements should adhere to the standard of span/240. The span of the test arrangement is 400 mm. Hence, the allowable deflection is 1.667 mm. The results were compared with the standard allowable limits of deflection.

During the first four weeks, the deflection increases steadily and the significant increment shows from the 6th to 11th week, indicating the panel is approaching a stable deflection state.

The 5 mm thick panel is within the allowable limit, but the 3 mm and 4 mm panels exceed the allowable limit. These results indicated that the 3 mm and 4 mm thick composite panels may not be suitable for ceiling applications. However, the 5 mm thick composite panel demonstrates a slight gradual increment in deflection over 16 weeks, with a diminishing increment rate, suggesting a trend toward

a stable state. Throughout the observation period, the panel's deflection consistently remains below the allowable limit of 1.67 mm, indicating its suitability for the applications with higher allowable deflection.
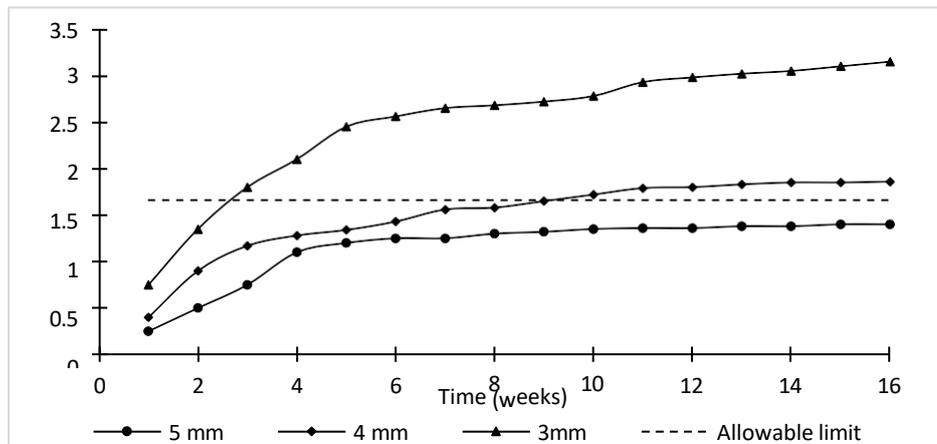

Figure 4: variation of the deflection on composite panels in different thickness

SWELLING OF THE COMPOSITE

The thickness of four edges on each sample was determined, and variations of thickness was plotted against the 30 days time period to evaluate the swelling of the composite. The variations of thickness of the panels are shown in Figure 5.
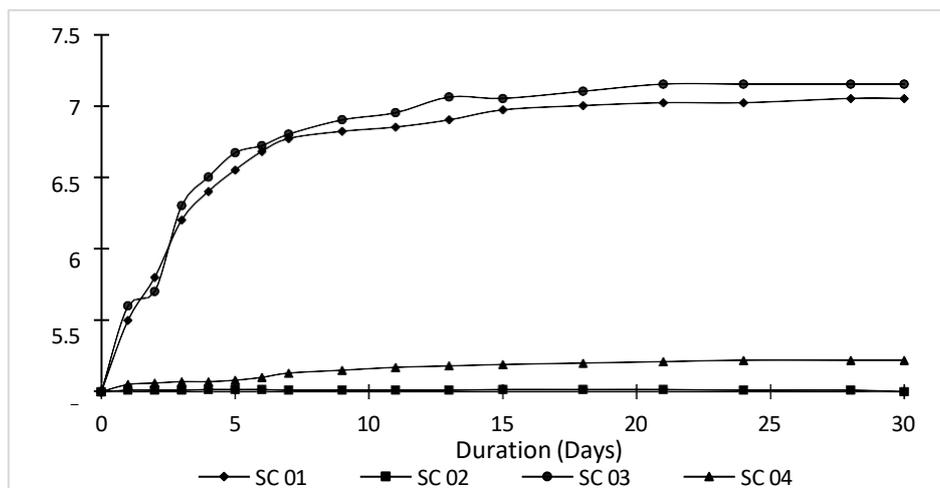

Figure 5: Thickness variation of the panels

The sample kept in the outdoor environment without applying the waterproofing shows the maximum swelling over the time followed by the samples kept in the indoor environment without applying the waterproofing. Initially the thickness increased rapidly and with time, the rate of swelling decreases. However, the samples which apply the waterproofing show the slight increment in thickness for both the indoor and outdoor environment. Further, it was realized that, there is no considerable swelling effect after 15 days for all samples. The results proved that, the application of water proofing causes to mitigate the swelling effect in the ceiling panel.

WATER ABSORPTION

According to the water absorption results, the maximum percentage of water absorption is 7 % in the sample WA1, and the minimum percentage of water absorption is 2.4 % in sample WA3. The variation of water absorption over time for the samples with different conditions is shown in Figure 6. However, the effect of applying a waterproofing agent on the top and bottom surfaces shows a small decrement, showing that the edges are contributing the highest water absorption. Therefore, it can be concluded that, water absorption occurred mostly at the edge of the composite samples. Because, during the

preparation of the sample, the top and bottom surfaces are highly compressed by the hot press machine, and both surfaces become sealed by the liquidating LDPE. However, while cutting the edges of the sample, the seal is damaged. Therefore, the edges should be sealed by waterproofing material. It is recommended to apply waterproofing agents to all the surfaces and the edges of the ceiling panel to prevent water absorption.
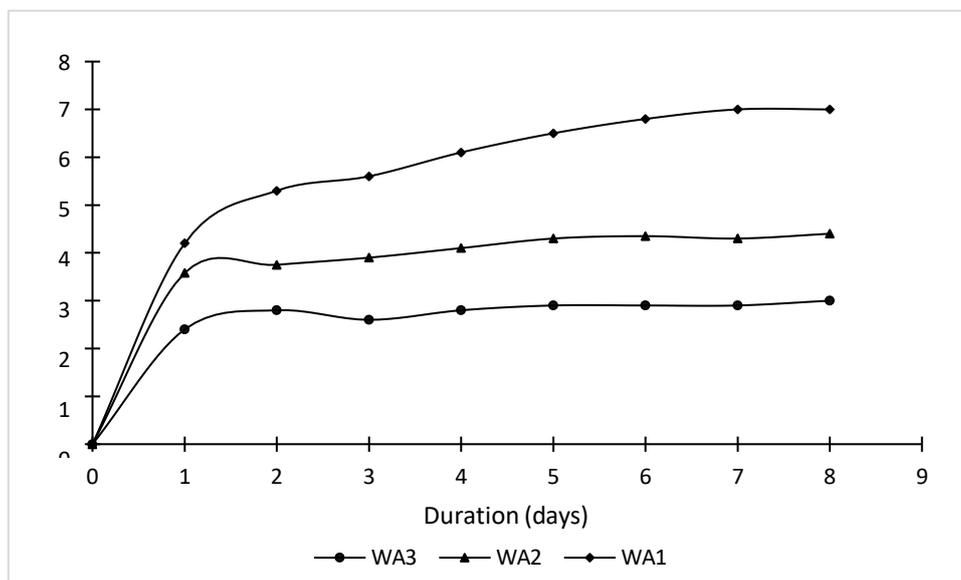

Figure 6: Water Absorption Percentage with duration

DISCUSSION

The research presented in this study focuses on the investigation of key parameters of deflection, swelling, and water absorption, in the production of a Coir-LDPE composite material as a ceiling panel for building. According to the composite production results, it can be concluded that the coir weight fraction 30 % to the LDPE weight fraction 70 % is the most suitable percentage to produce the composite out of the three tested ratios. The suitable length for coconut fiber is 3 cm. The research findings are validated by comparing the outcomes with previous studies as shown in Table 4.The following parameters were also identified during the material preparation.

The material preparation temperature	- 1400 C
The required pressure	- 4 MPa
The time required for hot pressing in the hot press machine	- 6 minutes The time required for
cooling at each sample	- 15 minutes

Table 4: Comparison with the previous studies

No	Coir length	Coir Content	Reference

01	3.0 cm	20% - 30%	[13]
02	1.5 cm	50%	[6]
03	3.0 cm	30%	Research Outcome

According to the deflection test results, it was observed that the composite samples sagged and exhibited the maximum deflection of the 3 mm and 4 mm thick panels as 3.05 mm and 1.85 mm respectively. The maximum deflection of 5 mm-thick panel was 1.38 mm. However, the deflection became constant in 4 mm and 5 mm panels after the 11th week.

The results indicated that, the 3 mm and 4 mm composite panels are not suitable for this application, due to exceeding the allowable deflection limits. The 5 mm thick composite panels can be recommended to use for this application because the observed value lies within the allowable deflection limits.

According to the swelling test results, the maximum variation in thickness obtained was 7.00 mm, showing the percentage increase the thickness was 40%. However, after the application of the waterproof agent, the swelling of the samples was reduced. The minimum variation in average thickness obtained was 0.01 mm for the samples after applying waterproofing. The variation of the thickness significantly reduced to the 0.2%.

CONCLUSION

The present study was carried out to develop composite material using coconut fiber and waste LDPE and to investigate the possibility of using composite as a material for ceiling construction.

It can be concluded that the composition of the material influences the development of the composite material. Hence, the optimum mix proportion of 3:7 (coir: waste LDPE) can be selected as the most suitable mix proportion. In the investigation of the mechanical behavior, it was observed that deflection and swelling of the composites exhibited significant time-dependent behavior.

The 5 mm panel emerged as the most favorable choice for application as ceiling material in the building construction industry. Furthermore, the application of a waterproofing agent appeared as a major aspect of this study. It was demonstrated that, this treatment effectively reduces the undesirable properties of swelling and water absorption in the composite panel. This finding highlights the importance of post-processing treatments to enhance the durability and performance of the Coir-LDPE composite in real-world applications.

RECOMMENDATIONS

This research aimed to develop sustainable construction material that can be used as a ceiling material. Accordingly, with the raw materials of coir fiber and waste LDPE, a new composite panel was developed. In this study, the deflection, water absorption, and swelling properties were investigated in the experiments. As per the conclusions, it is recommended to apply a waterproofing agent to the composite panel to reduce the swelling and water absorption.

However, there are a few important properties to be examined in future research to further enhance the features of the composite panel. A few of them are mechanical properties, such as micro-

hardness, impact strength, and in-plane and out-of-plane bending moments. Furthermore, in order to create the composite panel for industrial usage, testing for embodied energy, thermal conductivity, durability, biodegradability, fire resistance, thermal resistance and soundproofing ability, and life cycle costing is also recommended as a knowledge gap to be filled.

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BIM Utilization Case for Facility Management in Japan by PCKK: Mutsuzawa Wellness Town Project

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His recent focus is on overseas initiatives involving smart cities, urban and regional development, and logistics planning. He also brings deep expertise in energy, demand forecasting, economic evaluation, logistics analysis, disaster management, and port planning.

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Mr. Hiroshi Okada began his career at PACIFIC CONSULTANTS CO., LTD. in 1999 and has served as Chief Representative in Indonesia since 2017, overseeing the company's construction consulting business operations in the region. Early in his career, he supported urban and regional development initiatives for local governments in Japan's Tohoku region and contributed to post-disaster recovery and reconstruction efforts. Building on these domestic contributions, he transitioned to international operations and has continued to be actively engaged in overseas development. Most recently, he has promoted solutions to advance smart city initiatives, working collaboratively with regional authorities across Indonesia to foster creative and inclusive community development.

INTRODUCTION: BACKGROUND AND OBJECTIVES

In recent years, there has been growing interest in utilizing 3D models and integrated data developed during the design and construction phases for facility management (FM). With the widespread adoption of Building Information Modeling (BIM), FM support systems that centrally manage 3D models, equipment attribute data, daily maintenance records, and quantitative data from IoT sensors are expected to enhance the sophistication and efficiency of facility operations.

However, deploying commercially available advanced FM systems in small- to medium-scale facilities often leads to over-specification and operational complexity. Many facility management organizations lack IT specialists, and outsourcing system development and operation to external vendors frequently results in misalignment due to insufficient understanding of on-site operations.

This paper introduces a case study of the "Mutsuzawa Smart Wellness Town" in Chiba Prefecture, Japan—a public-private initiative for regional revitalization—where facility managers actively participated in the development of a BIM-based FM system. The requirement definition process was conducted internally, while system development was outsourced. The initiative aimed to resolve on-site challenges and improve service quality. As part of a digital twin strategy, the system visualizes building information and maintenance history, enabling rapid remote decision-making during emergencies. It also contributes to sustainable facility operations through real-time monitoring of environmental data such as CO_2 concentration and temperature/humidity, balancing energy efficiency and comfort, and enhancing disaster response capabilities. This case provides insights into the advancement and sustainability of FM in small-scale regional facilities using emerging technologies.

PROJECT OVERVIEW: MUTSUZAWA SMART WELLNESS TOWN

Mutsuzawa Smart Wellness Town (hereafter, Mutsuzawa SWT, Figure 1) is a complex facility developed as part of a regional revitalization initiative in Mutsuzawa Town, Chosei District, Chiba Prefecture (population approx. 7,000). The project was launched under a BOT-type PFI contract signed in 2017 and began operations in 2019. Covering approximately 2.86 hectares, the town centers around a "Roadside Station" and includes the following facilities:

- **Area A: Bathing facility, farmers' market, restaurant, library**
- **Area B: Agricultural processing facility, cycle station**
- **Exchange Plaza: BBQ area, dog park, disaster prevention plaza**
- **Public rental housing: High-quality private rental units**
- **Independent energy supply system: Solar panels, gas cogeneration-based microgrid**

In this project, Pacific Consultants Co., Ltd. (PCKK) served as the lead company, overseeing all phases from design and construction to operation and maintenance. Under a long-term contract spanning 23 years (2017–2040), the company ensures stable facility management. To address regional challenges such as population decline, aging demographics, and the need for enhanced disaster resilience, the project was developed under the concept of creating "a town where simply living promotes health." The initiative aims to generate social value across the entire area, including health promotion for residents—particularly the elderly—and the strengthening of disaster response capabilities.

As part of this effort, the town has implemented an independent energy system that ensures uninterrupted supply of electricity and heat even during disasters. Additionally, efficient facility

management has been realized through the introduction of a digital twin system utilizing Building Information Modeling (BIM).

Figure 1. Overview of Mutsuzawa Smart Wellness Town

SYSTEM DEVELOPMENT AND FUNCTIONAL REQUIREMENTS

Challenges identified in managing Mutsuzawa SWT included:

- **Maintenance Management: Within two years of opening (Sep 2019–Sep 2021), multiple equipment failures occurred, complicating record-keeping. Records were managed individually via Excel and paper ledgers, hindering information sharing.**
- **Operations and Energy Management: In summer, air conditioning was set low for user comfort, leading to increased electricity consumption. Raising temperatures for energy savings risked user dissatisfaction. COVID-19 further emphasized the need for proper ventilation and environmental monitoring.**
- **Information Utilization: Although a 3D model existed from the design phase, it was stored standalone and not linked to equipment ledgers or sensor data, limiting its utility in daily operations.**

To address these issues, the facility management team led the definition of system requirements and initiated development. The process included:

- **Needs Assessment: Interviews with maintenance staff and managers identified necessary functions and data items.**
- **Basic Design and Infrastructure Setup: Designed system architecture and prepared devices and network environment; built a cloud-based database.**
- **Hybrid Development: Outsourced development of the "3D Ledger System" requiring advanced programming; internal team developed IoT data analysis and visualization functions.**
- **Benefits of Internal Requirement Definition: Direct involvement of facility managers ensured usability and adaptability, resulting in a system with "just-right" functionality.**

This approach established the foundation for a facility management data platform.

SYSTEM FEATURES AND FUNCTIONALITY

The completed FM system is a web application integrating 3D BIM models and databases (Figure 2, Table 1).

Figure 2. Main Interface of the Ledger Management System Linked to the 3D Model

Table 1. List of System Functions

Function	Description
a. New Ledger Entry	Register new records via web; auto-email alerts for critical events
b. Status Management	Task tracking via status settings (unresolved, in progress, resolved)
c. Edit	Modify existing records
d. Facility Search	Zoom to selected facility in 3D model
e. 3D Model Viewer	View model and attribute data
f. Icons	Clickable icons for each facility to display related records
g. Record Viewer	View ledger records
h. Filter Search	Search by facility, date, category
i. CSV Export	Export filtered records to CSV
j. Document Download	Download attached inspection documents and images

Figure 3 illustrates the core architecture and data flow of the facility management system. The database and application are hosted on a central server, and users—including on-site staff, facility managers, and maintenance contractors—access the system via a web interface.
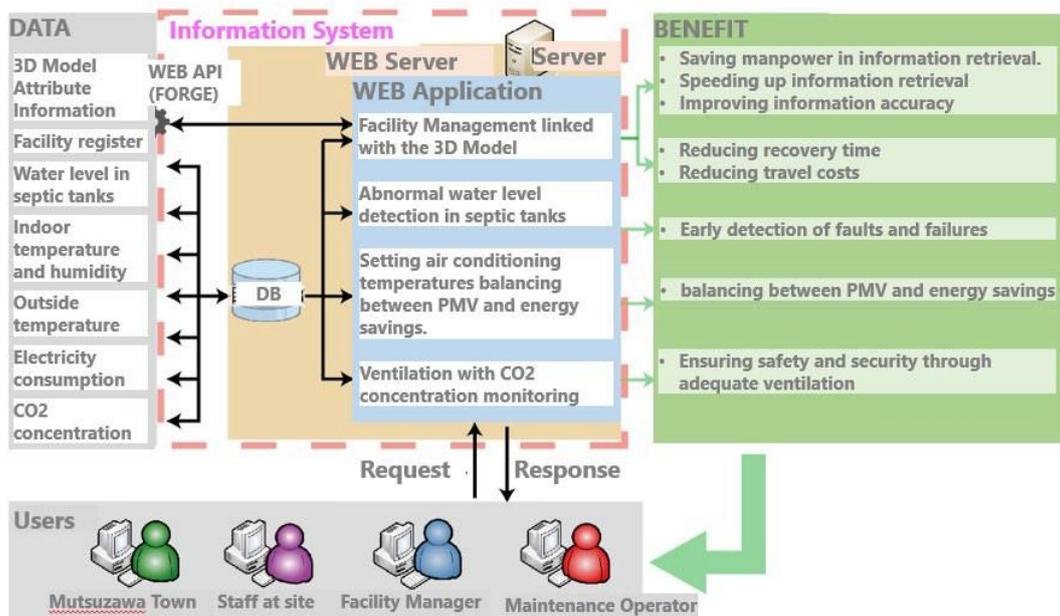
Figure 3. System Architecture and Data Flow Overview

System architecture includes:

- **Ledger Database ("Mutsuzawa DB"): Records equipment info and maintenance history.**
- **IoT Sensor Integration: Collects data on temperature, humidity, CO_2, power consumption,**
- **water usage, etc., at varying intervals.**
- **3D Model Viewer: Uses Autodesk Forge for browser-based viewing; allows inspection of hidden components and access to attribute data.**
- **Linked Display: Simultaneous display of 3D model and related ledger records; supports filtering and CSV export.**
- **Navigation: Virtual walkthroughs enable spatial understanding of facility layout.**

This comprehensive system enables unified access to spatial and attribute data, facilitating efficient information sharing and decision-making.

EMERGENCY RESPONSE USING BIM: PROOF-OF-CONCEPT

To verify the effectiveness of the developed FM support system, a proof-of-concept (PoC) exercise was conducted based on an emergency response scenario. In September 2024, as part of a joint research initiative with the University of Tokyo, a large-scale training session was held online, involving dozens of participants including facility managers, maintenance contractors, and municipal officials (Figure 4).

The scenario simulated a flooding incident in an underground pit caused by heavy rainfall—a situation that would be difficult to assess in real life. Despite being in remote locations, participants

were able to share the 3D model and real-time site footage via the system, collaboratively investigating the cause and discussing emergency response measures.
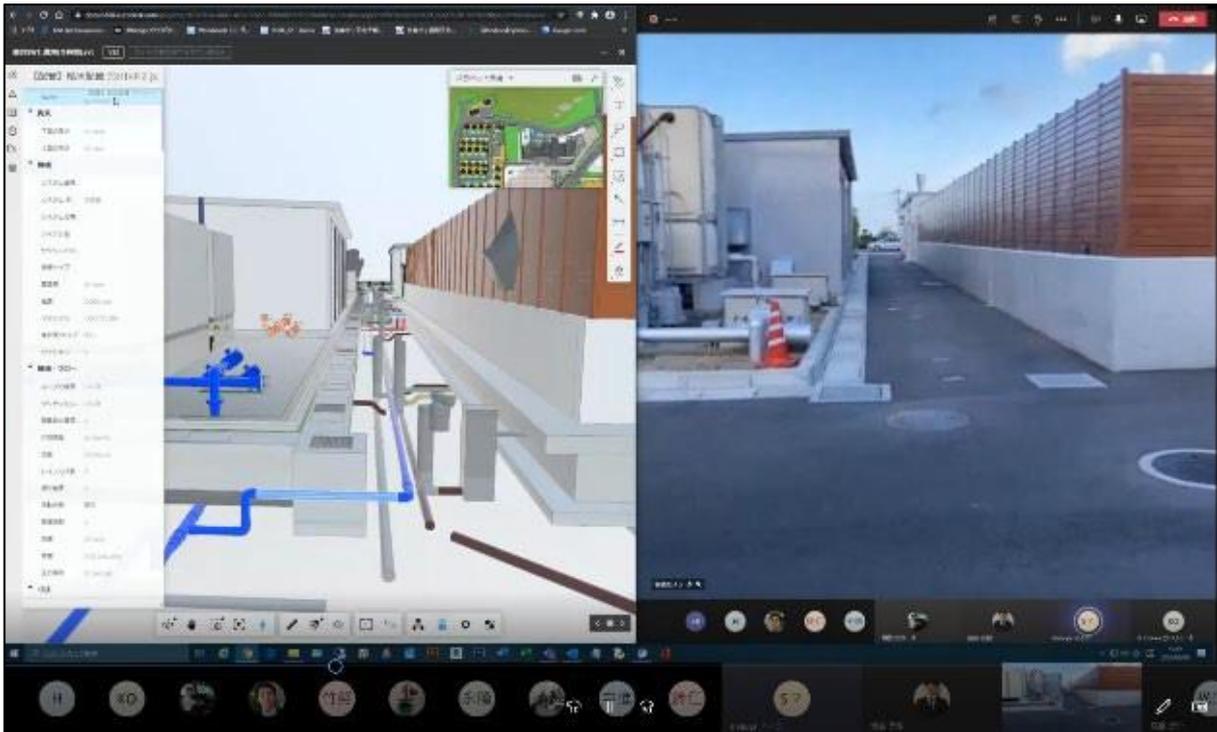
Figure 4. Remote Collaboration Using 3D Models to Share Attributes and Pipe Connections of Underground Installations Difficult to Inspect On-Site

Scenario steps:

- **Incident Reporting: On-site staff discovered water leakage from a manhole near the septic tank. Using a mobile device, they recorded live footage of the site and reported the situation to headquarters in Tokyo via a video conferencing system.**
- **Remote 3D Model Operation: Technical experts located in the Tokyo office operated the 3D model viewer within the system to examine the layout of underground pipelines around the manhole. In the virtual environment, they identified the pipe routes and valve positions connected to the manhole.**
- **Information Sharing and Instruction: All participants shared the 3D model screen and live site footage, enabling collaborative discussion of the situation. Based on the attribute data of the pipes (e.g., material, diameter, valve location) confirmed in the model, experts identified the valve that needed to be closed first and instructed the on-site staff via radio communication.**
- **Emergency Response Execution: Following the instructions, the on-site staff operated the designated valve and successfully stopped the leakage temporarily. Subsequently, they narrowed down the damaged area using the model and were able to immediately determine the necessary repair parts and arrange for specialized contractors.**

The proof-of-concept experiment yielded two major outcomes. First, it significantly accelerated the process of identifying the cause of the incident. Traditionally, understanding the layout of underground piping would have required time-consuming review of design drawings and on-site

inspections. However, with the 3D model, this information was instantly accessible, enabling rapid hypothesis testing and emergency response. As a result, the lead time from problem identification to temporary resolution was substantially reduced.

