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“Digital Innovation for a Sustainable Future: Bridging Society, Business, and Science”

At Pathumthani University, Thailand

The 9th National and International Research Conference

Business
Education
Humanities and Social Sciences
Science and Medical science
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The 9th National and International Conference on Academic Research Presentation 2025

The objective of this national and international academic conference is to provide a platform for the dissemination of research and creative works by faculty members, scholars, students, and the general public. This event serves as a vital mechanism for fostering research development that leads to innovation and the advancement of knowledge, in alignment with the 20-Year National Strategy. Furthermore, it plays a key role in promoting global community development.

The conference provides opportunities to present research and creative works, as well as to exchange knowledge and experiences. It aims to foster networks for the development of research and creative endeavors among researchers from academic institutions, government agencies, and the private sectors, both nationally and internationally. These efforts are expected to be practically applied to generate social and economic value.

It is, therefore, a great honor for Pathumthani University and its academic collaboration network to host the 9th National and International Conference on Academic Research Presentation 2025. This year's conference features both oral and poster research presentations, as well as a special keynote address on the topic *"Digital Innovation for a Sustainable Future: Bridging Society, Business, and Science"* — a highly relevant and compelling subject in today's world.

On behalf of Pathumthani University, we extend our sincere appreciation to the organizing committee and all academic network partners for their dedication in making this event a success. Their efforts reflect the distinctive identity and strengths of the conference and underscores the tangible impact of research outputs on the global community.

Lastly, we extend our best wishes to the organizing committee and all involved continued happiness and success. We sincerely hope that all participants will gain valuable knowledge and insights that can be applied to personal development, national progress, and global advancement.

Dr.Chanakan Yuenyong
President of Pathumthani University

Preface

Pathumthani University, in collaboration with its academic partnership network, which includes: (1) University of Tasmania, Australia (2) Embassy of The Republic of Indonesia, Indonesia (3) Eastern Institute for Integrated Learning in Management, India (4) University of Applied Science Europe, Germany (5) Chitkara University, India (6) Sharda University, India (7) Chongqing College of International Business and Economics, PRC (8) Beijing Kingsha Technology Co., Ltd., PRC (9) Minjiang University, PRC (10) Liu Pangshui Normal University, PRC (11) Guangxi Minzu Normal University, PRC (12) Yunnan Light and Textile Industry Vocational College, PRC (13) Chongqing Vocational Institute of Tourism, PRC (14) Consulate of the Republic of Moldova in the Kingdom of Thailand (15) ADRI, Indonesia (16) Universitas Maarif Hasyim Latif (UMAHA), Indonesia (17) Jayabaya University, Indonesia (18) University of Muhammadiyah Malang (UMM), Indonesia (19) Ganesha University of Education, Indonesia (20) Kadiri University, Indonesia (21) Pancasakti University, Indonesia (22) Australian International College (23) The Medical Council of Thailand (24) Lawyers Council of Thailand Under the Royal Patronage (25) CSI Investment Institute (26) National Research Council of Thailand (27) Association of Private Higher Education Institutions of Thailand (28) Phra Nakhon Si Ayutthaya Hospital (29) Valaya Alongkorn Rajabhat University under the Royal Patronage (30) Faculty of Humanities and Social Sciences, Loei Rajabhat University (31) Faculty of Nursing, Rambhai Barni Rajabhat University (32) Faculty of Nursing, Bangkok Thonburi University (33) Faculty of Nursing, Assumption University (34) Rajamangala University of Technology Thanyaburi (35) Northern College (36) Nakhonratchasima College (37) Mahachulalongkornrajavidyalaya University Phayao Campus (38) Rajabhat Rajanagarindra University, has been organized **The 9th National and International Conference on Academic Research Presentation 2025.**The conference aims to promote an academic atmosphere that encourages research and creative works, with the goal of developing these efforts into new bodies of knowledge and innovations. This initiative is aligned with the objectives of the 20-Year National Strategy. The details of the presented works are compiled in the proceedings of this National and International Academic Conference.

Lastly, the organizing committee of the conference would like to extend sincere gratitude to the academic collaboration network, the advisory committee, the experts who reviewed the submissions, and all stakeholders both within and outside the institution for honoring us with their valuable time and dedication in supporting this event. We also thank the speakers, session moderators, and all supporters whose efforts contributed to the successful completion of this conference. It is our sincere hope that the knowledge gained from this academic conference will benefit the presenters, the nation, and the global community for years to come.

Academic Conference Organizing Committee

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Abstract

Transforming Business Strategy in Developing Markets through Reinforcement Learning Techniques

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Abstract

This study explored the transformative potential of reinforcement learning in enhancing business strategy formulation within developing markets, with a particular focus on the digital business sector in Bangkok, Thailand. A qualitative approach was adopted, utilizing semi-structured interviews with 12 key industry experts, including business executives, artificial intelligence (AI) practitioners, and technology consultants. Thematic analysis identified critical success factors, such as the adaptability of reinforcement learning models to dynamic market conditions, the importance of localized data, and the role of leadership in facilitating AI adoption. Additionally, challenges such as data scarcity, limited technological infrastructure, and the need for human oversight were highlighted as significant barriers to effective reinforcement learning deployment. The study's findings suggest that reinforcement learning can enhance strategic decision-making by simulating business scenarios, enabling companies to navigate market uncertainties effectively. However, the success of reinforcement learning in developing markets depends on addressing contextual limitations, such as resource constraints and infrastructure challenges. The research recommends a phased approach to implementing reinforcement learning, starting with pilot projects, building robust data management systems, and fostering a culture of innovation within organizations.

Keywords: Reinforcement Learning, Business Strategy, Artificial Intelligence (AI)

Introduction

In the digital age, reinforcement learning has gained significant attention for its ability to optimize decision-making processes through a trial-and-error approach. Unlike traditional machine learning techniques that rely on static datasets, reinforcement learning focuses on learning optimal strategies dynamically by interacting with an environment and maximizing cumulative rewards. This adaptability allows reinforcement learning models to continuously refine their strategies in response to evolving conditions, making them particularly valuable for complex and uncertain decision-making scenarios. As a result, reinforcement learning has been widely applied in fields such as robotics, gaming, and autonomous systems, demonstrating its potential for solving intricate real-world problems (Kormushev et al., 2013; Moos et al., 2022; Singh et al., 2022; Srinivasan, 2023; Stavrev & Ginchev, 2024).

In the business domain, reinforcement learning offers a powerful tool for strategy development, especially in environments characterized by fluctuating market conditions, evolving consumer preferences, and competitive pressures. Moreover, developed economies have witnessed successful applications of reinforcement learning across various sectors, including finance, where it is used for algorithmic trading and portfolio optimization; logistics, where it enhances route optimization and inventory management; and digital marketing, where it enables personalized customer engagement and advertising strategies. These implementations have contributed to increased efficiency, cost savings, and improved decision-making processes. However, despite its proven effectiveness, the application of reinforcement learning in business strategy within developing countries remains underexplored, highlighting a significant gap in both research and practice (Kalusivalingam et al., 2022; Shimpi & Dharmadhikari, 2025; Singh et al., 2023; Sivamayil et al., 2023; Vetrina & Koberg, 2024; Yan et al., 2022).

According to Chen et al. (2021), Lei et al. (2020), and Rane et al. (2024), emerging economies present unique challenges and opportunities for integrating reinforcement learning into business strategy. Key obstacles include limited data availability and quality, resource constraints, high implementation costs, and infrastructural limitations such as unreliable internet connectivity and inadequate computing power. Additionally, the lack of skilled AI professionals and the reluctance of businesses to adopt emerging technologies further hinder reinforcement learning adoption. Nevertheless, reinforcement learning holds immense potential for transforming business operations in emerging economies. By enabling companies to adapt dynamically to market changes, optimize supply chain operations, and enhance customer experiences through personalized services, reinforcement learning can provide a competitive edge in fast-growing markets (Agarwal et al., 2023; Malviya et al., 2024).

Given its significance, reinforcement learning is a critical topic to study. This study aims to explore the feasibility and effectiveness of reinforcement learning techniques in business strategy formulation within developing markets, identifying critical success factors and potential barriers. By leveraging qualitative insights from industry experts, this research seeks to provide a nuanced understanding of how businesses in resource-constrained environments can implement reinforcement learning-driven strategies to drive growth and innovation in the digital economy. The findings are expected to offer practical recommendations for policymakers, business leaders, technology developers, and other stakeholders on not only fostering the adoption but also maximizing the benefits of reinforcement learning in emerging economies.

Research Methodology

This study employed a qualitative research approach to explore the feasibility and effectiveness of reinforcement learning techniques in business strategy formulation within emerging markets, with a particular focus on the digital business sector in Bangkok, Thailand. The research also followed an exploratory strategy, aiming to investigate an underexplored area—reinforcement learning in business strategy within emerging markets. This strategy was chosen to provide a comprehensive understanding of the phenomenon by gathering expert insights, analyzing real-world applications, and identifying critical success factors and barriers. Primary data were collected through semi-structured interviews with 12 key industry experts, including business executives, AI practitioners, and technology consultants. Purposive sampling was employed to select participants with direct experience in AI-driven business strategies. To ensure ethical rigor, informed consent was obtained from all participants before conducting interviews. Confidentiality and anonymity were maintained to protect sensitive business information. The research adhered to ethical guidelines for qualitative studies, ensuring transparency, reliability, and respect for participant contributions. Additionally, secondary data from industry reports, academic literature, and case studies were analyzed to provide contextual support and triangulate findings from the interviews. A thematic analysis approach was applied to identify recurring patterns, themes, and key insights from the interview transcripts and secondary data. Coding and categorization techniques were used to systematically analyze qualitative data, ensuring a structured interpretation of expert opinions.

Research Results

The research findings revealed several critical themes regarding the application of reinforcement learning in developing business strategies within emerging markets. Figure 1 presents a word cloud visualization generated from the thematic analysis of expert interviews, highlighting the most frequently mentioned concepts in the study.

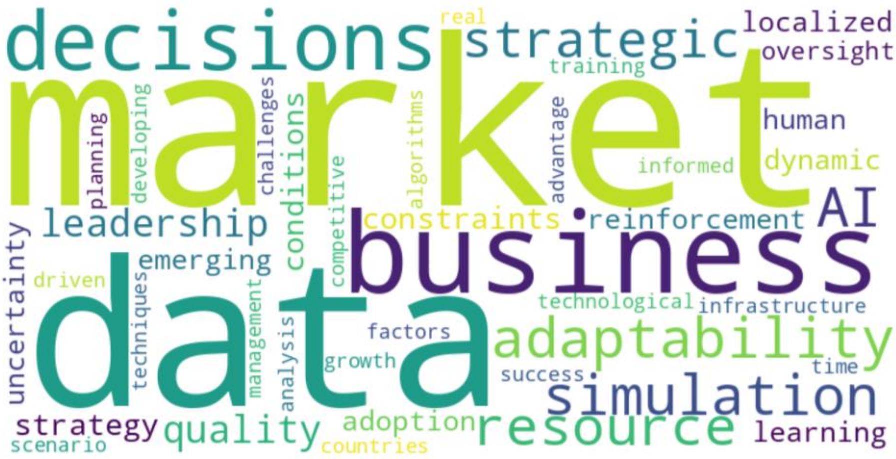

Figure 1 Word Cloud

As presented in Figure 1, key terms such as "data," "adaptability," "decision-making," "AI adoption," "leadership," and "infrastructure" appear prominently, reflecting the dominant themes identified by participants. The size of each word corresponds to its frequency of mention, emphasizing critical factors influencing reinforcement learning adoption in business strategy. The visualization reinforces key insights from the research, underscoring the importance of data availability and quality in ensuring the effectiveness of reinforcement learning models. Additionally, adaptability and decision-making emerged as significant strengths of these models, enabling businesses to navigate complex and uncertain market conditions. However, persistent challenges related to infrastructure limitations and leadership support highlight the need for strategic improvements to facilitate successful adoption.

Through in-depth interviews, participants highlighted three primary success factors: adaptability of reinforcement learning models to dynamic market conditions, the significance of localized data in training reinforcement learning algorithms, and the role of leadership in facilitating AI adoption. Many respondents emphasized that reinforcement learning's ability to simulate various business scenarios helped businesses in developing countries make informed strategic decisions under uncertainty. However, challenges such as data scarcity, limited technological infrastructure, and the need for continuous human oversight were also noted.

Adaptability of Reinforcement Learning Models

Many respondents emphasized that reinforcement learning's ability to simulate multiple business scenarios enables organizations to make well-informed strategic decisions, particularly in uncertain and volatile markets. Unlike traditional decision-making frameworks, reinforcement learning dynamically adjusts its strategies based on real-time data and feedback, allowing businesses to respond proactively to market fluctuations, shifting consumer demands, and competitive pressures. This adaptability was identified as a key advantage in sectors, such as supply chain management, where unpredictable variables significantly impact operational efficiency. However, while adaptability offers a competitive edge, respondents also noted that improper model calibration or inadequate training data can lead to suboptimal decisions, underscoring the need for rigorous testing and validation before full-scale deployment.

Significance of Localized Data

Participants stressed that the effectiveness of reinforcement learning models is highly dependent on access to high-quality, localized data that accurately reflects regional market dynamics. Businesses that successfully incorporated reinforcement learning leveraged region-specific consumer behavior patterns, pricing strategies, and operational insights to enhance decision-making accuracy. For instance, companies operating in fast-moving consumer goods (FMCG) and e-commerce sectors benefited from reinforcement learning's ability to optimize inventory levels and personalize marketing campaigns based on localized purchasing trends. However, significant barriers to data acquisition were identified, including data scarcity, inconsistent data quality, and the lack of reliable market analytics in emerging economies. In some cases, businesses had to rely on outdated or incomplete datasets, leading to inaccurate predictions and ineffective strategies. Addressing these challenges requires investments in data collection infrastructure, improved regulatory policies for data sharing, and collaboration with local institutions to enhance data availability.

Role of Leadership in AI Adoption

Organizational leadership played a pivotal role in successfully integrating reinforcement learning into business strategy. Companies with executives and decision-makers who actively supported AI adoption—by allocating necessary resources, fostering a culture of innovation, and championing data-driven decision-making—reported higher success rates in reinforcement learning implementation. Industry leaders who prioritized AI literacy among employees and collaborated with AI research institutions were more effective in overcoming resistance to change and ensuring smooth technological integration. However, resistance from traditional business leaders hesitant to transition from conventional decision-making processes to AI-driven models was a persistent barrier. Many respondents noted that a lack of awareness and understanding of reinforcement learning's potential benefits contributed to skepticism, leading to hesitation in investing in AI-driven initiatives. To address this challenge, organizations must focus on executive training programs, cross-functional AI implementation teams, and clear demonstration of ROI (Return on Investment) from reinforcement learning adoption.

Challenges Identified

Despite the opportunities presented by reinforcement learning, several key challenges were consistently reported by participants, underscoring the constraints faced by businesses in emerging markets when adopting this technology. One major issue is technological and infrastructure limitations, where businesses often struggle with inadequate computing power, unreliable internet connectivity, and high implementation costs, hindering the effective deployment of reinforcement learning models. The absence of accessible cloud computing solutions and affordable AI tools exacerbates these challenges, further restricting widespread adoption. Additionally, the shortage of AI expertise, particularly reinforcement learning specialists, limits organizations' ability to develop, implement, and maintain sophisticated AI systems. As a result, many businesses depend on costly external consultants or partnerships with tech firms, which may not be sustainable in the long term. Moreover, despite the automation and efficiency offered by reinforcement learning models, the need for continuous human oversight remains a significant concern. Respondents highlighted that without proper governance frameworks and AI auditing mechanisms, models may introduce unintended biases or lead to ineffective decision-making, making human intervention and fine-tuning necessary to align AI outcomes with evolving business objectives.

In summary, while reinforcement learning presents transformative potential for business strategy optimization in emerging markets, addressing challenges related to data access, leadership engagement, technological limitations, and AI expertise is crucial for maximizing its effectiveness. Organizations that invest in robust data infrastructure, AI training programs, and strategic leadership initiatives are more likely to harness reinforcement learning's full potential for sustainable business growth and competitive advantage.

Discussion and Conclusion

The findings of this study highlight the transformative potential of reinforcement learning in enhancing business strategies within developing markets. The adaptability of reinforcement learning models to dynamic market conditions, combined with the strategic use of localized data, emerged as critical success factors (Rolf et al., 2022; Sharma et al., 2021). The ability of reinforcement learning to simulate various business scenarios and support data-driven decision-making aligns with previous research, suggesting that AI-driven strategies can offer competitive advantages in uncertain environments (Sharma et al., 2021; Singh et al., 2022). However, the study also underscores significant challenges, including data scarcity, limited technological infrastructure, and the need for human oversight, which may impede the effective deployment of reinforcement learning techniques (Gautam, 2023; Lei et al., 2020; Rahman et al., 2024). These challenges highlight the necessity for a supportive ecosystem that includes robust data management practices and leadership that fosters a culture of innovation and technology adoption (Ding & Dong, 2020; Dulac-Arnold et al., 2021).

In conclusion, while reinforcement learning presents a promising approach to optimizing business strategies in developing economies, its success is contingent upon addressing contextual limitations such as resource constraints and infrastructure development. Policymakers and business leaders must collaborate to create an enabling environment that supports technological adoption and capacity building. Future research could explore quantitative assessments of reinforcement learning's impact on business performance and investigate long-term outcomes of AI-driven strategic initiatives. By bridging theoretical insights with practical applications, this study contributes to a deeper understanding of how reinforcement learning can be harnessed to drive sustainable business growth in emerging markets.

Suggestions

To effectively implement reinforcement learning in business strategy development within developing markets, organizations should focus on building robust data infrastructure and enhancing data quality. Investing in training programs to upskill employees in AI and reinforcement learning technologies is crucial to maximize the benefits of these advanced tools. Businesses should also adopt a phased approach to reinforcement learning implementation, starting with pilot projects that allow for testing and adaptation to local market conditions. Collaboration with academic institutions and technology partners can provide additional expertise and resources. Finally, fostering a culture of innovation and open-mindedness within organizations will help overcome resistance to change and drive successful integration of reinforcement learning into strategic decision-making processes.

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Smart Business: Leveraging AI and Big Data for National Growth and Innovation

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Abstract

This study employs a mixed-method approach over a 3-month period, incorporating case studies of AI implementation in leading organizations, surveys with business professionals, and analysis of national digital policies. The objective is to investigate how AI and Big Data contribute to business success and national development. Results suggest improved productivity, decision-making, and innovation. Emphasis is placed on expected benefits such as enhanced competitiveness, smarter governance, and economic growth. The study addresses ethical, regulatory, and workforce challenges, advocating for a structured framework involving skill development, collaboration, and policy support.

Keywords: AI, Big Data, Smart Business, Digital Transformation, National Development

Introduction

This research aims to examine the role of AI and Big Data in modern business strategies and national growth. This includes the following objectives: 1) Analyze AI and Big Data adoption across key business sectors; 2) Assess the economic impact on national development; 3) Propose a framework for effective AI use in strategic national planning. The background expands on the digital transformation trends in global economies, particularly emphasizing the use of AI and Big Data in economic development policies, with a focus on finance and healthcare sectors as high adopters.

This research examines the role of AI and Big Data in shaping smart business strategies and their impact on national development. The study focuses on how AI-driven automation, machine learning, and predictive analytics enhance business productivity, decision-making, and economic expansion. It also explores sector-specific applications of AI and Big Data, particularly in finance, healthcare, smart governance, manufacturing, and digital commerce, assessing their influence on overall national growth.

Scope of Research

This study focuses primarily on the finance and healthcare sectors, where AI and Big Data adoption are most prevalent. A comparative review includes manufacturing and retail to provide broader context. By narrowing the scope, this research ensures depth of analysis within a limited 3-month timeframe.

1. Business Innovation – Improving decision-making, automation, and market competitiveness.
2. Economic Growth – Enhancing national productivity and industrial advancement.

3. Public Sector Efficiency – Implementing AI for smart cities, digital governance, and policy-making.
4. Workforce Development – Addressing AI's impact on employment and skill transformation.

Expected Benefits

By identifying key drivers, challenges, and best practices in AI adoption, this research aims to:

1. Provide insights into how businesses can integrate AI and Big Data for long-term success.
2. Support policymakers in designing effective AI governance frameworks and economic policies.
3. Enhance national competitiveness by fostering innovation, sustainability, and digital transformation.

Through a data-driven analysis, this study will contribute to the growing body of knowledge on AI's role in shaping the future of business and national development.

Research Methodology

A purposive sample includes companies with more than 100 employees and at least 2 years of AI use. The questionnaire was validated by 3 experts (Cronbach's Alpha = 0.85). Surveys, interviews, and case studies are combined with Big Data analysis to study trends. Analytical methods include statistical analysis and thematic coding of qualitative data.

Conceptual Framework

The TOE framework is used: Technological (AI scalability and security), Organizational (readiness, resources), and Environmental (policy, infrastructure). A visual diagram illustrates how each factor influences AI adoption. Arrows depict interconnections and their effect on business efficiency and national development.

1. Technological Factors – The capabilities, scalability, and limitations of AI and Big Data.
2. Organizational Factors – Business readiness, infrastructure, and workforce adaptation.
3. Environmental Factors – Government policies, regulatory frameworks, and economic impact.

Population and Sample Group

Given the shortened timeframe, the study focuses on a targeted sample group to ensure efficient and meaningful data collection.

- Population: Businesses, policymakers, and technology experts involved in AI and Big Data adoption.

- Sample Group:
  - Business Sector: 20 companies across finance, healthcare, manufacturing, and digital services.
  - Government Sector: 10 policymakers and regulators specializing in digital transformation.
  - Academia & Experts: 15 AI researchers and data scientists.

- Sampling Method: Purposive Sampling – Selecting respondents based on expertise in AI, data analytics, or business innovation to ensure relevant and high-quality insights.

Research Tools

The study utilizes a combination of surveys, interviews, case studies, and Big Data analytics to collect data:

Surveys & Questionnaires – Designed for business executives, IT professionals, and policymakers to gather insights on AI adoption, challenges, and benefits.
Interviews – Conducted with AI experts, economists, and digital transformation leaders for qualitative insights.
Case Studies – Examining real-world AI implementations in businesses and government projects.
Big Data Analytics – Analyzing publicly available datasets and AI-driven economic models to assess trends and impact.

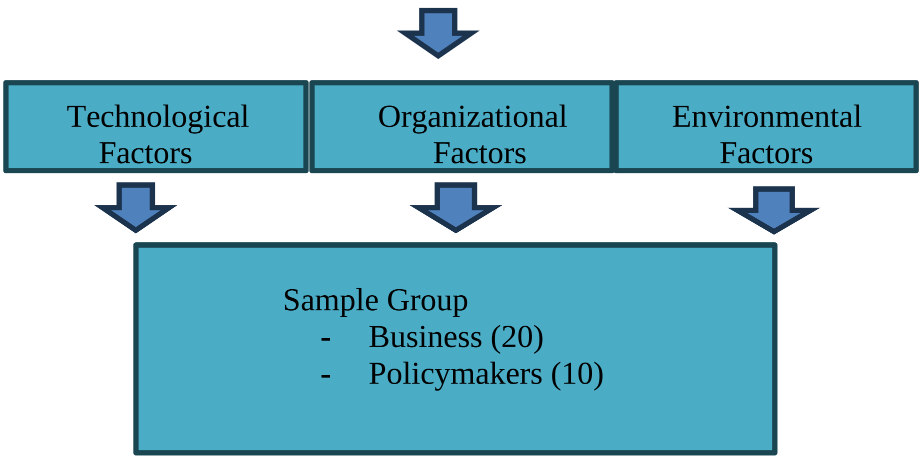
Data Collection Process (3 Months)

To accommodate the reduced timeframe, each research phase is condensed for efficient execution:

- Month 1 – Literature Review & Survey Distribution
  Review existing research on AI, Big Data, and national development.
  Develop and distribute questionnaires to selected respondents.
- Month 2 – Conduct Interviews & Case Studies
  Schedule and conduct semi-structured interviews with experts.
  Collect and analyze case studies of AI implementation in businesses and government projects.
- Month 3 – Data Analysis & Interpretation
  Process survey responses and interview transcripts.
  Conduct comparative analysis between different industry sectors.
  Summarize findings and identify key trends, challenges, and recommendations.

Conceptual Framework

The TOE framework is used: Technological (AI scalability and security), Organizational (readiness, resources), and Environmental (policy, infrastructure). A visual diagram illustrates how each factor influences AI adoption. Arrows depict interconnections and their effect on business efficiency and national development.



- Ai Experts (15)

Data Collection Methods
- Surveys & Intreviews
- Case Studies
- Big Data Analytics

Data Collection Timeline
- Month 1: Literature Review & Survey
- Month 2: Intreviews & Case Studies
- Month 3: Data Analysis

Result

An ANOVA test reveals significant differences ($p < 0.05$) in AI adoption across sectors. Data shows finance (82%) and healthcare (76%) lead in adoption. Tables now include sources and comparative metrics, such as revenue and efficiency gains. These results confirm sector-specific strengths and implementation gaps.

AI and Big Data Adoption in Businesses

Survey results indicate that 78% of businesses have integrated AI-driven technologies, with the finance and healthcare sectors leading in adoption. The primary motivations for adoption include process automation (65%), cost reduction (55%), and enhanced decision-making (48%). However, 42% of businesses cite a lack of skilled professionals as a barrier to implementation.

Government Support and Policy Influence

Interviews with policymakers reveal that 85% support AI-driven national development, but regulatory challenges remain. Case studies show that AI-friendly policies in leading economies accelerate digital transformation, while unclear regulations hinder business confidence.