Second, the system contributed to reduced travel time and costs. Experts were able to provide remote support without needing to travel to the site, thereby saving time and transportation expenses for multiple personnel. In fact, during Typhoon No. 15 in 2019, a similar remote support approach was estimated to have reduced expert travel time by approximately 26 hours. The system significantly enhanced emergency response capabilities and regional resilience.

As demonstrated above, the system has proven to significantly enhance emergency response capabilities. In facilities designated as evacuation centers during disasters, the use of BIM-enabled remote support systems plays a vital role in minimizing damage and facilitating rapid recovery. This approach contributes meaningfully to strengthening regional resilience.

ROUTINE USE AND EFFICIENCY GAINS

The developed FM system has proven effective not only during emergencies but also in routine facility management operations. An analysis of its usage over approximately one year following its release revealed a significant reduction in the effort required for information retrieval and record updates.

A total of 48 new entries were registered in the facility ledger, with 58 instances of content modification (editing), indicating active and consistent data accumulation by both on-site staff and management personnel. On average, more than one record was registered or updated per week. Each entry task was completed in approximately six minutes, resulting in a cumulative reduction of around 80 minutes in data input time compared to previous methods using Excel or paper-based individual management.

The system was accessed for search operations 163 times over the year, frequently utilized for daily inspection reporting and troubleshooting based on past incidents. During a 104-day trial period, on-site staff conducted 27 searches, while managers executed 24 searches, demonstrating widespread adoption across organizational levels. All search results were retrieved within 10 seconds, and compared to the time required to locate paper ledger files, the system achieved a total time savings of approximately 990 minutes (270 minutes for staff and 720 minutes for managers).

Enhancements in data accuracy and comprehensiveness were also notable. Previously fragmented inspection records managed individually by different personnel were consolidated, ensuring that the latest information was consistently shared. Users reported qualitative benefits such as reduced human error and prevention of information loss during personnel transitions.

In summary, the developed system has delivered measurable improvements in both efficiency (time savings) and sophistication (data-driven decision-making) in routine facility management. These outcomes represent substantial advantages for local public facilities operated with limited human resources and serve as a foundational element for sustainable facility operations.

Contributions to Sustainability and Continuity of BIM Utilization

This case study demonstrates multifaceted contributions from the perspective of sustainability. These contributions are categorized into three dimensions: social, economic, and the sustainability of BIM utilization itself.

1. **Social Contributions**

The system enhances safety and peace of mind for facility users and local residents. By visualizing indoor environmental data and managing ventilation, it helps reduce the risk of infectious diseases and maintain healthy indoor conditions. During disasters, the system enables rapid response,

minimizing facility downtime and ensuring its role as an evacuation center—thereby strengthening regional disaster resilience. The system has been recognized for its social value, with evaluations noting that "advanced facility management through digital twins enhances disaster response capabilities and provides reassurance to residents." Furthermore, the establishment of a shared information platform among stakeholders has facilitated the accumulation and transfer of operational know-how, which traditionally relied on individual experience. This contributes to organizational knowledge enhancement and supports human resource development and workstyle reform.

2.   Economic Contributions

The system also supports the financial sustainability of local governments and operating companies. Had a commercial FM system been adopted, significant licensing and operational costs might have been incurred. In contrast, this case achieved cost control by developing only the essential functions in-house. Additionally, the efficiency gains—such as reduced labor costs from streamlined search and record operations—represent substantial long-term savings. Preventing major failures and reducing downtime also help lower repair costs and mitigate losses from service interruptions. These direct and indirect economic benefits provide a strong foundation for sustainable operations in local public facilities with limited budgets.

3.   Sustainability of BIM Utilization

Beyond technical aspects, the case emphasizes the importance of mechanisms that ensure long- term usability. Rather than treating system development as a one-time effort, the team adopted an agile development process that allows for continuous improvement and functional expansion in response to evolving needs and technologies. Facility managers involved in development continue to lead system operations, maintaining and updating data internally. This approach avoids the common pitfall of BIM systems becoming obsolete due to lack of usability and ensures long-term alignment with on-site needs. The system also features a user-friendly interface designed for non-technical staff, supported by training and digital literacy initiatives to promote organization-wide adoption.

The case offers a valuable lesson: sustainability encompasses not only energy and environmental considerations but also operational and organizational strategies to ensure continued use of digital technologies.

In summary, this case contributes to sustainability across social and economic dimensions while also offering insights into maintaining BIM-based digital transformation initiatives over time.

FUTURE OUTLOOK: REGIONAL DISSEMINATION AND TECHNOLOGICAL ADVANCEMENT

The insights gained from the Mutsuzawa Smart Wellness Town initiative are applicable to other regions and projects. The lightweight FM system developed for small-scale facilities in this case study can serve as a model for similar public and private facilities across Japan. In particular, it offers valuable reference for improving maintenance efficiency in aging regional infrastructure and for implementing digital twin technologies as part of broader smart city strategies.

Internationally, the initiative is expected to contribute to sustainable urban development in the Asia-Pacific region. Indeed, this case was presented at the 2025 FIDIC Asia Pacific Conference, where it was recognized for its potential to inform resilient and sustainable urban and infrastructure management through regional dissemination. For example, the lessons learned here can be applied to infrastructure

management in small and medium-sized cities in Southeast Asia, or in regions facing challenges such as workforce shortages, where digital technologies can play a transformative role.

From a technological perspective, future developments may include the integration of artificial intelligence (AI) for predictive maintenance using accumulated big data, and the use of generative AI for extracting operational insights. In fact, within Pacific Consultants Co., Ltd. (PCKK), the implementing organization, trials have already begun using generative AI for document analysis and summarization. Looking ahead, system enhancements may enable automatic extraction of improvement proposals from vast maintenance records.

Ultimately, the most significant takeaway from this case is the emphasis on "site-driven digital transformation." Rather than simply introducing the latest technologies, the project focused on solving real-world challenges through tailored, partially in-house development. This approach demonstrated that even small-scale initiatives can yield substantial impact. It offers valuable lessons for municipalities and enterprises seeking to advance digital transformation in a practical and effective manner.

CONCLUSION

This paper has detailed the development, effectiveness, and sustainability contributions of a BIM-based facility management system implemented in the Smart Wellness Town of Mutsuzawa, Chiba Prefecture. As a case study of digital twin deployment in small-scale public facilities, it demonstrates how a site-adapted system—actively developed with user participation—can enhance emergency responsiveness, streamline routine operations, and contribute to sustainability across social and economic dimensions.

This initiative exemplifies how emerging technologies are transforming the civil and construction sectors. Its significance lies not only in the adoption of advanced tools but also in the creation of social value through practical application. Looking ahead, the insights gained from this case are expected to inform a wide range of domestic and international projects, contributing to the realization of resilient and sustainable infrastructure management.

Enhancing Urban Infrastructure Construction through 3D Data Capture & BIM Technology

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INTRODUCTION

This paper presents the framework, benefits, challenges and some way forward for 3D data capture and BIM adoption in planning, design and construction of utility infrastructure in land development projects. Within the backdrop of digital technologies in general (and BIM in particular coupled with 3D data capture for civil projects) as a crucial tool for the AEC industry, the desired outcome is a continuing conversation, advocacy and adoption using project studies of the authors within the Philippine context.

Architecture, Engineering and Construction (AEC), while being one of the top global industries, has traditionally been slow in the adoption of digital technologies[56].   Many studies, such as those conducted by Xichen, et al (2023)[57] which included more than 400 participants, indicated that while digital technologies such as BIM were recognized, AEC industry members usually small to mid-sized companies have some way to go in adopting BIM, while large companies showed greater knowledge but still have limited implementation within their operations. There is optimism, however, as AEC technology investments have also grown significantly, estimated at USD 50 billion from 2020-2022[58].

Various digital transformation-related articles have generally been consistent in listing the disruptors in the AEC industry. These include Building Information Modeling, 360-Image Capture (Point Cloud), Augmented Reality/ Virtual Reality and Data Analytics. In construction, the list also included DFMA (Design For Manufacturing & Assembly) and 3D Printing.

As an industry deeply rooted in conventional processes, firms understandably prefer familiarity to the risks of technology-driven innovation, slowing down BIM (and overall digital) adoption. Lack of awareness and upskilling, especially in developing countries (even among professionals), and lack of institutional frameworks further contribute to the gaps between digital technologies and the AEC industry.

In a 2018 study on BIM adoption across the globe, it was generally observed that AEC use was on the rise, with Europe leading the way. In Asia, Singapore was (and still is) the industry the leader.

In the Philippines, while BIM adoption studies have been limited, informal industry opinions suggest the same trend where awareness, skills and costs are among the factors impacting progress. A 2023

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[56] Manzoor, B., et al; Digital Technologies in the Architecture, Engineering and Construction (AEC) Industry—A Bibliometric—Qualitative Literature Review of Research Activities (2021); https://www.mdpi.com/1660-4601/18/11/6135

[57] Xichen Chen, et al; Digital technologies in the AEC sector: a comparative study of digital competence among industry practitioners (2023); https://www.tandfonline.com/doi/pdf/10.1080/15623599.2024.2304453

[58] McKinsey & Company; London 2023: Meet the Disrupters - Hyperscaling digitization in AEC (2023)

study[59] involving 105 respondents (evenly distributed amongst Clients as End-users, Consultants and Contractors) indicated the same trend and barriers.
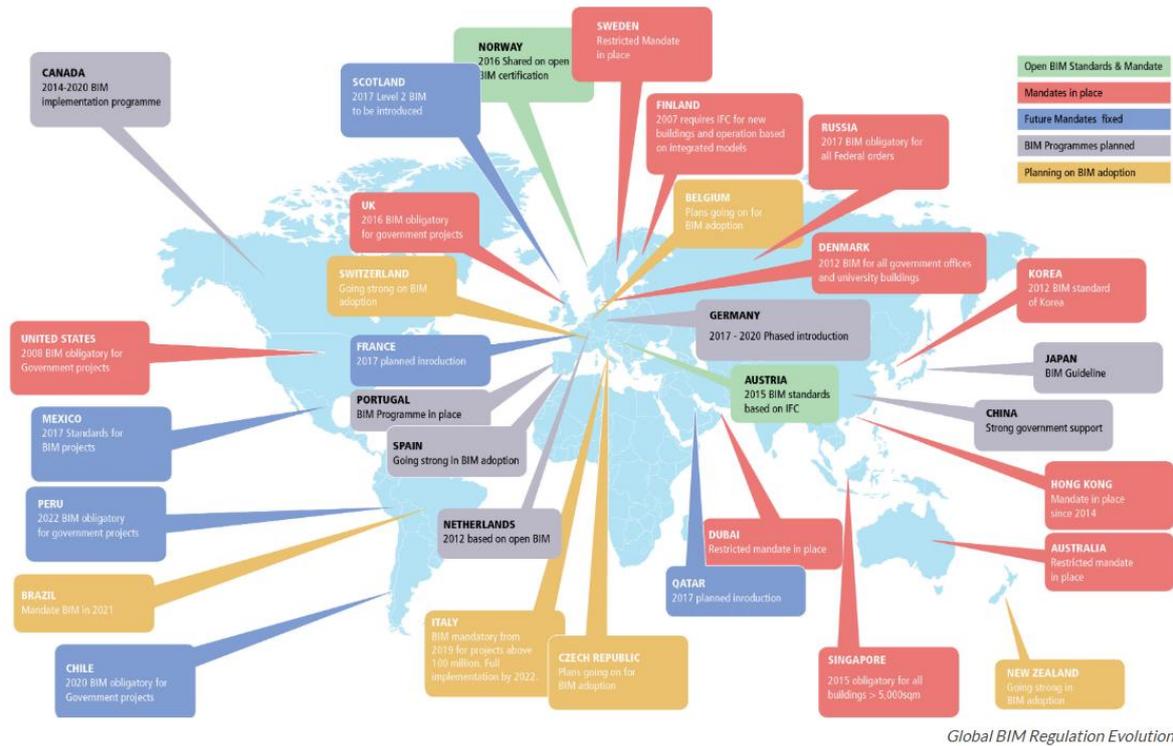

Global BIM Regulation Evolution

Figure 1. Global rate of globe BIM adoption (2018)[60]

In the past five years, estimates valued the AEC industry between USD 8-11 trillion, with some projecting upwards of USD 15 trillion in 2027. APAC, especially with rapid developments in China, India, Indonesia and Vietnam are driving its significant contribution to global AEC spending. Software markets, including those of CAD and BIM, is looking to scale to more than USD 13 billion by 2027. The local AEC sector is estimated to scale to USD 100 billion in 2027. This presents a continuing opportunity for leveraging of BIM to support not only the AEC industry but also the local economy.

In the Philippines, the project AEC industry value in 2025 is estimated to be between USD 35-40B, rising to USD 45B in 2027 and USD 50B by 2029.

BIM AND 3D DATA CAPTURE

"Building information modeling (BIM) is the holistic process of creating and managing information for a built asset. Based on an intelligent model and enabled by a cloud platform, BIM integrates structured, multi-disciplinary data to produce a digital representation (Autodesk)"

While the term "BIM" was already being used in the 2000s, the foundation for the development of tools that use information within the 2D & 3D environment started as early as the 1950s to 1970s,

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[59] Famadico, Jerome Jordan Faz; Building Information Modeling in the Architecture and Construction Industry (2023); https://ojs.imeti.org/index.php/AITI/article/view/9854/1357

[60] Shimonti Paul; "BIM adoption around the world: how good are we?" (2018); https://geospatialworld.net/article/bim-adoption-around-the-world-how-good-are-we/

with software such as Computer Aided Machining (CAM), Computer Aided Design (CAD) and Sketchpad. The jump to 3D modelling for buildings came during 1980s when visualization in 3D and improved database integration was done using the Building Description System.

Some BIM Historical highlights are as follows:

o **1950s - 1970s → emergence of computer-aided software, enhancing 2D designs**
o **1980s - 2000s → enhanced 3D modelling and visualization; embedding information in models**
o **2000s to present → AEC integration focusing on collaboration and efficiency; standardization (ISO) and use of AR/VR**

While BIM is just one of a wide range of digital solutions for the AEC industry, it is one with immediate impact in design and construction given the nature of data that is generated and integrated, and the impact of visualization in working out construction requirements.

However, BIM is also more than a visualization tool. Going beyond the 3-dimensional platform, the range of BIM dimensions with increasing detail and information are be applied to help other processes in the life cycle of building structures and development of projects. To summarize according to ISO 19650:

o **3D (Geometry)**: The basic visual representation of the building—its shape, structure, and spatial relationships. This is the core of BIM, enabling detailed modeling and visualization.
o **4D (Time)**: Adds the **construction timeline** to the 3D model. It helps in scheduling tasks, sequencing construction activities, and visualizing project progress over time.
o **5D (Cost)**: Integrates **cost estimation and budgeting** with the model. It allows for real-time cost analysis, tracking expenses, and evaluating financial impacts of design changes.
o **6D (Sustainability)**: Focuses on **energy analysis and environmental impact**. It supports decisions related to energy efficiency, carbon footprint, and sustainable materials.
o **7D (Facility Management)**: Extends BIM to **operations and maintenance**. It includes data for asset management, maintenance schedules, and lifecycle management of building components.
o **8D (Safety):** integrates **safety-related data and processes** into the BIM environment to proactively identify, assess, and mitigate safety risks throughout the lifecycle of a construction project.
o **9D (Waste Reduction)**: refers to the integration of **Lean Construction principles** into the BIM process, with a focus on waste reduction—not just in materials, but also in time, labor, and effort.
o **10D (Industrialized Construction)**: focuses on the use of **systematic production of building components off-site**, aiming to optimize productivity, reduce waste, and enhance quality through digital technologies, automation, and off-site manufacturing.

3D capture in geodetic engineering uses laser scanning to collect precise spatial data. Instruments emit laser pulses to measure distances, creating dense point clouds that represent surfaces and structures in 3D. This enables accurate mapping, modeling, and analysis for surveying, construction, and infrastructure projects.

Point cloud technology, while nearly 25 years old, found rapid growth in the past 15 years, especially in developed economies who have been able to leverage the technology for infrastructure projects.

Although it should be noted in recent years that equipment costs are on the decline, they are still cost-prohibitive with a lot of uncertainty of optimal utilization.

Equipment for point cloud data capture for terrestrial use (e.g. topographic surveys) have the ability to capture 500 thousand to 1 million data points per second, or between 20 to 80 million in a single scan. When used as reference for earthwork and road network design, this provides a very powerful tool in ensuring accuracy of the civil designs and greater alignment with their digital twins.

DESIGN - TO - CONSTRUCTION WORKFLOWS

Traditional workflow for many civil contractors in land development projects involve the following:
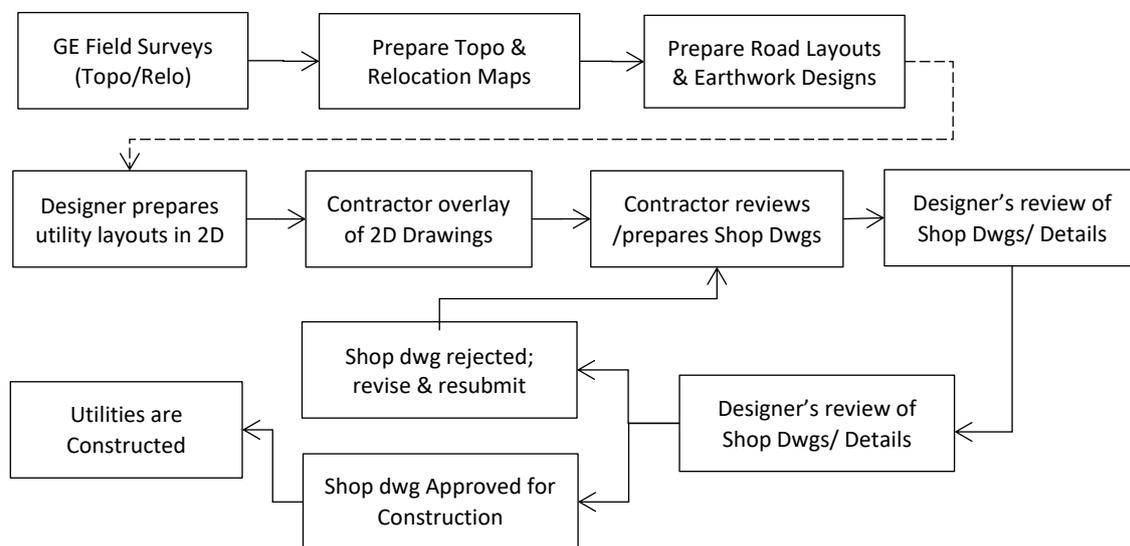

Figure 2. Sample (Typical) 2D-based workflow for utility integration in land development

Step 1: Data Collection (Geodetic Surveys) involving collection of data points using traditional methodology (e.g. total station); points are processed to determine site boundaries (relocation map) and existing levels (topographic map)

Step 2: Based on the approved project master plan, including right-of-way sections, road networks are designed with minimization of earthwork in mind while complying with standards for radii of curves, clearances, setbacks, etc. While surfaces may be generated through software, utility design is likely independent of the generated surface. It would not be unusual that the integration disconnect occurs as the 3D surfaces (if) generated are not fully utilized in utility designs

Step 3: Designers prepare independent 2D drawings for each utility, usually out-of-scale given the ratio of the sizes (e.g. pipes) against the dimensions of road right-of-way. Infra master plans, in coordination with the land plan, would produce sections showing utility placements on a typical cross section, and would adopt clearance rules governed by general design guidelines of specific requirements of utility companies.

Step 4: Contractor's blow-up overlay of utilities using CAD-based software. Where designers issue CAD drawings, contractors would prepare scaled blow-up drawings and plot more precise locations on plan and sections, noting finished grade levels of the road network, based on interpretation of road-related plans.

Step 5: Review and interpretation of utility clashes using typical cross section and utility clearance guidelines; preparation of individual shop drawings for each section, with proposed clash resolution. Each pair of utilities potentially clashing is resolved for each system, with pairing as follows:

Step 6: Submission to Designer for review; designers likewise interpret the 2D drawings and visualize the clash solution based on the contractor's drawings

Step 7: Revisions to shop drawings until approval and implementation onsite

BIM-based workflow, on the other hand, leverages the availability of point cloud data and fully integrates the surfaces (existing topography, earthwork/ site grading plan, road levels) with the utility infrastructure to create one coherent model which is then subjected to clash analysis enroute to a clash-free or clash resolved 3D model.
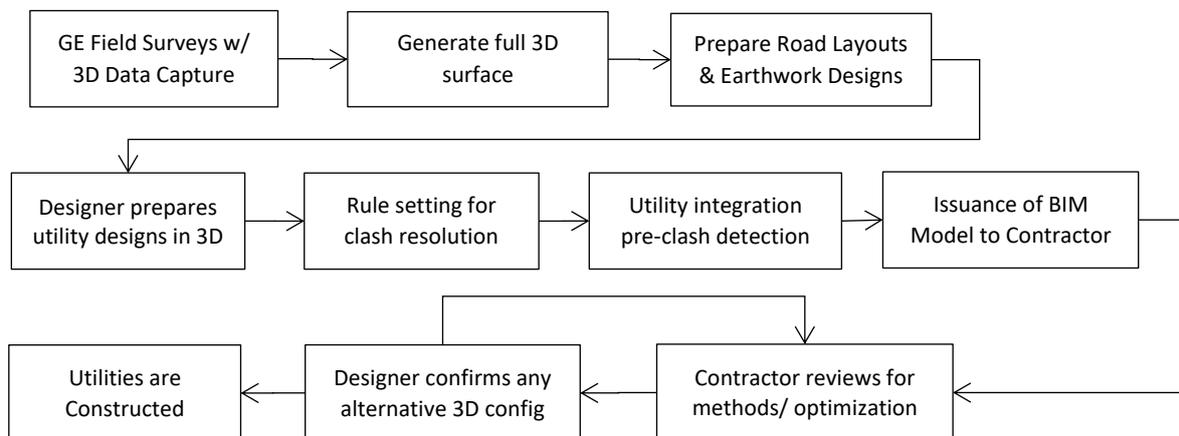
The process would be similar to the illustration below:

Figure 3. Sample 3D/BIM-based workflow for utility integration in land development

Step 1: Deployment of 3D scanning equipment completement by total station for collection of point cloud data for the whole site, and generation of full (existing), georeferenced site surface.

Step 2: Modeling and analysis of utility systems, especially those subject to gravity or pressure flow such as drainage, water and storm sewer. Software complements practical engineering approaches to routing, demand estimation, design guidelines etc.

Step 3: Designers' conversion of civil designs from 3D based analysis and design tools, and in lieu of drafting utilities on 2D plans, utility models.

Step 4: After rule setting to guide clearances, bends, levels and similarly important parameters, 3D software-based clash detection and clash resolution of utility system is done on pair-to-pair basis then further integrated into one buildable system

Step 5 - onwards: Collaboration with the project contractor beginning with issuance of model and continuing review and iteration to optimize the construction effort and be able to generate a digital twin.

BIM USE IN LOCAL LAND DEVELOPMENT PROJECT

In the sample project subjected to BIM utility integration, a 60-hectare mixed use, land development project was designed as a high-end residential subdivision with amenities typical in highly urbanized cities in the Philippines. Located on moderately rolling terrain, the project has typical lot cuts of 500sqm with three primary roads serving as main accesses. The innermost roads are two lane/two-way with sidewalks and planting strips, merging with four-lane/two-way main primary roads.

The utility infrastructure was designed as a fully underground system with hybrid street lighting, and a telecommunication system ready both for fiber optics and a future 100% wifi-driven system will be serving a projected 550 households.

The project road right-of-way (RROW) showing the planned set-up of utility infrastructure is shown below in 2D drawing (CAD format).
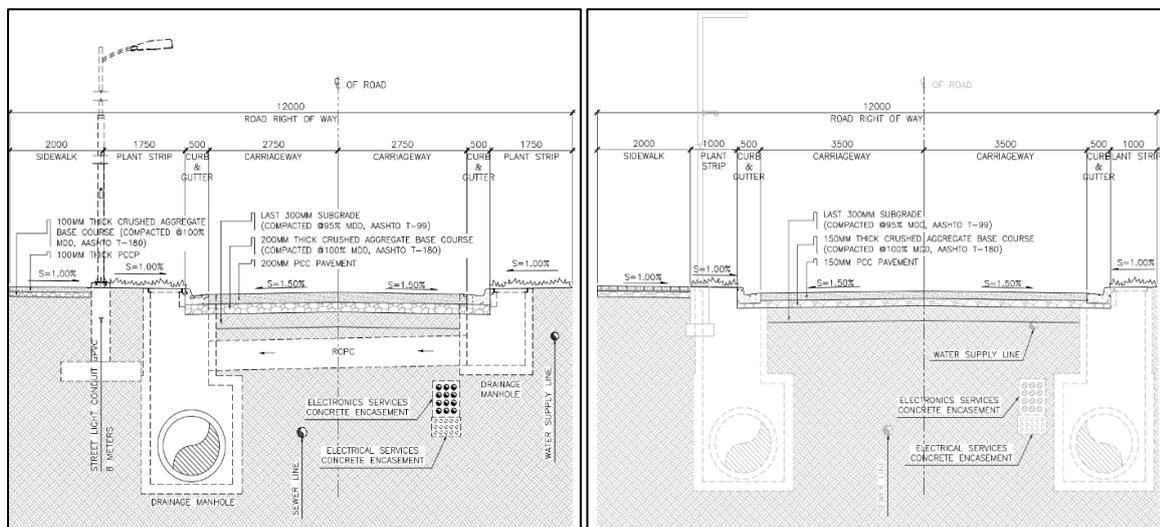

Figure 4. Sample RROW sections showing utility set-up

In order to derive a clash-free model, the BIM workflow (using Figure 3 as basis) involving various tools may look similar to the chart below:
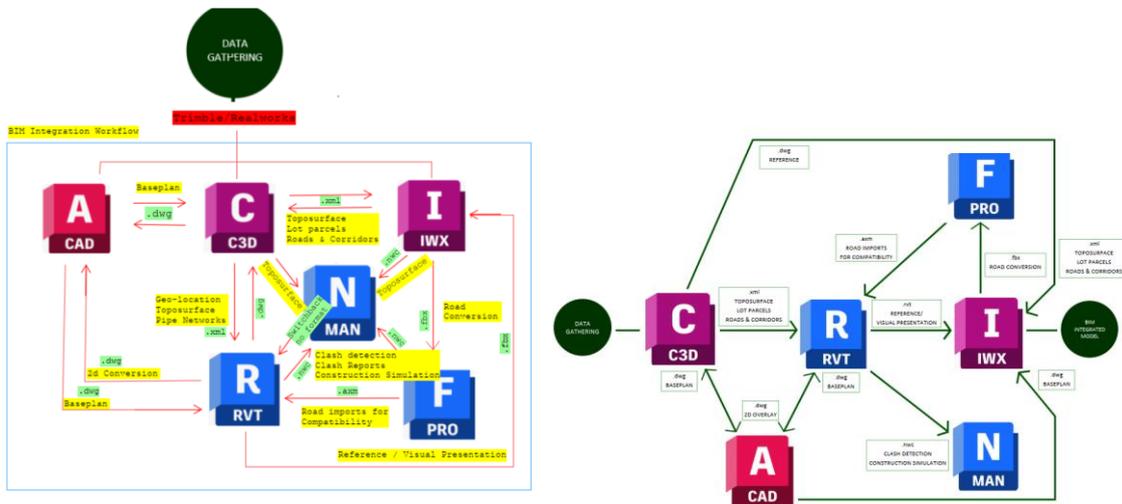
Figure 5. BIM Workflows: Draft (L) and Format Flow (R); softwares by Autodesk®

The approach to utility clash resolution involved the pairing of utility systems and evaluating these pairs within the BIM environment. Intelligent systems allow the flagging of utility clashes, tracking of progress and backward/forward compatibility in the updating of models.

For this project, approximately 165 critical clash locations were identified, which included road intersections, locations of critical electrical equipment such as transformers and switch gears

The typical utility pairings are as follows:

Table 1. Typical utility pairing for land development clash resolution

DR vs SS	ECE vs EE LGT	EE LGT vs WS
DR vs ECE	ECE vs EE PWR	EE LGT vs WS
DR vs LGT	ECE vs WS	EE PWR vs WS
DR vs EE PWR	ECE vs SS	EE PWR vs SS
DR vs WS	EE LGT vs EE PWR	WS vs SS

DR: Storm Drainage
EE PWR: Electrical Power
SS: Sewer/Wastewater
EE LGT: Street Lighting
ECE: Electronics & Communication
WS: Water Distribution

The clash resolution work, which started with almost 1200 clash points (on pair basis) across the project, and the rate of resolution through five rounds is shown below:
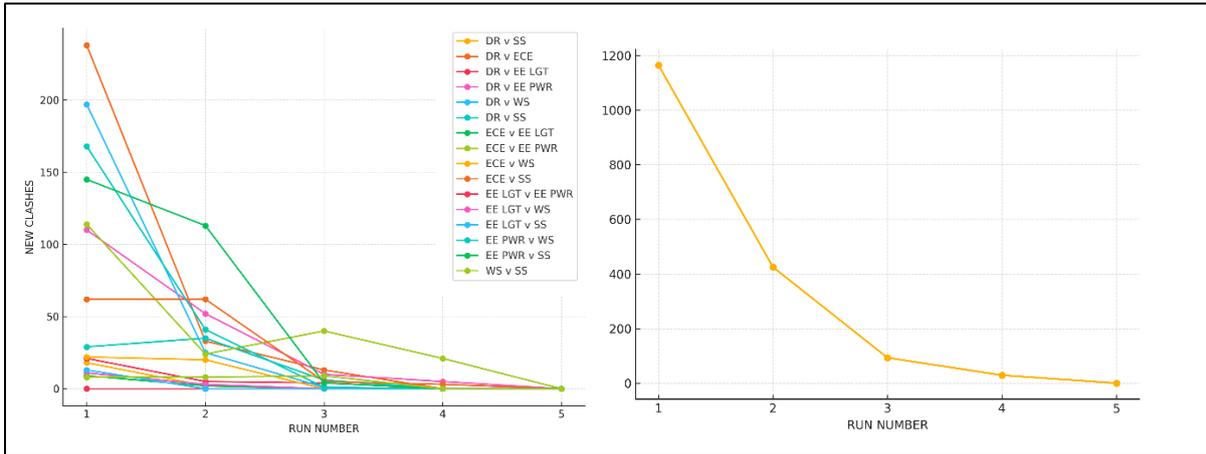
Figure 6. Downward trend in clash resolution through five utility integration runs

From the 2D overlay, pairing for clash analysis and full integration, the result would be a clash free model with sample snips below:
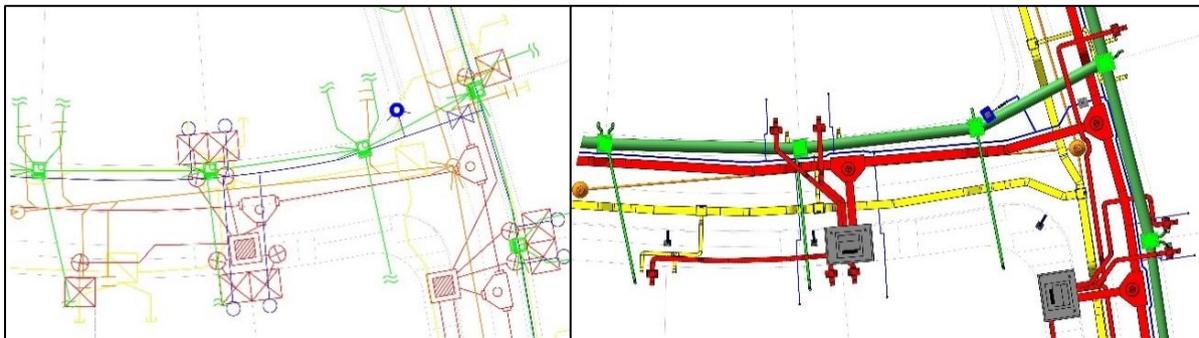

Figure *7*. Utility overlay in 2D format, pre-BIM (L) and a BIM-integrated format, post BIM

CONSTRUCTION BENEFITS

Adoption of BIM In the Philippine AEC setting may still be at a considerable time in the future, taking the needed steps such as adopting a 3D data capture and BIM-based approach to the design-construction workflow will certainly be beneficial to designers, contractors and end-users. Based on project experience and related studies in many countries, these benefits include the following:

1. Rapid Clash Detection and Clash Resolution. As shown in the prior section, working within the BIM platforms allowed the resolution of nearly 1,200 clash points at 165 critical locations within a substantially shorter period compared to what would have required a contractor the preparation of numerous shop drawings and be subjected to a tedious review process.

2. Improved Planning & Construction Guide. Without adopting BIM 4D or higher, the visual appreciation of the planned construction already provides guidance that 2D drawings, which may otherwise be subject to misinterpretation. In the 2025 study conducted by Deloitte for Autodesk[61], efficiency in project delivery is cited as a clear benefit when projects are delivered within this platform.

3. Construction Waste Reduction[62]. Industry studies are also showing that BIM-based work has the potential to lower construction waste, with figures estimated to be, on average, 4.5% to 5.5%. In the example shown where the construction cost may be in the range of USD 50M, such adoption may translate to savings of USD 2.5M, aside from lending support to the environment.

4. Improved Project Scheduling. Improvements in project scheduling would also be the natural consequence of reducing the cycle time to resolve clashes, prepare, review and approve shop drawings. The increased predictability (or reduction of uncertainty) will allow construction planners to improve overall schedule management.

5. Increase in revenue and productivity, time savings and efficiency in project delivery[63]

CHALLENGES

Embracing 3D data capture and BIM technology should be grounded in the understanding of roadblocks impeding such adoption, so that strategies may be derived as to how they will overcome these and reap the benefits. Data also shows that the industry is experiencing rapid growth, providing even stronger impetus for adaption of these technologies in order to reap the benefits.

Some of the identified challenges, based on corporate experience in adoption of these technologies and various studies made are the following:

1. **Challenge of First Cost**: Transitioning to new technologies and the presence of limited-service providers raise expenses for AEC firms. Investment necessary hardware or software can be prohibitive for small/medium enterprises, made worse by the uncertainty of first cost recovery.

2. **Challenge of Upskilling**: Additional costs for skills development of the workforce, especially considering risks of departure from for migration. Aside from this, the workforce is hampered by limited software training while studying to have A&E. Skills-based/ vocational training is available, but graduates still need to level-up of skills as 2- 3 years of BIM work does not guarantee a higher level of skill.

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[61] Omar Doukari et al; The efficient generation of 4D BIM construction schedules: A case study of the Nanterre 2 CESI project in France (2022); Volume 8 - 2022 | https://doi.org/10.3389/fbuil.2022.998309

[62] Arvin Rabbani Batee, et al; Analysis The Potential of Building Information Modeling (BIM) and Lean Construction in Reducing Construction Waste through Modeling: A Case Study of SMP Negeri 6 Surakarta (2025); https://proceedings.ums.ac.id/sipil/article/view/5589

[63] David Rumbens et al; State of Digital Adoption in the Construction Industry 2025 by Deloitte for Autodesk

3. **Challenge of Local Industry Opportunity**: The AEC industries that support 3d data capture and BIM tend to limit the practice of BIM skills to architectural models, BIM conversion and preparation of as-builts/CSDs, and there seems to be limited local industry opportunities to embrace BIM work. Clients may dismiss BIM as applicable only for building structures or may be unwilling to pay for value-adding services.

4. **Challenge of Collaboration**: It is crucial for teams to be working on the same platform (i.e. CDE – common data environment) especially for more complex building and infrastructure projects. Collaboration requires that parties involved in projects who may benefit from data capture and BIM be similarly invested in the infrastructure.

5. **Challenge of Government Framework.** Lack of guidance, regulation, and incentives naturally hamper the adoption of these digital technologies for business.

CONCLUDING NOTES

The Philippine Securities and Exchange Commission (SEC) lists almost 3,000 registered architectural and engineering design firms, while the Philippine Contractors Accreditation Board (PCAB) lists close 20,000 contractors, 90% of which are classified as small and medium enterprises. Considering industry estimates that no more than 1-2% of consultants and a mere handful of contractors are actively adopting the technologies in their workflow, these does exist a sizeable of opportunity.

Even incrementally, AEC firms must invest in digital technologies. 3D data capture, BIM, (and others such as generative AI, cloud software, mobile application and data analytics) must be part of the planning process, not just for design collaboration and coordination but to expand BIM tools to be applied to management of the designs processes and construction sites.

Conversations and actions must continue. Communication of benefits to adaptation, pilot testing, allotting budget for transitions, and business leaders' push for technology. Management that is led by supportive and proactive leadership stand to gain most by adapting BIM quickly, versus firms that approach trends in a reactionary manner. BIM action plans for organizations should consider the following[64]: (1) Establish a long-term BIM strategy with progressive milestones, (2) set-up initial targets and build on them in terms of scale and complexity as your firm grows; (3) enable all stakeholders within the organization so that BIM strategies are understood and implemented as planned.

Work towards for standardization and to adopt BIM in all processes, in accordance with ISO 19650.

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[64] Darniel V. Perez, et.al., BIM Adoption in Philippines. Report prepared for ARCADIS, 2021

Virtual Power Plant Drive the Development of China's New Power System

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Wenting Yang is an engineer at the Hydropower Division of Energy Business Department, China International Engineering Consulting Corporation. Her research focuses on hydropower project assessment, energy policy planning, and interdisciplinary studies in hydrology-water resources-remote sensing. Since 2022, she has led or contributed to over 40 hydropower project approvals/consultancies, 20 national-level major engineering assessments, and 10 strategic planning studies. She holds a Ph.D. in Hydraulic Engineering (2022) from Tsinghua University, where she developed multidisciplinary approaches integrating remote sensing for water resources management. As a National Natural Science Foundation of China grantee, she was selected for the 2019 Young Scientists Summer Program at the International Institute for Applied Systems Analysis (55 selected from 342 applicants across 26 countries). Her work appears in more than 10 peer-reviewed publications, including Nature Communications, Journal of Hydrology, and Water Resources Research.

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INTRODUCTION

Amid the global sustainability imperative, energy transition has emerged as a universal pathway toward low-carbon development. China is vigorously advancing its "Dual Carbon" goals, accelerating the establishment of a New Power System. Under energy transition framework, China's new power system faces challenges including high-penetration renewable energy integration and flexible regulation of power supply-demand. Meanwhile, the exponential growth of flexible load resources is also redefining power system dynamics. These resources transform traditional load challenges into grid flexibility assets, driving the power system to gradually shift from passive "generation-follows-load" to active "generation-load coordination". In addition, as the electricity marketization mechanism advances, price signals guide bidirectional adjustments across supply-demand chains.

Empowered by emerging technologies such as artificial intelligence (AI), Internet of Things, and digital twin, virtual power plant (VPP)—intelligent energy management systems that aggregate distributed energy resources through digital means to enable flexible dispatch and electricity market participation—have become critical solutions for enhancing grid flexibility and stability. VPP will become a key component in the implementation of regulatory capacity in the electricity market by responding to price signals, aggregating and regulating flexible resources, and ensuring the stable operation of power systems.

VPP is an advanced grid operational paradigm that utilizes digitalization and smart technologies to aggregate distributed generation resources and flexible loads, enabling coordinated participation in power system operations and market transactions. As a critical component of modern power systems, VPP integrate distributed energy resources including energy storage systems, controllable loads, and electric vehicles through information and communication technologies and software platforms. Rather than a physical power facility, a VPP functions as an AI-driven energy management platform, leveraging digital intelligence to unify decentralized resources (e.g., solar, wind, biomass), storage systems, and dispatchable loads into a cohesive energy network.

The technological core of VPP operations lies in its capabilities to aggregate, analyze, and control heterogeneous resources, while employing advanced models and algorithms to support dispatch and trading decisions. This enables observable, analyzable, and controllable management of complex, uncertain resources through high-efficiency granular coordination, ensuring reliable and flexible power supply/regulation for optimal economic outcomes. Based on aggregated resource profiles, VPPs are categorized into four archetypes: generation-dominant, load-dominant, storage- dominant, and hybrid integrated. Currently in China, pilot VPP projects are predominantly load- dominant.

Generation-dominant VPPs participate in market transactions as generation entities by aggregating distributed renewable energy resources (such as photovoltaic and wind power) and dispatchable generation resources (including biomass, coal-fired, and natural gas power). Load-dominant VPPs engage in demand-side management by integrating adjustable loads like building HVAC (i.e., Heating, Ventilation, and Air Conditioning) systems, electric vehicle charging networks, and industrial production processes. Storage-dominant VPPs aggregate diversified energy storage resources (e.g., commercial/industrial and residential energy storage systems) for participation in ancillary service markets. Hybrid VPPs combine the capabilities of all three aforementioned types, coordinating flexible resources across generation, load, and storage to participate in diversified market activities.

DEVELOPMENT STATUS OF CHINA'S VPPS

China's VPPs have progressed from policy pilots to large-scale commercial operation gradually, characterized by dual drivers of policy and market forces. On one hand, the National Energy Administration has designated VPPs as one of seven key pilot initiatives for the new power system, setting explicit capacity targets: over 20 GW of regulation capability by 2027 and over 50 GW by 2030. On the other hand, mechanism innovations such as granting VPPs independent market entity qualifications (e.g., in Shanghai) have promoted the commercial implementation of VPPs. VPPs can participate in the entire chain of power market transactions as independent entities, including medium and long-term contracts, auxiliary services, and spot markets.