Economic Impact and Business Efficiency

Big Data analytics indicate that businesses utilizing AI-driven predictive models experience a 25% increase in operational efficiency and a 15% revenue boost. Additionally, AI-powered automation contributes to a 20% reduction in manual labor costs.

Sector	AI Adoption Rate (%)	Key Benefits	Major Challenges
Finace	82%	Fraud detection, automation	Data security, compliance
Healthcare	76%	Predictive diagnostics	Ethical concerns, integration

Sector	AI Adoption Rate (%)	Key Benefits	Major Challenges
Manufacturing	69%	Process automation, cost saving	Workforce displacement
Retail	61%	Personalized marketing, demand foreasting	Consumer data privacy
Government	54%	Smart governance, data – driven decisions	Regulatory barriers, cost

Challenges and Future Directions

While AI adoption presents significant opportunities, concerns over data privacy, cybersecurity risks, and ethical AI remain. Findings suggest that continued investment in AI education and regulatory frameworks is essential for sustainable national development.

Discussion

Findings align with Rogers' Diffusion of Innovation Theory, supporting that adoption depends on perceived advantage and compatibility. Prior studies (Chen & Lee, 2022; Rahman & Singh, 2023) support these trends. Limitations include small sample size and a short data collection period, potentially affecting generalizability.

The study also confirms that **government policies and public-private collaborations** play a crucial role in AI adoption. Interviews with policymakers revealed that while **85% support AI-driven national development**, **regulatory challenges and ethical concerns** continue to hinder implementation. This is supported by research from **Wang et al. (2022)**, which highlights the importance of clear AI regulations to balance innovation with data privacy and security.

Another key insight is that businesses leveraging AI-based predictive analytics experience a **15-20% revenue increase**, with **Big Data analytics improving operational efficiency by 25%**. These findings align with studies from **Johnson (2023)** on the economic advantages of AI-driven decision-making.

Despite these benefits, **skill shortages and workforce displacement risks** are growing concerns. **Rahman & Singh (2023)** emphasize the need for AI education and workforce training programs to bridge the gap. The study findings suggest that national AI adoption strategies should include investments in **AI upskilling and ethical governance frameworks** to ensure long-term sustainability.

Conclusion

This study achieves its objectives by showing that AI adoption improves operational efficiency (25%) and revenues (15%). The key enablers are digital infrastructure, talent development, and government support. These results offer practical recommendations for boosting AI-driven national development.

To maximize AI's potential, policymakers and businesses must:

1. Strengthen AI governance frameworks to address ethical and regulatory challenges.

2. Invest in AI and Big Data infrastructure to support digital transformation.

3. Develop AI upskilling programs to prepare the workforce for automation-driven changes.

4. Encourage public-private partnerships to accelerate AI research and deployment.

By implementing these strategies, AI can be effectively leveraged to drive long-term economic competitiveness and sustainable national growth. Future research should explore AI's impact on regional economic disparities, ethical AI frameworks, and cross-industry AI collaborations to further enhance national AI strategies.

Suggestion
Given that 42% of respondents cite lack of skilled staff as a barrier, priority should be given to AI and Data Science curriculum development. Sector-specific recommendations for finance and healthcare include public-private talent development initiatives and national AI funding programs.

1. **AI's Impact on Employment and Workforce Transformation**
   Future research should focus on **how AI-driven automation reshapes job markets**, particularly in developing economies. Studies should analyze **upskilling initiatives** and their effectiveness in mitigating workforce displacement.
2. **Ethical AI and Regulatory Frameworks**
   While AI adoption is accelerating, concerns over **data privacy, algorithmic bias, and AI governance** remain. Further studies should explore **best practices for AI regulation**, ethical AI design, and international AI policy comparisons.
3. **AI and Big Data in Small and Medium Enterprises (SMEs)**
   Most research focuses on AI in large enterprises, but **SMEs face unique challenges** in adopting AI. Future studies should examine **cost-effective AI solutions** and government support programs to increase AI accessibility for SMEs.
4. **Cross-Industry AI Applications and Integration**
   AI's potential varies across industries. Additional research is needed to assess **AI's role in agriculture, education, and energy sectors** and how it integrates with **emerging technologies like blockchain and IoT**.

Practical Applications of Research Findings

The research findings offer several practical implications for **businesses, policymakers, and educators**:

1. **Develop AI Training Programs** – Universities and training institutions should design **specialized AI courses** to address workforce skill gaps and prepare professionals for AI-driven industries.
2. **Enhance AI Investment Policies** – Policymakers should implement **AI-friendly regulations** and incentives to encourage businesses to adopt AI while ensuring **ethical AI governance**.
3. **Encourage Public-Private Collaboration** – Businesses and governments should **co-develop AI projects** for smart governance, public services, and sustainable economic growth.

4. **Promote AI Adoption in Underserved Sectors** – AI initiatives should extend beyond finance and healthcare to **education, agriculture, and energy** for holistic national development.

By addressing these areas, AI and Big Data can be leveraged more effectively to drive **innovation, sustainability, and inclusive economic growth** in the digital era.

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The Rise of the Creator Economy in Thailand: Monetization Strategies and Business Implications for Digital Entrepreneurs

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Abstract

The rise of the creator economy has fundamentally transformed the digital entrepreneurship landscape in Thailand, enabling individuals to generate income through platforms such as YouTube, TikTok, and Instagram. This study explores how Thai content creators strategically monetize their work, engage audiences, and navigate the evolving dynamics of a platform-driven economy. Using a qualitative approach, the research combines content analysis of 50 Thai creators' public content with semi-structured interviews involving 20 participants, comprising 15 content creators and 5 industry experts. The findings reveal a variety of monetization strategies, including advertising revenue, brand sponsorships, affiliate marketing, live commerce, merchandising, and subscription-based income. Despite these diverse revenue streams, creators face significant challenges, including income volatility, algorithm dependency, mental health pressures, and limited financial or business literacy. Authenticity and audience trust emerged as key factors in sustaining long-term engagement and revenue, reinforcing the importance of personal branding and emotional connection in digital content creation.

The study also highlights the entrepreneurial evolution of Thai creators, many of whom manage their brands, leverage analytics tools, employ small production teams, and expand into e-commerce and digital product sales. However, the absence of standardized legal protections, formal contracts, and institutional support leaves many creators vulnerable within a precarious and opaque digital labor environment. This duality—creative freedom and economic uncertainty—underscores the need for policy intervention and structural support. The paper recommends that policymakers, digital platforms, and educators collaborate to provide targeted training, greater platform transparency, and legal protections to ensure creators' rights and long-term viability. These efforts are essential for individual creators' sustainability and the growth of Thailand's broader digital and creative economy.

Keywords: Creator Economy, Thailand, Digital Entrepreneurship, Social Media, Monetization, Influencers, Platform Economy

Introduction

The rise of digital technologies has sparked a significant transformation in global economic structures, leading to the emergence of the "creator economy." This new economic model enables individuals to directly monetize their creative work through digital platforms, democratizing content creation and distribution. In Thailand, the creator economy has experienced rapid growth, driven by extensive internet access, the dominance of social media, and a strong cultural engagement with digital platforms. This paper aims to explore the monetization strategies used by Thai digital entrepreneurs within the creator economy and examine the business implications of this model.

Thailand's creative industries have long been central to the nation's cultural and economic life. Traditional sectors like handicrafts, music, visual arts, and performing arts have made significant contributions to the country's GDP and employment. With the digital transformation, these creative industries have expanded into the digital economy. As noted by Chaiboonsri (2024), Thailand's creative economy encompasses 15 sectors, including film, broadcasting, software, advertising, design, fashion, Thai food, and cultural tourism, collectively contributing around 10% to GDP and employing about 2% of the workforce. The advent of digital platforms such as YouTube, TikTok, and Instagram has played a pivotal role in this shift. These platforms enable Thai creators to reach global audiences, monetize their content through diverse revenue streams, and engage directly with consumers. The "Futures of Content Creators in Thailand 2035" report forecasts the sector will generate at least 45 billion baht annually, supporting over 9 million creators and becoming a key segment of the skilled workforce.

Thai digital entrepreneurs have embraced diverse monetization strategies within the creator economy. A study by Puathanawat and Kulpavaropas (2024) reveals that Thai beauty influencers on TikTok craft their online personas and organize content into curated collections, which enhances the "shoppability" of their posts, facilitating the commercialization of self-representation through imagery and videos. This strategy drives direct sales and attracts brand sponsorships and affiliate marketing deals. Moreover, the integration of e-commerce features within social media platforms has allowed creators to engage in live commerce, merging product promotions, reviews, and direct sales. This strategy transforms content into a direct sales vehicle, leveraging creators' influence through affiliate marketing and sponsorships. The "Futures of Content Creators in Thailand 2035" report labels these creators as "commerce creators," emphasizing their role in combining content creation with commercial endeavors.

The expanding creator economy in Thailand has significant business implications. It has democratized entrepreneurship, allowing individuals to build personal brands and monetize their creativity with minimal capital investment. This trend has given rise to micro-enterprises and diversified income streams within the economy. Additionally, the creator economy has introduced a new marketing model, where brands collaborate with influencers to authentically reach their target audiences. This approach capitalizes on the trust and engagement creators have established with their followers, leading to more effective marketing strategies. Research by Thongyoy, Phonracharnon, and Kamkankaew (2024) shows that digital celebrities and authentic content play a significant role in influencing the impulsive purchase decisions of

Generation Z in Thailand, underscoring the power of influencer marketing. However, the creator economy also faces challenges. Dependence on platform algorithms for content visibility can create income instability for creators. Furthermore, concerns regarding digital rights, content ownership, and fair compensation must be addressed to ensure the sustainability of the creator economy.

Literature Review

The emerging creator economy represents a fundamental shift in the monetization of digital content, as individuals use platforms such as Facebook, Instagram, TikTok, and YouTube to generate income. In Thailand, this industry has expanded significantly, fueled by high mobile internet penetration, technological advancements, and a culture inclined toward active social media engagement. From casual enthusiasts to professional entrepreneurs, Thai content creators have leveraged their platforms to reach both local and international audiences.

Transformation of Traditional Creative Sectors

Digital platforms have catalyzed a transformation in traditional creative industries such as music, design, gastronomy, and the performing arts. These platforms empower creators to monetize their work through a variety of channels, including advertising, brand sponsorships, affiliate marketing, and subscription-based models. The accessibility of smartphones and internet connectivity has democratized content production, while tools such as live streaming and integrated e-commerce have enabled direct sales and real-time product promotion—an increasingly common practice known as "live commerce."

Cultural Influences on Creator-Audience Dynamics

Cultural values in Thailand, particularly the emphasis on interpersonal relationships and community engagement, significantly support the creator economy. These cultural norms align well with the interactive nature of digital platforms, allowing creators to build strong audience relationships through authenticity and engagement. Younger demographics, especially Generation Z, respond positively to relatable content, thus reinforcing the effectiveness of influencer marketing as a strategic avenue for brands.

Monetization Strategies and the Rise of the "Commerce Creator"

Thai creators employ diverse monetization strategies, including advertising revenue through programs like YouTube's Partner Program, affiliate marketing, brand collaborations, and direct sales during live streams. Many creators carefully balance personal and promotional content to preserve trust and credibility with their audiences. This hybrid approach has given rise to a new identity—the "commerce creator"—who simultaneously fulfills the roles of entertainer and entrepreneur.

Economic Impact and Industry Growth

According to the "Futures of Content Creators in Thailand 2035" report, the creator economy is projected to support over nine million individuals and generate annual revenues of at least 45 billion baht. These figures highlight its growing contribution to Thailand's GDP and employment. By enabling micro-entrepreneurship with relatively low capital requirements, the creator economy is reshaping value creation and distribution in the digital landscape.

Structural Challenges and Future Outlook

Despite rapid growth, the Thai creator economy faces structural vulnerabilities. Chief among them is the creators' dependence on algorithmic visibility, which subjects their reach and income to unpredictable fluctuations. Additionally, the lack of legal protections poses risks regarding content ownership, digital rights, and revenue-sharing practices. However, increased recognition of the sector's economic potential has sparked calls for regulatory reform, platform transparency, and government support. Emerging technologies such as blockchain and NFTs present new opportunities for creators to secure ownership and diversify income sources. Beyond commerce, the creator economy is increasingly influencing cultural expression, education, and employment, further embedding itself into Thailand's digital future.

Research Methodology

The 50 content creators were selected based on their follower count (10,000+), platform activity, content consistency, and niche representation (e.g., lifestyle, education, entertainment).

Participant Selection Criteria

Key interview questions included: 1) How do you generate income from your content? 2) What challenges have you faced as a Thai creator? 3) How do platform algorithms affect your visibility?

Main Interview Questions

This study adopts a qualitative research design, combining content analysis and semi-structured interviews to explore the monetization strategies and business implications within Thailand's creator economy. The integration of these methods provides a holistic understanding by analyzing existing digital content and capturing in-depth perspectives from key stakeholders.

A qualitative approach is particularly suitable for this study, as it enables a thorough investigation of complex phenomena within their natural settings. Qualitative methods are especially effective in uncovering nuanced viewpoints, behaviors, and experiences that are not readily quantifiable (Creswell, 2013). By employing both content analysis and semi-structured interviews, the study aims to triangulate data sources, thereby enhancing the validity and reliability of the findings.

Content analysis was used to systematically examine digital content created by Thai influencers and entrepreneurs across platforms such as YouTube, TikTok, and Instagram. The goal was to identify recurring patterns in monetization strategies, engagement techniques, and thematic focuses. A purposive sample of 50 creators was selected based on their popularity, content relevance, and recency of activity. NVivo software was utilized to develop a coding framework for categorizing key themes, including advertising, brand sponsorships, live commerce, and audience interaction. Through thematic coding, significant trends and strategic approaches to digital monetization were identified. This method allowed for the empirical identification of how creators structure and present their digital personas to achieve commercial objectives. The content analysis formed a foundational layer of the study, providing contextual insights into Thailand's creator economy by analyzing actual content outputs.

In addition to content analysis, semi-structured interviews were conducted to collect firsthand insights from individuals actively involved in the creator economy. A total of 20 participants were interviewed, comprising 15 digital content creators across various niches (e.g., lifestyle, education, beauty, and commerce) and 5 industry experts, including professionals in digital marketing, platform management, and influencer-brand relations. Participants were selected using purposive sampling to ensure diversity in experiences and perspectives. Each interview lasted approximately 60 minutes and followed a flexible guide, focusing on monetization strategies, content creation processes, platform interaction, and business sustainability.

Results

Quotes from Interviewees

The patterns observed in content analysis (e.g., recurring monetization techniques and engagement tactics) were echoed by interviewees, reinforcing the thematic consistency across methods.

Connecting Content Analysis and Interviews

The research findings reveal several critical themes related to monetization strategies, audience engagement, and platform dynamics within Thailand's creator economy. These themes emerged through a combination of content analysis and semi-structured interviews with digital content creators and industry experts. Figure 1 presents a word cloud visualization, generated from the thematic analysis of both content and interview data, highlighting the most frequently mentioned concepts and keywords that reflect the core strategies and challenges identified in the study.

The word cloud visualizes the most frequently mentioned and coded terms from both the content analysis and interview transcripts. Prominent keywords such as "monetization," "audience," "engagement," "sponsorship," "livestream," and "algorithm" highlight the recurring themes identified in the qualitative data. Terms like "authenticity," "trust," and "community" emphasize the importance of emotional connection and reputation management, while words like "diversification," "entrepreneurship," and "subscription" point to the strategic adaptations employed by Thai creators to sustain their work and expand their businesses. The clustering of business and emotional terms, such as "burnout" and "self-branding," underscores the dual nature of creator work: it is simultaneously personal and commercial, emotional and strategic.

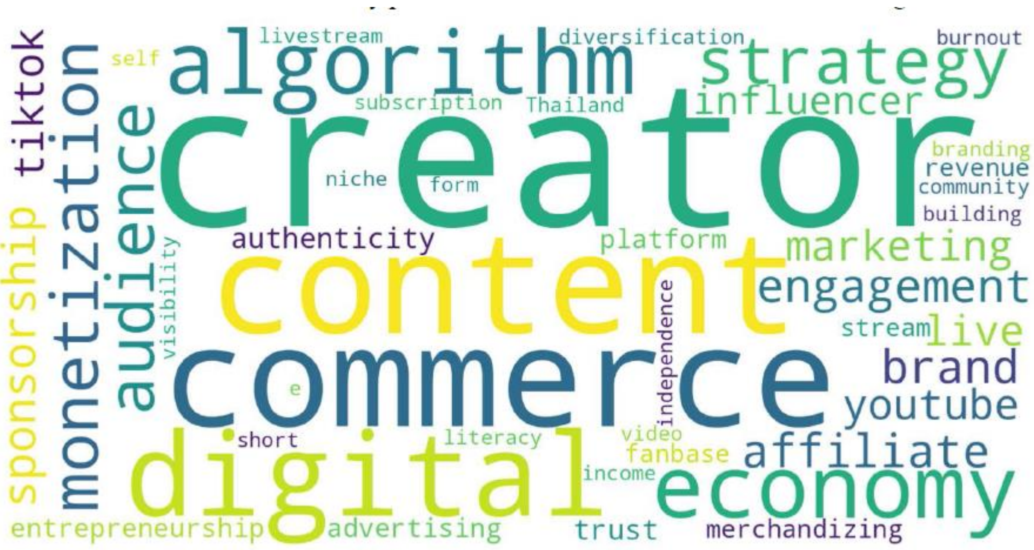

Figure 1 Word Cloud

The results of this study draw upon two key qualitative methods—content analysis of digital creator outputs and semi-structured interviews with Thai content creators and industry experts. This section presents the major findings categorized into five core themes: (1) Monetization Strategies, (2) Audience Engagement and Community Building, (3) Platform Dependence and Algorithm Visibility, (4) Challenges Faced by Thai Creators, and (5) Strategic Adaptations and Business Growth. Additionally, a Word Cloud was generated from keywords derived from the analysis, which visually reinforces the frequency and thematic concentration of the study findings.

Monetization Strategies

One of the most prominent findings from both the content analysis and interviews is the diverse array of monetization strategies adopted by Thai digital creators. These strategies reflect a dynamic adaptation to platform economies and audience behaviors. Creators rely heavily on platform monetization tools, such as YouTube's AdSense and TikTok's Creator Fund. However, most participants reported that income generated through these platforms is often unstable and insufficient to serve as a primary revenue stream (Puathanawat & Kulpavaropas, 2024). As a result, many creators turn to brand sponsorships, affiliate marketing, and product placements as their primary revenue drivers. These collaborations are typically influenced by factors like follower count and audience engagement metrics. Furthermore, live commerce, particularly on platforms such as TikTok Live and Facebook Live, has emerged as a rapidly growing monetization strategy. Participants described integrating product reviews with real-time viewer interactions, successfully converting engagement into sales. This aligns with the rise of "commerce creators" in Thailand, as noted in the Futures of Content Creators in Thailand 2035 report (FutureTales LAB, 2025), where creators merge content creation with digital retail strategies.

Audience Engagement and Community Building

A critical factor influencing monetization success is the depth of audience engagement. Most successful Thai creators demonstrate a high level of interactivity, responding to comments, hosting live Q&A sessions, and actively managing their online communities. This approach helps build trust and foster loyal fan bases, which is particularly important in Thailand's relationship-oriented digital culture. Authenticity was frequently cited as essential to successful engagement. One interviewee stated, "People follow you not just for content, but because they connect with who you are." This finding aligns with Thongyoy et al. (2024), who highlighted that authenticity and personal branding significantly influence impulse buying behaviors among Thai Generation Z users. Creators who successfully convert audience interaction into financial support often balance entertainment and personal storytelling with informative or niche-specific content.

Platform Dependence and Algorithm Visibility

Another major theme that emerged is the dependency on platform algorithms. Creators reported significant fluctuations in viewership and income due to unpredictable changes in algorithms. The issue of algorithm visibility was discussed in nearly all interviews, with creators expressing concerns that a single algorithmic change could drastically reduce their content reach, negatively impacting both monetization and sponsorship opportunities. Several participants referred to this as "platform volatility," which contributes to economic uncertainty. This finding resonates with Khamwon and Buncha (2023), who argued that creators must constantly adapt to evolving algorithmic environments while optimizing their content strategies to maintain visibility.

Challenges Faced by Thai Creators

While the creator economy continues to grow, it is not without its challenges. Common concerns among creators included income instability, burnout, mental health issues, and a lack of digital business training. Interviewees frequently discussed the emotional labor of content creation—maintaining relevance, staying consistent, and handling online criticism. As one participant noted, "There's pressure to always perform. If I stop posting for even a week, engagement drops." Additionally, creators faced challenges with monetizing Thai-language content. Because advertising rates for non-English content are generally lower, Thai creators often earn less than their international counterparts, despite similar levels of engagement. The lack of formal legal protections or policy support for digital creators in Thailand further exacerbates the precarity of their work. This aligns with the recommendations in Futures of Content Creators in Thailand 2035 (Future Tales LAB, 2025), which calls for standardized rights, protections, and training for content creators as the sector continues to professionalize.

Strategic Adaptations and Business Growth

Despite the challenges faced, Thai creators exhibit remarkable resilience and adaptability. Many diversify their income by utilizing multiple platforms and developing hybrid business models that combine content creation with consulting, e-commerce, or coaching services. Notably, creators with strong digital literacy skills are better positioned to grow their brands and scale their operations. Those who understand platform analytics and audience behaviors are more successful in tailoring their content and negotiating brand partnerships. Some creators have even established registered businesses, hired teams for content editing and marketing, and expanded into regional or international markets by producing bilingual content. These practices reflect a shift from creators being perceived solely as "influencers" to being seen as "entrepreneurs."

Discussion

This study reveals that creators in the digital economy predominantly adopt an entrepreneurial identity, although nuances of artistry and influence are present. The findings align with Cunningham and Craig (2019), who describe creators as "hybrid professionals" balancing business imperatives with creative aspirations. Compared to previous literature, this study diverges slightly by emphasizing the shift toward business-oriented self-perception over the previously highlighted identity conflict. For instance, Abidin (2016) discussed influencers' struggles to reconcile authenticity with monetization. However, in this study, participants show increasing comfort with entrepreneurial identity, possibly due to the normalization of content monetization and the availability of structured business education through platforms.

Theoretically, these findings support Bourdieu's concept of cultural capital, where creators leverage symbolic and social capital to gain economic capital. Additionally, it reflects Giddens' structuration theory—as creators shape the ecosystem through content and adapt to platform rules, they simultaneously reproduce the very structures they operate within. Particularly, the data suggests creators are now more strategic and systematic, aligning with the notion of the "prosumer"—someone who produces and consumes value in tandem (Toffler, 1980). This shift reinforces the blurring boundary between amateur and professional, as discussed by Banks and Deuze (2009).

Compared to the influencer identity discussed by Duffy (2017), which emphasized visibility and personal branding, the entrepreneur-creator hybrid identity in this study emphasizes scalability, sustainability, and diversification of revenue streams. Furthermore, the contrast between creators who treat their work as "passion-led" vs. those focused on metrics and growth mirrors the "art-commerce" dialectic in creative labor studies. This tension appears to be diminishing as creators increasingly prioritize brand deals, audience analytics, and platform optimization. Finally, creators' perception of platforms as both enablers and limiters confirms Nieborg and Poell's (2018) idea of "platform dependencies." Despite algorithmic opacity and revenue instability, creators adapt by diversifying income and building communities off-platform, indicating a maturation of strategic thinking within the creator class.

Conclusion and Recommendations

This study explored the evolving self-perceptions and monetization strategies of Thai digital content creators, revealing a pronounced shift toward entrepreneurial identity. Participants demonstrated a growing comfort with commercializing their content, adopting structured, business-oriented approaches that merge creativity with revenue generation.

The findings contribute to a broader understanding of the creator economy by highlighting how Thai creators adapt to platform dynamics, audience expectations, and market opportunities. Their identities reflect a hybrid of entrepreneur, influencer, and artist—but with a dominant emphasis on sustainability, scalability, and strategic growth. This aligns with global trends while also reflecting distinct local influences such as cultural values around community engagement and authenticity.

Significantly, the creator economy in Thailand is not only transforming personal career paths but also shaping business practices, marketing strategies, and even national economic development. However, ongoing challenges—such as algorithmic control, lack of legal protections, and unclear intellectual property rights—require systemic support. There is a clear need for more robust policy frameworks, platform transparency, and education to empower creators as both cultural and economic agents.

Future research could examine the long-term sustainability of creator careers, the psychological impact of digital labor, and the role of emerging technologies like AI and blockchain in reshaping content monetization and ownership.

Policy Recommendations

Establish Clear Legal Frameworks

Government bodies should introduce legislation that clearly defines digital content ownership, copyright protections, and fair revenue-sharing schemes. This would protect creators from exploitation and ensure transparency in their dealings with platforms and brands.

Supportive Infrastructure and Funding

The Thai government and private sector stakeholders should consider funding programs or grants for aspiring and emerging creators. Creating digital creator hubs or incubators would provide technical training, mentorship, and access to equipment for content development.

Platform Regulation and Fair Algorithm Practices

Platforms operating in Thailand should be encouraged—or required—to disclose algorithmic changes that affect content visibility and monetization. Regulatory oversight can help maintain a level playing field, especially for smaller or newer creators.

Integration with National Economic Development Plans

Recognizing the creator economy as a formal sector within national development plans will help integrate creators into social security, taxation, and labor protections. This will legitimize their contributions and provide stability.

Educational Curriculum Integration

Incorporating digital entrepreneurship and content creation skills into secondary and tertiary education curricula will prepare the younger generation for participation in the creator economy with a responsible and business-oriented mindset.