At present, operational projects across the country cover 21 provinces out of 34 provincial-level regions, and the types of aggregated resources have expanded from industrial loads to diverse scenarios such as vehicle-to-grid (V2G), public institutions, and distributed energy storage. However,

the overall development still faces challenges such as profit dependence on subsidies and lack of a standard system. The following delineates regional deployment progress, operational characteristics, and implementation models of representative projects.

f.   East China Region: Market-Oriented Mechanisms and Technology Leadership

The Lingang Virtual Power Plant in Shanghai transitioned into deep commercial operation with the release of its updated implementation plan on July 30, 2025. The facility integrates 23 operators, coordinating over 700 MW of flexible loads. Its building air-conditioning control system achieves second-level interruption responses within 55 seconds, operating as an independent market entity across comprehensive electricity trading segments—including forward contracts, ancillary services, and spot markets.

The Haoneng Virtual Power Plant in Shandong Province completed its registration on the electricity trading platform in July 2025. The facility aggregates 23.885 MW of capacity, including 6.25 MW of adjustable loads.

The Suqian Incremental Distribution Network Virtual Power Plant in Jiangsu Province commenced operation in May 2025. This facility aggregates 26 MW of distributed photovoltaic capacity, 105 kW/210 kWh of energy storage, and 145 MW of adjustable loads, achieving high power supply reliability. Through demand response participation, 203 end-users have gained economic benefits. As China's first integrated project combining an incremental distribution network with VPP technology, it operates via a grid-local joint venture and delivers unified dispatch of generation-grid- load-storage resources.

The Hefei Virtual Power Plant in Anhui Province commenced operations in February 2020, currently integrating 1,205.3 MW of aggregated resources. In 2023, it was upgraded to China's first "5G+ quantum encryption" VPP system, achieving internationally leading performance in both security and load regulation capabilities. The facility has completed large-scale V2G testing, participated in medium-to-long-term renewable energy transactions for distributed photovoltaic systems, and engaged in Yangtze River Delta regional power coordination. During the 2025 peak summer demand period, it undertook a critical supply assurance role for the regional grid.

g.   North China Region: Policy Innovation and Private Sector Participation

In February 2023, Shanxi Province completed construction of its first batch of 15 VPPs declared by nine electricity retail entities. These facilities collectively aggregate 1,847.4 MW of capacity, with 392

MW of adjustable resources. Shanxi Province introduced new VPP policies on July 24, 2025, relaxing adjustable capacity thresholds and piloting market-based capacity compensation mechanisms. The regulations actively support private enterprise participation in VPP development by streamlining approval processes and encouraging private electricity retailers to transition into integrated energy service providers. These entities will aggregate distributed photovoltaic and energy storage resources for electricity market participation, diversifying the historically state-dominated energy landscape.

h. Northeast Region: Deep AI Convergence

The Shenyang Virtual Power Plant in Liaoning Province commenced operations in May 2025, providing peak-shaving and valley-filling services for key provincial energy consumers to enhance grid regulation capacity. Leveraging deep learning and multi-source data integration, the facility achieves dynamic perception of electricity consumption environments and 7-day-ahead accurate electricity price forecasting. It generates real-time electricity trading strategies through algorithms to

intelligently match supply and demand relationships. The plant completes data interactions within milliseconds, enabling rapid power regulation. Additionally, it pioneers China's first intelligent cross-provincial electricity trading channel using blockchain technology.

i. Southwest Region: Resource Aggregation and Multi-Revenue Exploration

The Chongqing Large-Scale Virtual Power Plant obtained regulation capability certification on July 17, 2025. This facility aggregates 59 MW of controllable loads with a maximum adjustable capacity of 17 MW. It deploys a cloud-edge-device coordination platform for precise supply-demand forecasting and explores multi-revenue streams through integrated electricity spot markets, ancillary services, and carbon asset trading.

The Ziyang Virtual Power Plant in Sichuan Province commenced construction in April 2025 and completed its inaugural operational deployment in July. This facility integrates 143 commercial/industrial enterprises, 12 hospitals, and 75 charging stations, forming a 61.1 MW adjustable resource. During July 17-18, 2025, it executed 20 consecutive responses (9 hours), absorbing 18 MWh of electricity. By incorporating diverse public institutions and distributed energy resources, the plant delivers critical public service resilience through peak shaving, valley filling, and emergency backup capabilities.

In May 2024, Yibin Virtual Power Plant in Sichuan Province commenced trial operations, aggregating over 50 key participants across industrial enterprises, commercial complexes, public institutions, charging stations, and other multi-scenario users.

The Chengdu High-Tech Zone Virtual Power Plant project in Sichuan Province, with its agreement signed on July 25, 2025, is poised to set a new record for single-user-side energy storage capacity in Sichuan. By integrating VPP dispatch capabilities, it will significantly enhance park-level energy supply stability, reduce electricity costs, and achieve critical energy management objectives including peak shaving, valley filling, and emergency backup. This initiative provides foundational support for establishing a zero-carbon park district in Chengdu High-Tech Zone. Simultaneously, the project will serve as a premium flexible adjustable resource within Chengdu's VPP framework, participating in demand-side responses to address power supply gaps during peak periods. As a demonstration project for synergistic integration of VPPs and advanced energy storage systems, it ensures robust energy supply security implementation.

j.   Central China Region: Active Exploration and Implementation

The Huangshi Cihu Power Plant in Hubei Province has established a physically operational VPP, pioneering participation in the provincial electricity trading market to realize actual traded volumes of VPP resources. Currently, it delivers an annual dispatchable capacity of 240 MW, reduces carbon emissions by 40,000 tonnes, and enhances renewable energy integration by 280 MWh.

The first phase of the Yongzhou Virtual Power Plant project in Hunan Province integrates 227 MW of photovoltaic capacity and 51.5 MW of charging infrastructure capacity, with a total investment of approximately ¥750 million.

DEVELOPMENT CHARACTERISTICS OF VPPS IN CHINA

The advancement of AI has profoundly accelerated VPP development in China, driving technological capability enhancement, security architecture upgrades, unprecedented response speeds, and intensified regional coordination.

Security architecture has undergone critical evolution through region-specific breakthroughs. Hefei's integration of 5G and quantum encryption provides robust defense against cyberattacks while ensuring cross-regional transaction data integrity. Simultaneously, Shenyang's blockchain platform enables verifiable green electricity traceability and facilitates interprovincial trading, effectively resolving longstanding trust deficits in multi-stakeholder coordination.

Response speed has achieved revolutionary improvements, with Lingang's 55-second building HVAC control and Hefei's 15-second V2G response outperforming traditional hour-level demand response by orders of magnitude. These advancements establish the technical foundation for hyper-precise grid dispatch operations previously unattainable through conventional methods. Quantum encryption implemented in Hefei and blockchain transactions pioneered in Shenyang collectively represent significant leaps in grid modernization.

Resource diversification marks another breakthrough, as VPPs now integrate multi-dimensional assets extending far beyond traditional industrial loads. Examples include Hefei's vehicle-grid integration systems, participation of public institutions like Ziyang hospitals, and distributed storage synergy in Suqian—all collectively enhancing systemic resilience through heterogeneous resource pooling.

Regional coordination has intensified through strategic cross-provincial support mechanisms, exemplified by Hefei's emergency supply of 31 MW to Shanghai during peak demand. Such operations leverage China's ultra-high voltage transmission corridors to create a dual-track dispatch framework where VPPs and physical grid infrastructure cooperate to optimize nationwide resource allocation.

CHALLENGES

Market mechanisms for VPPs require significant refinement despite being essential for sector advancement. While robust regulatory frameworks are fundamental prerequisites for VPP development, current implementation protocols within power systems remain operationally immature. A critical symptom of this underdeveloped marketization is the heavy reliance of most projects on grid subsidies, coupled with minimal spot market engagement that constrains sustainable growth.

User participation continues to lag below optimal levels, presenting another barrier to market maturation. Engagement metrics serve as vital indicators of VPP commercial viability, yet current awareness among potential users remains critically low while participation willingness stays tepid.

Although economic incentives should theoretically drive adoption, the spot markets—constituting VPPs' primary revenue channel—remain embryonic in development. Their current dominance by planned transactions over market-based trading substantially diminishes financial appeal to prospective participants.

Standardization deficiencies further impede progress through fragmented governance frameworks. The absence of uniform cross-provincial trading rules creates jurisdictional friction, while inadequate cross-regional data interoperability protocols directly undermine resource aggregation efficiency.

These systemic gaps introduce unnecessary complexity in multi-regional VPP coordination and scaling.

Aggregator diversity remains constrained despite being crucial for rapid advancement. Current market dynamics show load aggregation predominantly controlled by electricity retail companies, which leverage existing consumer-side channels to cluster demand based on usage patterns for grid

regulation services. To meaningfully enhance VPPs' regulatory impact, broadening participant profiles is imperative. Strategic diversification must incorporate technical service providers, specialized energy management firms, and major energy-consuming enterprises into collaborative development ecosystems—thereby boosting both operational efficiency and economic returns through pluralistic innovation.

FUTURE DEVELOPMENT ROADMAP

With the deepening reform of China's power system, electricity marketization will progressively advance, accelerating VPPs' transition into a market-driven phase. VPPs will expand their operational scope from load-side management to generation-side and storage-side integration, further aggregating distributed generation and storage resources to participate in energy markets and ancillary service markets.

Technological integration will intensify. By developing high-precision load/output forecasting models, real-time analysis of market big data, and intelligent dispatch algorithms, VPP competitiveness will be significantly enhanced. AI, blockchain, and 5G-quantum encryption technologies will become core enablers. Aggregated resources will diversify. Through the integration of V2G and hydrogen energy storage systems, VPPs will strengthen multi-scenario adaptability.

Standardized frameworks will unify. Establishing consistent technical standards and market protocols will facilitate cross-regional data transmission and trading for VPPs.

Future progress through technological advancements, improved market mechanisms, policy synergy, and user engagement will accelerate breakthroughs in VPP technologies and operational models, facilitating China's energy system transformation toward digitalization and low-carbon sustainability.

Enhancing Urban Infrastructure Construction through 3D Data Capture & BIM Technology

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Sekar Mawar Oktavina, Indonesia

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INTRODUCTION

Performance-Based Seismic Design (PBSD) is the new design approach that is just developed recently. This practice for seismic design of high-rise buildings in Indonesia is gradually advancing as the need for better controlling and measuring the performances of earthquake-resistant building designs grows, particularly given that Indonesia is one of the most seismically active countries in the world. In the last two decades, Indonesia has faced a great number of destructive earthquakes. This has increased public and government awareness to have a safer and more secure buildings with better measured performance under earthquake, especially in major and densely populated cities like Jakarta, Surabaya and other major cities in Indonesia.

Performance-based seismic design (PBSD) procedure allows engineers to design structures based on desired performance during an earthquake, rather than simply following the conventional code requirements that are mostly prescriptive and ingredient based. With this approach, engineers will have more freedom in choosing structural system and configuration for high-rise buildings; for example, a dual system is not the only alternative when someone is combining structural walls and moment resisting frames in seismic design category D. Height limits stated in SNI 1726:2019 for certain structural system (e.g. for shear walls as a bearing wall system or as a building frame system) may also be relaxed. This makes PBSD is getting more popular lately not only in Indonesia, but also in other Asia regions that are prone to earthquake such as Philippines, Thailand, and Taiwan.

This paper discusses the implementation of PBSD in Indonesia. Design guidelines and requirements, codes/standards and current best practices used in the construction industries in Indonesia for designing high-rise buildings using PBSD will be presented. In addition, the PBSD approach is not only used for designing new buildings but also used in evaluating seismically the existing buildings. In the last part of the paper, some examples of tall buildings that are designed and also evaluated using PBSD will be given.

CURRENT SEISMIC DESIGN PRACTICES IN INDONESIA

The Indonesian seismic code SNI 1726 with comprehensive seismic hazard map was first published in 1989 (BSN, 1989). In the map, Indonesia is divided into 6 (six) seismic zones, i.e. from seismic zone 1 (the lowest seismicity) to seismic zone 6 (the highest seismicity). The Indonesia seismic Code was then revised in 2002 with the updated seismic hazard map (BSN, 2002). The main parameter in this seismic hazard map is Peak Ground Acceleration (PGA) at base rock, which was developed using earthquakes with the probability of being exceeded of 10% in 50 years. Using more recent seismic data, the Indonesia seismic code was then revised again in 2012 with updated seismic hazard maps (BSN, 2012). The main parameters of the map are spectral values at 0.2 second and 1 second periods at base rock, with the probability of being exceeded of 2% in 50 years. These spectral values are formulated as the risk-targeted maximum considered earthquake (MCER). Compared to the two previous Indonesian seismic codes, this updated Code is more comprehensive. The Code also accomodates the provision for designing base-isolation system in building structures and the provision for nonlinear time history analysis. This SNI code and the corresponding seismic hazard map is later updated again in 2019, to accommodate the data from recent earthquakes (BSN, 2019). Since the update of the seismic code of 2012, the ASCE 7 seismic provision has been used as the main reference. Currently, the National Research Center for Earthquake (Pusgen) is working on finalizing the Indonesian seismic hazard map

of 2025. This update of seismic hazard map will then normally be followed by the updating of the Indonesian seismic code (SNI 1726).

The Indonesian seismic code is mostly prescriptive and still adopts the force-based approach for seismic design. In the code, the level of seismic demand can be reduced by a factor of R (i.e. response modification factor) to allow for inelastic behavior in the structures. In the case of high-rise buildings, the requirement of minimum base shear mostly governs the seismic base shear demand for the buildings (Figure 1). This makes the high-rise building design sometime becoming unnecessarily more expensive than it should be. Nevertheless, SNI 1726-2019 also provides provisions for performance-based procedures for seismic building design. Two procedures are provided, i.e.:

1) **explicit procedure, in which conditional probability of failure caused by the MCER shaking is set to be not more than 10% for risk category II (please note that high-rise buildings in Indonesian practices are commonly assigned to risk category II)**
2) **implicit procedure, in which the building should satisfy both local and global acceptance criteria when subjected to 11 sets of selected ground motions.**

Performance based seismic design (PBSD) procedure allows engineers to design structures based on desired performance during an earthquake, rather than simply following minimum code requirements. With the conventional prescriptive approach, the base shear strength of the building is determined on the design earthquake (DE) level, i.e. 2/3 of MCE. The strength in this case is calculated as Cs I W/R, where Cs ≥ Csmin. With this strength, the building is expected to behave elastically under frequent earthquake (or service earthquake (SE)). The building design should also accommodate the seismic detailing requirement, based on the seismic design category assigned to it. With the properly designed and installed seismic detailing, the building is expected to survive both design earthquake (DE) and maximum considered earthquake (MCE). However, the achievement of the performance objective at DE and MCE levels is never been measured with the conventional prescriptive approach. Figure 2 shows the level of performances expected for different level of earthquakes for each building risk category. With the performance based seismic design approach, the performance level for frequent earthquake, design earthquake and maximum earthquake can be measured. This makes PBSD is getting more popular lately in Indonesia.
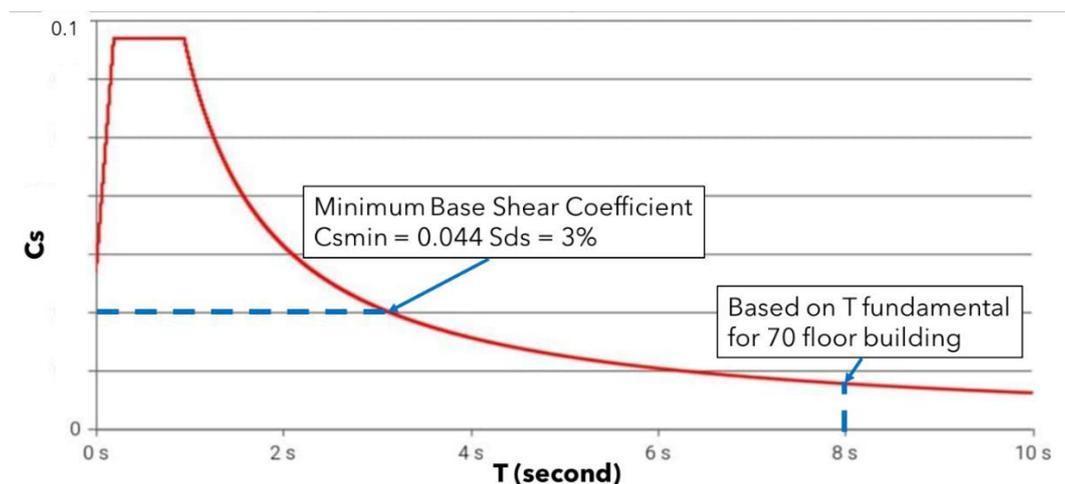

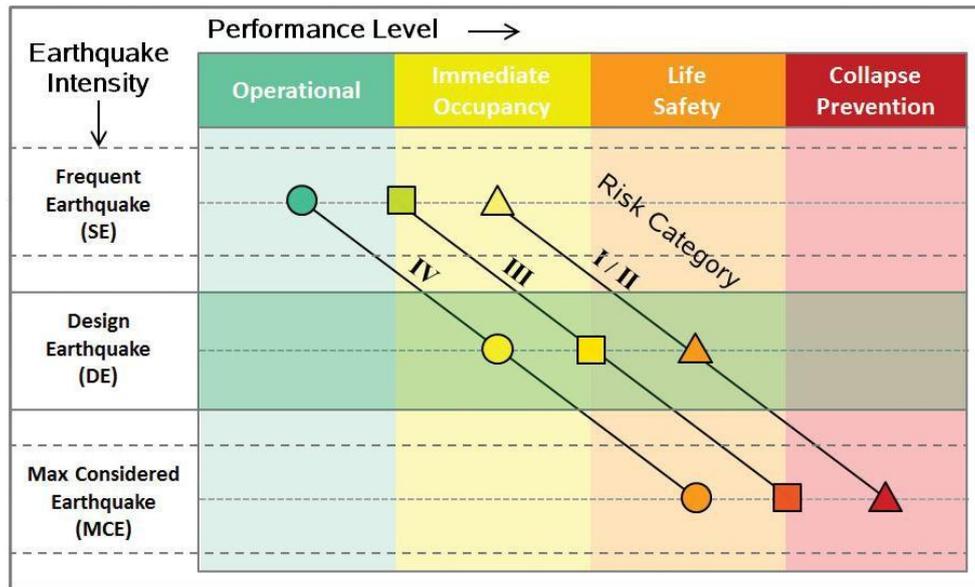Figure 1 Seismic Coefficient of Jakarta for Buildings with R = 7

Figure 2 Performance Objectives

Some motivations of using PBSD in Indonesia:

a. As a means of verifications of the performance of the high-rise buildings being designed
b. To get away from the requirement of minimum base shear (Csmin*W) for tall buildings (there are still some unresolved issues regarding this as the SNI 1726 still requires the fulfillment of the minimum base shear even though the building is designed with the nonlinear time history analysis approach),
c. To use structural systems that are not covered yet in the Indonesian seismic code, such as structural system with outrigger/belt-truss etc.,
d. To use structural systems that are not permitted in the region with high seismicity, such as core wall + gravity frame systems etc.,
e. As a means for optimization, especially for high-rise buildings in which the base shear is usually governed by the minimum base shear requirement. Reinforced concrete is still the most popular construction materials in Indonesia, even for the tall buildings. This PBSD practice can alleviate rebar congestion in structural concrete elements and therefore, increase constructability,
f. As a means for comprehensive seismic evaluation and retrofit strategies for existing buildings. This approach not only enhances the structural resilience of aging infrastructure but also aligns with broader sustainability goals by extending the service life of buildings.

Government of Indonesia, through the national center for earthquake studies, recently provides necessary guidelines or standard to support the implementation of PBSD, especially for the development of selected ground motions to be used in the nonlinear time history analysis. Some of the documents are:

a. De-aggregation map of seismic hazards of Indonesia, the National Center for Earthquake Studies (PUSGEN)
b. Procedure for selecting and modifying earthquake ground motions, SNI 8899-2020 In addition, PUSGEN has also setup the platform to help the engineers to select and modify

earthquake ground motions for every location in Indonesia. The design of high-rise buildings in Indonesia should go through review process by high rise building committee. Each city has its own

building committee. There is an additional requirement for the approval of buildings designed with PBSD, i.e.: the detail engineering design should be peer-reviewed by a consultant with many experiences on the use of PBSD for high rise buildings. Right now, not many local consultants are qualified for peer review process in Indonesia. The peer review process is then mostly conducted by foreign consultants. References that are mostly used and have been accepted by the high-rise building committee for PBSD are TBI, LATBSDC, ASCE 41, ACI 369.1, and ASCE 7.

There are at least two levels of seismic hazard to be considered for PBSD implementation in Indonesia, i.e.:

i) **service level earthquake (SE) (i.e. earthquake with 50% probability of exceedance in 30 years or equivalent with earthquake of 43-year return period) and**

ii) **maximum considered earthquake (MCE) (i.e. earthquake with 2% probability of exceedance in 50 years or earthquake with 2500-year return period).**

The design earthquake level (DE) or equal to 2/3 of MCE is also sometime considered in the design of tall buildings.

STRENGTH DESIGN IN PBSD

The strength design is commonly carried out using base shear coefficient of SLE or DE (2/3 MCER/R or Csmin). In the city of Jakarta, building approval can sometime be obtained partially. As an example, approval for the foundation can be obtained first in order to be able to start the foundation work sooner. As the review process of PBSD design usually takes longer time, then the foundation strength design is sometime still carried out with the prescriptive procedure using base shear coefficient of the largest of 2/3 MCER/R or Csmin. The overstrength factor, Ω, is also applied to achieve strength hierarchy between foundation and upper structures. There is also other case of building designed using PBSD in Indonesia, in which the building was initially designed with prescriptive code, but later switched to PBSD during the construction in order to optimize the design.

In summary, these are the examples of current PBSD practices in Indonesia for the strength design of the buildings:

a. **Preliminary strength design of the buildings is done based on base shear coefficient of the largest of 2/3 MCER/R (=DBE/R) and Csmin.**

b. **Preliminary strength design is done based on the modified seismic response coefficient (say, a number between 2/3 MCER/R and Csmin). This is sometime done as the service level earthquake is not yet available. However, there is no strong basis on the use of this approach. If in the end it has to be used then the probability of failure should be computed explicitly under MCER and should satisfy the requirement of SNI 1726.**

c. **Preliminary strength design is done based on SLE. But, to get partial approval for foundation, the foundation strength design is then carried out based on base shear coefficient of the largest of 2/3 MCER/R*Ωo and Csmin*Ωo**

NLTHA UNDER MCER

A critical technical aspect of implementing PBSD is the reliance on NLTHA, a method to evaluate structural behavior under realistic earthquake scenarios. NLTHA typically involves the use of multiple ground motion records (i.e. 11 pairs of horizontal components) to capture the variability and uncertainty of seismic demands. Each pair is carefully selected and scaled to match the target

response spectrum defined at the risk-targeted maximum considered earthquake (MCER) level, ensuring that the results reflect expected seismic conditions at the site. Conducting NLTHA requires advanced computational methods and tools, as it involves advanced nonlinear modelling of structural elements, time-step integration, and complex post-processing structural performance check (i.e. interstory drifts, plastic hinge rotations, energy dissipation, etc.). The methodology of NLTHA is presented as a flow chart shown in Figure 3. NLTHA is basically used to validate the strength design of both upper structures and foundations. In many cases, those PBSD practices are proven successful with minimum design adjustment when the building design is subjected to MCER. So far, from Indonesia experiences of implementing PBSD, the ratio of base shear demand from MCER to DBE ranges from 2.5 to 2.9. So, this is close to the value of overstrength Ωo of SNI 1726- 2019, which is equal to 3. However, these conclusions are only valid if the upper structures are designed efficiently, especially for deformation-controlled elements, as those elements in fact determine the lateral strength of the upper structures.
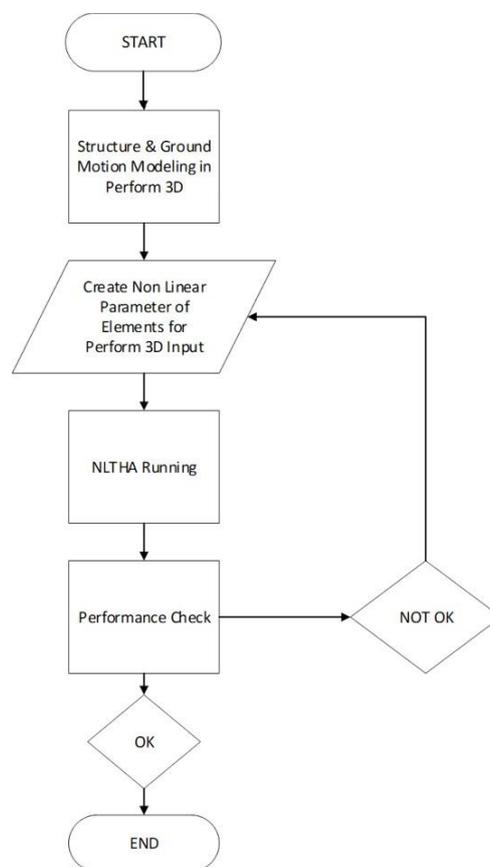
Figure 3 Methodology of Nonlinear Time-History Analysis (NLTHA)

SEISMIC INSTRUMENTATIONS AND SENSORS

In some countries, like Philippines and US, high-rise buildings designed with Performance-Based Seismic Design (PBSD) shall be equipped with seismic instrumentation or sensors. In Indonesia, this mandatory requirement is not there yet in the seismic code. Once installed, the measurement from the sensors are very useful to be used to understand the building real dynamic performance. In addition, in the event of earthquake, the measurement from accelerometer sensors can also be analysed to indicate any potential damage (from the reduction of natural frequency of the buildings) or residual deformation that may occur in the building due to the earthquake. This information is very

important to complement the post-earthquake evaluation before it is decided to do repair, strengthening or retrofit to the buildings.

SEISMIC EVALUATION OF EXISTING BUILDINGS

The existing buildings are becoming a big concern in Indonesia as there is a substantial increase in seismic hazard level in some regions in the updated/current seismic hazard map of Indonesia. This increase in hazard level may subsequently result in an increase in the seismic detailing requirements as well. There are many examples of some existing buildings in Jakarta and other major cities in Indonesia that have been evaluated seismically using performance based seismic design procedure. This is usually done to evaluate whether the performance of the existing buildings designed under older seismic code is acceptable or not. As long as the performance requirements are met, no retrofit is needed even though the buildings have deficiency in seismic strength and detailing when they are evaluated using the prescriptive approach. The seismic evaluation of the existing buildings, which is then followed by seismic rehabilitation, is becoming popular lately in Indonesia. To help the engineers to do the seismic evaluation, the Ministry of Public Work of Indonesia has already published a new SNI for seismic evaluation and retrofit of existing buildings (i.e. SNI 9273 (BSN 2024)).

EXAMPLES OF BUILDINGS IN INDONESIA DESIGNED USING PBSD

There have been several buildings in Jakarta that are recently designed using PBSD procedure. The construction some of these buildings have been completed. Some examples of the buildings are:

a. **Autograph Tower (the tallest building in Indonesia and also in the southern hemisphere), with the total height of 385 m (Figure 4)**
b. **Luminary Tower with the total height of 304 m**
c. **Indonesia One with the total height of 303 m**
d. **Wisma Sudirman with the total height of 260 m (Figure 5)**
e. **Ciputra Tower with the total height of 250 m**
f. **Oasis Central with the total height of 320 m**

In addition to that, some existing buildings in Indonesia have also been evaluated seismically using performance-based procedure. This is done to assess whether the performance of the existing buildings is still acceptable or not, as there are an increase in hazard level in the updated seismic hazard map and also the increase in seismic detailing requirement. If the performance is not acceptable then the buildings should be retrofitted.

CONCLUSION

- **PBSD is the alternative approach of seismic design for high-rise buildings that gives better measure of the building performances under different levels of earthquakes.**
- **In some examples of PBSD practices in Indonesia, the use of base shear/overturning moment due DBE* Ω_o or Cs min* Ω_o gave a good and conservative estimate of seismic demand for the design of foundation. Usually, no adjustments are needed for the foundation design after the completion of NLTHA.**
- **From Indonesia experiences, the ratio of MCE/DBE ranges from 2.5 to 2.9. So, it is close to Ω_o (i.e. 3).**
- **These conclusions are only valid if the upper structures are designed efficiently, especially for deformation-controlled elements, as those elements in fact govern the lateral strength of the structures.**

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Figure 4 Autograph Tower (Left, View from West) and Luminary Tower (Right, View from East)

Figure 5 Wisma Sudirman (Left) and Indonesia One (Right)

Integrating Engineering and Construction into Smart Farming through Collaborative Technologies

Chungwon Seo, Republic of Korea

Chungwon Seo currently serves as an International Development Project Specialist in the Business Strategy Department at Dohwa Engineering Co., Ltd. With over 17 years of experience, he has led and managed a wide range of international projects encompassing bidding and contract acquisition, project implementation, and the development of Public-Private Partnership (PPP) initiatives abroad.

In recent years, he has played a key role in promoting smart agriculture development projects, and is currently overseeing an energy efficiency-focused PPP project in Indonesia. He also serves as Vice Chair of the Young Professional Committee under the Korea Engineering Association.

Looking ahead, he anticipates a growing role for construction engineering in the agricultural sector, an area he believes will attract increasing global attention. To align with this emerging paradigm, he is currently completing a Bachelor's degree in Agricultural Studies, complementing his existing Master's degree and reinforcing his interdisciplinary expertise.

INTEGRATING ENGINEERING AND CONSTRUCTION INTO SMART FARMING THROUGH COLLABORATIVE TECHNOLOGIES

This paper presents the framework, benefits, challenges and some way forward for 3D data capture and BIM adoption in planning, design and construction of utility infrastructure in land development projects.

Agriculture, once regarded as a traditional sector dependent on seasonal cycles and manual labor, is now experiencing a transformation unprecedented in scale. This transformation is being driven by global challenges such as climate change, water scarcity, and the rising urgency of food security.

What was once a matter of subsistence for local communities has now become an issue of national strategies and international policy frameworks. The modern reality is that agriculture can no longer be understood solely as farming; rather, it must be regarded as infrastructure. It is deeply intertwined with energy systems, water management, logistics, and environmental engineering. In this context, the role of engineering and construction (E&C) industries becomes indispensable. These industries, long associated with highways, dams, and power plants, are now extending their expertise into agriculture by designing and constructing the systems that enable smart farming to operate at scale.

The global agricultural paradigm is undergoing a decisive shift. Climate change has disrupted weather patterns across continents, causing floods, droughts, and heatwaves that destabilize traditional farming practices. Water scarcity is now recognized as one of the greatest constraints on agricultural productivity, particularly in arid and semi-arid regions. At the same time, the world faces the challenge of feeding a population projected by the United Nations to peak at 10.4 billion in the 2080s. These pressures have accelerated investment in agricultural technologies. The global smart farming market, valued at roughly USD 20 billion in 2023, is expected to exceed USD 60 billion by 2033, growing at an annual rate of more than 11 percent. This rapid growth reflects an increasing recognition that technological and infrastructural solutions are essential for the resilience of food systems. Agriculture is no longer a peripheral activity but a central component of national economic and security strategies.

Engineering and construction are at the heart of this new agricultural model. The first area of intervention lies in water infrastructure. Smart farming depends on closed-loop irrigation and fertigation systems that deliver water and nutrients with precision, minimizing waste and runoff. E&C professionals not only design these systems but also construct the physical infrastructure— pipelines, pumps, filters, and sterilization facilities—that ensure efficient use of every drop of water. Beyond irrigation, drainage water treatment and recycling systems are now integral to sustainable farming. Runoff from greenhouses and fields can be captured, purified, and reused, preventing environmental contamination while conserving scarce resources. In this way, E&C does not merely support farming but redefines its ecological footprint.

Energy systems represent another crucial domain where E&C expertise transforms agriculture. Smart farming facilities require stable, efficient, and clean energy for automated operations, climate control, and lighting. Ground-source geothermal heat pumps allow for cost-effective heating and cooling of greenhouses, while waste heat recovery systems redirect surplus energy from nearby industrial facilities into farm operations. Solar arrays, placed on rooftops or in open fields, provide renewable electricity for monitoring and automation, and biomass digesters convert organic waste into biogas, creating a closed-loop cycle of energy production. These systems are not abstract ideas; they are

engineering realities built, maintained, and optimized by construction professionals. Through them, farms become self-sufficient and resilient energy systems in themselves.

The structural and civil aspects of farming also underscore the importance of E&C. Modern greenhouses are no longer simple shelters but advanced facilities designed to integrate robotics, hydroponics, and environmental control systems. Such structures require advanced engineering analyses to support heavy equipment and withstand climatic stresses. In parallel, civil works such as grading, drainage, and access roads enable autonomous machinery to function effectively and harvested crops to reach markets without delay. The construction of durable infrastructure ensures that smart farms are not only technologically advanced but also physically robust and future-ready.

Waste-to-resource systems further highlight how agriculture and E&C intersect to achieve sustainability. Engineering solutions for wastewater treatment enable the recovery of valuable nutrients such as nitrogen and phosphorus, which can be reused as natural fertilizers. At the same time, crop residues and organic waste are processed in anaerobic digesters to generate renewable biogas and digestate, closing the loop between production and resource recovery. Such systems transform what was once agricultural waste into energy and inputs, reducing environmental burdens while strengthening circular economies.

The application of these principles is already evident in real-world projects. An example can be found in Kyrgyzstan, where a five-hectare smart greenhouse complex was designed, constructed, and is now operated by DOHWA Engineering. The project integrates nutrient solution systems, wastewater recycling, geothermal heat pumps, and water treatment facilities to achieve higher yields at reduced operational costs. In one year alone, 350 tons of tomatoes were harvested and sold both locally and in neighboring markets. More importantly, the project became the first agricultural initiative to receive a Multilateral Investment Guarantee Agency (MIGA) guarantee. This recognition signaled to governments and financial institutions that smart farming is not an experimental concept but a form of critical infrastructure worthy of large-scale investment. The Kyrgyzstan case illustrates how E&C expertise can turn agricultural projects into bankable, sustainable ventures that can be replicated across developing regions.

A second case, in Spain's Almería region, demonstrates the indispensability of E&C at scale. Known as the "Sea of Greenhouses," this agricultural cluster covers more than 30,000 hectares and produces over 3.5 million tons of vegetables annually, much of which is exported to Europe.

However, its location in a semi-arid environment posed a severe water scarcity problem. The solution lay in massive engineering projects—desalination plants, water reclamation systems, and integrated water policies. Leading international E&C firms such as Sacyr, ACCIONA, and Ayesa provided the technical and financial capabilities required to implement these solutions. The success of Almería confirms a fundamental point: large-scale agricultural systems cannot exist without the technical, structural, and financial contributions of the engineering and construction industry.

Looking to the future, Asia—and particularly Indonesia—presents vast opportunities for scaling smart farming through E&C. Despite agriculture employing nearly one-third of Indonesia's workforce and contributing over 13 percent to GDP, more than half of the country's irrigation infrastructure is damaged and crop productivity has been declining at a rate of 1.5 percent annually. Recognizing this, the Indonesian government has allocated substantial investment to expand irrigation coverage by 2 million hectares, amounting to approximately USD 800 million. Moreover, smart agriculture has been identified as a priority within the National Development Plan for 2025–2029, with strong support from

the Ministry of Agriculture in building data platforms and financing programs for young farmers. International organizations such as the World Bank and the Asian Development Bank have also joined in, providing avenues for public–private partnerships and regional collaboration.

To ensure success, the expansion of smart farming in Asia requires an integrated approach. Engineering and construction firms must deliver the physical foundations: climate-resilient greenhouses, renewable energy systems, and advanced irrigation infrastructure. Technologies must be adapted to local conditions, with AI- and IoT-enabled fertigation and climate control systems tailored for tropical and monsoon climates. Policy frameworks must align land, water, and energy management while encouraging private investment through risk-sharing mechanisms. Finally, regional collaboration is essential to drive down costs and accelerate innovation through the sharing of research and expertise across Asia.

In conclusion, smart farming is no longer a futuristic concept but a present reality that requires the integration of engineering and agriculture. The challenges of climate change, water scarcity, and food security cannot be met by farmers alone; they require the technical, structural, and operational expertise of the E&C industry. The experiences of Kyrgyzstan and Spain prove that agriculture, when treated as infrastructure, can achieve sustainability, efficiency, and resilience at scale. The opportunities emerging in Indonesia and across Asia further suggest that the convergence of E&C and agriculture will define the future of food systems. As the demand for sustainable food production grows, engineering and construction are not peripheral actors but central architects of a new agricultural paradigm. Smart farming, supported by collaborative technologies and robust infrastructure, is set to become not only a driver of food security but also a critical new market for the global E&C industry.

"Outcry for National AI Policy in Nepal's Civil Engineering" A Comparative Study of FIDIC Asia Pacific AI Readiness

Mandakini Karki, Soil Test Consulting Engineers
Engineering Ethics to Build Nation, Copyright © 2025 Soil Test P.Ltd

ABSTRACT

Civil engineering aims to deliver practical, sustainable, and innovative solutions for infrastructure projects. The rapid integration of Artificial Intelligence (AI) represents a transformative development with intelligent automation replacing labor-intensive activities, offering significant contributions in planning, design optimization, simulation, and advanced decision-making that support both sustainability and economic growth.

A critical gap identified in the literature review is the absence of a regional benchmarking system comparable to global assessments for AI Policy of FIDIC (International Federation of Consulting Engineers) Asia Pacific member countries. Without such mechanisms, excellence remains concentrated in a few countries. Regional excellence must be driven by collective progress, because inequalities that privilege only a few high performing countries threaten the pursuit of balanced organizational development for FIDIC Asia Pacific.

To date, no equivalent benchmarking has been conducted at the regional level of FIDIC Asia Pacific.

To address this, the paper conducts a comparative analysis of AI policies across FIDIC Asia Pacific member countries, considering AI Policy release timelines, revisions, and underlying strategies. Based on the comparative analysis of AI Policy and the Oxford Insights Report 2024, this study proposes both ranking and a new categorization framework for FIDIC Asia Pacific. This study argues that the challenge lies not only in adopting AI, but in strategically integrating it within robust policy frameworks.

This paper examines the dimensional linkage between technological limitations in AI applications and systemic weaknesses in policy frameworks

This paper advocates for AI-driven transformation across the scope of civil engineering projects encompassing feasibility studies, planning, design, construction, operation, and maintenance thereby spanning the entire project lifecycle.

The paper reinforces the role of FIDIC Asia Pacific closely to regionalize AI initiatives and provide targeted support to member nations, thereby ensuring equitable and collective progress in the integration of AI within the civil engineering sector. Finally, paper sets strategy as per its categorization and draws conclusive advocacy to the government of these nations.

Keywords: *AI in Civil Engineering Projects, Gap in AI Implementation, Government AI Readiness Index, ToR, Scope of Works, Sustainability in Infrastructure Development, Policy Integration, Cost Overrun, Project Delay, Road Construction*

INTRODUCTION

The fundamental of civil engineering lies in designing practical, sustainable and innovative solutions, whether it be large or small infrastructure project. Labor-intensive, repetitive and time-consuming activities are being replaced by intelligent automation and productive solutions.

The accelerated integration of Artificial Intelligence (AI) represents a transformative breakthrough in the engineering sector. Lately, its contribution in planning, design optimization, simulation and advanced decision making has been skyrocketing promoting sustainable and economic growth.

Despite the advancement of AI, many countries of FIDIC Asia Pacific region lack effective policy, suitable technology, tools and resources to administer wide application of AI in civil engineering.

In this context, it is imperative to address the outcry from the civil engineering sector not merely for the adoption of AI, but for its strategic integration underpinned by robust policy frameworks. Such foundational reforms are essential to unlock the full potential of AI.

RESEARCH METHODOLOGY

This sections details on the methodology adopted during this research study. The methodology procedure is listed below:

k. **Gap Finding: This paper is an attempt to identify the underlying gaps in the usage of AI within civil engineering industry and advocates for its full utilization to achieve sustainable development practices.**

l. **Comparative Analysis: The paper undertakes a brief comparative analysis of AI polices across the FIDIC Asia Pacific member countries on factors such as their release timelines, revisions, and underlying strategies.**

m. **AI Readiness Ranking: The ranking of the FIDIC Asia Pacific member countries is undertaken as per AI Readiness Index published by Oxford Insights (2024).**

n. **Categorization: This paper proposes its own categories of the FIDIC Asia Pacific member countries based on its own finding.**

o. **Regional Cooperation: The paper dismisses the notion of "One Size Fits All". FIDIC and FIDIC Asia Pacific must cooperate to regionalize and support the member countries in context of AI Policies to collective progressiveness of the countries.**

p. **A strategical roadmap is proposed as the key tool for the FIDIC Asia Pacific member countries in each category to accelerate the AI adoption**

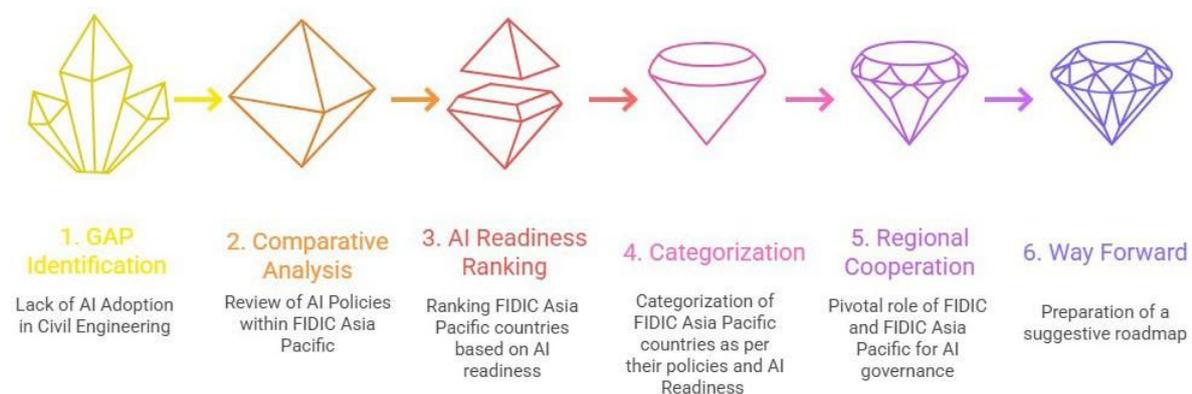| 1. GAP Identification	2. Comparative Analysis	3. AI Readiness Ranking	4. Categorization	5. Regional Cooperation	6. Way Forward
Lack of AI Adoption in Civil Engineering	Review of AI Policies within FIDIC Asia Pacific	Ranking FIDIC Asia Pacific countries based on AI readiness	Categorization of FIDIC Asia Pacific countries as per their policies and AI Readiness	Pivotal role of FIDIC and FIDIC Asia Pacific for AI governance	Preparation of a suggestive roadmap

Figure 2.1: Methodology adopted in the research

GAP IN USE OF AI AND TECHNOLOGIES IN CIVIL ENGINEERING IN NEPAL

The life cycle of an engineering project typically encompasses multiple phases, including feasibility assessment, planning, design, construction, and operation and maintenance. In the context of Nepal, the integration of advanced technologies and Artificial Intelligence (AI) remains limited across nearly all stages of the project cycle.

A comprehensive gap assessment of AI adoption across all engineering disciplines and project stages lies beyond the scope of this study. Instead, the paper concentrates on identifying deficiencies in the application of such technologies within selected domains of road infrastructure projects—namely, road construction, intelligent traffic management, and traffic survey operations.