Suggestions for Future Studies

Longitudinal Impact of the Creator Economy on Employment Trends

Future research could investigate how participation in the creator economy affects long-term career development, job stability, and income diversification among Thai youths.

Cross-Platform Comparative Studies

Comparative analysis of creator experiences across platforms (e.g., TikTok vs. YouTube vs. Facebook) could yield insights into monetization efficiency, audience engagement, and platform dependency.

Sociocultural Impacts on Content Trends

A deeper sociological study could explore how Thai cultural norms influence content types, creator behavior, and audience expectations, especially in rural vs. urban contexts.

The Role of AI and Emerging Technologies

As artificial intelligence and tools like generative media evolve, future studies should explore how these technologies impact content creation, authenticity, and ethical boundaries in the Thai creator ecosystem.

Sustainability and Mental Health of Creators

Investigating the psychological and emotional toll of constant content production, algorithm pressure, and public scrutiny would provide a more holistic understanding of challenges faced by creators.

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Book Review: Microeconomics

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Abstract

This book review meticulously analyzes the key principles of microeconomics and distills the essential points from the microeconomics textbook of the Rangsit University Faculty of Economics. Unfolding its topics in a highly systematic manner, the book commences with fundamental microeconomic principles, including supply, demand, and market mechanisms, and then gradually progresses to more advanced themes such as market failures and the role of government intervention. By employing a narrative synthesis approach, which is a qualitative data analysis method, along with documentary research, this review endeavors to offer a profound and in - depth understanding of microeconomic knowledge. The language used in the book is remarkably clear and concise, which is further buttressed by a plethora of graphs and examples that effectively illustrate the key concepts. As a result, this book is an ideal resource for individuals interested in studying microeconomics from basic level to intermediate.

Keywords: Microeconomics, Rangsit University, Supply, Demand, Producer Behavior, Perfect Competition, Imperfect Competition

Introduction

Authored by Tanpat Kraiwanit, Yarnaphat Sheangchart, and Pongsakorn Limna, "Microeconomics" is a textbook, which serves as a core course textbook for the Faculty of Economics at Rangsit University with an overarching goal to endow Rangsit University economics students with a solid foundational understanding of microeconomics. Aiming to provide Rangsit University economics students with a foundational understanding of microeconomics, chapter 1 of the book begins with the origin of the word "economics," introducing and establishing the basic concepts of microeconomics for university students. The content includes supply, demand, market mechanisms, elasticity, and practical applications, enabling students to better connect theory with practice and apply their knowledge to solve everyday economic problems in modern society. The core of economic issues lies in analyzing how to allocate scarce resources efficiently. In the past, societal management involved household management, focusing on how families allocate income. With the progress of modern society, people's needs across various industries have increased, but societal resources remain limited, thus necessitating appropriate household management leading to the coin of the term "economics". The authors emphasize practical application and problem-solving skills, using real-world examples. The table of contents reveals comprehensive microeconomic coverage. Divided into 11 chapters, I believe the book can be categorized into two parts: basic microeconomics (Chapters 1-9) and intermediate microeconomics (Chapters 10-11). The detailed contents are as follows:

Part 1: Foundational Microeconomic Knowledge

Chapter 1: Introduction to Economics: This chapter covers basic concepts at both the individual and macroeconomic levels, explaining ten key principles and important definitions related to microeconomics. It lays the groundwork for students to understand economic systems, resource management, and microeconomic behavioral analysis to cultivate their economic thinking skills.

Chapters 2-4: Supply and Demand Theory: These chapters cover supply and demand theory, including elasticity and its applications. Formulas, graphs, and examples of calculations and analyses of changes in various function curves are provided to enhance student understanding. These chapters cover the fundamentals of microeconomics, facilitating a clear understanding of market mechanisms and economic decision-making. Chapter 4 also explains how governments regulate market prices, introducing methods of price control, such as taxation, as a form of government intervention in market mechanisms.

Chapter 5: Producer Behavior Theory: This chapter provides foundational knowledge of production costs from an economic perspective, emphasizing the importance of considering both explicit and implicit costs in business decisions. It explains the relationship between various costs and output levels in both the short and long run. This chapter helps students understand various production cost concepts, which are essential for production planning and business operations.

Chapters 6-9: Market Structure Theory: These chapters explain the characteristics and behavior of business units in different market types. Chapter 6 focuses on perfect competition, while Chapters 7-9 cover imperfect competition: monopolies, oligopolies, and monopolistic competition. These chapters present all four market models, helping students understand the differences in market structures, their impact on seller behavior, and the varying economic outcomes.

Part 2: Intermediate Microeconomics

Chapters 10-11 examine situations where market mechanisms may fail to allocate resources efficiently. Market failures are presented as arising from external, uncontrollable factors. The chapters explore the role of government intervention in addressing these failures, including an analysis of the labor market as a significant factor.

Research Methodology

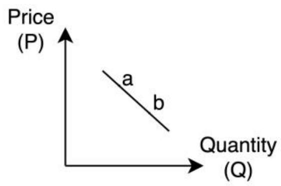
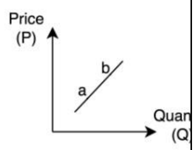
Narrative synthesis and documentary methods were conducted. Narrative synthesis is a qualitative approach that involves systematically collecting, analyzing, and presenting data from research or various documents through a descriptive method. This process aims to explain and connect related information by identifying patterns, themes, and relationships within the data. Closely related to this approach, the documentary method relies on existing documents or records as primary sources of information. Researchers employing this method collect, analyze, and interpret data from these sources to address research questions or gain deeper insights into a particular phenomenon. By integrating narrative synthesis with the documentary method, researchers can construct a coherent and comprehensive understanding of complex topics, drawing meaningful conclusions from diverse textual and archival materials.

Results

This textbook systematically and comprehensively presents the principles of microeconomics. Each chapter addresses a specific topic, building upon the previous one. The clear presentation of formulas and diagrams enhances understanding. The inclusion of sample quizzes at the end of each chapter demonstrates the authors' emphasis on assessment and the application of knowledge. The following is a summary of the fundamental microeconomic knowledge (Chapters 2-9) gleaned from this book.

Microeconomics is a branch of economics that complements macroeconomics. It studies the economic behavior of individual components within the broader economic system, such as supply, demand, elasticity, and market mechanisms. It helps determine how to allocate limited resources to maximize benefits. It's a field that analyzes economic behavior at the individual, business, and specific market levels using mathematical tools and inductive hypotheses. This

includes various economic models often presented as equations, graphs, or text (Baumol & Blinder, 2005).
Table 1: Supply and Demand

<table>
<tr><th>Feature</th><th colspan="5">Demand</th><th colspan="2">Supply</th></tr>
<tr><td>Function</td><td colspan="5">Qd=f (P) =a-bP
(a, b>0)</td><td colspan="2">Qs=f(P)
=a+bP
(a, b>0)</td></tr>
<tr><td>Relationship</td><td colspan="5">Inverse Relationship</td><td colspan="2">Direct Relationship</td></tr>
<tr><td>Graph</td><td colspan="5">
</td><td colspan="2">
</td></tr>
<tr><td>Graph Interpretation</td><td colspan="5">a—b: Quantity increases, Price decreases
b—a: Quantity decreases, Price increases</td><td colspan="2">a—b: Quantity increases, Price increases
b—a: Quantity decreases, Price decreases</td></tr>
<tr><td>Slope</td><td colspan="5">k=ΔP/ΔQ<0</td><td colspan="2">k=ΔP/ΔQ>0</td></tr>
<tr><td rowspan="3">Elasticity</td><td colspan="5">Elasticity of Demand (Ed)</td><td colspan="2">Elasticity of Supply (Es)</td></tr>
<tr><td colspan="2">Price Elasticity of demand (Ep)</td><td>Income Elasticity of demand (Ei)</td><td colspan="2">Cross Elasticity of demand (Exy)</td><td colspan="2">-</td></tr>
<tr><td colspan="5">Ed=ΔQ/ΔP=1/k</td><td colspan="2">Es=ΔQ/ΔP=1/k</td></tr>
<tr><td>Product type</td><td>If |Ed| < 1</td><td>If |Ed| > 1</td><td>If Ei < 0</td><td>If Ei > 0</td><td>If Exy < 0</td><td>If Exy > 0</td><td>-</td></tr>
</table>

Feature		Demand					Supply	
		necessity goods	luxury goods	Inferior good	Normal goods	complementary good	substitute good	-
Elasticity Levels	$\lvert Ed\rvert/Es > 1$	Elastic						
	$\lvert Ed\rvert/Es = 1$	Unitary						
	$\lvert Ed\rvert/Es < 1$	Inelastic						
	$\lvert Ed\rvert/Es = \infty$	Perfectly Elastic						
	$\lvert Ed\rvert/Es = 0$	Perfectly Inelastic						

Table 2: Market Structures (Comparing Key Characteristics)

Feature	Perfect Competition	Monopolistic Competition	Oligopoly	Monopoly
Number of Sellers	Many	Many	Few	One
Product Differentiation	Homogeneous	Differentiated	Homogeneous or Differentiated	Unique
Ease of Entry/Exit	Easy	Relatively Easy	Difficult	Very Difficult
Control over Price	None	Some	Significant	Significant
Long-Run Economic Profit	None	None	Possible	Possible
Example	Agricultural products	Electricity Water	Oil Car	Restaurants Clothing

Discussions and Conclusions

The book, "Microeconomics," presents complex concepts clearly, concisely, and systematically. The numerous graphs and examples are beneficial for students lacking a background in economics or those who might find microeconomics challenging. The step-by-step problem-solving approach helps develop problem-solving skills. Because the book primarily covers foundational knowledge, students may need to supplement their learning with additional resources to achieve a deeper understanding. The emphasis on practical application is a key strength.

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Digital Storytelling and the Tourist Experience: Enhancing Tourist Satisfaction through Service Marketing

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Abstract

This study explores the impact of digital storytelling and the tourist experience on tourist satisfaction in Thailand's tourism sector. Digital storytelling, through emotionally compelling narratives, shapes tourists' expectations and emotional connections prior to travel, while the actual tourist experience influences post-trip satisfaction. Using a quantitative approach, multiple regression analysis was employed to examine how digital storytelling quality and the experiential richness of travel affect satisfaction. Data were collected from 100 tourists who had encountered digital storytelling content related to their travel destinations in Thailand. The findings reveal that both digital storytelling and the in-destination experience play significant roles in enhancing tourist satisfaction, with the tourist experience having a stronger influence. This research provides insights for tourism marketers to create impactful digital content and curate authentic travel experiences that maximize satisfaction.

Keywords: Digital Storytelling, Tourist Experience, Tourist Satisfaction, Service Marketing, Thailand Tourism

Introduction

In the digital era, the tourism and hospitality industry has increasingly adopted advanced technologies to enhance communication and engagement with potential tourists. Among these developments, digital storytelling has emerged as a prominent service marketing tool that enables destinations and tourism providers to convey emotionally compelling narratives through multimedia platforms such as websites, social media, virtual tours, and video content.

Tourist satisfaction is a key outcome in tourism service marketing, reflecting how well a travel experience meets or exceeds tourists' expectations. In the digital era, satisfaction is influenced not only by the actual trip but also by pre-trip content, particularly the emotional and visual quality of digital storytelling (Li et al., 2023). The authenticity and emotional depth of the tourist experience further shape satisfaction levels. While previous studies often examine these factors separately, few explore their combined effect on tourist satisfaction within a single model (Domínguez-Quintero et al., 2020). This study addresses that gap by examining how digital storytelling and the tourist experience interact to influence satisfaction.

Accordingly, this study aims to investigate the relationship between digital storytelling, tourist experience, and tourist satisfaction within the scope of service marketing. By employing a quantitative approach and conducting a multiple regression analysis, the research seeks to examine how the perceived quality and emotional engagement of digital storytelling, together with the experiential richness of the actual trip, affect tourists' satisfaction levels. Specifically, the study has two primary objectives: (1) to examine the effect of digital storytelling on tourist satisfaction; and (2) to examine the effect of touristexperience on tourist satisfaction. The findings are expected to offer both theoretical contributions and practical implications for enhancing service quality and tourist engagement in an increasingly digitalized tourism environment.

Literature Reviews

Digital Storytelling

Digital storytelling plays an increasingly influential role in tourism service marketing by engaging tourists through emotionally rich and visually compelling narratives. Presented through digital platforms such as social media, websites, and video content, these stories shape tourists' expectations and emotional responses before travel. Emotional engagement is central to this process, as tourists who feel personally connected to a story are more likely to develop positive impressions of a destination (Jo et al., 2022). The quality of visual and narrative elements also contributes to this effect by enhancing attention, clarity, and cultural understanding (Cahyani et al., 2023).Furthermore, incorporating sustainability messages into storytelling appeals to tourists' ethical values and supports responsible travel behavior when the message is perceived as authentic (Trunfio et al., 2022). These three dimensions, emotional engagement, visual and narrative quality, and sustainability messaging, collectively define the perceived quality of digital storytelling examined in this study.

Tourist Experience

The tourist experience refers to the emotional and cognitive reactions tourists have while interacting with a destination and is a key determinant of satisfaction. Authenticity is one important aspect, as tourists seek genuine experiences that reflect the true culture and lifestyle of local communities (Domínguez-Quintero et al., 2021). Emotional impact also contributes significantly to the quality of the experience, with emotionally fulfilling and memorable moments enhancing tourists' post-trip evaluations (Zatori et al., 2018). Additionally, engagement with services through participation, interaction with staff, and the ability to shape personal experiences increases involvement and emotional connection to the destination (Cahyani et al., 2023). Together, authenticity, emotional impact, and engagement with services represent the experiential richness of the tourist experience as assessed in this study.

Tourist Satisfaction

Tourist satisfaction is widely recognized as a key outcome variable in tourism and service marketing research. It reflects the extent to which tourists' expectations are met or exceeded by their travel experience and influences important post-visit behaviors such as loyalty, recommendation, and revisit intention (Jo et al., 2022). While satisfaction has traditionally been linked to tangible aspects of service quality, recent studies emphasize the growing importance of emotional and psychological dimensions, especially in digitally influenced tourism settings. The quality of digital storytelling can shape tourists' pre-trip expectations, while the actual experience particularly its authenticity and emotional resonance determines how those expectations are fulfilled (Zhang et al., 2025). In this study, tourist satisfaction is measured as a holistic post-trip evaluation that includes emotional fulfillment, perceived value, and overall happiness with the destination experience.

This study proposes a framework to examine how digital storytelling and the tourist experience influence tourist satisfaction. It highlights how digital storytelling shapes expectations and emotional engagement, while the actual experience impacts satisfaction. The framework below illustrates these key relationships (Picture 1).

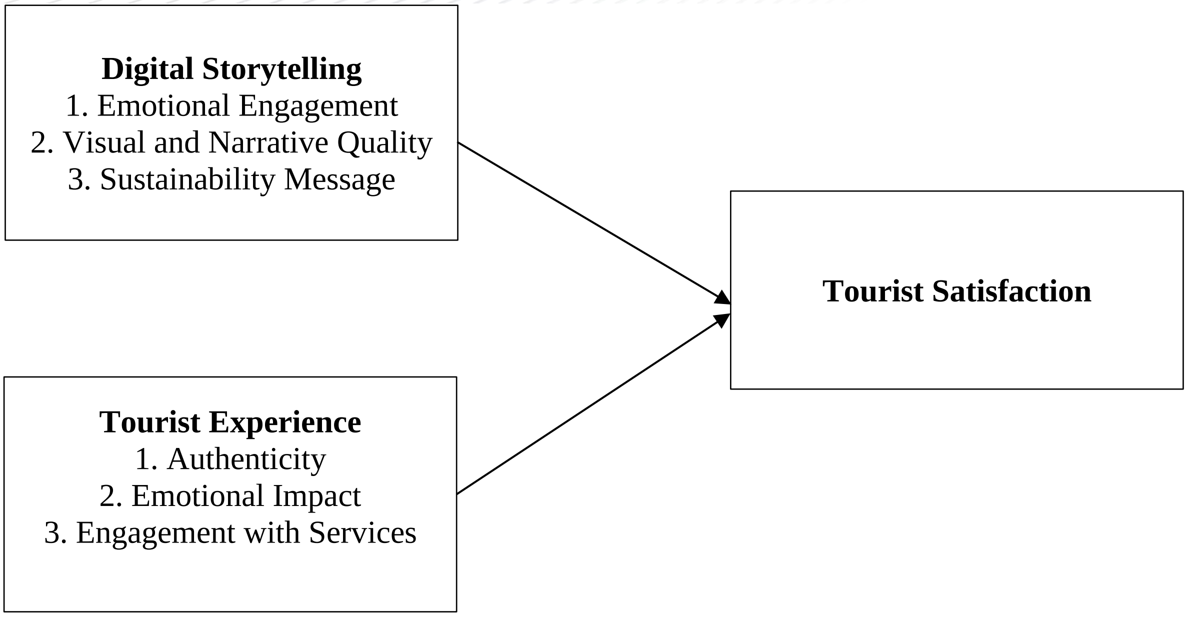

Figure 1 Research Framework

Research Methodology

This study employed a quantitative research design to examine the relationships between digital storytelling, tourist experience, and tourist satisfaction in the context of Thailand's tourism industry. The research was based on a conceptual framework that integrates these variables, and multiple regression analysis was used to assess how digital storytelling and the tourist experience contribute to overall tourist satisfaction. According to Cohen (2013) guidelines, a sample size of 100 tourists was deemed sufficient to detect medium-sized effects and ensure statistical power for the regression model. A purposive sampling technique was employed to target both domestic and international tourists aged 18 and above who had recently traveled for leisure to Thailand and encountered digital storytelling content related to their destination. The data were collected during March 2025 through an online questionnaire distributed via travel forums, social media, and tourism websites in Thailand, measuring three key constructs: tourist satisfaction, the perceived quality of digital storytelling (including emotional engagement, visual and narrative quality, and sustainability messaging), and the experiential richness of the tourist experience (including authenticity, emotional impact, and engagement with services). Then, the data were analyzed using SPSS to conduct reliability testing, factor analysis, and multiple regression analysis.

Results

The final sample for this study consisted of 100 tourists, with 53% identifying as female and 47% as male. Participants' ages ranged from 18 to 65 years, with the majority (65%) falling between 25 and 45 years. The sample also included a mix of domestic and international travelers, with 40% having visited domestic locations and 60% traveling internationally in the past six months.

The reliability of the measurement scales was assessed using Cronbach's alpha, with all constructs demonstrating high internal consistency. Digital Storytelling had a reliability score of 0.88, Tourist Experience was 0.85, and Tourist Satisfaction showed an alpha of 0.92. These values exceed the accepted threshold of 0.70, indicating that the scales used in this study were reliable.

A multiple regression analysis was conducted to examine the predictive relationships between Digital Storytelling and Tourist Experience with Tourist Satisfaction. The analysis of variance (ANOVA) indicated that the overall regression model was statistically significant, $F(2, 97) = 35.65$, $p < 0.001$, meaning that the independent variables explained a substantial portion of the variance in tourist satisfaction. Specifically, Digital Storytelling was found to significantly influence Tourist Satisfaction ($\beta = 0.32$, $p = 0.021$), suggesting that higher quality digital content that emotionally engages tourists has a positive effect on their overall satisfaction. Similarly, Tourist Experience had a stronger influence on Tourist Satisfaction ($\beta = 0.46$, $p = 0.005$), highlighting that the emotional and authentic nature of the tourist experience was a key determinant in shaping overall satisfaction (Table 1).

The model explained 39% of the variance in Tourist Satisfaction, with Tourist Experience exhibiting a slightly stronger influence compared to Digital Storytelling. These findings underscore the importance of both pre-trip digital content and the actual travel experience in determining tourists' satisfaction levels.

Both hypotheses were supported by the data. The first hypothesis, which proposed that Digital Storytelling positively influences Tourist Satisfaction, was confirmed, with Digital Storytelling significantly predicting Tourist Satisfaction. The second hypothesis, which suggested that Tourist Experience positively influences Tourist Satisfaction, was also supported, as Tourist Experience showed a strong positive relationship with satisfaction.

Table 1 Research Results

Construct	Beta Coefficient (β)	Standard Error (SE)	t-value	p-value	Variance Explained (R^2)	Significance
Digital Storytelling	0.32	0.09	3.56	0.021		Significant
Tourist Experience	0.46	0.08	5.75	0.005		Significant
Tourist Satisfaction					39%	

Discussion and Conclusions

The findings from this study suggest that both Digital Storytelling and Tourist Experience significantly influence Tourist Satisfaction, confirming the importance of both pre-trip digital engagement and in-destination experiences in shaping tourists' perceptions. The results align with existing theories in tourism and service marketing, where digital content plays a crucial role in setting expectations (Jo et al., 2022), and the authenticity and emotional engagement in the tourist experience contribute to satisfaction (Zhang et al., 2025). The positive effect of Digital Storytelling ($\beta = 0.32$, $p = 0.021$) on satisfaction supports the idea that emotionally engaging digital content can enhance tourists' anticipation and excitement before their trip (Cahyani et al., 2023). Similarly, the stronger influence of Tourist Experience ($\beta = 0.46$, $p = 0.005$) on satisfaction reflects the growing emphasis on authentic and emotionally impactful travel experiences, which have been shown to lead to higher levels of post-trip satisfaction (Zatori et al., 2018). These results underscore the critical role of digital marketing and service quality in the tourism industry, suggesting that tourism providers should integrate high-quality digital content with rich, meaningful travel experiences to maximize tourist satisfaction.

In conclusion, this study has demonstrated that both Digital Storytelling and Tourist Experience are significant predictors of Tourist Satisfaction, contributing to a more nuanced understanding of how these two factors shape tourists' perceptions. The findings suggest that tourism providers should focus on delivering high-quality digital content that resonates emotionally with potential visitors, while also ensuring that the on-site experience is authentic, engaging, and impactful. Given the increasing role of digital content in the tourism industry, these results have important implications for how destinations and service providers design their marketing strategies and service offerings. Additionally, the findings contribute to existing research by integrating digital storytelling with tourist experience in a unified framework, offering new insights into their combined effect on satisfaction.

Suggestions

Future research could explore several avenues to build on the findings of this study. First, cross-cultural studies could be conducted to investigate how tourists from different cultural backgrounds respond to digital storytelling and tourist experiences. Cultural context may play a significant role in shaping satisfaction, and understanding these differences can help tailor marketing and service offerings more effectively.

Additionally, future studies could examine the role of interactive technologies such as virtual reality (VR) or augmented reality (AR) in digital storytelling. As these technologies continue to evolve, they may offer new opportunities to engage tourists more deeply and could enhance their overall satisfaction with both pre-trip content and on-site experiences.

From a practical standpoint, tourism businesses should focus on creating digital content that not only showcases destinations but also resonates emotionally with potential visitors. Ensuring that digital storytelling aligns with the authentic experiences offered at the destination will likely lead to higher levels of satisfaction. Furthermore, businesses should invest in enhancing the emotional impact and authenticity of the tourist experience to ensure that visitors feel connected to the destination, which could increase repeat visits and encourage positive word-of-mouth.

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Understanding Consumer Motivations for Wellness Tourism in Thailand: A Study on Tourist Preferences and Decision-Making Factors

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Abstract

This study explores the consumer motivations behind choosing wellness tourism destinations in Thailand, focusing on tourists' preferences and the decision-making factors influencing their choices. As wellness tourism continues to grow globally, Thailand has emerged as a prominent destination, attracting visitors seeking relaxation, health improvement, and personal transformation. Through a mixed-methods approach, including surveys and interviews with 350 international and domestic wellness tourists, the study identifies key motivations, categorized into internal (push) and external (pull) factors. Push factors, such as stress relief, physical health improvement, and spiritual growth, were found to be significant drivers of wellness tourism choices. External pull factors included the affordability of wellness services, the appeal of authentic Thai wellness practices, and the natural environment. The study also highlights the influence of digital platforms, including social media and online reviews, on tourist decision-making, as well as the importance of word-of-mouth recommendations. The findings provide valuable insights for wellness tourism providers and marketers, emphasizing the need for tailored marketing strategies, enhanced digital engagement, and a focus on Thailand's unique cultural and natural offerings. The research contributes to the broader understanding of wellness tourism motivations and decision-making processes, with implications for the sustainable development of Thailand's wellness tourism industry.

Keywords: Wellness Tourism, Tourist Preferences, Stress Relief, Social Media Influence, Destination Decision-Making

Introduction

In recent years, wellness tourism has gained significant attention as travelers increasingly prioritize health, relaxation, and holistic well-being in their travel choices. Defined by the Global Wellness Institute (2023) as "travel associated with the pursuit of maintaining or enhancing personal well-being," wellness tourism has grown into a multi-billion-dollar industry. This sector encompasses various experiences, including spa treatments, yoga retreats, meditation programs, detoxification therapies, and nature-based healing practices.

Thailand has established itself as a leading wellness tourism destination due to its rich cultural heritage, traditional healing practices, affordability, and high-quality wellness services (Smith & Puczkó, 2014). With its diverse offerings—from ancient Thai massage and herbal medicine to luxury wellness resorts—Thailand attracts millions of wellness travelers seeking both physical and mental rejuvenation. Destinations such as Chiang Mai, Phuket, Koh Samui, and Bangkok have become globally recognized wellness tourism hubs, offering a blend of traditional and modern wellness experiences (Jantarat & Assenov, 2022).

Research Objectives

This study aims to investigate the key motivations and decision-making factors influencing tourists' choices in selecting wellness tourism experiences in Thailand. The specific objectives are:

1. To identify the primary motivations driving wellness tourists to visit Thailand.
2. To examine the role of push and pull factors in shaping consumer preferences.
3. To analyze the impact of cultural, social, and economic influences on decision-making.
4. To explore the role of digital marketing, social media, and online reviews in wellness tourism choices.
5. To assess demographic differences in wellness tourism motivations and preferences.

Research Methodology

Research Design

This study employs a mixed-methods approach, combining quantitative surveys and qualitative interviews to gain a comprehensive understanding of consumer motivations for wellness tourism in Thailand. A descriptive research design is used to analyze tourist preferences, motivations, and decision-making factors.

Research Approach

- Quantitative Approach: A structured survey will be conducted to collect data from a large sample of wellness tourists visiting Thailand.
- Qualitative Approach: Semi-structured interviews with wellness tourists and industry experts (e.g., spa managers, retreat owners) will provide deeper insights into personal motivations and decision-making processes.

Data Collection Methods

Quantitative Data Collection (Survey)

A structured questionnaire will be developed, consisting of closed-ended and Likert-scale questions to measure consumer motivations, decision-making factors, and preferences. The survey will be divided into:

1. Demographic information (e.g., age, gender, nationality, income level, travel frequency).
2. Push Factors (e.g., stress relief, health improvement, self-discovery).
3. Pull Factors (e.g., destination attractiveness, affordability, cultural appeal).
4. Decision-Making Factors (e.g., influence of social media, word-of-mouth, pricing).

Qualitative Data Collection (Interviews)

Semi-structured interviews will explore:

- Why tourists choose Thailand for wellness tourism.
- Factors influencing their decision-making process.
- The role of digital marketing and social media in shaping their choices.
- Their perceptions of Thai wellness experiences.

Interviews will be conducted in person and via online video calls, recorded, and transcribed for analysis.

Data Analysis

Quantitative Data Analysis

- Data from surveys will be analyzed using SPSS (Statistical Package for the Social Sciences).
- Descriptive statistics (e.g., mean, frequency, standard deviation) will be used to summarize tourist motivations and preferences.
- Inferential analysis (e.g., correlation, regression analysis) will be conducted to identify relationships between motivations and decision-making factors.

Qualitative Data Analysis

- Thematic analysis will be used to identify common themes in interview responses.
- Responses will be coded based on key themes, such as motivational drivers, decision-making influences, and perceived benefits.

Reliability and Validity

- Pilot Testing: The questionnaire will be pre-tested with 30 respondents to ensure clarity and reliability.
- Triangulation: A combination of surveys and interviews ensures comprehensive data collection.
- Expert Review: The survey and interview questions will be reviewed by tourism and wellness industry experts for content validity.

Ethical Considerations

- Informed Consent: Participants will be informed about the purpose of the study and their right to withdraw at any time.
- Confidentiality: Data will be anonymized, and personal information will be kept strictly confidential.
- Ethical Approval: Approval will be sought from an institutional ethics committee before data collection.

Result

Overview of Respondents

The survey and interview data were collected from a total of 350 wellness tourists, of which 30% were domestic tourists and 70% were international tourists. The demographic breakdown of respondents revealed a diverse sample, with ages ranging from 18 to 65 years. The majority (55%) were between 25 and 45 years old, and 60% were female. In terms of income, 40% of respondents had a middle-income level, while 35% had a high-income level. The respondents primarily came from Europe (30%), North America (25%), and Asia (20%).

Motivations for Wellness Tourism

The survey responses highlighted several key motivations for wellness tourists choosing Thailand as their destination, which can be categorized into push and pull factors.

Push Factors (Internal Motivations)

- Stress Relief and Relaxation: The top motivation identified by 70% of respondents was stress relief and relaxation. Many respondents cited the need to escape their busy work and daily lives as a primary driver for selecting wellness tourism experiences. This aligns with previous studies that show a strong connection between wellness tourism and the desire for mental rejuvenation (Han et al., 2018).
- Health Improvement: Physical health improvement was the second most common push factor (65%), with many tourists specifically seeking detox programs, weight loss, or spa treatments. This finding supports the notion that wellness tourists often aim for preventive health care and holistic healing (Chen et al., 2013).
- Self-Discovery and Spiritual Growth: About 50% of respondents sought personal growth through wellness tourism, such as meditation and yoga. This finding aligns with research suggesting that wellness tourists are often motivated by the opportunity for self-discovery and spiritual fulfillment.

Pull Factors (External Motivations)

- Affordability and Value for Money: Approximately 60% of respondents indicated that affordability was a significant factor in their choice of Thailand as a wellness destination. Compared to Western destinations, Thailand offers high-quality wellness services at a relatively lower cost, which was a major draw for international tourists.

- Authenticity and Cultural Heritage: The cultural appeal of Thailand's traditional wellness practices, such as Thai massage, herbal treatments, and Buddhist meditation, was a key pull factor. 65% of tourists mentioned that they chose Thailand for its authentic wellness offerings. This supports previous studies highlighting Thailand's rich cultural heritage as a strong attraction for wellness tourists (Tepsing, 2021).

Decision-Making Factors

The data revealed several important factors that influenced tourists' decision-making processes when choosing wellness tourism experiences in Thailand.

Influence of Social Media and Online Reviews

Social media platforms like Instagram, Facebook, and YouTube played a significant role in the decision-making process. Over 70% of respondents mentioned that they had been influenced by social media content, such as wellness influencers, travel bloggers, and wellness-related hashtags. Additionally, 50% of respondents stated that they relied heavily on online reviews on platforms like TripAdvisor and Google Reviews before finalizing their decision. This supports findings by Kim and Fesenmaier (2021), who argue that digital content and online recommendations are increasingly central to consumer decision-making in tourism.

This study has explored the consumer motivations behind choosing wellness tourism in Thailand, examining both tourist preferences and decision-making factors. Through a combination of quantitative surveys and qualitative interviews, it was found that wellness tourists are primarily motivated by internal factors (push factors) such as stress relief, health improvement, and personal growth, as well as external factors (pull factors) such as affordability, cultural authenticity, and the natural environment.

Key findings revealed that stress relief and physical health improvement were the most significant motivations for tourists. The unique cultural offerings of Thailand, including traditional wellness practices, affordable wellness services, and the country's scenic beauty, make it a desirable wellness destination for international travelers. Additionally, social media, online reviews, and word-of-mouth recommendations were found to be the most influential decision-making factors, shaping tourist choices regarding wellness destinations.

Recommendations

Based on the findings, the following recommendations are provided for wellness tourism providers, marketers, and policymakers in Thailand:

Enhance Digital Marketing and Social Media Engagement

The influence of social media and online reviews on tourist decision-making cannot be overstated. Wellness tourism providers in Thailand should invest in robust digital marketing strategies, including collaborations with wellness influencers, social media advertising, and content creation showcasing authentic wellness experiences. Utilizing platforms like Instagram, YouTube, and TripAdvisor to promote real customer experiences and wellness activities can increase visibility and attract more tourists. Additionally, it is important for wellness resorts and spas to maintain an active online presence by responding to reviews and sharing engaging content related to wellness practices, local culture, and health benefits.

Promote Thailand's Unique Wellness Offerings

Wellness tourists are drawn to the cultural authenticity of Thailand's traditional wellness practices, such as Thai massage, meditation, and herbal treatments. Wellness tourism providers should emphasize these authentic Thai wellness experiences in their marketing campaigns to distinguish Thailand from other wellness destinations. Moreover, promoting the integration of wellness with local traditions, such as Buddhist meditation retreats or Ayurvedic spa treatments, can appeal to tourists looking for meaningful, transformational experiences.

Focus on Wellness Packages for Health Improvement and Personal Growth

Given that the primary motivations for wellness tourism are related to health improvement and personal transformation, wellness tourism providers should develop tailored wellness packages that emphasize holistic health. Packages that combine detox programs, yoga retreats, stress management, and spiritual growth can attract tourists seeking a deeper, transformative experience. Special offers, such as long-term wellness retreats, personalized fitness plans, or wellness coaching, could appeal to those looking for more personalized journeys toward health and self-discovery.

Ensure Competitive Pricing and Value for Money

Affordability is a key decision-making factor for wellness tourists. Wellness tourism providers in Thailand should continue offering competitive pricing and value-for-money packages while maintaining high-quality service standards. Offering discounts for early bookings, special promotions, and all-inclusive wellness packages could help attract a broader audience, especially from high-income markets seeking affordable yet high-quality wellness experiences. Additionally, offering customizable wellness packages allows tourists to choose the services that best suit their needs, making wellness tourism more accessible to a diverse range of visitors.

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Digital Technology and the Future of Public Management of Thailand

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Abstract

This article aims to study the influence of digital technology on the transformation to digital government. It was found that the public management of Thailand in the past emphasized stability through the Chatudom system, namely, the Department of the City, the Palace, the Treasury, and the Rice Field. Later, during the reign of King Rama V, there was a reform by adopting Western management concepts to apply to the Thai bureaucracy. As a result, the bureaucracy developed into a new management style that was more transparent and people-centered. Digital technology was applied to public management, but it still faced many challenges, such as economics, politics, and changes in digital technology. The bureaucracy had to adapt by developing digital skills of civil servants, using technology to enhance cybersecurity, improving databases, promoting transparency, and issuing policies and laws that support technology to make the bureaucracy more efficient, reduce redundancy, and better respond to the people, as well as increase competitiveness in the global economic system.

Keywords: "Digital Technology", "Future of Public Management", "Thailand"

Introduction

Digital technology began with the concept of calculation and data processing for decision-making in various activities, both human life activities and various duties. It has been continuously developed since the 20th century until it plays an important role in facilitating people's lives and increasing the efficiency of management of various organizations, whether they are private business organizations or government organizations. Thailand has developed and improved the government system to be more efficient in many aspects, such as data management of the government, using an electronic database (e-Government) that allows for fast access and analysis of data, reducing the use of paper documents, increasing accuracy and reducing errors, using it as a route or device for public services (Digital Services) via online systems, developing Government as a Platform (GaaP) systems, such as government websites, government service applications, Single Sign-On systems, such as government contact services via digital ID cards, and one-stop services, etc.

We cannot deny that digital technology helps create transparency and accountability in the government system, preventing corruption or corruption in the old ways are more difficult because if they are done, it can be recorded as evidence, which is difficult for corrupt government officials to deny. In the past, similar actions often lacked evidence. But now, digital technology communication tools can be used to record evidence effectively. The impact of digital technology on the transition to Digital Government Transformation is thus the objective of this article. This is the objective of this article. The study was conducted using descriptive analysis collected from documents and articles related to digital technology and government management.

Concepts of Digital Technology

Digital technology is a concept that encompasses systems, devices, and processes that use digital data to process, store, and exchange data. This technology plays an important role in all sectors of society, including the economy, education, public health, and daily life. The capabilities of digital technology that have been developed and used in various industries are due to the following main components: 1) Hardware, which are devices such as computers, mobile phones (Smart Phones), servers, and Internet of Things (IoT) devices; 2) Software, such as programs, operating systems, applications, and algorithms used to process data; 3) Networks and Communications, such as 5G Internet, cloud computing, which is a form of computer services via the Internet without the need for its own hardware or infrastructure; and wireless communications, etc.; and 4) Data and Artificial Intelligence (Data & AI) for analyzing Big Data and using AI for decision-making and trend forecasting (Cotactic Media. (n.d., 2025; Thailand Massive Open Online Course, 2025)

Digital technology is a broad concept that encompasses systems, devices, and processes that use digital data for processing, storing, and exchanging information. This technology plays a crucial role in all sectors of society, including the economy, education, public health, and daily life. The capabilities of digital technology have been developed and applied across various industries due to its key components, which include 1) Hardware – Devices such as computers, smartphones, servers, and Internet of Things (IoT) devices. 2) Software – Includes programs, operating systems, applications, and algorithms used for data processing. 3) Networking & Communication – Includes the internet, 5G, and cloud computing, which provides computing services via the internet without requiring dedicated hardware or infrastructure, as well as wireless communication. 4) Data & AI – Used for Big Data analysis and AI-driven decision-making and trend prediction. (Cotactic Media, n.d., 2025; Thailand Massive Open Online Course, 2025)

Digital technology plays an important role in creating faster processing and data transmission speed and accuracy. The system can connect and exchange current and immediate data (Connectivity), flexibility and adaptability. Digital technology is continuously developed through software updates, intelligence with AI and machine learning systems that help analyze and make decisions automatically. In addition, digital technology plays many roles in society that make it 1) Digital economy, such as promoting online businesses, e-commerce and fintech, etc. 2) Development of education and online learning systems (e-Learning) and the use of AI to develop teaching and learning, etc. 3) Public health, such as electronic medical record systems, telemedicine and AI for disease diagnosis, etc. 4) daily Life, facilitates smart homes, cashless technology, digital money and the use of IoT in daily life, etc. 5) Electronic government (E-government) uses artificial intelligence to provide automatic citizen questioning services to answer questions about taxes and official documents, analyze economic trend data, public health data, budget allocation and analyze citizen needs to reduce repetitive workloads, including use in online elections (E-Voting) and government procurement (E-Procurement), among other applications.

Digital technology continues to develop relentlessly, driving and accelerating the transition into a technological society where human devices and tools are interconnected through the Internet of Everything (IoE). This includes the Metaverse, a virtual world where robots can perform tasks comparable to or even surpassing human capabilities in certain cases. Robots, created through digital technology, enable users to interact with them via avatars, which serve as digital representations of humans. The Metaverse integrates multiple advanced technologies, such as Virtual Reality (VR), Augmented Reality (AR), Blockchain, Artificial Intelligence (AI), and the Internet of Things (IoT). Blockchain technology is particularly utilized for decentralized data storage, ensuring security through a chain of encrypted blocks that are interconnected. Each block is securely recorded, making data tamper-resistant and transparent. Since the information within each block cannot be easily modified or deleted, blockchain enhances security and trust in digital interactions.

Digital technology has become a crucial factor in driving the global economy and society, impacting various sectors such as the economy, education, healthcare, and public administration. The advancement of technologies like artificial intelligence (AI), blockchain, the internet of things (IoT), and big data is transforming work processes, business operations, and people's lifestyles.While digital technology presents numerous opportunities, countries that fail to develop human capital in line with these changes risk being left behind. A significant obstacle to this adaptation is the education and learning system, which still adheres to traditional approaches. In the past, education primarily focused on theoretical knowledge and specialized skills, which no longer align with the demands of the digital age.Today, the most sought-after skills in the digital era include critical thinking, complex problem-solving, creativity, and digital literacy. If the education system fails to adapt to these changes, the younger generation may lack the essential skills needed for future employment.

Adapting Public Management to Digital Government

The adaptation of the civil service system to digital technology is a process that requires time and cooperation from many sectors, which can be carried out in many dimensions simultaneously. For the transformation to digital government, the government needs to set policies to support digital administration (e-Government) and digital government along with developing digital skills of civil servants. There must be training and capacity building for government officials to use digital tools effectively, including implementing the following measures:

1. The use of technology in public services by implementing online systems or applications in various processes, such as document submission or communication with the public. E-Participation refers to the use of technology to enable public participation, such as online complaint systems, platforms for providing feedback to the government, or reporting criminal activities.

2. The use of digital technology in the public sector to reduce cybersecurity risks, but it is necessary to prioritize cybersecurity and personal data protection to prevent potential impacts on citizens and national security.

3. Executives must learn the importance of modern technology and support its use in public administration. Senior executives must have a vision for using digital technology in administration and support change.

4. Developing government information systems by creating and developing a digital database that can collect and process information quickly and safely.

5. Promoting transparency and preventing corruption using Blockchain and AI can help reduce corruption and increase transparency in government operations. Use digital technology to disclose information related to work management so that citizens can follow government work.

6.Legislation and policies should be modernized to accommodate changes. The government should introduce new laws to support emerging technologies, such as laws on artificial intelligence (AI), digital finance, public asset management, and the use of big data. Additionally, outdated laws and those that do not yet support digital operations should be revised to remove obstacles to development.

The above adjustments will help the civil service work faster, reduce redundancy, and respond to the needs of the people more effectively. The government needs to accelerate the development of the digital government system to be effective through data integration and the creation of a central platform for various agencies, along with investing in the development of digital skills of civil servants to enable them to use technology to its full potential. In addition, it needs to strengthen cybersecurity measures and tighten the protection of people's data, while promoting transparency and public participation through technologies such as the Open Data system and e-Participation. The Thai civil service system must adapt to the development of digital technology in order to be able to manage its work efficiently, transparently, and up-to-date, and appropriately support the changes in the digital age. This is because digital technology plays an important role in the management of civil service work by helping to increase the efficiency of public services, promote transparency, reduce costs, increase competitiveness in the international economic system, and stimulate public participation. The development of a safe and efficient digital civil service system will be an important foundation for driving the country into the digital age in full.

Conclusion

Thailand's public management in the past prioritized security, dividing its main functions into four areas: Wiang (Defense), Wang (Palace Affairs), Khlang (Treasury), and Na (Agriculture), collectively known as Chatusadom. Later, during the reign of King Rama V, management reforms were introduced, incorporating Western governance concepts and adapting them to each era. These reforms evolved from the traditional bureaucratic system to New Public Management (NPM), Good Governance, Network Governance, and New Public Service (NPS) respectively, which emphasizes efficiency, transparency, and citizen-centric management. At the same time, rapid advancements in digital technology have played a significant role in public sector management. However, challenges remain, including economic and geopolitical conditions, climate change, and emerging infectious disease outbreaks.

The rapid advancement of technology has impacted multiple sectors, necessitating the adaptation of government management systems to embrace digital technology. This transition requires time and collaboration from various stakeholders and can be implemented across multiple dimensions simultaneously. For the transition to a digital government, the following actions should be taken,namely, 1) Develop digital skills among civil servants. 2) Integrate digital technology into government operations to mitigate cybersecurity risks**.** 3) Ensure that government leaders recognize the importance of modern technology and support its application in public administration. 4) Enhance government data systems by creating and improving digital databases that can efficiently collect, process, and secure information. 5) Promote transparency and prevent corruption by utilizing technologies such as blockchain and AI. 6) Enact modern laws and policies to accommodate the evolving digital landscape.

Such adaptations will enable the government to operate more efficiently, reduce redundancy, and better meet public needs. Additionally, it will enhance the country's competitiveness in the global economy. Therefore, the government must accelerate the development of an effective digital public administration system by integrating data and establishing a central platform for various agencies while simultaneously investing in the digital skill development of civil servants. A secure and efficient digital government system will be a crucial foundation for propelling the country toward a fully digital era.

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Causal relationships among factors influencing performance of the logistics service business according to the strategy to drive the Thai economy

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Abstract

The objectives of this research are 1) To examine innovation levels in organization, management, logistics, and brand value, as well as the operational performance of logistics service businesses in Thailand. 2.To explore the causal relationships among organizational innovation, logistics management, and brand value, and their impact on business performance in the logistics sector. 3. To validate the causal links between organizational innovation, logistics management, and brand value, and their effect on logistics business performance in Thailand. The study involved 372 high-level executives from logistics service companies in Thailand, using a questionnaire for data collection and structural equation modeling for analysis.

Results show that participants perceive organizational innovation ($\overline{X}$=3.91), logistics management ($\overline{X}$=4.02), and organizational brand value ($\overline{X}$=3.98) at a high levels, with organizational performance also rated highly ($\overline{X}$=3.92). Correlations between 11 variables management, logistics, brand value, and performance—ranged from 0.200 to 0.731. Structural equation modeling showed good fit (χ^2/df = 1.34, p = 0.09, CFI = 0.97, TLI = 0.96, GFI = 0.94, AGFI = 0.98, RMSEA = 0.05, RMR = 0.01). Findings indicate that logistics management directly impacts business performance and indirectly influences it through brand value. Organizational innovation and brand value also have significant direct effects on performance.

Keywords : organizational innovation, organizational commitment, logistics management, corporate brand value, organizational performance.

Introduction

Thailand is investing heavily in logistics infrastructure, including mass transit projects in Chiang Mai, Phuket, Nakhon Ratchasima, and Khon Kaen, as well as key Eastern Economic Corridor (EEC) developments like Laem Chabang Port, Map Ta Phut Industrial Port, and U-Tapao Airport. Aligned with China's Belt and Road Initiative, these projects boost connectivity and attract private investments, such as Alibaba's Smart Digital Hub. However, high logistics costs persist due to road transport reliance and limited technology adoption. To stay competitive under Thailand 4.0, businesses must embrace innovation, improve efficiency, and adapt to global market shifts.

Logistics services are essential for growing transportation demands. In January 2022, 444 new logistics businesses were registered, a 39.6% rise from the previous year. Logistics usage increased from 804.52 million tons in 2013 to 848.45 million tons in 2019, with road transport dominating. Under the 20-Year National Strategy, Thailand aims to enhance logistics providers (LSPs) for global competitiveness. Strategy 7 focuses on infrastructure, regulations, and IT integration for efficient transport and tracking. The government supports LSP-industry collaboration, offers financial incentives, and promotes logistics technology investment.

This study examines the impact of logistics management, organizational innovation, and brand value on service performance, aiming to enhance competitiveness, economic growth, and sustainable logistics development.

Objectives

A study on the causal relationships of factors influencing logistics service business performance under strategies driving the Thai economy. Objectives include:

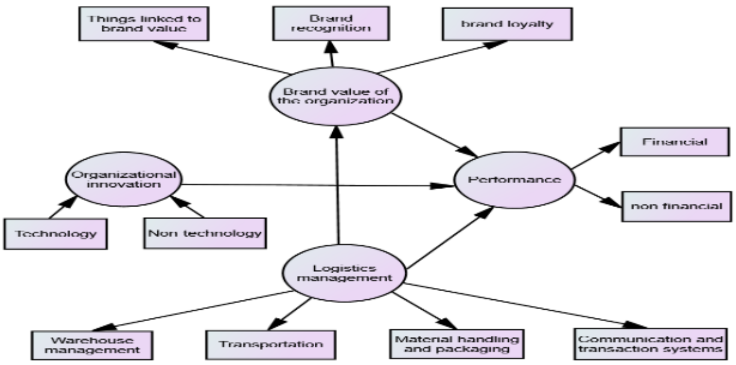
1. To examine innovation levels in organization, management, logistics, and brand value, as well as the operational performance of logistics service businesses in Thailand.

2.To explore the causal relationships among organizational innovation, logistics management, and brand value, and their impact on business performance in the logistics sector.

3.To validate the causal links between organizational innovation, logistics management, and brand value, and their effect on logistics business performance in Thailand.

Research Conceptual Framework

The researcher aims to examine the causal relationship between corporate innovation, logistics management, and brand value, and their impact on logistics service performance in Thailand. A review of both domestic and foreign literature has been conducted to develop the conceptual framework, as shown in Figure 1.



Figue 1: Research conceptual framework

Causal factors that influence the performance of logistics service businesses in Thailand.

1.Organizational Innovation: The study found overall organizational innovation to be high ($\bar{x}$ = 3.91, SD = 0.63). Non-technological innovation received the highest rating ($\bar{x}$ = 3.97, SD = 0.67), followed by technological innovation ($\bar{x}$ = 3.86, SD = 0.78).

2.Logistics Management: Logistics management was rated highly ($\bar{x}$ = 4.02, SD = 0.57). Transportation was the most valued aspect ($\bar{x}$ = 4.07, SD = 0.63), followed by equipment and packaging management ($\bar{x}$ = 4.06, SD = 0.71), communication and transaction systems ($\bar{x}$ = 4.00, SD = 0.70), and warehouse management ($\bar{x}$ = 3.94, SD = 0.65).

3.Brand Equity: Brand loyalty was rated high ($\bar{x}$ = 3.98, SD = 0.63), with the highest opinion on brand loyalty itself ($\bar{x}$ = 4.00, SD = 0.72), followed by brand-related factors ($\bar{x}$ = 3.99, SD = 0.74), and brand recognition ($\bar{x}$ = 3.95, SD = 0.71).

4.Firm Performance: Organizational performance was rated high ($\bar{x}$ = 3.92, SD = 0.62), with financial performance being the highest-rated aspect ($\bar{x}$ = 3.93, SD = 0.68), followed by non-financial performance ($\bar{x}$ = 3.91, SD = 0.63).

Results of analysis of the relationship between variables

The analysis of the relationship between 11 variables in logistics management, organizational brand value, and performance showed positive correlations ranging from 0.200 to 0.731, with no pairs exceeding a 0.80 correlation coefficient.

Confirmatory factor analysis results

1. **Organizational Innovation**: The confirmatory factor analysis confirms construct validity with good fit indices (NFI = 0.95, RMR = 0.03, RMSEA = 0.04). Non-technology innovation (NI) has the highest factor loading (0.94), followed by technological innovation (TI: 0.83).

2. **Logistics Management**: The model demonstrates construct validity (NFI = 0.98, RMR = 0.00, RMSEA = 0.00). Transportation (TD) has the highest factor loading (1.04), followed by communication (LC: 1.00), equipment/packaging management (EM: 0.92), and warehouse management (WM: 0.76).

3. **Brand Value:** The model aligns with empirical data (X^2 = 2.89, df = 1, P = 0.08, TLI = 0.98, GFI = 0.99, AGFI = 0.95, CFI = 0.97, NFI = 0.99, RMR = 0.03, RMSEA = 0.06). Brand awareness (BW) has the highest factor loading (0.85), followed by brand association (BA: 0.83) and brand loyalty (BL: 0.72).

4 Component and Model Fit Analysis Results: The confirmatory factor analysis validates the organization's performance, demonstrating structural validity (CFI = 0.99, RMR = 0.01, RMSEA = 0.03). Financial performance (FP: 0.95) and net profit (NP: 0.84) show the highest factor loadings.