FROM CONVENTIONAL TO AI-DRIVEN METHODOLOGY IN CIVIL ENGINEERING PROJECTS

There are several projects that are on the verge of becoming chronic and require upgrading their methodology to accomplish the required scope of works. Cost overrun and project delays are major challenges in infrastructures projects of Nepal, largely attributable to inadequate planning and minimal progress in execution.

The following section presents selected examples of current practices in road construction, intelligent traffic management, and traffic survey, and compares them with international projects where the application of Artificial Intelligence (AI) has facilitated substantial cost reduction and minimization of time delays.

q. Road Construction

One of Nepal's national pride projects, the Kathmandu–Terai/Madhesh Fast Track (KTFT), has become emblematic of chronic project delays, experiencing both cost and time overruns. Initiated in 2017 with an estimated budget of NPR 175 billion and a planned completion period of four years, the project's timeline has now been extended to 2027, with the revised cost estimate rising to NPR 211.93 billion.[65]

Narayanghat–Butwal Road Project has faced repeated deadline extensions and escalating costs. Initially scheduled for completion in July 2022, the deadline has been successively pushed to August 2023, July 2024, July 2025, and now July 2026, with only 69% overall progress reported as of July 2025.[66]

One principal common factor among these chronic projects is time overrun, primarily resulting from inadequate planning and scheduling. The use of AI-driven scheduling software to mitigate such challenges remains absent, to say nothing of AI-enabled site equipment.

China (a FIDIC Asia Pacific member country) in East Asia has recently completed 158 km section of Beijing-Hong Kong-Macao Expressway entirely using AI-operated equipment, drones, and machinery, without requiring human presence on site. This method demonstrated unparalleled advantages in efficiency, precision, and safety over traditional, labor-intensive road construction methods.[67]

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[65] https://risingnepaldaily.com/news/61163

[66] https://myrepublica.nagariknetwork.com/news/narayanghat-butwal-road-sees-only-69-percent-progress-as-deadline-nears-end-51-11.html

[67] www.highwaysindustry.com/china-just-resurfaced-158-km-of-highway-using-only-robots-and-drones/

Beyond the FIDIC Asia Pacific region, in the United States, an interstate highway reconstruction and widening project in the eastern region utilized the AI-based scheduling software ALICE to generate multiple scenarios, optimize the project plan, recover lost time, and ultimately finish ahead of schedule, achieving cost savings exceeding USD 25 million.[68]

r. **Intelligent Traffic Management System**

Nepal remains in the early stages of adopting Artificial Intelligence (AI) in traffic management. Currently, the Lalitpur Metropolitan City has installed smart traffic lights at only five locations, stressing the need for acceleration towards a fully integrated Intelligent Traffic Management System (ITMS).

In contrast, several FIDIC Asia Pacific member countries have made significant progress. India has implemented the Bengaluru Adaptive Traffic Control System (BATCS), which regulates traffic signals at 165 intersections using real-time traffic data to reduce delays and improve efficiency. Delhi Integrated Multi Modal Transit System (DIMTS) Ltd has deployed an Adaptive Traffic Control System (ATCS) at more than 170 intersections, with ongoing expansion to an additional 127 intersections. Comparable systems are operational in Pune, Jammu, Surat, Ahmedabad, and Srinagar.[69]

Singapore, a global leader in AI innovation, has established multiple AI-driven traffic management systems. Its Expressway Monitoring and Advisory System (EMAS) operates along 10 major arterial road corridors, detecting accidents, vehicle breakdowns, and other incidents via a network of cameras to enable rapid response and alleviate congestion.

The Green Link Determining (GLIDE) system, installed at approximately 2,700 intersections, dynamically adjusts signal timings based on traffic volume, extending green light phases to facilitate smoother traffic flow.

There are other AI-based systems such as Green Man+ for elderly and disabilities pedestrian assistance, Junction Electronic Eyes for strategic junction monitoring, Parking Guidance Systems for efficient parking utilization, Signalized Pedestrian Crossings for safety enhancement, and TrafficScan for real- time road network performance monitoring.[70] Together, these systems enhance traffic flow, improve network efficiency, and strengthen overall road safety.

s. **Traffic Count Survey**

Nepal has been conducting traffic count surveys since 1994, primarily through traditional on-site manual vehicle counting. The conventional on-site approach is gradually being replaced by video-based counting; wherein recorded footage is analyzed at office locations. Even the limited use of computers and cameras has yielded significant benefits, reducing manpower requirements by over 80% and overall costs by more than 65%. The traffic count survey remains a critical exercise, as it follows assessments derived from the International Roughness Index (IRI) and Surface Distress Index (SDI) forming the basis for determining the national budget allocation for periodic road maintenance.

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[68] https://blog.alicetechnologies.com/case-studies
[69] https://indiaai.gov.in/article/ai-and-traffic-control-in-india-revolutionizing-road-management
[70] www.lta.gov.sg/content/ltagov/en/getting_around/driving_in_singapore/intelligent_transport_systems.html

In order to enhance accuracy and efficiency while keeping pace with international best practices, the Highway Management Information System–Information and Communication should pronounce AI implementation with provision of budget into its Terms of Reference at project procurement stage.

While the use of cameras and computers enhances efficiency and accuracy by enabling verification of traffic count data, video-based counting remains resource-intensive compared to AI-enabled global standards. Limitations include poor performance in low-light conditions, reduced visibility during adverse weather, and lengthy data processing time.

In Vietnam, AI-based traffic counting has achieved an accuracy rate of 93.80% (Nguyen et al., 2022). The system employs a software-based method integrating a tracking algorithm with a Single Shot Detector (SSD) for object detection, and is currently deployed in District 10, Ho Chi Minh City due to its high accuracy.

Beyond the FIDIC Asia Pacific region, the United States, recognized as a global leader in AI has seen companies such as Omnisight successfully implement Fusion Sensor technology, which integrates HD3D radar with HD video for real-time traffic analysis and decision-making. These traffic monitoring systems are currently operational in cities including Phoenix and Richmond, with plans for nationwide expansion.[71]

Nepal needs to adopt AI-driven traffic survey methodologies to enhance efficiency, accuracy, and reliability while reducing reliance on manual intervention and aligning national practices with progressive sustainable standards. However, the success of such an initiative depends on collective efforts, requiring collaboration among stakeholders and organizational bodies, with strong leadership and initiation from the government playing a critical role.

LEVERAGING AI POLICY FOR CIVIL ENGINEERING TOWARDS SUSTAINABLE INFRASTRUCTURE DEVELOPMENT

AI needs to be mainstreamed into civil engineering practice through coherent national policy frameworks in order to accelerate the transition toward sustainable and resilient infrastructure systems.

The AI-driven methodologies in civil engineering projects leverage sustainability in any infrastructure development. AI into civil engineering projects optimizes resource utilization, minimizes environmental impact, and enhance quality of life.

With sufficient data, AI can analyze the historical patterns to forecast the required resources, anticipate fluctuations in project demands and evaluate potential risk scenarios, thereby supporting proactive and data-driven decision-making. Leveraging large-scale data, AI algorithms further optimize material allocation, labor management, scheduling, reducing delays and cost overruns.

The use of AI-based Intelligent Traffic Management System regulates traffic signals using real-time traffic volume data from all directions, prioritizing routes with higher congestion to facilitate smoother traffic flow and reduce delays. This not only improves mobility and quality of life but also reduces the overall carbon footprint, increases air quality and contributes significantly towards the sustainable future.

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[71] www.msn.com/en-us/news/technology/local-tech-firm-omnisight-revolutionizes-traffic-management-with-ai- at-intersections/ar-AA1B7kLt

Likewise, AI-powered traffic counting systems provide real-time data that enable engineers to make timely, evidence-based decisions to mitigate congestion and improve safety. By eliminating the need for manual surveys, these systems reduce project costs, shorten timelines, and increase operational efficiency—key attributes of sustainable infrastructure.

The observed shortfalls of AI applications in selected domains of civil engineering reveal not only technical and operational challenges but also systemic weaknesses in national policy formulation and implementation. To address this dimensional linkage, a brief comparative analysis of national AI policies among FIDIC Asia member countries is presented in Sections 6 and 7.

STATUS OF NATIONAL AI POLICIES OF FIDIC ASIA PACIFIC MEMBER COUNTRIES

This section presents a comparative analysis of the release and revision dates of AI policies among all member countries of the FIDIC Asia–Pacific region using a tabulation method. The timeline and status of policy publications for each country are examined to identify trends and gaps. While some countries have already updated and implemented comprehensive AI frameworks, others are still in the process of drafting mandatory AI-based regulations, and a few rely on voluntary standards designed to progressively guide and educate stakeholders. A clear observation is made on the timeline and status of the policies publication of each of the nation.

A tabulated of policy release dates and subsequent revisions year shows that several national policies and guidelines have not been updated for nearly a decade. This highlights how far behind some nations remain in adopting and upgrading their national AI policies. This is in-turn has been reflected with minimal implementation of AI in multi sectors including civil engineering.

AI policy should therefore be regarded as living instruments that require frequent revisions to capture the dynamic natures of emerging developments and risks. Instead of static documents revised only occasionally, policies need adaptive mechanisms that allow for timely updates in line with the accelerated progression of AI technologies.

The following table summarizes the national AI policies and guidelines of FIDIC Asia Pacific countries, with particular focus on their timelines and governance implications:

Table 6.1: Prevailing National AI Policies of FIDIC Asia Pacific Member Countries

S.No.	Country	National Policies/Guidelines	Date of Release*
1	Singapore	Smart Mobility 2030; Model AI Governance Framework; Singapore National AI Strategy 2.0 (NAIS 2.0)	2014; 2019; 2023
2	Republic of Korea	National Strategy for Artificial Intelligence	2019
3	Australia	Office of National Intelligence Act 2018; Voluntary AI Safety Standard; Policy for the responsible use of AI in government; National framework for the assurance of artificial intelligence in government	2023; 2024; 2024; 2024
4	Japan	AI Strategy	2022
5	China, Hong Kong	Generative Artificial Intelligence Technical and Application Guideline	2025
6	China, Taiwan	Taiwan AI Action Plan 2.0 (2023-2026); AI Basic Act (Draft)	2023; 2024
7	China	Next Generation AI Development Plan (2017-2030); New Generation of AI Ethics Code; Measures for the Management of Generative Artificial Intelligence Services 2023	2017; 2021; 2023

8	Malaysia	National Artificial Intelligence Roadmap (2021–2025); National Guidelines on AI Governance and Ethics (AIGE)	2021; 2024
9	Thailand	Thailand National AI Strategy and Action Plan (2022– 2027)	2022
10	Indonesia	National AI Strategy (2020–2045)	2020
11	New Zealand	New Zealand's Strategy for Artificial Intelligence	2025
12	India	National Artificial Intelligence Strategy	2018
13	Vietnam	National Strategy on Research, Development and Application of Artificial Intelligence	2021
14	Philippines	The National AI Strategy Roadmap 2.0 (NAISR 2.0)	2021
15	Uzbekistan	Uzbekistan Digital Economy Overview and Vision 2030	2020
16	Kazakhstan	Concept for Artificial Intelligence (AI) development in 2024-2029	2024
17	Bangladesh	National Strategy for Artificial Intelligence (2019–2024)	2019
18	Sri Lanka	Sri Lanka's National Strategy on AI (Draft)	2024
19	Iran	Comprehensive Document on the Development of AI in the Country	2024
20	Mongolia	National Strategy on Big Data and Artificial Intelligence	2025
21	Pakistan	National AI Policy; Digital Pakistan Policy	2025; 2018

* To the best available references in open source. Some countries might have updated version.

The comparative analysis of the key strategies of each nations' AI Policy is given below in section below.

KEY STRATEGIES OF NATIONAL AI POLICIES OF FIDIC ASIA PACIFIC MEMBER COUNTRIES

The policies and guidelines of each nation are based on their national goals and visions, socio-economic environments and pace of technological advancements. This section has attempted to draw the key strategies which forms as a basis for member countries of FIDIC Asia Pacific.

The underlying strategies for forming the National Policies/Guidelines of each nation within FIDIC Asia Pacific region are listed below in Table 7.1.

Table 7.1: Strategies of National AI Policies/Guidelines of FIDIC Asia Pacific Member Countries

S.No.	Country	Key Strategies	Remarks
1	Singapore	• Prioritize transparent and ethical AI usage to amplify human capabilities with AI education and training programs, infrastructural capacity development and fostering a trusted environment to enhance data security and innovation.	Robust AI Frame work
2	Republic of Korea	• Focus on leading the AI world by educating people and promoting innovative, responsible and ethical usage of AI. • Industry-specific plan for the development of AI	
3	Australia	• Shift from voluntary application of AI to governance, building public trust, balanced regulation with data protection and security, hence evolving and developing over time.	
4	Japan	• Incorporation of AI principles in private sectors. • Focus on human-centric, inclusive, sustainable, ethical and harmonized governance.	
5	China, Hong Kong	• Enhance resilience of the AI industry ecosystem • Ethical and responsible application of AI by ensuring human oversight for accountability of generative AI	

6	China, Taiwan	• Legally enforceable ethics with focus on education, public-private cooperation and international collaborations for sustainable, human-centric, transparent and equitable development	
7	China	• Centralized system with binding laws and mandatory AI governance • Focus on research, education and investment in key sectors to emerge into the AI landscape and global competitiveness.	
8	Malaysia	• Voluntary AI policy, not enforceable by law. • Focus on fairness, reliability, safety, privacy, inclusiveness, transparency, accountability and human benefit.	
9	Thailand	• Focus on innovation-based infrastructures and collaboration among public and private sectors • Promote AI usage for economic and sustainable development.	
10	Indonesia	• Strong set of open-government data, which supports localized modeling. • Prioritize health, governance, education, food and smart cities to promote the application of AI with strong ethical foundation	
11	New Zealand	• Focus on indigenous rights of Māori people, public consultation and collaborative development. • Investments in education, research and international partnerships to increase the adoption of AI.	
12	India	• Hybrid strategy of integrating state policies with private-sector innovation.	

There is a need for infrastructure-centered AI policy so that the dimensional linkage is drawn in the field of civil engineering industry. The existing policies are generalized with no targeted applicability and priority given to infrastructure specific civil engineering. This calls for a standalone AI policy in civil engineering works under AI for infrastructure. The inclusion of AI fundamentals in the existing curriculum of civil engineering and promoting dedicated AI courses in the application for civil engineers should be the one of strategy of AI adaptation process.

Innovative AI policies should be developed by learning the approach of developed countries that are in the front-line of AI advancement but not aligning exactly with their policies. Most of all, the AI algorithm and technologies should be based on the country's unique geopolitical condition, infrastructure, socio-economic demand and its priorities ensuring high data security and usage by trained professionals.

Inadequate AI policies, combined with fragmented governance structures, limit the ability of civil engineering institutions to adopt and integrate emerging technologies effectively.

Bridging the gap between technological potential and practical application therefore requires the development of coherent national AI policies, supported by institutional strengthening and capacity-building initiatives.

Joint research and development, collaborative initiatives with international aid, engagement in regional and global knowledge sharing platforms can benefit the developing countries in defining the regulatory frameworks to suit the local needs.

The direct adoption of international governance model might introduce risks and vulnerabilities in terms of data security or even significant administrative and financial burdens for least developed and developing countries.

The countries like Nepal and Maldives face significant challenges in balancing effective AI governance with the pursuit of innovation and advanced technologies. Limited digital infrastructure, socio-economic constraints, lack of skilled professionals, and insufficient data further hinder progress. Therefore, collaboration with regional and global AI leaders is vital to strengthen national AI strategies.

The developing countries should learn and integrate the strategies from international practices into its policy to align with the local needs.

A strategic road map or flow chat or tool for policy makers engineers including all the relative stakeholders should also be added in AI policies and guidelines. This will vary between countries due to their different standing position in AI policy. Some are leading the way while others are still catching up.

The section below successfully positions FIDIC Asia Pacific member countries in the realm of the Global AI readiness ranking. The paper attempts to dimensionally link the AI harnessing power of nation to its status of implementation on the civil engineering industry. The correlation of the nation's strength on applicability of AI policy onto civil engineering industry to that of AI policy that the nation is the basis of this analysis of the study as Infrastructure is one of the three indicators for AI Readiness,

POSITIONING FIDIC ASIA PACIFIC MEMBER COUNTRIES WITHIN THE GLOBAL AI READINESS

The readiness of government to incorporate AI in public services is measured every year in terms of Government AI Readiness Index. As per Oxford Insights (2024), there are 40 indicators across three core pillars depicting AI Readiness; Government, Technology Sector and Data & Infrastructure.

t. Global AI Readiness

The Government AI Readiness Index 2024 published by Oxford Insights categorizes countries around the world into nine regions reproduced in Table 8.1. North America leads the global AI landscape followed by Western Europe, East Asia, Eastern Europe, Middle East & North Africa, Pacific, Latin America & the Caribbean, South & Central Asia and Sub-Saharan Africa.

Table 8.1: Region-wise Global AI Readiness, 2024

S. No.	Region	Rank	Average Score
1	North America	1	82.60
2	Western Europe	2	69.56
3	**East Asia**	**3**	**57.95**
4	Eastern Europe	4	57.88
5	**Middle East** & North Africa	**5**	**48.50**
6	**Pacific**	**6**	**44.92**
7	Latin America & the Caribbean	7	42.99
8	**South & Central Asia**	**8**	**42.28**
9	Sub-Saharan Africa	9	32.70

Source: Government AI Readiness Index 2024, Oxford Insights

FIDIC Asia Pacific member countries are from East Asia, Middle East, Pacific and South & Central Asia. Table 8.2 outlines the regional categorization of these member countries.

Table 8.2: Regional Categorization of FIDIC Asia Pacific Member Countries

S. No.	Region	FIDIC Asia Pacific Member Countries
1	East Asia	Singapore, Republic of Korea, Japan, China Taiwan, China, Malaysia, Thailand, Indonesia, Vietnam, Philippines, Mongolia, China Hong Kong
2	Middle East	Iran
3	Pacific	Australia, New Zealand
4	South & Central Asia	India, Uzbekistan, Kazakhstan, Bangladesh, Sri Lanka, Pakistan, Nepal, Maldives

u. AI Readiness Ranking of FIDIC Asia Pacific Member Countries

This section presents the ranking of FIDIC Asia Pacific Member Countries based on the Government AI Readiness Index 2024 published by Oxford Insights. Singapore ranks highest among FIDIC Asia Pacific members, supported by a robust AI framework and strong institutional capacity.

In contrast, Nepal and the Maldives rank among the lowest, highlighting the urgent need for policy and framework reforms to harness the transformative potential of AI and related advanced technologies.

Table 8.3: Ranking of FIDIC Asia Pacific member countries based on AI Readiness Index, 2024

S. No.	Country	Rank among FIDIC Asia Pacific member countries	Overall Rank in the world (Oxford Insights)	Total Score* (Oxford Insights)
1	Singapore	1	2/188	84.25
2	Republic of Korea	2	3/188	79.98
3	Australia	3	10/188	76.45
4	Japan	4	12/188	75.75
5	China, Taiwan	5	16/188	74.58
6	China	6	23/188	72.01
7	Malaysia	7	24/188	71.4
8	Thailand	8	35/188	66.17
9	Indonesia	9	38/188	65.85
10	New Zealand	10	40/188	63.98
11	India	11	46/188	62.81
12	Vietnam	12	51/188	61.42
13	Philippines	13	56/188	58.51
14	Uzbekistan	14	70/188	53.45
15	Kazakhstan	15	76/188	51.41
16	Bangladesh	16	80/188	47.12
17	Sri Lanka	17	85/188	45.29
18	Iran	18	91/188	43.88
19	Mongolia	19	98/188	42.36
20	Pakistan	20	109/188	40.47
21	Nepal	21	150/188	33.14
22	Maldives	22	156/188	31.43
23	China, Hong Kong	no data available		

* The presented performance of two countries, China and China Hong Kong may be affected by limited data availability and reduced accessibility to relevant information (as per the publishers of the Government AI Readiness Index 2024).

v. AI Readiness Categorization of FIDIC Asia Pacific Member Countries

After a rigorous study and comparative analysis, this paper proposes its own categorization in order to assess how ready the FIDIC Asia Pacific member countries are in terms of facing the challenges and tackling the inevitable consequences that the AI will bring in the future. The categorizations are given below:

3.1. Category I: Robust AI Framework

The countries in the first quartile of AI Readiness Index as per Oxford Insights (1st to 47th position globally) are classified under category I. These countries have strategically prepared their AI policies/guidelines, hence possess robust AI framework.

The FIDIC Asia Pacific Member Countries under Category I are tabulated below.

Table 8.4: Countries with Robust AI Framework

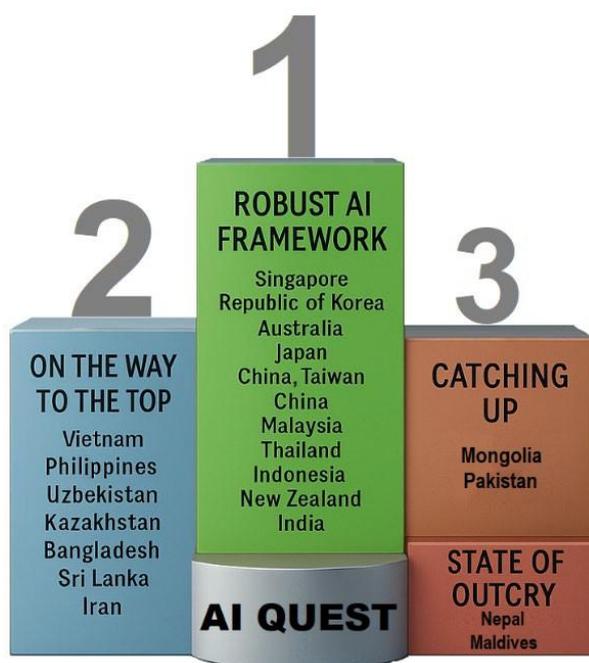| S.No.	Country	S.No	Country
1	Singapore	7	Malaysia
2	Republic of Korea	8	Thailand
3	Australia	9	Indonesia
4	Japan	10	New Zealand
5	China, Taiwan	11	India
6	China		

Figure 8.1: Categorization of FIDIC Asia Pacific member countries based on AI readiness of 188 countries

3.2. Category II: On the Way to the Top

The countries in the second quartile of AI Readiness Index as per Oxford Insights (48th to 94th position globally) are classified under category II. With emerging AI strategies, these countries focus on infrastructure, technological skills development and responsible AI usage. The countries are following the leaders and climbing their way to the top.