Discussion of study results

Organizational Innovation

Organizational innovation significantly enhances logistics service performance in Thailand. This aligns with Sarawasi (2021), who identified technological and non-technological innovations as key drivers. Boonrod (2018) found IT-integrated innovations boost marketing performance in hotels, while Rathanachaikul (2021) confirmed innovation improves SME profitability.

Logistics Management

Effective logistics management strongly impacts business performance. Somboon and Narunat (2020) found improvements benefit Thailand's automotive sector, while Mutua et al. (2020) reported a strong correlation ($R \geq 0.63$, $p < 0.001$) in Kenyan firms. Sarawasi (2021) highlighted the positive role of green logistics in Thailand.

Corporate Brand Value

Brand value is crucial in Thailand's logistics sector. Devis et al. (2009) found service providers prioritize brand strength, influencing pricing. Kuekudling et al. (2022) linked quality and social responsibility to efficiency, while Kansomsap and Sarawasi (2021) confirmed brand value drives SME success and customer loyalty.

Organizational Performance

The study found high organizational performance ratings ($\bar{x}$ = 3.92, S.D. = 0.62), with financial performance ($\bar{x}$ = 3.93) slightly exceeding non-financial performance ($\bar{x}$ = 3.91). While financial metrics influence value and investment, non-financial factors like service quality and sustainability ensure long-term success. The Balanced Scorecard (Kaplan & Norton, 1992) effectively integrates both aspects.

Suggestions

Research on causal factors influencing logistics service performance in alignment with Thailand's economic strategy includes the following recommendations:

Suggestions from research

1. Organizational innovation drives growth, efficiency, and competitiveness in Thai logistics by reducing costs and enhancing operations. Companies should foster an innovative culture, engage employees, and invest in development. Government support through R&D funding, knowledge exchange, and investment access is key to global success. Effective logistics management optimizes supply chains, reduces costs, and improves customer satisfaction through integrated strategies and technology.

2. Corporate brand value significantly impacts Thai logistics performance, boosting financial gains, competitiveness, and sales. Strengthening brand equity—awareness, quality, association, and loyalty—enhances business success. Key strategies include improving service quality, customer experience, and marketing. Government support in R&D, knowledge exchange, and capital access is essential for global competitiveness.

Suggestions for next research

1. Conduct in-depth qualitative studies (e.g., focus groups, interviews, depth interviews) for deeper insights.

2. Logistics performance is influenced by industry size, location, and digital adoption. AI, big data, and IoT are transforming the sector, warranting further study on their impact in Thailand.

3. Apply this model to various sectors—agriculture, industry, and services—to broaden its scope.

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The Canonical Correlation Analysis for Public Administration Research

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Abstract

This article explores the use of canonical correlation analysis in public administration research, demonstrating its application through a study on organizational commitment among public relations department civil servants. The analysis examines the relationship between opinions on organizational climate and organizational commitment using structural coefficients of .30 or greater. The study follows three steps: data preparation in SPSS, command execution, and result interpretation. Findings show a strong relationship between the two variable sets, with organizational climate explaining 77% of the variability in organizational commitment.

Keywords: Canonical Correlation Public Administration Research

Introduction

This research in public administration exemplifies the relationship between opinions on the organizational climate and the organizational commitment of the public relations officers at the Department of Public Relations. It stipulates that opinions regarding the organization serve as the independent variable, while the dependent variable is the organizational commitment of these public relations officers. In the past, public administration research has typically employed survey methods, using questionnaires as a tool for data collection, and the statistical analyses used have generally been simple hypothesis tests, such as t-tests and one-way analysis of variance. However, there has been a lack of research focusing on the analysis of multiple variables using canonical correlation analysis-a technique that is useful for generating knowledge that can serve as information for public management. Moreover, it can be effectively applied in designing advanced quantitative research in the field of public administration. For these reasons, the author presents the analysis of canonical correlation coefficients as a guideline for data analysis in public administration research, thereby broadening the scope of advanced quantitative research knowledge in public administration in Thailand.

Objectives of the Study

To examine the concepts and examples of canonical correlation analysis in public administration research.

The Concept of Canonical Correlation Analysis

Canonical correlation analysis, derived from multiple regression, is a multivariate technique similar to factor and multiple regression analysis. Unlike traditional methods, it groups variables into independent (predictor) and dependent (criterion) sets rather than classifying them individually. The number of variables in each group can vary, and each set functions as a composite variable. This method analyzes relationships between variable groups rather than individual pairs. Before assessing intergroup relationships, intra-group correlations must be examined to identify key variables. Weights are then assigned carefully to maximize the canonical correlation coefficient, ensuring a rigorous balance of qualitative and quantitative analysis (Samran Mee Jaeng, 2001).

Objectives of Canonical Correlation Analysis

Samran Mee Jaeng (2001) stated that canonical correlation analysis identifies relationship patterns between two variable sets, maximizing their correlation. The number of variables in each set may vary, and their weights are determined by coefficients that optimize the canonical correlation.

Kalaya Vanichbancha (2552) described the technique as creating canonical variables—linear functions of original variables—whose correlation defines the canonical correlation.

The objectives of canonical correlation analysis are:

1.Identify how canonical variates combine original variables (X, Y) with weights and their
relationships.

2.Assess the statistical significance of canonical correlations.

3.Compute canonical loadings (correlations between original variables and canonical \variates) and cross-loadings.

4.Interpret canonical variates using correlations and standardized coefficients.

5.Determine redundancy, measuring how much variance in each set is explained by canonical variates.

Benefits of Canonical Correlation Analysis for Research

Samran Mee Jaeng (2001) identified three key benefits of canonical correlation analysis:

1.It maximizes the relationship between two variable groups within the same dataset.

2.It reduces data complexity by creating composite variables (canonical variates).

3.Canonical variate scores enable ranking of analysis units, aiding in variable positioning.

Boonchom Srisat (2004) highlighted that canonical correlation analysis enhances validity by simultaneously analyzing multiple independent and dependent variables, effectively capturing their natural interrelationships.

Characteristics of the Data Used in Canonical Correlation Analysis

Samran Meejaeng (2544) states that canonical correlation analysis requires interval-scale data or bivariate 0-1 variables, like in multipleregression. However, the analysis uses a correlation matrix of variable groups.

Steps in Canonical Correlation Analysis

The author used SPSS, a widely known statistical package popular in public administration research.

Step 1: Data Preparation

Ensure the number of variables in SPSS matches the study variables.

Step 2: Writing Commands

Navigate to File → New → Syntax and enter the command.

```
Manova  y1  y2  y3 .....yn with x1 x2 x3..... xn
/discrim all alpha(1)
/print=sig(eigen dim).
```

Ensure variable names match those in Step 1, and check symbols and spacing to avoid errors. After writing the commands, click **Run** → **All** in the Syntax window.

Step 3: Interpreting the Results

When analyzing results, key statistical values must be considered (Cheanchana, 2015):

Multivariate Test of Significance: Includes Pillai's Trace, Hotelling's Trace, Wilks' Lambda, and Roy's Largest Root. A significance level (Sig.) < .05 indicates a valid model, with Wilks' Lambda commonly used to assess unexplained variance.

Dimension Reduction Analysis: Identifies linear functions representing variable relationships. Only statistically significant functions (Sig. < .05) are used for interpretation.

Eigenvalue and Canonical Correlations: Higher canonical correlations indicate stronger variable relationships.

Standardized Canonical Coefficients & Correlations: Display relationships for dependent and independent variables using structure coefficients. A coefficient ≥ |0.45| is meaningful (Sherry & Henson, 2005).

Relationship Strength Categories:

0.30 – 0.50 → Moderate

0.50 – 0.70 → High

0.70 – 1.00 → Very High

Example of Analysis and Interpretation

This study examines canonical correlations in public administration research, focusing on organizational commitment among Public Relations Department officers. It analyzes the relationships between organizational climate variables (structure, support, rewards, conflict, and unity) and organizational commitment variables (goal acceptance, effort, and retention), as illustrated in Figure 1.

Step 1: Data Preparation in SPSS

Independent variables (organizational climate, "climate"):

x1: Structure , **x2**: Support, **x3**: Rewards, **x4**: Conflict, **x5**: Unity

Dependent variables (organizational commitment, "commit"):

y1: Goal acceptance, **y2**: Effort, **y3**: Retention

As shown in Figure 2, all data must be at the interval scale or higher.

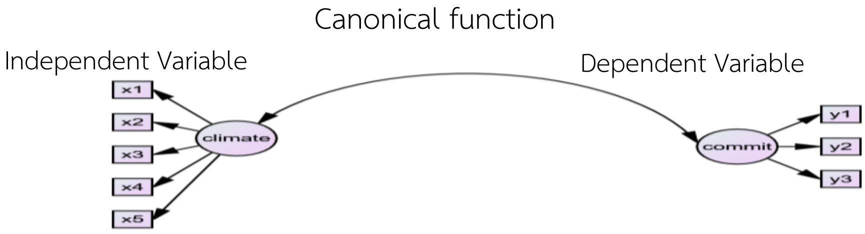


Figure 1. Conceptual framework for Canonical Correlation Analysis

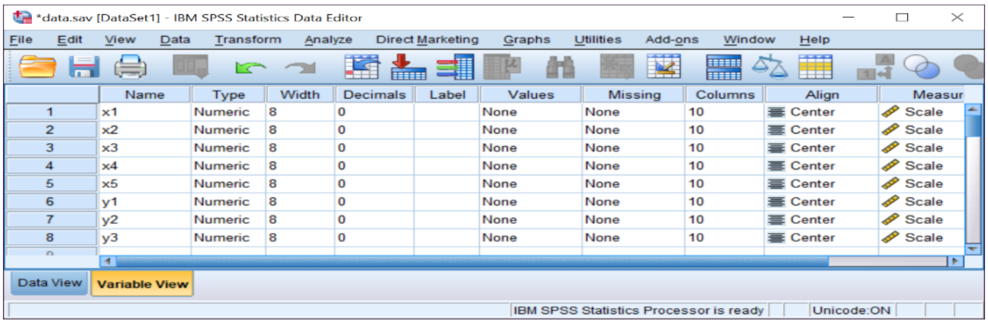


Figure 2: Preparing Data in the SPSS Program

Step 2: Write the command to analyze the canonical. Go to the main menu and select File → New → Syntax, as shown in Figure 3.

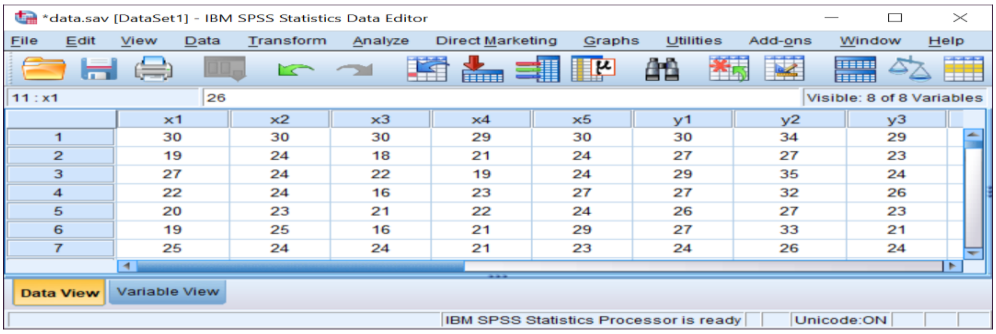
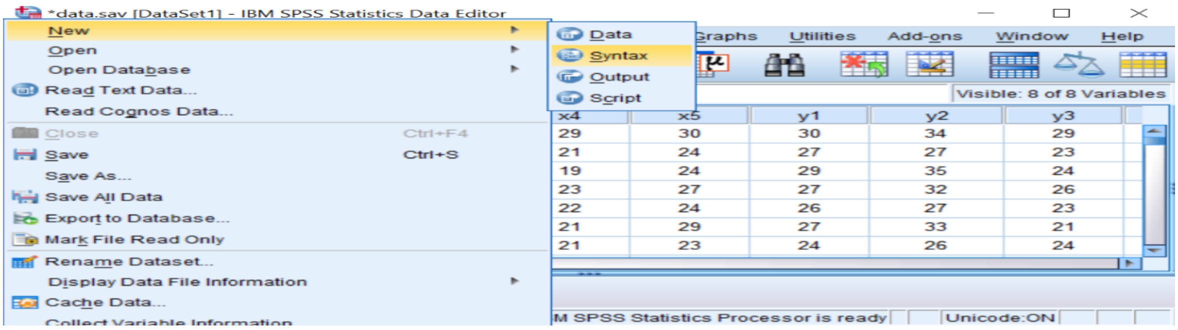


Figure 3: Selecting the menu in the SPSS program to write the canonical analysis



command

Then, write the command for SPSS to analyze the canonical correlation as follows (Garson, 2015)

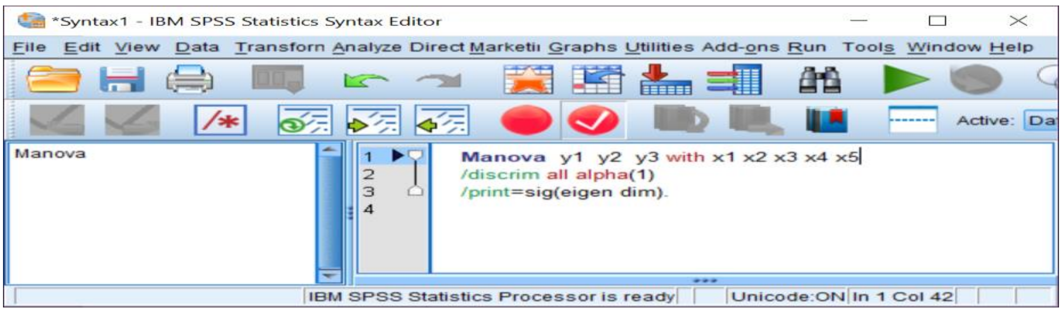


Figure 4: The Syntax Window Used for Writing Commands

Then click the "Run → All" button as shown in Figure 5.

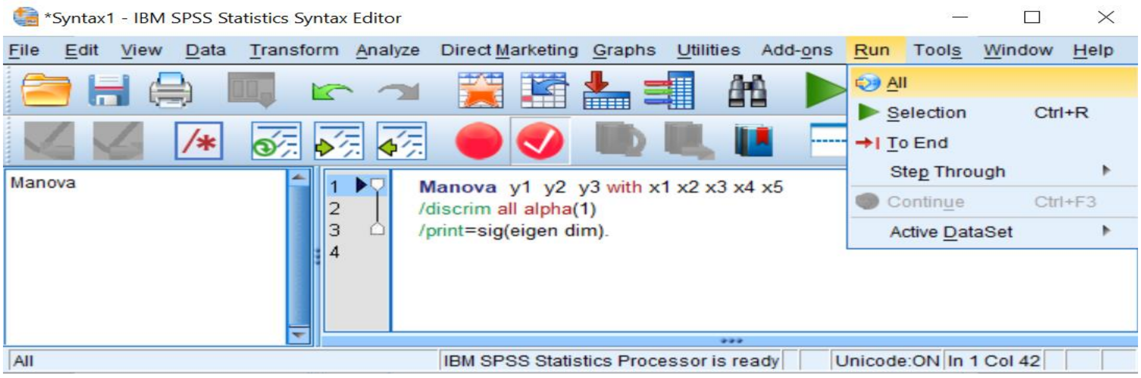


Figure 5: Running the program by clicking the Run → All button.

The Output window will appear to display the results of the canonical correlation analysis as shown in Figure 6.

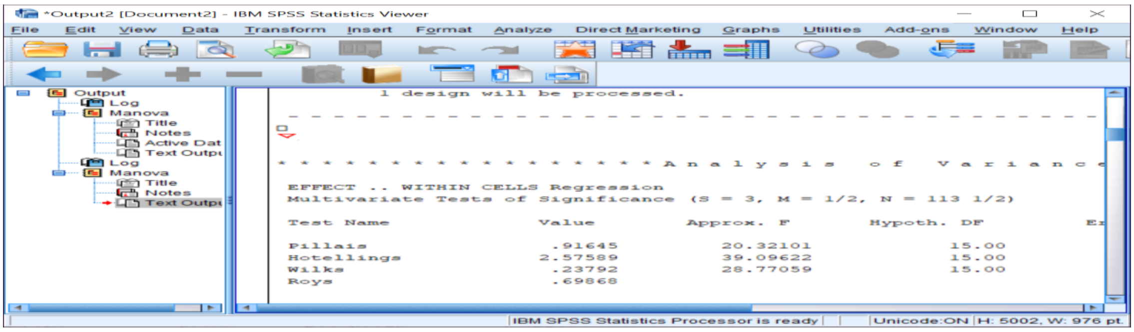


Figure 6: Output window displaying the results of canonical correlation analysis.

The analysis results are as follows.

* * * * * * * * * * * * * * * * * A n a l y s i s   o f   V a r i a n c e -- Design 1 * * * * * * * *

EFFECT .. WITHIN CELLS Regression

Multivariate Tests of Significance (S = 3, M = 1/2, N = 113 1/2)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	.91645	20.32101	15.00	693.00	.000
Hotellings	2.57589	39.09622	15.00	683.00	.000 ①
Wilks	.23792	28.77059	15.00	632.57	.000
Roys	.69868				

- -

Eigenvalues and Canonical Correlations

Root No.	Eigenvalue	Pct.	Cum. Pct.	Canon Cor.	Sq. Cor
1	2.31871	90.01593	90.01593	.83587	.69868
2	.21357	8.29129	98.30722	.41951	.17599
3	.04360	1.69278	100.00000	.20441	.04178

②

- -

③

Dimension Reduction Analysis

Roots	Wilks L.	F	Hypoth. DF	Error DF	Sig. of F
1 TO 3	.23792	28.77059	15.00	32.57	.000
2 TO 3	.78958	7.20963	8.00	460.00	.000
3 TO 3	.95822	3.35751	3.00	231.00	.020

- -

Standardized canonical coefficients for DEPENDENT variables

Function No.

Variable	1	2	3
y1	-.36651	.20974	1.28102
y2	-.15306	-1.33103	-.27309
y3	-.61280	.88789	-.92383

④

- -

Correlations between DEPENDENT and canonical variables

Function No.

Variable	1	2	3
y1	-.83974	-.01480	.54279
y2	-.75933	-.64094	-.11231
y3	-.93994	.16894	-.29659

⑤

- -

Standardized canonical coefficients for COVARIATES

CAN. VAR.

COVARIATE	**1**	**2**	**3**
x1	**-.22993**	**-.39365**	**.84684**
x2	**-.25171**	**.97577**	**.35560**
x3	**-.11285**	**.83739**	**-.87829**
x4	**.18495**	**-.78098**	**-.75153**
x5	**-.70259**	**-.69672**	**-.03022**

⑥

- -

Correlations between COVARIATES and canonical variables

CAN. VAR.

Covariate	1	2	3
x1	-.73350	.22652	.16059
x2	-.79301	.30388	-.08664
x3	-.60908	.51155	-.48710
x4	-.45293	-.18617	-.61716
x5	-.92054	-.31417	-.10573

⑦

- -

Figure 7: Results of Canonical Correlation Analysis (continued)

The results of the canonical correlation analysis above can be presented in table form to display the data analysis for the research, as shown in Tables 1 and 2.

Table 1: Canonical correlation between the variables of opinions on organizational climate and organizational commitment.

Function	Canonical correlation	Square correlation	Wilk's Lambda	F	df	Error	p-value
1	.83	.69	.23	28.77	15	32.57	.00
2	.41	.17	.78	7.20	8	460.00	.00
3	.20	.04	.95	3.35	3	231.00	.00
Multivariate test of significance (Wilks' Lambda = 0.23, F(15, 32.57) = 28.77, p = .00)							

Table 1 presents the relationship between organizational climate (structure, warmth and support, rewards, conflict, and unity) and organizational commitment (goal acceptance, effort, and membership retention).

Function 1: Rc2=0.69R_c^2 = 0.69Rc2=0.69, p<.01p < .01p<.01 (Wilks' Λ=0.23\Lambda = 0.23Λ=0.23, F(15,32.57)=28.77F(15, 32.57) = 28.77F(15,32.57)=28.77).

Function 2: Rc2=0.17R_c^2 = 0.17Rc2=0.17, p<.01p < .01p<.01 (Wilks' Λ=0.78\Lambda = 0.78Λ=0.78, F(8,460)=7.20F(8, 460) = 7.20F(8,460)=7.20).

Function 3: Rc2=0.04R_c^2 = 0.04Rc2=0.04, p<.01p < .01p<.01 (Wilks' Λ=0.95\Lambda = 0.95Λ=0.95, F(3,231)=3.35F(3, 231) = 3.35F(3,231)=3.35).

All functions are significant at p<.01p < .01p<.01, but only Function 1 is discussed in detail (Table 2). Functions 2 and 3 follow a similar interpretation

Table 2: Standardized Canonical Correlations and Structure Coefficients between the Sets of Variables.

variable	Function 1		
	Coefficients	Structure Coefficient	Square Structure Coefficients (%)
Organizational commitment variables			
Confidence and acceptance of goals and values	-.36	-.83	70.51
Willingness to put in the best effort in doing work	-.15	-.75	57.65
A strong desire to maintain membership Image	-.61	-.93	88.34
Organizational climate opinion variable set			
Organizational Structure	-.22	-.73	53.80
Warmth and support	-.25	-.79	62.88
Rewarding	-.11	-.60	37.09
Conflict	.18	-.45	20.51
Organizational unity	-.70	-.92	84.73

Underline means the absolute value is greater than or equal to .45

Table 2 shows that in Function 1, three organizational commitment variables had absolute canonical structure coefficients of 0.45 or higher: desire to maintain membership (0.93), belief in goals and values (0.83), and willingness to exert full effort (0.75). Five organizational climate variables met the same threshold: unity (0.92), warmth and support (0.79), structure (0.73), rewards (0.60), and conflict (0.45). All variables showed negative correlations, indicating that lower perceptions of organizational climate correspond to lower organizational commitment. Overall, organizational climate explains 77% of the variance in organizational commitment (1–Wilks'Lambda)×100=(1–0.23)×100(1 – Wilks' Lambda) × 100 = (1–0.23)×100(1–Wilks'Lambda)×100=(1–0.23)×100.

Conclusion

This paper presents the concept and application of canonical correlation analysis (CCA) in public administration research. CCA identifies relationships between two variable sets using canonical structure coefficients (≥0.45).The analysis involves three steps:1) data preparation in SPSS, 2) command execution, and 3) result interpretation. An example study on public relations officers shows that perceptions of organizational climate correlate with organizational commitment—positive perceptions increase commitment, while negative ones decrease it. These findings enhance teaching and research, reinforcing public administration as a science.

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New Public Service Delivery Focused on Digital Technology and Sustainability: Challenges and Opportunities

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Abstract

This article introduces the New Public Service Delivery (NPDS) model, integrating digital technology with sustainable development to enhance service quality, efficiency, and transparency. It emphasizes equal access, citizen participation, and key components such as data management, digital infrastructure, and data security. The article also highlights the role of digital literacy and addresses challenges like cybersecurity, the digital divide, and bureaucratic barriers. Drawing from international and domestic case studies, it provides policy insights for the digital era. Findings suggest that blending digital innovation with sustainability is crucial for efficient and adaptable public service delivery.

Keywords: digital public service; sustainability; digital technology; citizen participation; government innovation; cybersecurity

Introduction

Digital technology has significantly transformed the way people live and work. It not only changes the business and industrial sectors but also has the potential to improve public services, such as healthcare, education, transportation, and resource management. However, the integration of digital technology into public service delivery still faces challenges, including data security, equitable access, the digital skills gap, and bureaucratic adaptation. (World Economic Forum, 2021). Sustainability has become a critical issue in society. Sustainable development means the efficient use of resources and environmental protection for the benefit of both current and future generations. Therefore, integrating digital technology with sustainable principles in public service delivery is a promising solution to address various societal challenges. (World Bank, 2021).

The development and presentation of the concept "New Public Services Focused on Digital Technology and Sustainability (NPDS)" respond to the emerging needs and challenges. The fusion of digital technology and sustainability not only enhances service efficiency but also minimizes environmental impacts and fosters long-term sustainability (Forbes, 2020).

This article aims to examine the key components, challenges, and opportunities of the new public service delivery model that emphasizes digital technology and sustainability. It also reviews successful international examples of its application, with the hope that the insights will inform policy development and implementation across various sectors in Thailand.

Key Components of the New Public Service Model

The NPDS model consists of several interrelated components that establish a foundation for effective, sustainable public service delivery in the digital age. **1) Data Integration & Management** – Effective integration of public and private sector data supports decision-making while ensuring security and privacy (UNDESA, 2020). **2) Digital Infrastructure** – High-speed internet, cloud computing, and 5G are crucial for seamless digital services (McKinsey & Company, 2020). **3) Sustainable Services** – Public services should minimize resource use, emissions, and enhance energy efficiency (Gartner, 2021). **4) Security & Privacy** – Strong cybersecurity measures, including encryption and authentication, protect personal data (OECD, 2020). **5) Digital Skills** – Training programs enhance digital literacy for officials and citizens (ITU, 2020). **6) Sustainability** – Smart energy management reduces resource consumption and environmental impact (United Nations, 2015). **7) Public Engagement** – Digital platforms foster inclusive and responsive service design (European Commission, 2020).In summary, the delivery of public services in the digital age requires integrated data management, robust infrastructure, accessible services, strong security, digital skills, sustainable resource management, and public engagement.

Evolution of the NPDS Model

The new public service delivery model (NPDS) has gained attention due to environmental and social changes, with digital technology starting from online tax payments and evolving into blockchain for security and sustainable innovation. (Smith, 2020).

Development of Digital Technology in Public Services

2012–2018: Integration of digital technology into public services
2018–2022: Adoption of modern technology to address environmental issues and promote sustainability From 2023 onward: Acceleration of digital technology to enhance efficiency, accessibility, and sustainability, particularly in responding to health and environmental crises

Key Success Factors

Efficient public service delivery must meet societal needs through collaboration between government agencies and partners, fostering adaptive innovation in the rapidly evolving digital and sustainable landscape.

Process for Implementing NPDS

The implementation of the NPDS model begins with understanding the needs and challenges in service delivery within communities or organizations. It includes needs analysis, assessment of appropriate technologies, operational planning with performance indicators, technology development, testing and evaluation, and continuous improvement of public services. (Brown & Dennis, 2011).

Challenges in NPDS Implementation

Implementing a digital and sustainable public service model involves various challenges, including:

1) Cybersecurity

Cyber Attacks: Increased cyber threats targeting public sector systems necessitate high-level security measures (National Cyber Security Agency [NCSA], Thailand).

Data Privacy Protection: Strict adherence to data protection laws and standards is required to safeguard personal information (Personal Data Protection Commission [PDPC], Thailand).

2) Digital Divide

Access to Technology: Unequal access to high-speed internet and digital devices may exacerbate service inequities (World Bank, 2020).

3) Digital Literacy: Training for both citizens and government personnel is essential to fully harness digital tools (Thailand Professional Qualification Institute [TPQI]).

4) Bureaucratic Adaptation: Adjusting traditional bureaucratic processes to incorporate new digital technologies can be challenging (Bertot, Jaeger, & Grimes, 2010).

5) Investment and Budget: The high cost of developing and maintaining digital infrastructure requires effective budget allocation (Accenture, 2019).

6) Interagency Coordination: Collaboration between diverse government agencies, including sharing information and resources, is critical but can be hindered by operational mismatches (National Academy of Public Administration [NAPA], 2020).

7) Sustainability: Ensuring that public services consider natural resource management and climate adaptation is vital for long-term success (Intergovernmental Panel on Climate Change [IPCC], 2021).

Opportunities in NPDS

Adopting digital technology and sustainable practices in public service delivery opens numerous opportunities: 1) **Enhanced Service Efficiency:** Streamlined processes (e.g., online document submission and mobile service applications) reduce operational costs and improve service delivery (Accenture, 2019). **2) Transparency and Accountability:** Real-time data access and open data initiatives enhance public oversight and trust in government operations (Bertot, Jaeger, & Grimes, 2010). **3) Public Participation:** Digital platforms enable broad citizen involvement in policy-making and service design, enhancing democratic governance (UNDESA, 2018). **4) Innovation and Development:** Research and development in digital technologies (e.g.,AI and machine learning) foster innovative solutions that stimulate economic growth and improve public services (Harvard Business Review, 2019). **5) Skill Development and Lifelong Learning:** Digital training programs increase the capacity of citizens and public servants to engage with new technologies (National Skills Development Corporation [NSDC], 2020).

6) Improved Responsiveness: Digital services provide 24/7 access and rapid response during emergencies, such as through mobile alert systems (National Digital Service [UK], 2020).**7) Building Sustainability:** Energy-efficient technologies and resource optimization initiatives support long-term environmental sustainability (International Institute for Sustainable Development [IISD], 2020). **8) Creating a Connected and Equitable Society:** Integrated digital platforms facilitate equal access to services, thereby reducing social inequalities (World Bank, 2021).

Successful International Case Studies

Successful international case studies, such as **United Arab Emirates (UAE):** In Dubai and Abu Dhabi, digital technology is used to enhance public services. For example, Smart Dubai uses blockchain to secure data related to finance, education, and health, while Abu Dhabi's Sustainable Smart City employs digital systems to manage traffic and reduce pollution. (smartdubai.ae; abudhabisustainabilityweek.com)., **Estonia:** Estonia's e-Estonia program offers comprehensive online public services, including e-Residency, e-Tax, e-Voting, and a Digital ID system (e-estonia.com)., **Singapore:** Singapore's Smart Nation initiative focuses on smart homes, comprehensive e-government services, and integrated urban mobility solutions

(smartnation.gov.sg)., **Finland:** Helsinki Smart City projects, such as smart grids and Mobility as a Service (MaaS), demonstrate the effective use of digital technology to improve urban sustainability (hel.fi/smart/en/)., **Japan:** The Society 5.0 initiative in Japan utilizes robotics, AI, and smart agriculture to enhance quality of life and ensure sustainability (soumu.go.jp)., **Netherlands:** Amsterdam Smart City focuses on smart energy grids, sustainable mobility,
and environmentally friendly urban infrastructure (amsterdamsmartcity.com)., also include **Norway**, **Sweden, Canada, Australia, South Korea** as well.

Application in Thailand

Thailand has adopted the NPDS model through various projects and policies that integrate digital technology with sustainability, including: **1) Smart City Projects:** Pilot projects in cities such as Phuket, Chiang Mai, and Khon Kaen—featuring IoT systems, smart surveillance, traffic management, and energy optimization—illustrate Thailand's commitment to urban innovation (smartcitythailand.or.th). **2) National e-Payment System:** The National e-Payment project, which includes systems like Prompt Pay and QR Code payments, demonstrates the adoption of digital transactions for improved public service efficiency (bot.or.th). **3) Digital Government Initiatives:** Thailand's Digital Government project includes the Government Information Network (GIN) and various online public services (dga.or.th). **4) Renewable Energy and Waste Management:** Projects promoting solar energy, waste segregation, recycling, and waste-to-energy technologies illustrate the country's efforts toward sustainable public service delivery (dede.go.th). **5) Thai Digital ID:** The Thai Digital ID initiative enhances electronic authentication to improve the security and convenience of online transactions (thaidigitalid.com). **6) Smart Transportation:** Bangkok and other major cities are developing intelligent transportation systems—including smart traffic management and mobile applications—to improve public transit efficiency (bangkok.go.th).

Factors Influencing NPDS Effectiveness

The effectiveness of digital and sustainable public service delivery is influenced by several factors, including: **1) Investment in Technology:** Modern technological investments improve efficiency, reduce operational costs, and enhance service delivery through tools such as AI, IoT, and blockchain (OECD, 2018). **2) Policy and Legislation:** Clear policies and supportive legislation provide a structured framework that facilitates digital transformation (European Commission, 2020). **3) Expertise and Skills of Personnel:** Continuous training and skill development are vital for the effective implementation of digital technologies (UNDESA, 2018). **4) Interagency Collaboration:** Effective coordination and resource sharing among government agencies enhance service delivery efficiency (Wirtz & Kurtz, 2018). **5) Public Awareness and Participation:** Citizen engagement through feedback and participation improves the responsiveness and relevance of public services (Nam & Pardo, 2011). **6) Resources and Budget:** Adequate funding and resource allocation are essential for sustaining digital and sustainable public service initiatives (IMF, 2020).

Future Trends in NPDS

Digital technology will increasingly integrate with sustainability in public service delivery in the future, with key trends including: **1) Digital Adoption –** Mobile apps and automation will streamline public services**. 2) Real-Time Services –** Big data analytics will enhance service monitoring and efficiency. **3) Sustainability Focus** – Public services will prioritize renewable energy and resource efficiency. **4) Tech Innovation –** AI and blockchain will improve security and service quality. **5) Interagency Collaboration** – Government, private, and community cooperation will drive innovation. **6) Inclusive Society** – Digital platforms will ensure equitable access to services. **7) Digital Democracy –** Digital tools will enhance transparency and citizen participation**. 8) Financial Efficiency –** Digital solutions will optimize budgeting and resource allocation**. 9) Sustainable Innovation –** Technology-driven sustainability will be key. **10) Ongoing Digital Education –** Continuous training will enhance tech literacy. **11) Eco-Friendly Infrastructure –** Paper reduction and energy efficiency will be prioritized. **12) Security & Risk Management –** Advanced measures will protect data and public trust. **13) Community Innovation –** Knowledge-sharing platforms will drive service improvements. **14) Collaborative Workspaces** – Open hubs will foster public service advancements. **15) Policy Innovation** – Forward-thinking policies will sustain digital transformation (World Economic Forum, 2021).

Conclusion

This article, "New Public Service Delivery Focused on Digital Technology and Sustainability: Challenges and Opportunities," explores the trends and directions of public service development in an era where digital technology is integral to daily life. By integrating digital innovation and sustainability, the proposed model aims to enhance service quality, reduce complexity, and better meet citizens' needs. Despite challenges such as data security, bureaucratic adaptation, and the digital skills gap, there exist vast opportunities to create efficient, sustainable public services. Successful implementation will depend on addressing these challenges and leveraging interagency cooperation and innovation to foster a resilient public service ecosystem (OECD, 2021).

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The Role of Technology and Social Media in the Local Election Process

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Abstract

The use of technology in campaigning, the use of social media in organizing the process of local and regional elections for political benefits and decision-making in local elections. In today's society, life relies primarily on technology and digital media. Communication to connect relationships and coordinate quickly, easily access information, express opinions or analyze and criticize political elections at both local and regional levels. The election process has been adjusted and developed according to the constitution. It has been changed to fit the context of society in the globalization era. Technology and social media therefore help people access election information, election decisions, and information for decision-making more conveniently and quickly. People can express their opinions in each election, and people can also use technology and social media channels to analyze and suggest the work processes of local administrative organizations and the Election Commission. Technology and social media are therefore important tools that allow people to better access political parties and politicians. Politicians can use media to allow people to access and share their opinions on various issues, such as party policies, candidates, and campaigning through various social media, which saves on public relations budgets. At the same time, public relations in the form of social media can allow people to express their opinions or attitudes, both negative and positive, which can affect public popularity. Guidelines for practice to ensure that the use of social media is under the guaranteed provisions. The role of social media is a process in which citizens can access the election process and enable elections to proceed according to democratic governance so that citizens have true rights, freedom, and equality.

Keywords: "Social Media", "Election process", "Local government"

Introduction

Social media plays a role in the lives of people of all ages. At present, communication is a process of exchanging attitudes, beliefs, and opinions from one person to another, called the communication process. The communication process (David K, Berlo, 1960) has basic components: the sender, which is the starting point of the communication process because he is the one who sends his thoughts, feelings, or objectives to another person through the message, which will be in the form of content or symbols, through the five senses: hearing, seeing, touching, tasting, or smelling, collectively called the channel, in order to reach the receiver, which is the destination of the communication process. Political communication is a process that will lead to political work. That is, how life and society will be depends on the ability of the people to exchange information with each other, or in other words, communication is a tool for supporting or demanding politics (Pichit Tanong, 2007).

In digital world, technology and social media have played an important role in changing the political process, including local elections. In the past, the election process was controlled by the media and methods that had limited access to information. However, in this era, technology and social media have opened up opportunities for people to access information about elections and candidates more easily, without having to rely on news distribution from traditional media such as newspapers or television. In other words, the role of technology and social media in enhancing the local election process, public participation, and local political development. However, the election process will lead to the development of local administrative organizations. Local government is a form of government that is important in politics and governance. Local elections enhance the participation of local people in decision-making and resource management in their communities, which results in effective local development and responding to the needs of local people (Pradhan Kongritsuksakon, 2010: 6). Local administration is a system of administration within a local area or community, in which local agencies are established to oversee development and provide various services to people in that area, with the aim of promoting public participation and responding to local needs.

Therefore, social media is an important factor in developing the election management process to allow the public to participate in the development of local government, to allow the public to participate in policy-making, and to plan the development of local government organizations for sustainable management. At present, it can be seen that government agencies and organizations give importance to social media, especially digital media, because it allows the public to access information sources and decentralizes the administration of local government organizations. The public can access information conveniently and quickly to provide services to the public. The government sector has also given importance to social media by using government applications to play a role in managing personal data so that the public can access government information in many agencies and to further develop and promote technology for the work of the government and local government organizations so that it can be developed efficiently and produce the greatest results for the public.

Concepts and theories on social media and local government election management

Social media means media that is a tool for social operations to communicate among each other in social networks through various programs that are connected to the Internet, emphasizing that users, both senders and receivers, integrate together creatively.

The Royal Institute (2011) defined the term "Social Media" which means electronic media, which is a medium that allows the general public to participate in creating and exchanging various opinions through the Internet. These media are provided by various companies through their websites, such as Facebook, Twitter, Wikipedia, etc.

(Somkwan Kawiyya, 1992) Communication can strengthen and stabilize the socio-political system by providing information and knowledge to the public to understand the structure and political roles of the government and the public. At the same time, it also collects information and opinions from the media and the public to develop the government mechanisms and find solutions to the country's problems together. It can be concluded that political communication is a dynamic element of the political system. Political processes, political refinement, political participation, and political selection all rely on political communication The components of a political communication system include:

1. The source of the massage
2. The content of the massage
3. The channel through which the message is delivered to the audience
4. Feedback

Important characteristics of the local election process

Local elections refer to the election of local council members to administer the local government organization or local government. The eligible voters are citizens living in local administrative areas, starting from the sub-district or province level. In Thailand, there are administrative areas, such as the Provincial Administrative Organization (PAO), Sub-district Administrative Organization (SAO), and Municipality. Local elections are therefore a way for local people to participate in politics by selecting their representatives to exercise political decision-making power. Local people therefore do not only have a role in voting in local elections, but also have a role in monitoring and inspecting the work of the representatives and local administration who have been elected to administer the work (Thanet Charoenmuang, 1997: 283-284).

Local government representatives in each area are directly elected by the people and are divided into 2 groups

1. The legislative branch is responsible for enacting local laws and overseeing local administration, including:

1). Subdistrict Administrative Organization (SAO) members
2). Municipality Council (MC) members
3). Provincial Administrative Organization (PA) members
4). Pattaya City Council members
5). Bangkok Metropolitan Council (BMC) members

2. The executive branch has the duty to control and manage the local affairs, including:

1). Subdistrict Administrative Organization President
2). Mayor
3). Provincial Administrative Organization President
4). Pattaya City Mayor
5). Bangkok Governor

Local elections have received widespread attention. It is important to examine the extent of public interest in local elections, by comparing the level of participation in local people in exercising their voting rights. Another aspect is to study the intensity of competition for seats in local councils and the role of local candidates belonging to large and small political parties, including the role of local candidates who do not belong to political parties (Colin Rallings and Michael Thrasher, 1997: 9).

Thailand has had the idea of local government elections since 1974, during the government of General Kriangsak Chamanan as Prime Minister. However, this idea did not achieve tangible results in 1985, with the enactment of the Bangkok Metropolitan Act. In addition to Bangkok, the first general local government organization to hold elections was the Municipality Act of 1953, amended in 2000, which was enacted into law and adopted the direct local government election model.

1. In the past, the administration of local government organizations was not stable in administration and could not work continuously because the local council was able to determine the direction of the administration of the administration too much.

2. Direct election of local government administrators will enable people to respond to their needs quickly because the administration is directly elected by the people.

3. Direct election of local government administrators will allow people to have more political choices, both in terms of policies and candidates. The problem of instability of the administration is the main problem that causes those involved and supporters to want direct election of local government administrators to solve the problem (Noraniti Setthabut, 2001: 1-2). In 2003, various local laws were amended to allow direct election of local government administrators. This is considered very interesting for the development of the local government system in Thailand because in the past, local government in Thailand was slow and did not usually change in terms of structure. However, changing the administration of local government organizations to be directly elected is considered a change in the structure of Thai local government. The Ministry of Interior or the government has therefore pushed for all forms of local government organizations in Thailand to use the direct election of local government administrators format at the end of 2003.

There are two types of local government in Thailand: general and special.

1. General types include Provincial Administrative Organizations (PAOs), Municipalities, and Subdistrict Administrative Organizations (SAOs).

Provincial Administrative Organization (PAO) consists of 2 parts: Provincial Administrative Organization Council, which has 24-48 members who are directly elected by the people, serving a term of 4 years, acting as the legislative branch; Provincial Administrative Organization President, who is directly elected by the people, serving a term of 4 years, acting as the executive branch under the supervision of the governor.

Municipality is the oldest local administrative unit of Thailand, established in 1933. There are 3 types of municipalities in Thailand: city municipality, town municipality and sub-district municipality. The structure is divided into 2 parts:

1) Legislative branch: By the municipal council, directly elected by the people, serving a term of 4 years, responsible for controlling and inspecting the executives and the committee. 2) Executive branch: By the mayor or the council, directly elected by the people. Subdistrict.

Administrative Organization (SAO) developed from the subdistrict council (Subdistrict Council Act B.E. 2537/2542 and 2546), consisting of: 1). Subdistrict Administrative Organization Council is directly elected by the people. It is responsible for controlling and inspecting the executives. The executives are in power for a term of 4 years. 2). Subdistrict Administrative Organization Executive Board, led by the Subdistrict Administrative Organization Chief, who is directly elected by the people. The executives are in power for a term of 4 years.

2. Special type: Bangkok and Pattaya City

Bangkok (BMA) The Bangkok Administration Act B.E. 2518 and B.E. 2528 opened the opportunity for the administration of Bangkok to be independent from the central administration, with the following components:

1). District Council, consisting of District Council members from 50 districts in Bangkok, directly elected by the people, serving a term of 4 years, performing legislative duties only in the district area.

2). District Office, consisting of a group of hired officials to provide services to the people in each district under the administration of the Governor of Bangkok, who is directly elected by the people, serving a term of 4 years

3). Bangkok Council, consisting of Bangkok Council members directly elected by the people, serving a term of 4 years, performing legislative duties.

Pattaya City was established by the Pattaya City Administration Act of 1978 and revised in 1999. Its internal structure consists of:

1). Pattaya City Council consists of Pattaya City Council members who are directly elected by the people and serve a term of 4 years. They are responsible for legislative affairs.

2). Pattaya City Mayor is responsible for the administration of Pattaya City. He is directly elected by the people and serves a term of 4 years.

Conclusion

Local government is very important in developing people's way of life and livelihood to reach their basic needs. Important factors in life depend on the environment and context of each area. Technology is another basic factor that helps people access information and helps local administrative organizations reach people's needs more conveniently and quickly. At present, it can be said that social media plays a role in life because communication is an important channel that makes information and various needs more convenient and faster. Local administrative organizations are agencies that can reach people in the area quickly and promptly. Social media plays a part in development and public relations. It can be seen that technology and social media are used to help in election campaigns, public relations, and provide channels for people to express their opinions, propose needs, and participate in local development effectively. Therefore, it can be said that technology plays a direct and indirect role in organizing local elections and can also be extended to central elections. Therefore, technology and social media are very important parts of the local election process. In the future, the election process may change from the original process of voting at the polling station, but in the future, there may be a direction in which AI (Artificial Intelligence) will play a role in the election process to make it more convenient and faster.

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Factors Influencing the Beer Export Volume of the 20 Leading Beer Exporters

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Abstract

This study aims to analyze the factors influencing beer export volume across countries using cross-sectional data from the top 20 beer-exporting nations in 2023, sourced from the Trade Map database. The analysis employed multiple regression models, including Linear and Log-linear Models, along with an independent t-test to compare beer export volumes between countries that import barley and those that do not. The results revealed that positive factors influencing beer exports include export value, barley import volume, and per capita beer consumption, while unit value negatively impacts export volume. Furthermore, the comparison indicated that countries not importing barley have significantly higher beer export volumes than those that do. These findings provide actionable insights for enhancing export strategies and improving the global competitiveness of the beer industry.

Keywords: Beer, Beer Exports, Beer Export Value, Barley

Introduction

Beer is one of the oldest alcoholic beverages in the world, with historical evidence indicating that humans began brewing beer over 7,000 years ago. Early beer production was a simple process that evolved from the fermentation of barley or other grains using natural yeast. Today, brewing technology has advanced significantly with the integration of scientific knowledge and modern technology, resulting in a diverse range of beer flavors and types to meet consumer demands worldwide (Bamforth, 2009). Beyond being just a beverage, beer plays a significant role in both the economy and culture. The brewing industry provides employment and generates revenue for many countries. Additionally, beer exports contribute to global economic value. However, beer production in different countries is influenced by various factors, such as climate conditions suitable for growing raw materials like barley and hops, the quality of water used in brewing, technological innovations, and legal regulations regarding production and distribution. Furthermore, regional drinking cultures affect beer preferences and market trends (Oliver, 2014). In the modern era, environmental concerns and global economic changes have had a noticeable impact on beer production. For instance, climate change affects the quality and availability of raw materials. At the same time, consumers are increasingly prioritizing sustainably produced products that minimize environmental impact. Adapting to these trends is essential for the long-term survival and growth of the beer industry (Smith, 2020).

Therefore, studying the factors influencing beer production across different countries is crucial. This research aims to analyze these key factors to help brewers and researchers optimize brewing processes to enhance efficiency and better meet consumer demands. Additionally, this study provides deeper insights into beer's role in the global economy and its social context.

Research Objectives

1)To study the factors that influence beer exports in different countries.

2)To compare the volume of beer exports between countries that import barley and those that do not.

Scope of the Research

This study analyzes the factors affecting the beer export volume of the 20 major beer-exporting countries, with the variables used in the study shown in Figure 1.

Independent variable Dependent variable

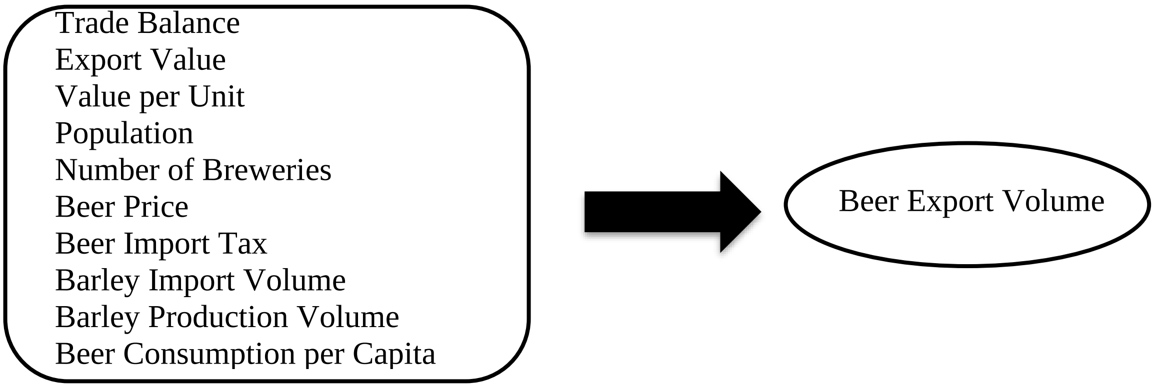

Figure 1 Conceptual framework

Research Methodology

In analyzing the factors influencing beer exports from various countries, multiple regression analysis is employed. Additionally, the t-test is used to compare beer export volumes between countries that import barley and those that do not.

The research uses two regression models to assess the impact of different factors on beer exports

Model 1 (Linear Model)

$QEX = \beta_0 + \beta_1 VEX + \beta_2 TB + \beta_3 UV + \beta_4 POP + \beta_5 FAC + \beta_6 BP + \beta_7 TAX + \beta_8 BIV + \beta_9 BVC + \beta_{10} BCPC + \mu$

Model 2 (Log-lin Model)

$\log(QEX) = \beta_0 + \beta_1 VEX + \beta_2 TB + \beta_3 UV + \beta_4 POP + \beta_5 FAC + \beta_6 BP + \beta_7 TAX + \beta_8 BIV + \beta_9 BVC + \beta_{10} BCPC + \mu$

The data for this study is obtained from the Trade Map database for the year 2023. The data includes various variables that are necessary to examine the relationships between the independent and dependent variables as outlined in the regression models above.

Research Results

Table 1: Results of the Analysis of Factors Affecting Beer Export Volume

Variable	Linear Model		Log-linear Model	
QEX	β (t)	Robust S.E	β (t)	Robust S.E
VEX	11.94*** (0.000)	0.0592725	1.95* (0.083)	0.000000354
TB	0.79 (0.449)	0.0627693	0.48* (0.064)	0.000000311

Variable	Linear Model		Log-linear Model	
UV	-3.61*** (0.006)	182.6459	-2.02* (0.074)	0.0008269
POP	-2.27** (0.049)	332.737	-1.22 (0.253)	0.00145
FAC	1.48 (0.174)	78.75172	1.09 (0.305)	0.0003125
BP	2.10 (0.66)	10822.2	2.27** (0.049)	0.0714822
TAX	1.11 (0.295)	4457.278	0.82 (0.432)	0.0335685
BIV	3.02** (0.015)	0.0374364	2.33** (0.045)	0.000000149
BCV	-1.66 (0.131)	0.0079586	-3.61*** (0.006)	0.0000000305
BCPC	1.84* (0.099)	706.9048	1.78 (0.109)	0.0051394
R-squared	0.9969		0.9006	
F	2681.04		26.65	
Prob >F	0.0000		0.0000	
Obs	20		20	

Note: * Significant at the 0.1 level ** Significant at the 0.05 level *** Significant at the 0.01 level

Research Results

From this study, it was found that Model 1 (Linear regression), which consists of 10 independent variables, is valid because the Prob > F value is less than 0.05, indicating that the independent variables have an impact on the dependent variable. The model shows that the R-squared value is 0.99, which means that the 10 independent variables can explain 99% of the variation in the dependent variable, which is beer export volume. Factors that affect the beer export volume in the same direction include export value, barley import volume, and beer consumption per capita at significance levels of 0.01, 0.05, and 0.1, respectively. Factors affecting beer export volume in the opposite direction include unit value and population at significance levels of 0.01 and 0.05, respectively.