The FIDIC Asia Pacific Member Countries under Category II are tabulated below.

Table 8.5: Countries on the Way to the Top

S.No.	Country	S.No	Country
1	Vietnam	5	Bangladesh
2	Philippines	6	Sri Lanka
3	Uzbekistan	7	Iran
4	Kazakhstan		

3.3. Category III: Catching Up

The countries in the third quartile of AI Readiness Index as per Oxford Insights (95th to 141st position globally) are classified under category III. These countries are actively developing national AI policies focusing on budget to strengthen skills and introduction of emergent technologies. They are trying their best to catch up with those who are on the top.

The FIDIC Asia Pacific Member Countries under Category III are tabulated below.

Table 8.6: Countries Catching Up

S.No.	Country
1	Mongolia
2	Pakistan

3.4. Category IV: State of Outcry

The countries in the fourth quartile of AI Readiness Index as per Oxford Insights (142nd to 188th position globally) are classified under category IV. These countries are in alarming state and require urgent upgradation on their AI Policy Framework.

The FIDIC Asia Pacific Member Countries under Category IV are tabulated below.

Table 8.7: Countries in the State of Outcry

S.No.	Country
1	Nepal
2	Maldives

Based on above analysis, the AI readiness scores of the FIDIC Asia Pacific member countries are presented as per the categorization system developed by this research paper below in Figure 8.2.
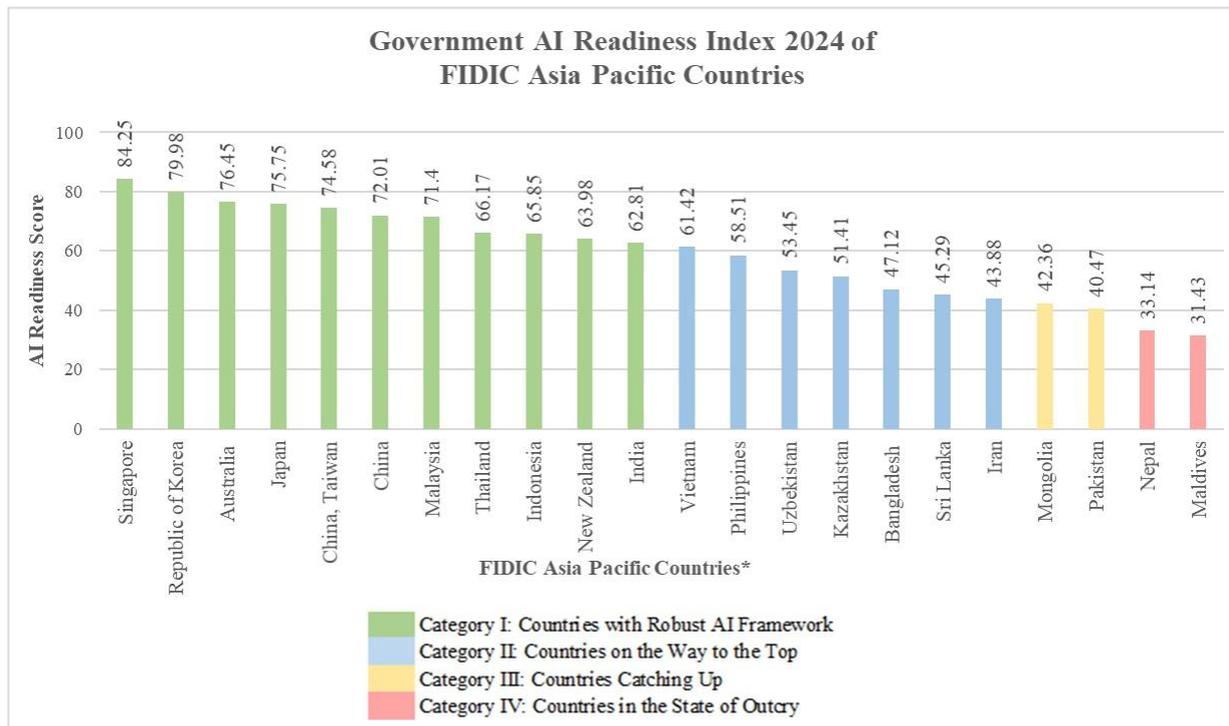

Figure 8.2: Government AI Readiness Index 2024 of FIDIC Asia Pacific Member Countries (Data Source: Oxford Insights)

* The presented performance of two countries, China and China Hong Kong may be affected by limited data availability and reduced accessibility to relevant information (as per the publishers of the Government AI Readiness Index 2024).

Overall, the South and Central Asian countries of the FIDIC Asia Pacific, particularly Nepal and Maldives exhibit a concerning state of AI readiness. These nations must accelerate their progress through robust policy development and effective governance to bridge the gap with global trends.

The recent approval of Nepal's National AI Policy (2025) in Nepal and ongoing draft of Maldives' AI Masterplan represent significant milestones in fostering the ethical and strategic application of AI. Although, it may not bring these countries on a par with international trends and AI driven advancements, such initiatives will certainly guide them through significant technological transformation in upcoming days.

REGIONAL COOPERATION THROUGH FIDIC AND FIDIC ASIA PACIFIC FOR AI GOVERNANCE

Although FIDIC and FIDIC Asia Pacific do not function as regulatory authorities, their influence on engineering standards and professional practices across member countries is significant. Leveraging this position, these organizations can play a pivotal role in advancing AI adoption and governance through a range of strategic measures:

1. **Facilitating Technology and Knowledge Transfer** – Encourage member countries with high AI readiness, particularly in Category I and Category II, to share AI platforms, technological innovations, and best practices with nations in the Category III and Category IV. Such exchanges would foster international collaboration, enabling mutual capacity building for both technologically advanced and developing nations. FIDIC can play a significant role via their conditions of contract adapted by countries like Nepal for execution of large infrastructure funded by Multilateral Development Banks (MDB).

2. **Developing Contractual AI Governance Templates** – Assist member countries in creating standardized templates for AI-related contractual clauses. These should address areas such as AI system usage, compliance requirements, accountability for AI-generated outputs, ethical AI application, and mechanisms to ensure transparency and responsibility.

3. **Promoting AI Integration in the Engineering Sector** – Advocate for and support the implementation of AI in engineering practices, including but not limited to enhancing construction site safety, optimizing resource management, improving quality control processes, and advancing project monitoring capabilities. This should be channelled through multistakeholder such as MDBs, Governments.

4. **Providing Targeted Capacity-Building Programs** – Conduct regular training programs for engineers, consultants, and other industry stakeholders focused on the effective and ethical application of AI in engineering projects. This should undertake with the support of member association, their government and FIDIC training Academy.

5. **Linking AI Compliance to Funding Eligibility** – It is recommended that verification of AI compliance be institutionalized as a mandatory criterion for accessing financial support from governments or donor agencies. Such conditionality would function as a regulatory incentive, ensuring adherence to established AI policies and governance frameworks while promoting responsible and standardized implementation.

WAY FORWARD - A SUGGESTIVE ROAD MAP WITH AI POLICY STATUS CATEGORIZATIONS

The section 8.3 of this research paper establishes an analytical framework that classifies FIDIC Asia Pacific countries into four categories according to their AI readiness index and their nations' AI policy. The proposed strategies for the way forward are aligned with these categorizations, ensuring relevance to each country's AI policy. The Table 10.1 below highlights the targeted pathways and measures that the policy makers can adopt to step into the AI integration. The framework proposes differentiated strategies aligned with each category's current status and capacity, thereby offering a progressive pathway for advancing AI integration in civil engineering and related sectors.

A suggestive strategy table is proposed as a practical tool for FIDIC Asia Pacific organization and also their member countries to advocate for implementation of AI via policy integration, facilitate monitoring, provide technical support, and deliver targeted training. Such a framework can accelerate the transition from conventional engineering practices to AI-driven approaches, ensuring more balanced and sustainable advancement across the region.

Table 10.1: Tabulation of way forward for countries under each category

S.No.	Category I: Robust AI Framework	Category II: On the way to the top	Category III: Catching Up	Category IV: State of Outcry
1	Ethical usage	Technological Literacy	Introduction of advanced software	Strengthen AI Governance
2	Encourage Public Private Partnership	Skills Enhancement	Budgeting	Official release of AI strategy
3	International Partnerships with developing countries for mutual capacity building	Accelerate Innovation	Research and Development	Update in Curriculum and Education
4	Innovating in robust AI Infrastructure	Technological Infrastructure Development	AI Research Papers	Encourage STEM Education
5	Open-source AI models		Data Cloud and Data Protection Measures	Connectivity and data availability
6				Collaboration among Client, Consultant and Contractor

Category I: Robust AI Framework

Category I countries are advised to consolidate leadership by ensuring ethical AI use, fostering public–private partnerships, enhancing international collaboration, and investing in robust infrastructure and open-source models.

Category II: On the Way to the Top

For countries progressing toward maturity, priorities include technological literacy, skills enhancement, innovation acceleration, and infrastructure development.

Category III: Catching Up

Countries in transition require software adoption, budget allocation, R&D investment, and the establishment of data protection frameworks supported by AI research outputs.

Category IV: State of Outcry

Nations at an early stage must first strengthen AI governance, publish national strategies, reform education and STEM curricula, and improve connectivity and collaboration within the engineering ecosystem.

The critical path for the countries in Category III (Catching up) and Category IV (State of Outcry) necessitates the adoption of a holistic framework for integrating artificial intelligence across all phases of civil engineering projects—from initial planning to project completion phase.

The category II member countries are suggested to prioritize technological literacy, with skill enhancement as the priority. The AI policy of these member countries is suggested to have directives to accelerate innovation for AI enhanced technological infrastructure development. While Category I countries are working to excel their innovation and partake in supporting the countries in other categories jointly with FIDIC Asia Pacific origination.

However, persistent challenges, including weak governance structures, limited technical capacity, and budgetary constraints continue to hinder the effective adoption of AI and advanced technologies in these contexts.

In addition to the strategies discussed, this paper advances the following conclusions:

w. **Institutional Governmental Frameworks: Governments should establish dedicated agencies or departments to strengthen procurement processes by embedding AI-related clauses and compliance conditions into Terms of Reference (ToR) from the earliest stages of project development.**

x. **Budget Allocation and Capacity Building: A defined share of project budgets should be earmarked for AI-enabled tools, structured training programs, and the development of a pool of AI specialists across member countries.**

y. **Curriculum and Advocacy: The inclusion of AI in civil engineering curricula is vital to strengthen foundational knowledge among young engineers. FIDIC and FIDIC Asia Pacific are urged to advocate for nations in the "catching up" and "outcry" categories, including consideration of a dedicated AI committee within the regional framework.**

z. **Call for AI Committee in FIDIC Asia Pacific: A newly formed AI committee should unify member countries by promoting integration, support, and exchange of expertise, given the novelty and rapid evolution of AI technologies.**

aa. **Professional Upskilling: Engineers must acquire proficiency in AI-powered project management software for real-time tracking, data analytics, resource allocation, and risk mitigation. Targeted upskilling programs, as well as restructuring workflows for consultants and contractors, will be necessary to align with AI-driven project execution.**

bb. **Global and Regional Collaboration: International bodies, particularly FIDIC and FIDIC Asia Pacific, have a critical role in enabling technology transfer, fostering cross-border collaboration, promoting ethical AI policies, and developing AI-oriented contracting models.**

cc. **Human–AI Collaboration: AI adoption should focus on complementing human expertise, enabling collaborative intelligence, and accelerating the transition to intelligent engineering practices. This paper recommends that FIDIC and its Asia Pacific branch encourage adoption of the generalized roadmap (Figure 10.1) to foster coordinated action among governments, engineers, consultants, and contractors. Nepal, despite its limited readiness, has expressed its willingness to collaborate with FIDIC, regional bodies, and global AI leaders to strengthen its AI foundation.**

dd. **Tiered Roadmap. The proposed framework emphasizes that uniform approaches to AI adoption are ineffective. Instead, tiered and context-specific strategies are required. While advanced countries should focus on refining and exporting innovations, those with limited readiness must prioritize governance, education, and infrastructure. Collectively, this staged approach promotes balanced and inclusive AI advancement across FIDIC Asia Pacific member countries.**

The figure representing the strategical road is the outcome of this research paper. It can serve as a guideline for FIDIC, FIDIC Asia Pacific and all the member countries.

Figure 10.1: Suggestive Roadmap with AI Policy Status Categorizations 2025 of FIDIC Asia Pacific member countries

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AI-Enabled Country Index for Overseas Green Energy Investment: Reshaping Intelligent International Investment Decision-Making
—A Case Study of Asia-Pacific Investors

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RESEARCH BACKGROUND

a. Dual Challenges of Global Energy Transition and Energy Security

As we enter the third decade of the 21st century, addressing climate change has become a global consensus. Guided by the temperature control targets set forth in the Paris Agreement, countries worldwide are advancing energy systems transformation toward clean, low-carbon, and sustainable pathways with unprecedented determination and scale.[72] The rapid development and cost reductions in green energy technologies—including solar photovoltaics (PV), wind power, and energy storage—have underpinned this profound energy revolution.

However, the path to energy transition is fraught with complexity. Recent geopolitical disruptions have led to severe volatility in global energy markets, repositioning energy security at the core of national strategies. Consequently, the global energy landscape today features two coexisting themes: accelerating the energy transition and ensuring supply security. In this context, cross-border green energy investment emerges not only as a blue ocean for corporate growth but also as a strategic imperative for countries seeking to diversify energy supply and reinforce industrial chain resilience.

b. Unique Opportunities and Perspectives for APAC Investors

The Asia-Pacific (APAC) region plays an indispensable role in the global green energy ecosystem. On one hand, it is the world's fastest-growing energy consumer, characterized by enormous electricity demand gaps and abundant renewable resource endowments—such as hydropower and solar in Southeast Asia, and wind and solar in Australia. On the other hand, APAC countries, led by China, Japan, and South Korea, have established themselves as epicenters of green energy technologies, equipment manufacturing, and capital export.

For APAC-based investors, overseas green energy investment holds distinctive strategic significance. Beyond capital flows, it represents a systemic export of technological standards, supply chain advantages, and management expertise. Nevertheless, APAC investors also confront unique challenges in their outbound endeavors: navigating complex political and legal landscapes in target countries, integrating with local cultures and business practices, and aligning overseas projects efficiently with their robust domestic supply chains. This highlights the urgent need for an investment evaluation system that fully reflects APAC investors' concerns and integrates regional considerations such as the Belt and Road Initiative (BRI) and the Regional Comprehensive Economic Partnership (RCEP).

c. Research Questions and Core Objectives

While the market potential for overseas green energy investment is vast, inefficiencies in decision-making arise from information asymmetry, limited evaluation dimensions, and delayed risk identification, constraining investment effectiveness and success rates. Existing country risk

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[72] Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., & Zhou, B. (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the IPCC. Cambridge University Press.

evaluation models—from international rating agencies and energy organizations alike—fail to fully satisfy the dynamic complexity of today's market and the personalized needs of investors.

This study hence focuses on a pivotal question: How can we construct an AI-powered, intelligent decision-support framework that integrates multidimensional dynamic information, aligns with distinct investor requirements, and possesses forward-looking predictive capabilities, thereby enhancing the scientific rigor and success probability of overseas green energy investments?

The primary objective of this research is to design and validate the **Overseas Green Energy Investment Country Index**, an AI-powered quantitative scoring model that transcends traditional static assessments. Leveraging artificial intelligence, this framework offers APAC and global investors a dynamic, transparent, interactive, and highly customizable decision tool—establishing a new paradigm for international investment decision-making.

INDUSTRY LANDSCAPE AND REVIEW OF EXISTING EVALUATION METHODOLOGIES

d. Global and APAC Green Energy Investment Landscape

Global investment in green energy has sustained rapid growth in recent years. According to the International Energy Agency (IEA), global clean energy investments are projected to reach USD 2 trillion in 2024, nearly double the investment in fossil fuels.[73] Solar PV and wind power remain the primary investment sectors. The APAC region has outperformed others in this trend, contributing nearly half of the global newly added renewable energy capacity, while dominating key supply chain segments.

Despite this, investment distribution remains highly uneven geographically. Large capital inflows concentrate in a few developed economies, whereas developing economies with tremendous potential receive disproportionately less investment relative to their resource endowments and demand. This uneven allocation reflects a prevalent risk-averse stance among investors when confronting unfamiliar markets due to inadequate evaluation mechanisms.

e. Analysis of Existing Mainstream Investment Evaluation Approaches

Current overseas investment evaluation methodologies predominantly originate from international credit rating agencies and global energy organizations.

International Credit Rating Agencies: Moody's, Standard & Poor's (S&P), and Fitch have incorporated environmental, social, and governance (ESG) factors into their sovereign and corporate credit rating frameworks. For instance, Moody's employs a cross-disciplinary ESG risk methodology, delivering Issuer Profile Scores (IPS) to quantify exposure to various risks.[74] Nonetheless, their core logic remains anchored in "credit-risk-repayment" perspectives designed primarily for debt investors, emphasizing default probabilities. This approach presents limitations for equity investors seeking long-term operational returns and strategic value.

International Energy Organizations: Bodies such as the IEA and the International Renewable Energy Agency (IRENA) publish authoritative data on national energy policies, market statistics, and technological trends. For example, IRENA's Global Renewables Outlook provides macro-level guidance on national energy transition paths. These organizations excel in data comprehensiveness and

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[73] International Energy Agency, World Energy Outlook 2024 , IEA Publishing.
[74] Moody's Investors Service, Environmental, Social, and Governance (ESG) Factors in Credit Ratings Methodology, 2023.

credibility but generally provide macro-policy advice or data aggregation without delivering structured micro-level decision support tailored to specific investment projects.

f. Four Fundamental Limitations of Existing Evaluation Models

Detailed analysis reveals four systemic shortcomings in guiding contemporary green energy investments:

1. Insufficient Policy and Country Adaptability

Conventional models typically evaluate policy environments with static scoring, treating regulatory conditions as fixed snapshots. This fails to capture the policy lifecycle—from promulgation, implementation, and revision to potential repeal. Given green energy investment's heavy reliance on subsidies, tax incentives, and power purchase agreements (PPA), even minor policy fluctuations can jeopardize project viability. Existing frameworks lack mechanisms for dynamic monitoring and early warning of policy continuity and enforcement, resulting in evaluations disconnected from reality.

2. Lack of Multidimensional Factor Integration

The success of green energy investments depends on complex, nonlinear interactions between multiple factors. For instance, excellent solar resource endowment is insufficient if antiquated grid infrastructure cannot absorb generated power or if there is a shortage of skilled installation and maintenance personnel. Reviews of existing approaches show disconnected assessment of such elements; for example, S&P may account for resource reserves without linking that to downstream supply chain readiness or financial innovation. This "linear additive" evaluation method fails to reveal the nonlinear coupling between policy, resource endowment, industrial maturity, and technology pathways, leading to misjudgments in overall investment value.

3. Inadequate Mapping of Investor-Specific Needs

Traditional frameworks predominantly reflect creditor perspectives. In contrast, equity investors—especially APAC strategic investors with industrial linkages—seek long-term stable returns, manage currency exchange risks, ensure repatriation of profits, optimize supply chain synergies, and assess real geopolitical operational risks. While Fitch's project-level analysis touches on revenue risk, it does not precisely align outputs with investors' unique risk preferences, investment horizons, and strategic goals—creating a disconnect between model results and actual investor decision-making requirements.

4. Low Level of Dynamism and Intelligent Automation

Most existing models rely on annual or quarterly reports with lagging data updates. However, green energy markets shift rapidly: a breakthrough battery technology may disrupt the energy storage segment within months; critical mineral price spikes such as lithium or cobalt can alter supply cost structures; and unforeseen political events could invalidate existing plans overnight. Making decisions based on static data is thus akin to "carving a mark on a boat." Notably, present methodologies lack the deployment of AI-driven real-time data acquisition, high- frequency analytics, and predictive foresight to meet the demands of contemporary investment decisions.

AI-POWERED INTEGRATED EVALUATION FRAMEWORK WITH AN APAC INVESTOR FOCUS

To effectively overcome the limitations of traditional methods, this study proposes an AI-driven, comprehensive evaluation framework tailored for APAC's green energy investment landscape. By scientifically designing multidimensional indicators and leveraging advanced data mining techniques, the framework aims to enhance evaluation comprehensiveness, objectivity, and foresight.

g. Design of Primary Indicator Dimensions

At the highest level, the framework comprises five mutually reinforcing, holistically covering core dimensions to ensure both breadth and depth:

1. **Macroeconomic and Business Resilience: Evaluates the stability of the national economic foundation and its recovery capability in response to external shocks.**
2. **Energy Transition Commitment and Policy Credibility: Measures governmental political will to advance the green transition, alongside policy coherence and enforcement robustness.**
3. **Green Resource Endowment and Infrastructure: Assesses the abundance of solar, wind, and other natural resources in conjunction with supportive grid and logistics infrastructure.**
4. **New Energy Market Dynamism and Innovation Ecosystem: Examines market competitiveness, technology adoption rates, industry chain completeness, and financing environment.**
5. **Geopolitical Connectivity and Regional Cooperation: Analyzes the country's geopolitical context, trade relationships, and participation in regional energy collaborations.**

h. AI-Driven Indicator Construction

The framework's core innovation lies in harnessing AI—particularly natural language processing (NLP)—to extract alternative indicators from vast unstructured textual data, thereby deepening insights into critical dimensions like energy transition commitment and policy credibility.