Subsequently, Model 2, which uses the Log-linear regression form with 10 independent variables, is also valid because the Prob > F value is less than 0.05, showing that the independent variables have an effect on the dependent variable. The model shows that the R-squared value is 0.90, meaning that the 10 independent variables can explain 90% of the variation in the dependent variable, with the remaining 10% explained by other factors. The F-value is 26.65, showing that the model can significantly explain the change in the dependent variable. Factors affecting the beer export volume in the same direction include export value and trade balance at a significance level of 0.1. Beer price and barley import volume affect the beer export volume at a significance level of 0.05. Factors affecting beer export volume in the opposite direction include unit value and barley production at significance levels of 0.1 and 0.01, respectively.

From this study, the reasons for the factors influencing the volume of beer exports can be explained as follows:

Export Value: This factor influences beer export volume in the same direction. When the export value increases, it indicates higher exports, which leads to higher income in the country, thus increasing beer export volume as well.

Unit Value: This factor influences beer export volume in the opposite direction. When the unit value increases, the price of exported beer decreases, leading to a reduction in beer export volume.

Barley Import Volume: This factor influences beer export volume in the same direction. When barley import volume increases, it indicates a higher production capacity for beer, which leads to increased income in the country and, consequently, an increase in beer export volume.

Table 2: Results of the Comparison of Beer Export Volumes Between Countries that Import and Do Not Import Barley

Group	Mean	Std. Err.	Std. Dev.	t	p
Countries that do not import barley	1826464	791507.9	1583016	3.6279	0.0010***
Countries that import barley	387257.3	80282.49	321130		

Note: *** Significant at the 0.01 level

From the hypothesis testing to compare the mean of net beer exports between countries that import barley and those that do not, the Pr(T>t) value is 0.0010 at the 0.01 significance level, indicating that the average net beer export volume differs. Countries that do not import barley have higher net exports, with an export volume of 1,826,464 liters, compared to 387,257.3 liters in countries that import barley, resulting in a difference of 1,439,206.7 liters.

Conclusion and Discussion

This study found that the economic factors influencing beer export volume can be divided into factors with positive and negative effects:

Export Value (VEX) has a positive relationship with beer export volume. This is consistent with the Comparative Advantage Theory of Head & Mayer (2014), which suggests that countries with lower production costs and sufficient resources can increase export volumes. The study aligns with Bieleková & Pokrivčák (2020), who found that countries with good production potential and cost management can boost export values.

Barley Import Volume (BIV) has a positive effect on beer exports, as barley is a key ingredient in beer production. Increased imports enable higher beer production, supporting Gusso (2023), who stated that supply chain management and raw materials are crucial for export potential.

Beer Consumption Per Capita (BCPC) also has a positive effect on beer exports. Higher domestic consumption boosts the industry and facilitates market expansion abroad. This is consistent with Török et al. (2020), who found that beer industries with strong domestic markets tend to expand more easily to international markets.

Unit Value (UV) has a negative effect on beer export volume. This means that higher unit prices may reduce competitiveness in the global market. This finding aligns with Dreyer & Fedoseeva (2016), who pointed out that product price fluctuations and exchange rates affect competitive ability in international trade.

Population (POP) has a negative effect on beer exports. This could be because countries with large populations tend to have higher domestic consumption rates, leaving less beer for export.

Comparison between countries that import and do not import barley: The study found that countries that do not import barley have significantly higher beer exports than those that import barley. This can be explained by the Gravity Model of Trade of Melitz & Redding (2014), which suggests that countries that produce their own raw materials have lower production costs, making them more competitive in the market.
Policy

Recommendations

1.Government Investment in Technology and Raw Material Management: The government should invest in technology and raw material management to reduce production costs, improve production efficiency, and enhance competitiveness in the global market.

2.Brand Development and Promotion of Premium Products: The government should focus on creating unique beer brands and promoting the image of premium products in international markets. Additionally, trade agreements should be negotiated to reduce tax and tariff barriers, lowering export costs.

3.Development of Logistics Systems: The government should improve logistics systems, such as enhancing transportation efficiency and supply chain management. This will reduce costs and improve the ability to compete in the market.

4.Supportive Measures: The government should implement supportive measures such as tax reductions, commercial training programs, and research and development initiatives to ensure the sustainability of the beer industry.

5.Consumer Behavior Research and Product Innovation: The government should study consumer behavior in target markets and develop new beer formulas that meet consumer demands, such as producing specialty beers or those focused on sustainability.

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BIAXIAL FLEXURAL STRENGTH OF DIFFERENT TRANSLUCENCE CAD-CAM CERAMIC MATERIAL

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Abstract

The increasing demand for esthetic and durable dental restorations has driven the development of advanced CAD/CAM ceramic materials with improved mechanical and optical properties. Among these, monolithic zirconia and advanced lithium disilicate ceramics have gained popularity due to their high strength and enhanced translucency. CEREC Tessera™ (Dentsply Sirona) incorporates lithium disilicate and virgilite crystals to offer rapid processing and high flexural strength, while Bloomzir® zirconia ceramics (Ultra Translucent and 3D Pro Multilayer) represent new generations of yttria-stabilized zirconia engineered for both strength and esthetics. However, variations in translucency and thickness may influence the mechanical performance of these materials, particularly their biaxial flexural strength, which is critical for long-term clinical success.

This in vitro study aimed to evaluate and compare the biaxial flexural strength of three translucent CAD/CAM ceramic materials: CEREC Tessera™ (CE), Bloomzir® Ultra Translucent Multilayer (UT), and Bloomzir® 3D Pro Multilayer (ST) at various thicknesses. A total of 135 disc-shaped specimens per material group (n = 15 per thickness) were fabricated in nine thicknesses (0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, and 2.0 mm ± 0.02 mm). The CE group specimens were prepared with a diameter of 12 mm, while the ST and UT groups were fabricated with a diameter of 15 mm. All specimens were sectioned from CAD/CAM ceramic blocks using a low-speed diamond saw, polished, ultrasonically cleaned, and sintered according to manufacturer protocols. Biaxial flexural strength was tested using a piston-on-three-ball method per ISO 6872. SEM and XRD analyses were conducted to evaluate microstructure and crystalline phases. Results showed significant differences in strength between materials and thicknesses ($p < 0.05$), with ST exhibiting the highest mean strength (864.8 ± 105.98 MPa), followed by UT (813.97 ± 100.5 MPa) and CE (412.02 ± 95.85 MPa). Superior performance in ST and UT was attributed to denser microstructures and higher t-phase content. These findings emphasize the importance of material selection and thickness in achieving optimal performance for dental restorations.

Keywords: Biaxial flexural strength, CAD/CAM ceramics, Translucent zirconia, Lithium disilicate, Ceramic thickness

Introduction

In modern dentistry, there is a growing emphasis on providing dental restorations that are both highly esthetic and mechanically durable. This increased demand stems from patients' rising expectations for restorations that closely resemble natural teeth and ensure reliable clinical performance over the long term. Ceramic materials have been extensively utilized in restorative dentistry due to their desirable properties, including excellent biocompatibility, chemical stability, wear resistance, and outstanding esthetic qualities. Despite these benefits, traditional ceramic restorations have often faced limitations, typically demonstrating either superior esthetics combined with inadequate mechanical strength or exceptional mechanical properties accompanied by lower translucency. This dichotomy has historically posed challenges for clinicians aiming to deliver restorations that successfully balance natural appearance with functional durability. Advancements in computer-aided design and computer-aided manufacturing (CAD/CAM) technology have significantly improved the quality and precision of dental restorations, facilitating the development of new-generation translucent ceramic materials. Among these innovations are advanced lithium disilicate ceramics, such as CEREC Tessera™, which incorporate virgilite crystals to enhance their flexural strength and optical characteristics. Simultaneously, multilayered zirconia ceramics have gained attention due to their impressive strength derived from transformation toughening, a mechanism involving the stress-induced transformation of zirconia's tetragonal crystals into a monoclinic phase, effectively resisting crack propagation. Increasing yttria concentration within zirconia ceramics has further improved translucency, although this enhancement often reduces mechanical strength due to the greater presence of the cubic phase. In clinical practice, material thickness also plays a crucial role in determining the performance and longevity of ceramic restorations. Clinicians commonly aim for minimal restoration thickness to conserve natural tooth structure, achieve superior esthetics, and enhance patient comfort. However, reduced thickness can adversely affect mechanical durability, particularly flexural strength, thereby increasing the risk of clinical failures such as fractures or chipping. The correlation between ceramic thickness and mechanical performance has been widely studied, generally revealing that greater thickness positively influences strength and reliability. Nevertheless, identifying the optimal minimal thickness that maintains sufficient mechanical integrity without compromising esthetics is an ongoing challenge and a critical research area.

This study aims to systematically evaluate and compare the biaxial flexural strength of three different translucent CAD/CAM ceramic materials at various clinically relevant thicknesses. The objective is to determine an optimal balance between mechanical properties and material thickness, ultimately providing clinicians with evidence-based recommendations for selecting suitable ceramics and minimum restoration thicknesses. The expected outcome of this research is to assist dental professionals in achieving predictable clinical success, optimizing long-term restoration durability, enhancing esthetic outcomes, and ultimately improving overall patient satisfaction.

Research Methodology

This in vitro experimental study employed a quantitative research design to evaluate the biaxial flexural strength of three types of translucent CAD/CAM ceramic materials: CEREC Tessera™ (CE), Bloomzir® Ultra Translucent Multilayer (UT), and Bloomzir® 3D Pro Multilayer (ST). The study was structured to investigate the influence of material type and thickness on mechanical performance, based on a controlled and replicable experimental framework.

Materials

The sample size, calculated using flexural strength data from Yilmaz et al., was 15 specimens per group. A total of 405 disc-shaped specimens were fabricated, comprising 135 specimens per material group. Each group was subdivided into nine thickness categories (0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, and 2.0 mm). The CE specimens were prepared with a diameter of 12 mm, while UT and ST specimens had a diameter of 15 mm, following the dimensional requirements specified in ISO 6872. A purposive sampling method was adopted, selecting representative commercial CAD/CAM ceramic blocks with clinically relevant translucency and composition for comparative analysis.

Specimen preparation

All specimens were sectioned from pre-sintered ceramic blocks using a low-speed diamond saw (Isomet® 1000; Buehler Ltd., USA) and polished on both surfaces with silicon carbide abrasive papers of progressively finer grit sizes (#360 to #2000). Final thickness was verified using a digital vernier caliper (Mitutoyo 500-196-30; Japan) with a measurement accuracy of ±0.02 mm. Specimens were cleaned in an ultrasonic bath with distilled water for 15 minutes and air-dried at room temperature. Each material group underwent sintering according to the manufacturer's recommended protocol.

Data collection procedure

Mechanical testing was conducted using a universal testing machine (LR30K; Lloyd Instruments, UK) equipped with a piston-on-three-ball fixture[4], in compliance with ISO 6872 guidelines (Figure 1). The loading piston, with a diameter of 1.87 mm, applied a central compressive force at a crosshead speed of 0.5 mm/min until specimen failure occurred. The fracture load (N) was recorded, and the biaxial flexural strength (MPa) was calculated using the standard formula specified in the ISO protocol. Fractured specimens were examined under a scanning electron microscope (SEM) (Hitachi S-3000N; Japan) to assess surface morphology and crack propagation patterns. Selected specimens from each group were also subjected to X-ray diffraction (XRD) analysis (Empyrean; PANalytical, Netherlands) using Cu Kα radiation to identify crystalline phase compositions. Diffractograms were analyzed within a 2θ range of 20°–40° using a step size of 0.02° and an integration time of two seconds.

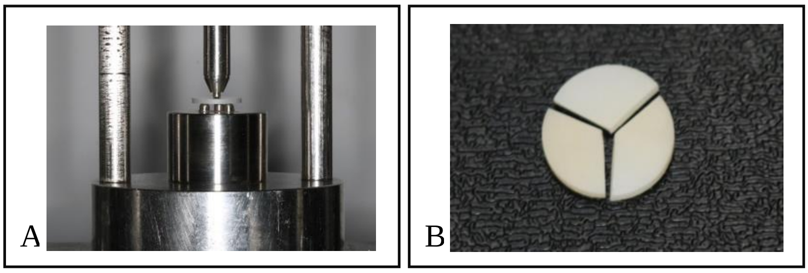

Figure 1 (A); The specimens on the piston-on-three balls (B); The specimen fracture

Data analysis

Statistical analysis was performed using IBM SPSS Statistics version 22 (IBM Corp., USA). Descriptive statistics, including mean, standard deviation (SD), and 95% confidence intervals (CI), were computed for each group. Two-way analysis of variance (ANOVA) was used to assess the effects of material type and thickness, as well as their interaction, on biaxial flexural strength. Post-hoc comparisons were conducted using the Bonferroni correction. Weibull analysis was performed to determine the characteristic strength (σ_0) and Weibull modulus (m) for reliability assessment. A significance level of $\alpha = 0.05$ was adopted for all statistical tests.

Result

This in-vitro study evaluated the effect of material type and thickness on the biaxial flexural strength of three translucent CAD-CAM ceramic materials: CEREC Tessera™ (CE), Bloomzir® Ultra Translucent Multilayer (UT), and Bloomzir® 3D Pro Multilayer (ST). The mean flexural strength, standard deviation (SD), characteristic strength (σ_0), and Weibull modulus (m) for ceramic thicknesses ranging from 0.4 to 2.0 mm are summarized in Table 1.

Among the tested materials, ST exhibited the highest overall mean flexural strength (864.8 ± 105.98 MPa), closely followed by UT (813.97 ± 100.5 MPa). In contrast, CE demonstrated significantly lower mean strength (412.02 ± 95.85 MPa) across all thicknesses. Statistical analysis using two-way ANOVA revealed significant main effects of ceramic material type, thickness, and their interaction on flexural strength ($P < 0.05$, Table 2). Post-hoc Bonferroni multiple comparisons confirmed statistically significant differences between each pair of materials (ST > UT > CE; $P < 0.001$). Additionally, while material thickness had a significant impact overall, certain incremental increases in thickness did not produce statistically significant differences in flexural strength ($P > 0.05$). X-ray diffraction (XRD) analysis further provided insights into structural distinctions among the tested ceramics. ST ceramics demonstrated a predominantly tetragonal (t-phase) crystal structure (up to 77.4% t-phase in the cervical region), which contributed significantly to their superior mechanical performance. UT primarily consisted of cubic-phase (c-phase) crystals (58.6%) combined with a moderate proportion of tetragonal-phase crystals (41.2%). In contrast, CE contained a crystalline structure of lithium disilicate and silica oxide without robust zirconia reinforcement. Scanning electron microscopy (SEM) analysis revealed marked differences in microstructural characteristics in Figure 2. ST and UT exhibited densely packed grains with minimal porosity, which effectively enhanced resistance to crack propagation. CE, however, displayed a looser crystal arrangement with greater porosity, corresponding to lower strength values. Fracture patterns observed in CE revealed linear and sharp cracks typical of brittle materials, while UT and particularly ST showed broader crack patterns, indicative of superior fracture toughness in Figure 3.

Table 1 The mean ± SD of flexural strength and maximum load, and Weibull modulus

Material	Thickness (mm)	Flexural strength, σ (MPa)	SD of Flexural strength	95% CI		Characteristic strength, σ_0 (MPa)	Weibull modulus, m
				LB	UB		
CE	0.4	605.964	70.561	573.534	638.394	636.672	9.595
CE	0.6	505.052	64.752	472.621	537.482	533.330	8.700
CE	0.8	352.537	57.128	320.107	384.967	376.864	6.840
CE	1.0	395.556	41.404	363.126	427.987	415.716	9.694
CE	1.2	354.683	23.978	322.253	387.113	366.926	14.928
CE	1.4	375.498	21.001	343.068	407.928	385.266	19.766
CE	1.6	355.414	68.655	322.984	387.844	383.430	5.759
CE	1.8	355.627	31.382	323.197	388.057	370.272	12.261
CE	2.0	407.809	40.249	375.378	440.239	427.788	10.310
UT	0.4	767.005	81.564	734.575	799.436	802.918	10.491
UT	0.6	770.131	63.698	737.701	802.562	798.725	13.549
UT	0.8	745.548	66.690	713.118	777.978	776.016	12.210
UT	1.0	755.628	60.608	723.198	788.059	782.881	13.959
UT	1.2	793.233	63.408	760.803	825.663	822.094	13.842
UT	1.4	834.809	105.577	802.379	867.239	882.955	8.398
UT	1.6	820.676	65.773	788.246	853.106	851.249	13.511
UT	1.8	861.246	75.358	828.815	893.676	894.883	12.813
UT	2.0	977.422	87.124	944.992	1009.852	1016.533	12.495
ST	0.4	735.543	80.862	703.113	767.973	771.423	10.081
ST	0.6	759.124	51.349	726.693	791.554	782.589	16.446
ST	0.8	841.221	50.329	808.790	873.651	864.333	18.621
ST	1.0	817.653	67.058	785.222	850.083	848.244	13.469
ST	1.2	817.729	25.393	785.299	850.159	830.292	34.209
ST	1.4	917.710	62.237	885.280	950.141	946.107	16.440
ST	1.6	985.207	34.193	952.777	1017.638	1002.718	29.545
ST	1.8	940.687	86.537	908.257	973.117	980.443	11.861
ST	2.0	968.360	81.939	935.929	1000.790	1005.053	13.220

CE= CEREC Tessera^{TM}, UT= Bloomzir® Ultra-translucent multilayer, ST= Bloomzir® 3D Pro multilayer, LB= Lower bound of 95% confident interval, UB= Upper bound of 95% confident interval

Table 2 Two-way ANOVA of flexural strength of all ceramic with various thickness

Source	Sum of squares	df	Mean square	F test	P value
Corrected model	19159864.27	26	736917.86	180.596	<.001
Intercept	196712328.95	1	196712328.95	48208.28	.000
Material	16612477.41	2	8306238.70	2035.61	<.001
Thickness	684326.18	8	85540.77	20.96	<.001
Material *Thickness	1863060.69	16	116441.29	28.54	<.001
Error	1542416.65	378	4080.47		
Total	217414609.87	405			
Corrected total	20702280.92	404			

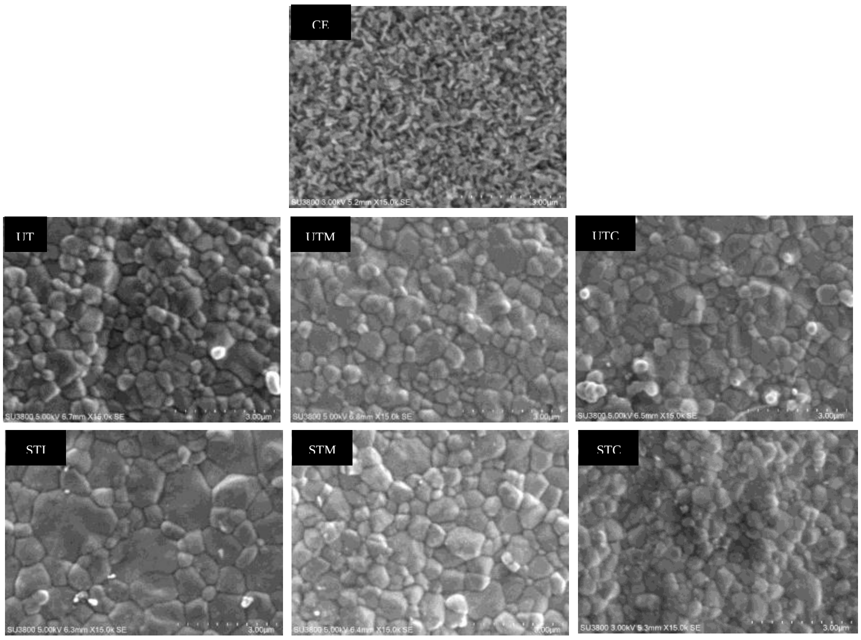

Figure 2 SEM image at 15000X of CE= CEREC Tessera^{TM}, UT= Bloomzir® Ultra-translucent multilayer, ST= Bloomzir® 3D Pro multilayer, I= Incisal, M= Middle, C= Cervical

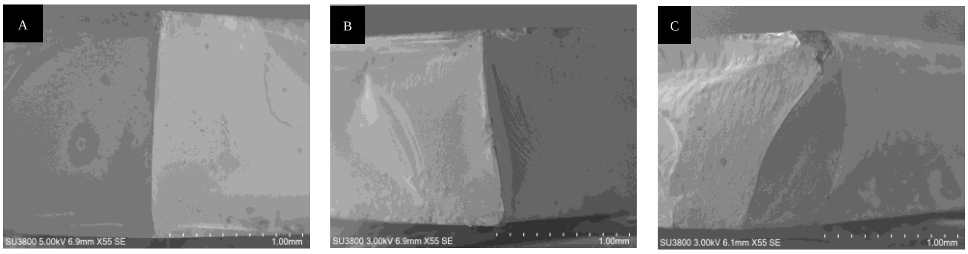

Figure 3 Fracture characteristic image at 55X of (A); CEREC Tessera^{TM} (B); Bloomzir® Ultra-translucent multilayer (C); Bloomzir® 3D Pro multilayer

Discussion and Conclusion

The results showed significant differences in flexural strength among the ceramics tested. Zirconia-based ceramics (ST and UT) exhibited higher flexural strength compared to lithium disilicate-based ceramic (CE), consistent with previous research demonstrating zirconia's superior fracture resistance due to its crystalline structure and transformation-toughening mechanism. X-ray diffraction (XRD) analysis revealed that ST ceramics contained a higher proportion of tetragonal-phase (t-phase), enhancing mechanical strength and crack resistance through transformation toughening. In comparison, UT ceramics demonstrated a balanced cubic and tetragonal phase content, maintaining robust properties. CE ceramics, composed mainly of lithium disilicate crystals reinforced by virgilite within a glass matrix, lacked transformation-toughening mechanisms, leading to lower strength and increased brittleness. Scanning electron microscopy (SEM) confirmed these findings, with ST and UT-ceramics exhibiting dense microstructures, while CE displayed loosely arranged crystals and greater porosity.

Within the limitations of this study, material type and thickness significantly impacted the flexural strength of translucent CAD/CAM ceramics. Zirconia-based ceramics, particularly Bloomzir® 3D Pro Multilayer (ST), showed the highest mechanical reliability, making them suitable for posterior and high-stress restorations. Although CEREC Tessera™ (CE) offers esthetic advantages and efficient processing, its lower mechanical strength suggests its use primarily for anterior or low-stress posterior restorations. Clinicians should carefully consider material properties and restoration thickness to achieve optimal clinical outcomes.

Suggestions

Future studies should explore additional mechanical properties such as fracture toughness, fatigue resistance, and wear characteristics to provide a deeper understanding of the clinical performance of translucent CAD-CAM ceramics. Long-term clinical investigations are also recommended to confirm the laboratory results and evaluate actual restorative outcomes in patients.

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Antioxidant Properties of Thai Medicinal Herbs: A Potential Therapeutic Approach for Alzheimer's Disease

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Abstract

Alzheimer's disease is the most common neurodegenerative disorder found in the elderly. It is primarily caused by the aggregation of amyloid-β (Aβ) proteins and neurofibrillary tangles of tau proteins. The accumulation of Aβ is known to stimulate the production of reactive oxygen species (ROS), leading to neuronal cell apoptosis and cognitive decline. *Clerodendrum petasites*, a traditional Thai medicinal plant, has previously been reported to exhibit neuroprotective effects. However, its ability to ameliorate Aβ-induced cellular injury has not yet been explored in animal models. Therefore, this study aimed to investigate the effects of *C. petasites* extracts on ROS accumulation and chemotaxis behavior in Aβ-overexpressing *Caenorhabditis elegans* (CL2355 and CL2006 strain). It is hypothesized that the extracts can reduce ROS accumulation and improve chemotaxis behavior, an indicator of cognitive function in neuronal cells. We found that that *C. petasites* extract exhibits dose-dependent antioxidant

effects in *C. elegans*, especially in the Aβ-expressing CL2006 strain. By significantly reducing intracellular ROS levels and showea markedly increased the chemotaxis index, the extract may contribute to neuroprotective mechanisms against Aβ-induced oxidative stress. These findings suggest that *C. petasites* has the potential to serve as an alternative treatment for Alzheimer's disease. However, as this is a preliminary study, further research is required to elucidate the underlying mechanisms and to validate these results in additional experimental models.

Keywords: Anti-neurodegenerative effects, Alzheimer's disease, *C. petasites*, *C. elegans*, amyloid-β

1. Introduction

Alzheimer's disease (AD) is a progressive neurodegenerative disorder characterized by cognitive decline and memory loss, primarily caused by the accumulation of amyloid-β (Aβ) plaques and neurofibrillary tangles in the brain, that stimulate reactive oxygen species (ROS) overproduction leading to neuronal dysfunction and cell death, due to oxidative stress (Kamatham et al., 2024; Rajmohan & Reddy, 2017). Despite extensive research, there is currently no cure for AD; existing treatments offer only symptomatic relief and do not target the underlying mechanisms of neurodegeneration (Passeri et al., 2022).

In recent years, natural compounds have gained attention as potential therapeutic agents for neurodegenerative diseases. *Clerodendrum petasites* (*C. petasites*), a traditional medicinal plant, has been reported to exhibit neuroprotective properties (Brimson et al., 2019). However, its potential to prevent Aβ accumulation and enhance cognitive hevavior remains unclear.

Caenorhabditis elegans (*C. elegans*) is a widely used model organism for investigating neurodegenerative disorders, including Alzheimer's disease (AD) (Sillapachaiyaporn et al., 2024). In this study, the transgenic strain CL2355, which expresses human Aβ proteins and exhibits behavioral impairments and Aβ aggregation, was used to mimic AD pathology and to assess the neuroprotective effects of bioactive compounds.