- **NLP Policy Sentiment Analysis: To quantify the otherwise intangible indicators of "policy stability" and "execution willingness," the framework deploys a finely tuned RoBERTa model trained on extensive specialized corpora. This model conducts deep semantic analysis of official policy documents, government press releases, and ministerial speeches from target countries. Surpassing basic keyword matching, it captures nuanced textual meaning and sentiment, applying multi-level sentiment scoring that converts ambiguous policy rhetoric into quantifiable metrics.**
- **NLP Risk Event Monitoring: Traditional annual risk assessments miss emergent, abrupt risk events. To address this, an AI-powered risk event auto-monitoring system is implemented. Employing NLP event extraction techniques, the system scans real-time global news flows and industry reports to identify and score the frequency and severity of critical adverse events such as "community protests," "supply chain disruptions," and "policy shifts," generating dynamic risk alerts.**

AI Empowerment—Architecture and Implementation of the Intelligent Decision Support System

A cutting-edge evaluation framework requires a robust underlying technological system. This chapter details the core technical architecture and implementation pathways underpinning the AI-powered intelligent decision support system, with an emphasis on AI applications in automated data flows and dynamic weighting.

i. Construction of AI-Enabled Automated Data Flows

The system foundation rests on efficient, precise automated data pipelines that emphasize not just coverage but also data quality. AI is leveraged principally to resolve common data processing challenges.

- **AI Data Cleaning and Enhancement Techniques: In preprocessing, simplistic approaches such as mean or median imputation are discarded, as they distort original distribution and time-series characteristics. Instead, an innovative "intelligent missing value imputation" strategy is employed: a LightGBM regression model is trained to predict and fill missing values using the full historical and current data of all related indicators for the same entity. This method produces a scientifically sound estimation of missing data, preserving input quality for subsequent modeling.**

j. Machine Learning–Driven Dynamic Weighting

Assigning scientifically valid weights to hundreds of granular indicators is arguably the most challenging aspect of index construction. Departing from subjective expert-driven weighting, this framework adopts a data-driven machine learning approach that allows the market dynamics themselves to dictate factor significance.

- **Model Training Process: The central principle is learning from historical data what truly drives capital inflows. Training features comprise historical multidimensional country indicators over the past 5–10 years, with green energy foreign direct investment (FDI) flows within the corresponding periods serving as labels. Using high-performance models such as gradient boosting trees, the system autonomously uncovers complex relationships between features and investment outcomes. Careful application of cross-validation safeguards against overfitting and ensures model generalizability.**

Compared with traditional subjective weighting, this AI-driven approach offers distinct advantages: it is objective, as weights derive entirely from historical data without human bias; dynamic, allowing periodic retraining to adapt to market shifts; and capable of detecting nonlinear drivers and intricate variable interactions beyond the reach of simple linear combination models.

CONCLUSION AND FUTURE OUTLOOK

k. Summary

This study confronts fundamental pain points in current overseas green energy investment decision-making, offering a comprehensive critique of traditional evaluation methods. Building on this foundation, it proposes and substantiates an innovative country evaluation framework powered by AI and tightly aligned with APAC investor priorities. The framework integrates policy coordination, industrial chain resilience, financial environment, and technological potential through a "rule-based pre-screening plus four-dimensional evaluation" logic. It also details the application of cutting-edge AI techniques—including NLP, knowledge graphs, and time series forecasting—to overcome systemic deficiencies in dynamism, integration, practicality, and anticipation inherent in conventional methods. This research not only advances academic discourse but also establishes a clear theoretical and technical blueprint for developing next-generation intelligent decision support systems in investment circles.

l. Future Prospects

Looking ahead, the continued evolution and deployment of this research framework will pursue several key trajectories:

- **Continuous Model Iteration and Explainability Enhancement: Algorithmically, exploration of more advanced Transformer architectures and reinforcement learning models will be pursued to improve predictive accuracy and decision optimization. Parallel development of explainable AI (XAI) techniques aims to demystify model decision processes and generate interpretable attribution analyses, boosting investor confidence in AI recommendations.**
- **Model Open Sourcing and Development of a Proprietary Overseas Green Energy Investment Database: Future efforts will promote ongoing open-source releases of the model to enhance universality and transparency, enabling APAC investors to implement localized deployments and custom upgrades. Leveraging Zhongzi Company's extensive international new energy project experience, a comprehensive overseas green energy investment database characterized by authoritative sources, regular updates, and rich content will be constructed. This database will tightly integrate with the model, fostering an open innovation ecosystem galvanizing APAC investors' input on indicators and methodologies—jointly building an open-source green energy investment model and regional database.**
- **Platform Commercialization and Ecosystem Building: Aggressive promotion of prototype system development and deployment will ensue, collaborating with leading investment firms, energy enterprises, and policy research institutions to validate and refine the model in real-world investment decisions. The ultimate ambition is to establish the AI-Powered Overseas Green Energy Investment Country Index as a periodic, authoritative benchmark report, cultivating broad industry influence, encouraging data and insight sharing, and forging an open, collaborative, mutually beneficial global green energy investment support ecosystem— contributing wisdom and capability toward achieving global carbon neutrality goals[75].**

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[75] United Nations Conference on Trade and Development (UNCTAD), World Investment Report 2024.

System Assurance (SA) in Public Transit Projects

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Benedict Indran has more than 40 years of experience as an engineer with the last 30 years being in the implementation of railway and transit system projects.

He has been involved in the design, planning, feasibility study, construction management, testing and commissioning of light rail, heavy rail, high speed and rapid bus systems.

As part of railway and transit project implementation, he has been involved as team leader in the scope of system interface, system integration, system assurance, verification and validation. Currently, Benedict Indran is Corporate Vice President of Minconsult.

Nur Hafizah Basiron, Minconsult, Malaysia

Nur Hafizah Basiron has over 14 years of experience in engineering consultancy within the railway industry, with extensive involvement in light rail projects, project management, engineering procurement, planning, feasibility studies, system assurance, construction, authority liaison, system–civil interfaces, and field support during project pre-closure. Currently focused on system assurance (Reliability, Availability, Maintainability, Safety) for railway systems and civil works in Jakarta LRT Phase 1B.

Darys Imandar, Minconsult, Indonesia

Darys Imandar has over two years of experience in the transport sector, with a background in civil and mobility engineering. He has been involved in railway and transport planning projects, with expertise in system assurance, (Reliability, Availability, Maintainability) safety, and data-driven transport analysis. He is currently working as a System Assurance Engineer for light rail transit project in Jakarta, Indonesia. He holds a Master's degree in Mobility Engineering from Politecnico di Milano and a Bachelor's degree in Civil Engineering from the University of Indonesia.

BACKGROUND

This paper presents the framework, benefits, challenges and some way forward for 3D data capture and BIM adoption in planning, design and construction of utility infrastructure in land development projects. Within the backdrop of digital technologies in general (and BIM in particular coupled with 3D data capture

The development of system assurance as a process parallels the increasing complexity and criticality of technology in certain essential infrastructure such as in a rail transit system. While the core concepts of ensuring quality and reliability have existed for centuries, system assurance as a formal discipline emerged in the 20th century, driven by the demands of complex and safety critical projects where the effects of an accident could be disastrous.

QUALITY CONTROL

The fundamental idea of assurance can be traced back to ancient civilizations and the medieval guilds. These early practices focused on quality control through inspections and standardized procedures to ensure products met a certain standard. The Industrial Revolution introduced mass production, which necessitated new approaches to quality control. These approaches emphasized standardized processes and inspections to maintain quality in large-scale manufacturing.

The early 19th century saw the introduction of **statistical process control (SPC).** This had the development of control charts provided a scientific method for monitoring and improving quality, a key precursor to modern quality assurance methodologies.

SYSTEMS ENGINEERING AND ADVANCEMENTS

The term "systems engineering" itself originated in the 1940s to manage the complex, interdisciplinary projects of the time. This holistic approach, which considers the entire system lifecycle, laid the groundwork for a broader understanding of assurance.
Following World War II, the rebuilding of industries, particularly in Japan, was heavily influenced by quality assurance that promoted a more comprehensive, collaborative approach to quality management, which emphasized continuous improvement and a focus on the entire process, not just the final product.

THE EMERGENCE OF SYSTEM ASSURANCE IN CRITICAL FIELDS

The formalization of system assurance as a distinct discipline was primarily driven by the need for high-confidence systems in critical domains like defence, aerospace, and nuclear power.

- **Military and Aerospace: In the 1960s, the military's development of complex systems like the Safeguard Anti-Ballistic Missile System led to the creation of Independent Verification and Validation (IV&V). This process, where an independent team verifies that a system meets its requirements and validates that it fulfils its intended purpose, became a cornerstone of system**

assurance. NASA's software assurance programs also emerged from this period, driven by the need for reliable, mission-critical software.

- **Safety and Security: The history of system assurance is also marked by tragic failures. The Therac-25 incident in the 1980s, where a radiation therapy machine's software malfunctioned with fatal consequences, highlighted the critical importance of software safety assurance. This incident and others like it demonstrated that assurance needed to move beyond just quality and reliability but to encompass safety and security.**

MODERN SYSTEM ASSURANCE

Today, system assurance is a multifaceted discipline that extends beyond traditional quality control. It is defined as the justified confidence that a system functions as intended and is free of exploitable vulnerabilities throughout its lifecycle. This confidence is achieved through a planned, systematic, and multidisciplinary set of activities.

Modern system assurance is characterized by:
- **Holistic Approach: It considers the entire system, including hardware, software, human factors, and the environment in which it operates.**
- **Risk-Based: Assurance activities are tailored to the specific risks of the project, focusing on areas with the highest potential for failure or negative impact.**
- **Assurance Cases: This approach, which gained prominence in recent years, involves building a structured argument and providing evidence to demonstrate that a system meets its safety, security, or other assurance requirements.**
- **Integration with Modern Methodologies: System assurance is no longer a separate, end-of-project activity. It is integrated into modern development methodologies where continuous testing, monitoring, and validation are essential.**

In essence, the history of system assurance has evolved from a focus on inspecting products to a comprehensive, ongoing process of building confidence in the entire system, especially in an era where technology is deeply embedded in our most critical and everyday functions.

QUALITY ASSURANCE AND SYSTEM ASSURANCE RELATIONSHIP

Quality assurance (QA) and system assurance are closely related but distinct concepts**. Quality assurance is a critical component of system assurance.** System assurance is the broader, more encompassing discipline, and quality assurance provides the foundational activities and processes that help build the overall confidence that a system is trustworthy.

Here's a breakdown of their relationship:
Quality Assurance (QA)

- **Focus: QA focuses on the process of creating a product or service. Its goal is to prevent defects from occurring in the first place by establishing and following a set of planned and systematic activities.**
- **Key Activities: QA includes a wide range of activities such as:**
  - **Defining quality standards and procedures.**
  - **Process audits and inspections.**
  - **Training and documentation.**
  - **Continuous process improvement.**

- **Outcome: The primary goal of QA is to ensure that a product or service is created correctly, according to established standards and requirements. It provides confidence that the development process itself is sound.**

SYSTEM ASSURANCE
- **Focus: System assurance focuses on the entire system as a whole, throughout its entire lifecycle. Its goal is to build justified confidence that the system functions as intended, is free of exploitable vulnerabilities, and meets all its specified requirements (including safety, security, and reliability).**
- **Key Activities: System assurance encompasses a much broader range of activities than QA, including:**
  - **All of Quality Assurance's activities.**
  - **Safety Assurance: Activities to ensure the system will not cause harm.**
  - **Security Assurance: Activities to ensure the system is protected from malicious**
  - **attacks and unauthorized access.**
  - **Reliability, Maintainability, and Availability (RMA) Assurance: Activities to ensure the system is dependable over time.**
  - **Independent Verification and Validation (IV&V): An independent team's assessment to confirm the system meets its requirements and serves its purpose.**
  - **Assurance Cases: Developing a structured argument and providing evidence to demonstrate that the system is trustworthy.**
- **Outcome: The outcome of system assurance is a high degree of confidence and evidence that the system as a whole is fit for its intended purpose in its operational environment.**

QA AS A PILLAR OF SYSTEM ASSURANCE

The best way to visualize the relationship is to see quality assurance as a foundational pillar that supports the larger structure of system assurance.

- **QA Contributes to System Assurance: By ensuring that the processes for designing, developing, and manufacturing a system are robust and well-controlled, QA helps prevent a wide range of potential problems. A system built with a strong QA foundation is more likely to be reliable, secure, and safe.**
- **System Assurance Extends Beyond QA: While QA is crucial, it's not enough on its own. For example, a quality-assured software development process might produce a high-quality product that meets its specified requirements, but those requirements might not adequately address critical safety or security concerns. System assurance would step in to ensure that those critical concerns are addressed, validated, and assured.**
- **System Assurance is the "Why": System assurance is concerned with the ultimate question: "Can we trust this system?" Quality assurance is one of the key "hows" that helps answer that question: "We can trust it, in part, because it was built using a well-defined and controlled process that is designed to prevent defects."**

THE STANDARD FOR SYSTEM ASSURANCE

The authors of this paper are familiar with the Standard of control for the Systems Assurance process that is being employed during the whole lifecycle of a railway or transit system which is EN 50126 1999: Railway Applications – The Demonstration and Specification of Reliability, Availability, Maintainability and Safety (RAMS). This Standard provides details on the requirements of the Systems Assurance process during Design, Construction, Installation, Operation and Decommissioning, that is throughout the whole lifecycle of the transit system project.

SCOPE OF SYSTEM ASSURANCE

The scope of System Assurance of a transit system covers the system assurance activities and integrated system of Design, Construction & Installations (C&I), Testing & Commissioning (T&C), Trial Running and the Commercial Operation. This system assurance activities cover the following:

a. **Railway Systems**
1. **Power Supply System.**
2. **Signalling and Train Control System.**
3. **Third Rail System.**
4. **Platform Screen Door (PSD).**
5. **SCADA Power.**
6. **SCADA Facility.**
7. **Telecommunications.**
8. **Automated Fare Collection (AFC).**

b. **Civil and Architectural**
1. **Linear Infrastructure.**
2. **Trackwork.**
3. **Stations, depots and ancillary buildings including building services.**

TERMINOLOGY AND DEFINITIONS

Implementing a transit system project and operating one is incredibly complex, composed of numerous subsystems (e.g., signaling, power, rolling stock, communications) that must work together seamlessly. System assurance terminology provides a standardized way to describe and manage the relationships, interfaces, and dependencies between these components. Public transportation projects are inherently safety-critical. A failure in one system can have catastrophic consequences.

Transit system projects and operations are heavily regulated, and projects must comply with a wide range of national and international standards. A specific vocabulary is essential to ensure consistent interpretation and application of these standards.

Standardized terms prevent misunderstandings and ensure everyone is working toward the same goals, from the initial design phase to operations and maintenance. As such, system assurance adopts certain terminology and definitions to describe an understanding among project team members and the operator of the transit system. Some terminology is defined in table below.

| Term	Definition
Assurance	Confidence in achieving a goal being pursued. Declaration intended to give confidence.
As Low as Reasonably Practicable (ALARP)	A principle that allows safety efforts to be focused on relevant topics and decisions to be made when safety efforts are deemed sufficient.
Audit	Systematic, independent, documented process for obtaining records, statements of fact or other relevant information and accessing them objectively to determine the extent to which specified requirements are fulfilled.
Availability	The probability of a system or component to perform its required functions under stated conditions at a given point in time.

Corrective Maintenance	Corrective Maintenance covers the repair of defective equipment/system and will be confined to modular or equipment replacement at station
Failure	A Failure is an event which causes loss of function or performance within any part of the system and requires a maintenance intervention to restore full functionality and performance
Maintainability	The probability that a failed component or system will be restored or repaired to a specified condition within a period of time. It is the probability of repair in a given time.
Mean Time to Repair (MTTR)	The average time to restore equipment system and sub-system to full functionality
Preventive Maintenance	Preventive Maintenance include routine servicing, periodic inspections, Equipment fault diagnosis and module replacement and will be done on a planned schedule to disclose and rectify potential; faulty condition and to prevent machine breakdown at stations
Reliability	The probability of a system or component to perform its required functions under stated conditions for a specified period time. Reliability can also be expressed as the number of failures over a period
Safety	Freedom from unacceptable hazards.
Safety Integrity Level (SIL) Assessment	The process of analysis and testing to determine whether the system / product performing the safety function us able to achieve the allocated SIL requirements.
System Assurance	The planned an systematic set of activities that assure systems engineering process and products conforms with system requirements for safety, reliability, maintainability, standards, procedures and regulations.
Validation	Confirmation, through the provision of objective evidence, that the requirements for a specific intended use or applications have been fulfilled.
Verification	Confirmation, through the provision of objective evidence, that specified requirements have been fulfilled.

PROJECT LIFECYCLE

System Assurance activities are present during all phases of the design lifecycle through to commissioning as shown in the standard V-lifecycle for the project lifecycle. The broad project stages are:

1. **Concept & System Requirement Specification.**
2. **Preliminary Design (PD) / Final Design (FD).**
3. **Construction and Installation (C&I).**
4. **Testing & Commissioning.**
5. **Handover to operator and the warranty.**
6. **Operations.**
7. **Decommissioning at the end of lifecycle.**

The project development lifecycle program as described in EN 50126 is shown in the diagram below:

EN 50126 Lifecycle (V-Diagram)
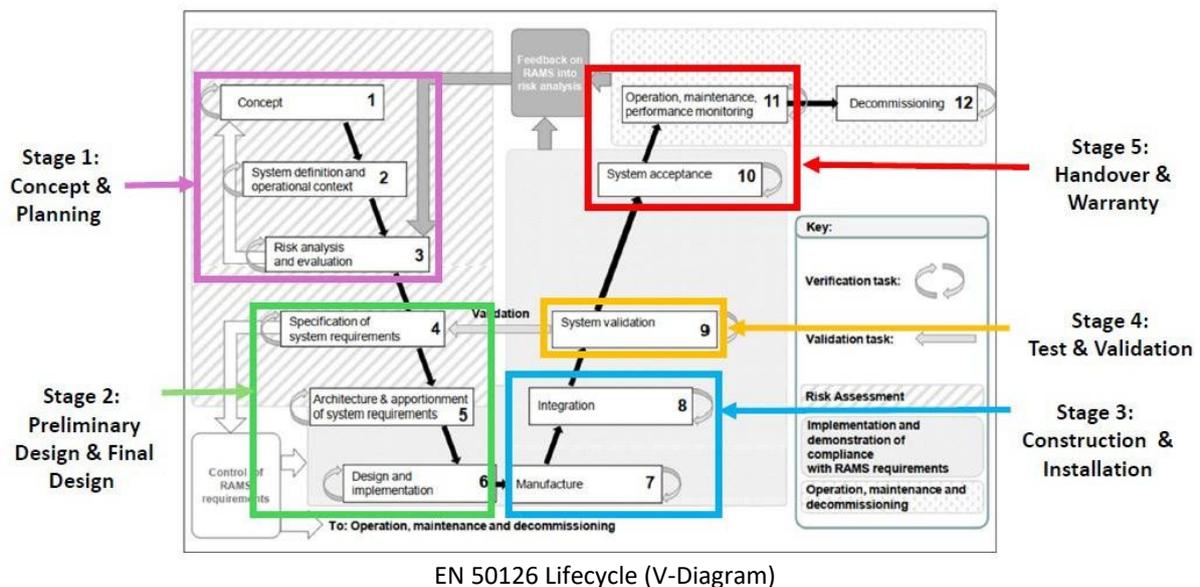
OUTCOME OF SYSTEM ASSURANCE

The implementation of system assurance practices throughout the transit system project lifecycle has proven to be a critical factor in ensuring safety, reliability, availability, and maintainability of the system. By integrating system assurance from the early design stages through to testing, commissioning, and operations, a transit project would have achieved a structured, traceable, and auditable pathway toward compliance with relevant international standards (e.g., EN 50126/50128/50129).

When implemented correctly, the system assurance process could enhance and achieve several aspects:

1. **Improved Compliance and Risk Management**

The application of systematic SA processes enabled early identification of hazards, functional risks, and operational constraints. This will lead to timely implementation of mitigation measures, reducing the likelihood of late-stage design changes and rework.

2. **Enhanced Reliability, Availability & Maintainability (RAM) Performance**

RAM targets established in the early concept and design stages would have been consistently monitored and verified through progressive reviews and audits. This would enable the transit system to meet or exceed contractual RAM requirements, resulting in reduced operational disruptions and higher passenger service reliability.

3. **Strengthened Stakeholder Confidence**

Regular system assurance audits, transparent reporting, and alignment with both civil and system interface requirements enhance confidence among stakeholders that includes the client, regulatory authorities, and the public.

4. Efficient Lifecycle Integration

By embedding SA activities across all lifecycle stages — from concept design to pre-closure — the project minimized integration issues between subsystems, particularly at the system–civil and system–system interfaces. The relationship between RAMS and LIFE Cycle Cost (LCC) is very close because RAMS directly affects the total LCC of a system. The reliability, availability, and maintainability of a system directly influence maintenance costs, component replacement costs, and repair costs, all of which are important factors in calculating the LCC of a system. The integration of RAMS and LCC can help determine the Key Performance Indicators (KPIs) of a system so that the system's performance can be known and used as a tool in decision-making throughout the transit system's lifecycle.

WAY FORWARD

a. **Early Involvement is Crucial — System Assurance team members must be engaged from the project's initiation to effectively influence design and procurement decisions.**
b. **Close Interface Coordination — Collaboration between all disciplines and operation teams is key to avoiding scope gaps and ensuring compliance.**
c. **Data-Driven Assurance — Using quantitative methods, such as reliability growth models and fault tree analysis, enables more objective performance validation.**
d. **Standards as Guiding Frameworks — International standards should be adapted to project-specific needs while maintaining compliance requirements.**

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