2. Research Methodology

2.1. Preparation of *C. petasites* leaf extract

C. petasites leaf were washed and dried at room temperature before being ground into a fine powder. The powdered sample was extracted using 70% ethanol via maceration for 48 hours. The extract was then filtered, concentrated using a rotary evaporator. The final extract was stored at -20°C until further use.

2.2. Maintenance and synchronization of *C. elegans*

All *C.elegans* strains used in this study were obtained from the Caenorhabditis Genetics Center (University of Minnesota, MN, USA), including CL2006 [pCL12(unc-54/human Abeta prptide 1-42 minigene) + rol-6(su1006)], CL2122 [(pPD30.38)unc-54(vactor) + (pCL26) mtl-2::GFP], and CL2355 [pCL45 (snb-1::Abeta 1-42::3' UTR(long)) + mtl-2::GFP]. The worms were maintained on a nematode growth medium (NGM) agar supplemented with the *Escherichia coli* (*E. coli)* strain OP50 as a food source in a 16 °C incubator. For egg synchronization, the gravid hermaphrodites were lysed by lysis buffer (5 M of NaOH and 5% NaOCl) in vortex condition for 6 min. The synchronized eggs were harvested by centrifuging at 2000 rpm for 2 min and then washed twice with M9 buffer. To get the L1 larvae, the synchronized eggs were hatched in the M9 buffer at 20 °C overnight. The L1 larvae were plated on fresh NGM agar containing *E. coli* strain OP50, and the synchronized worms were utilized in subsequent experiments.

2.3.Chemotaxis behavioral assay

To evaluate the effects of *C. petasites* on chemotaxis, the CL2355 and CL2122 nematodes were used as β-amyloid-over-expressed and control *C.elegans*, respectively. The synchronized worms were cultured in an S-medium containing *E. coli* OP50 and designed treatments for 72 h in a 20 °C incubator (60 worms/condition). At the end of the incubation period, the treated worms were tested in the chemotaxis behavior experiment. A 60 mm of NGM agar plate was utilized for the chemotaxis experiment. The plate was divided into four quadrants, including two attractant (0.1 % benzaldehyde +0.25 M sodium aside) and two controls (95 % ethanol +0.25 M sodium azide). The treated worms were placed in the center of the plate and continuously incubated at room temperature for 1 h. The number of worms in each quadrant was quantified. The Chemotaxis Index (CI) was calculated using the equation:

$$CI = \frac{\text{Number worms in both attractant quadrants} - \text{Number of worms in both control quadrants}}{\text{Total number of scored worms.}}$$

2.4. ROS accumulation assay

The transgenic strain CL2006 (which expresses human amyloid-β) and the wild-type strain (N2) were used in this experiment. Synchronized L4-stage of worms were transferred to 24 wells plates containing different concentrations of *C. petasites* leaf extract (0.1, 0.25, 0.5, 1, 5 and 10 µg/mL). The worms were exposed to the extract for 48 hours before move to 96 well plate (60 worns/well) and continuously incubate with the 50 uM H_2DCFDA reagent for 45 min at 20 °C. The light intensity indicating ROS accumulation was determined by microplate reader at an excitation wavelength of 490 nm and an emission wavelength of 525 nm.

2.5. Statistical Analysis

All experiments were performed in triplicate. Data were analyzed using one-way ANOVA followed by Tukey's post hoc test. Results were expressed as mean ± SEM, with statistical significance set at $p < 0.05$.

3. Results

3.1 The effects of C. petasites on chemotaxis (CI) behavior

CL2122 untreated, DMSO, and extract-treated groups all exhibit high CI values at 0.75, 0.79, and 0.65, indicating intact neuronal function and normal chemotactic behavior. In contrast, CL2355 untreated and vehicle-treated groups show a significantly reduced CI (0.33 and 0.30, resprctively), consistent with Aβ-induced neurodegeneration and impaired chemotaxis. Treatment with 0.25-1 ug/mL *C. petasites* showed a significantly increase in chemotaxis index in a dose-dependent manner. However, the effect diminishes slightly at 5 and 10 µg/mL when compare to 1 µg/mL, suggesting that the extract have mild toxicity at higher concentrations (Fig.1). These findings suggest that *C. petasites* leaf extract can ameliorate Aβ-induced ROS accumulation, which is a cause of behavioral deficits in a *C. elegans* model of Alzheimer's disease.

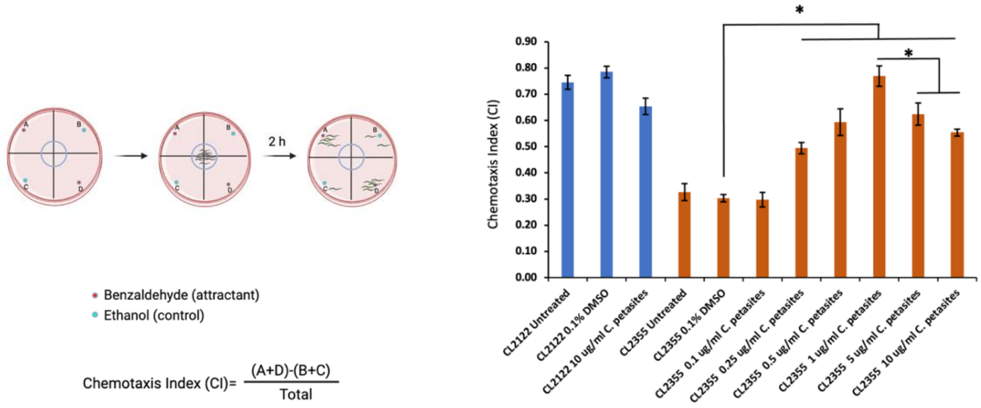


Fig 1. The schematic representation of the chemotaxis assay and the chemotaxis behavior of *C. elegans*.

CL2122 (control strain with vector) and CL2355 (Aβ transgenic worm) were treated with *C. petasites* or DMSO (vehicle) for 72 h. The chemotaxis index (CI) was calculated by the number of worns at the control point and divided by total number of worms.

3.2 The effects of *C. petasites* on ROS accumulation

To support this finding, the intracellular ROS accumulation was observed in the transgenic strain CL2006 (which expresses human amyloid-β) by comparing the wild-type strain (N2), under treatment with the extract. This result in Fig.2 revealed that, N2 untreated and DMSO controls show low ROS levels when compared to CL2006, reflecting normal cellular redox balance. CL2006 untreated and DMSO-treated animals exhibit significantly elevated ROS, consistent with oxidative stress induced by amyloid-β aggregation, while treatment with *C. petasites* extract reduces ROS levels. Notably, 0.25-5 µg/mL leads to the greatest suppression of ROS like the ROS levels of N2 controls. Nevertheless, At 10 µg/mL, ROS levels rise slightly again to increase when compared to the condition of 5 µg/mL, suggesting a possible loss of efficacy or a mild pro-oxidant effect at higher doses that correlated with the previous result in Fig.1.

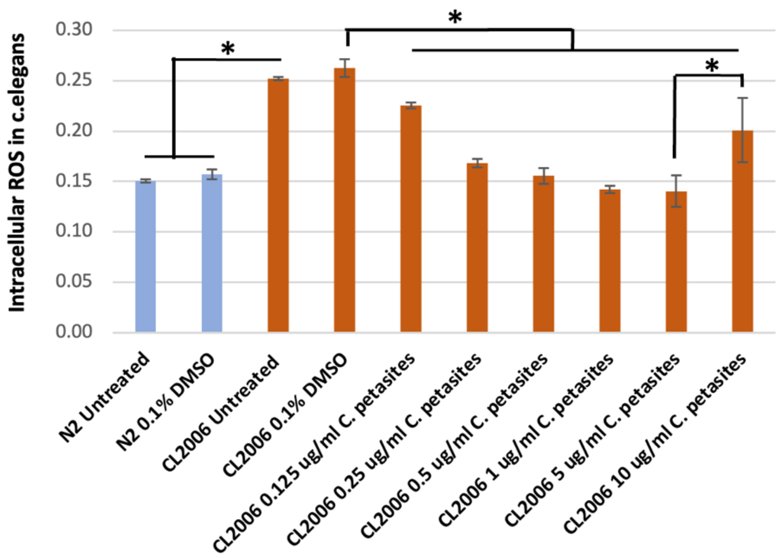


Fig 2. Effect of *C. petasites* on intracellular ROS accumulation. N2 (wild-type worm) and CL2006 (Aβ transgenic worm) were treated with *C. petasites* or DMSO (vehicle) for 72 h. Intracellular ROS accumulation was measured by H_2DCF-DA assay.

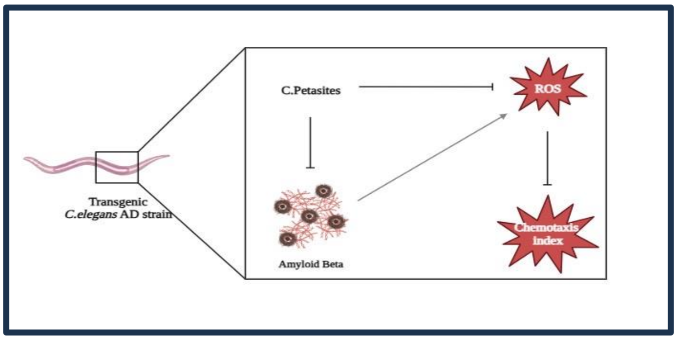
4. Discussion and conclusions

This study aimed to investigate the neuroprotective effects of *C. petasites* extract on Alzheimer's disease (AD)-like phenotypes using *C. elegans* models that overexpress human amyloid-β (Aβ) proteins. Our findings demonstrate that *C. petasites* extract significantly reduces intracellular reactive oxygen species (ROS) accumulation and improves chemotaxis behavior, both of which are impaired in transgenic AD worm models. The reduction in ROS levels in CL2006 worms after treatment with *C. petasites* highlights the extract's potent antioxidant activity. These results are consistent with previous reports that identified various phytochemicals in *C. petasites* with free-radical scavenging capabilities (Thitilertdecha et al., 2014). Oxidative stress, mediated by excessive ROS production, plays a central role in Aβ-induced neurotoxicity and neuronal apoptosis (Tamagno et al., 2021). By mitigating ROS accumulation, *C. petasites* may interrupt this deleterious cascade, thereby preserving neuronal function. Furthermore, the improvement in chemotaxis behavior observed in the CL2355 strain supports the hypothesis that *C. petasites* can rescue Aβ-induced behavioral deficits. Chemotaxis assays, which assess sensory and cognitive function in *C. elegans*, serve as a proxy for neuronal integrity. The dose-dependent increase in chemotaxis index suggests that the extract not only exerts antioxidative effects but also functionally benefits the nervous system.

However, the reduced efficacy at higher concentrations (10 μg/mL) indicates a potential threshold beyond which the extract may lose its neuroprotective benefit or become mildly toxic, possibly due to pro-oxidant effects at higher doses (Schieber & Chandel, 2014). These findings are consistent with the hormesis theory (Nitti et al., 2022), which proposes that low doses of phytochemicals can induce beneficial stress responses, while high doses may become detrimental. It is also worth noting that although *C. petasites* significantly reduced Aβ-related oxidative damage and behavioral impairments, the exact bioactive components responsible for these effects remain to be identified, and their mechanisms of action warrant further investigation.

5. Suggestion

The present study provides preliminary evidence that Clerodendrum petasites extract exerts neuroprotective effects in *C. elegans* models of Alzheimer's disease by reducing ROS accumulation and enhancing chemotactic behavior. These results suggest the potential of *C. petasites* as a natural therapeutic candidate for combating Aβ-induced oxidative stress and neurodegeneration. However, this study is limited to invertebrate models, and further investigations are required to validate these findings in mammalian systems. Future work should focus on isolating and characterizing the active compounds within the extract and elucidating their molecular mechanisms. Additionally, long-term studies on safety and efficacy are essential before considering clinical applications. Nevertheless, these findings contribute valuable insights into the development of plant-based interventions for Alzheimer's disease.



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Electric generation from building waste water

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Abstract

Urban population growth and increasing building density have led to higher energy and water resource consumption, resulting in the generation of significant volumes of wastewater on a daily basis (Islam, 2023; Gray, 2004). Improper management of this wastewater can pose environmental and public health challenges (Gargari et al., 2023). This study investigates the potential for electricity generation and water reuse from wastewater in residential condominium buildings by applying the concept of a micro hydro turbine system (Tahir et al., 2020; Sinagra et al., 2022). The objective of this research is to convert the kinetic energy from wastewater flow into electrical energy and assess the potential for treated water reuse.

An estimation based on 202 residential condominium buildings shows that approximately 118 m³ of wastewater are produced daily, equivalent to 3,540 m³ per month (Khooprasert, Snidvongs, & Supahitanukul, 2025). This amount is sufficient for energy recovery and water reuse applications. By utilizing a micro hydro turbine coupled with a generator operating at an average efficiency of 70% and a water head of 3 meters, it is possible to generate approximately 0.67 kWh of electricity per day or 20.2 kWh per month (Tomczyk et al., 2025; Smith & Doe, 2023). Although the electricity generated is relatively small compared to the total building demand, it highlights the feasibility of converting wastewater into a usable energy source.

In terms of water management, the study found that up to 60% of the wastewater, approximately 2,124 cubic meters per month, can be treated and reused (Zhao et al., 2023). The reclaimed water is suitable for non-potable purposes such as irrigation, cleaning, and toilet flushing. This integrated approach contributes to sustainable resource management in urban environments and aligns with carbon reduction strategies (Gargari et al., 2023; Weerakoon & Assadi, 2023). This study indicates that, although the potential for electricity generation from wastewater is relatively low, when combined with water reuse strategies, the system can significantly reduce dependence on external resources and alleviate environmental burdens. Moreover, it aligns with the concept of sustainable development, particularly within the context of urban communities where space and resources are limited (Sarkar et al., 2023). Broad implementation of this approach could enhance energy efficiency and strengthen water resource security in the long term.

Keywords: carbon reduction, energy recovery, micro hydro turbine, urban sustainability, wastewater reuse.

Introduction

The growth of business and urban expansion in Thailand has continually led to an increase in building construction from the past to the present, and this trend is expected to persist in the future. According to the Bangkok Economic and Investment Information Center, building construction can be categorized into 14 types, including residential buildings, commercial buildings, office buildings, hotels, industrial plants, hospitals, educational institutions, as well as agricultural and transportation-related buildings. As of now, there are a total of 44,303 buildings that have been granted construction permits (Bangkok Economic and Investment Information Center, 2024).

Each building type integrates several essential engineering systems, such as electrical systems, fire alarm systems, air conditioning systems, elevator systems, telecommunications, wastewater treatment systems, and water supply systems. Among these, the wastewater treatment system is particularly important, as it is legally mandated in all residential buildings to prevent environmental impacts (Pollution Control Department, 2022).With advancements in engineering and technology, new approaches have been developed to enhance the efficiency of internal building systems. One such approach is the concept of sustainable resource reuse—specifically, generating electricity and reclaiming water from the building's wastewater treatment system. This method presents an opportunity to reduce environmental burdens and promote efficient resource utilization (United Nations Environment Programme [UNEP], 2020). Moreover, it can be used as a mechanism to claim carbon credits, a market-based tool for reducing greenhouse gas emissions, which can further benefit organizations financially and enhance their environmental responsibility (Intergovernmental Panel on Climate Change [IPCC], 2021).Therefore, this research focuses on the study of electricity generation and greywater reuse from wastewater within buildings. While many studies have examined energy production from wastewater and water reclamation at industrial or community scales (Nguyen et al., 2019; Zhang & Liu, 2020), there remains a lack of in-depth research that applies these technologies to high-density urban residential buildings, which are constrained by space and infrastructure—factors that differ significantly from large-scale systems. Furthermore, economic analysis and financial feasibility studies related to the installation of micro-hydro turbine systems in residential buildings are still lacking, as are systematic evaluations of environmental impacts and greenhouse gas reduction potential (Chen et al., 2021).

This research thus aims to explore the factors, challenges, and constraints involved while applying engineering principles to analyze and design systems that maximize sustainable energy and resource use within buildings. The study is based on data collection, literature review, relevant theories, and technical formulas as described below.

Hydroelectric Power Generation

Hydroelectric power generation is the process of converting the potential energy of water into mechanical energy using a water turbine, which is then converted into electrical energy through a generator. The fundamental principle is that when water flows from a higher elevation to a lower elevation, it creates pressure or inertia (hydraulic head), which can be used to rotate the turbine. The rotating shaft of the turbine, connected to a generator, produces electricity through this motion.

Key Factors Affecting Power Generation

Flow Rate (Q)

The volume of water passing through the turbine per unit of time, measured in cubic meters per second (m^3/s). The greater the flow, the higher the mechanical and electrical energy that can be generated.

Head (H)

This is the vertical distance between the water source and the nozzle of turbine, measured in meters (m). A higher head increases the potential energy and hence, the capacity to convert it into mechanical and electrical energ that can be generated

The approximate power produced can be calculated from the formula:

$$P = \eta \rho g Q H \qquad (1)$$

Where

P	=	Power	Watts
η	=	System performance	value between 0 and 1
ρ	=	Water density	approx. 1000 kg/m^3
g	=	Earth gravity	9.81 m/s^2
Q	=	Water flowrRate	m^3/s
H	=	Water fall height	meters

Types of Water Turbines

The selection of a water turbine depends on the characteristics of the water source, head height, and flow rate, and can be classified as follows:

Pelton Turbine

Suitable for high-head and low-flow water sources. Commonly used in mountainous or high-pressure systems.

Francis Turbine

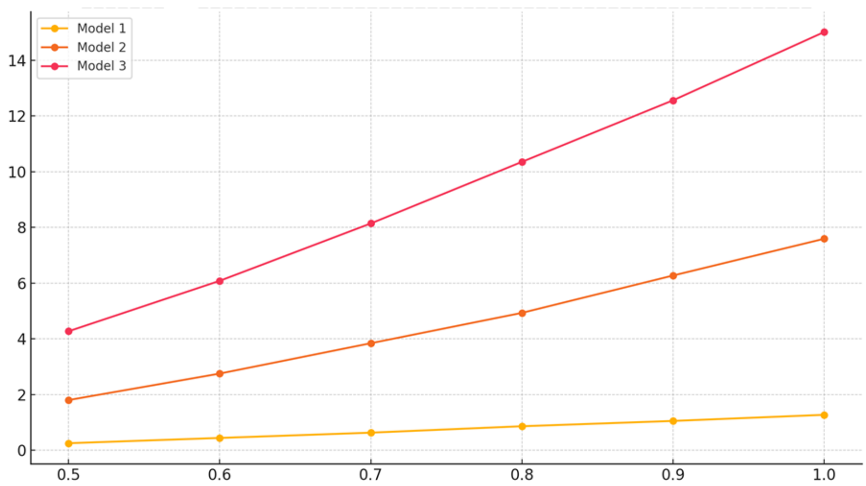
Designed for medium-head water sources. This radial-flow turbine is widely used in medium to large-scale hydroelectric dams.

Kaplan Turbine

Best suited for low-head, high-flow water sources. Often used in flat areas or fast-flowing rivers

Application in Urban Buildings and Communities

In urban settings, hydroelectric power can be applied to waste water or recycled water systems within buildings, leveraging water pressure and gravitational force in piping systems, such as water flowing from upper floors to lower levels. While the system is relatively small (Micro Hydro Power), it can provide energy for specific parts of the building, such as lighting, water pumps, or automated systems. When integrated with a waste water treatment and water reuse system, this approach significantly promotes sustainable resource management and carbon emission reduction. Furthermore, it holds strong potential for carbon credit eligibility, offering both environmental and economic advantages for sustainable building operations.



Comparison of Electrical Power Output from Three Types of Micro Hydro Turbines

According to the data presented in the above table, Model 3 (PELTOR Turbine) demonstrates the highest suitability for building installation.

Research Methodology

This study uses a quantitative methodology in combination with engineering system simulation and technical estimation. To assess the feasibility of generating electricity and reusing wastewater from buildings. It consists of the following steps:

1) Study documents and research related to energy production from wastewater and micro-hydro turbines.

2) Collect data on the building's wastewater system. Data was collected on water consumption and wastewater generated in 202 residential condominium buildings based on the average water consumption per person per day, as well as data from field surveys and reports on building water consumption.

3) Choosing a Micro Hydro Turbine (PELTOR Turbine) suitable for use with indoor waste water, considering the characteristics of uneven flow.

4) Analyze the amount of electricity produced by calculating the potential to produce energy from wastewater flows using the gravitational potential energy formula.

5) Summary of study results with suggestions for practical application.

Results

1) Data collection from the building's wastewater system

According to the data from the residential condominium project, there are a total of 202 units, divided into 2 types based on area size as follows:

- Residential units with an area of less than 35 square meters comprise 180 units with an average of 3 residents per unit.
- Residential apartments with an area of more than 35 square meters. Each resident has an average water consumption of 200 liters per person per day, based on data from the Metropolitan Waterworks Authority and the Pollution Control Department. , which can be calculated as follows:

$$\text{Total water consumption/day} = \frac{(180\ x\ 3\ x\ 200)}{1{,}000} + \frac{(22\ x\ 5\ x\ 200)}{1{,}000}$$

$$= 108 + 40$$

$$= 148 \quad m^3/\text{Day}$$

Then, the wastewater volume is estimated to be 80 percent of the water used, as follows:

$$\text{Total wastewater/day} = 0.8 \times 148$$

$$= 118 \quad m^3/\text{Day}$$

$$= 3{,}540 \quad m^3/\text{Month}$$

2)Results of the analysis of the potential to generate electricity from wastewater

Basic data from the project:

Total wastewater volume = 118 m^3/day,

Which is equivalent to 3,540 m^3/month or 3,540,000 liters per month.

A micro hydro turbine can be installed within the waste water treatment system or in the waste water pipeline to harness the energy from water flow, both potential energy and kinetic energy, for electricity generation at an altitude of 3 m (H).

From the energy equation, Equation 1, we define

System efficiency η = 0.7,

Water density	ρ	=	approx. 1000 kg/m³
Earth gravity	g	=	9.81 m/s²
Water flow rate	Q	=	0.0013657 m³/s
Height of the water drop	H	=	3 m (when installed in a vertical pipe or tank).

The energy is produced as follows:

$$P = \eta \rho g Q H$$
$$= 0.7 \times 1{,}000 \times 9.81 \times 0.0013657 \times 3$$
$$= 28.08 \text{ W}$$

Daily Electricity Power:

$$P = 673.92 \text{ Wh/day}$$
$$= 0.67 \text{ kWh/day}$$
$$= 20.2 \text{ kWh/month}$$

3) results of the water reuse potential analysis indicate that treated wastewater can be reused for purposes such as watering plants, washing floors, or flushing toilets. Secondary treatment systems can recover approximately 50–70% of the waste water entering the system. The water reuse rate is determined to be 60%.

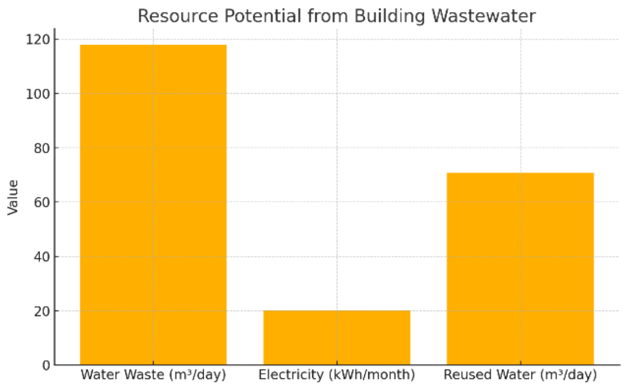
$$\text{Reusable water} = 118 \times 0.6$$
$$= 70.8 \text{ m}^3\text{/day}$$
$$= 2{,}124 \text{ m}^3\text{/month}$$

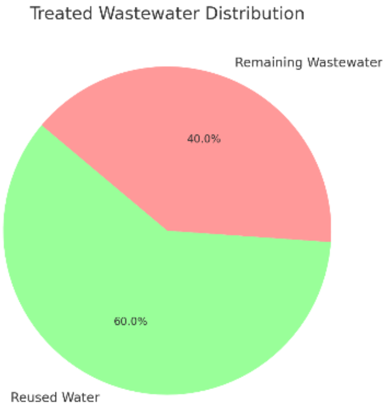
Based on the data collected and the analysis of the potential for electricity generation from water and water reuse, as summarized in Table 1.

Table 1 : Summary of Potential Assessment Results

Flow rate	118.00	m³/day		
Electric generation wastewater	0.67	kWh/day	20.20	kWh/month
Water reuse	70.80	m³/day	2,124 .00	m³/month

Discussion and conclusions





Based on a study of the potential for power generation and water recovery from waste water from 202 residential condominium buildings, which include apartments not exceeding 35 square meters, with 180 units (3 people/unit) and apartments larger than 35 sq.m., it was determined that the average water consumption rate is 200 liters per person per day. The total water consumption is 148 cubic meters per day, and the total volume of wastewater (80%) is 118 cubic meters per day, resulting in a monthly wastewater volume of 3,540 cubic meters or 3,540,000 liters. The system operates at a head of 3 meters and an efficiency of 70%, capable of generating approximately 0.67 kWh per day, or about 20.2 kWh per month. Additionally, an assessment of the potential for water reuse after secondary treatment indicated that around 60% of the wastewater volume could be reused, equivalent to 70.8 cubic meters per day. Although the potential for electricity generation from wastewater at the building level is relatively low compared to the overall electricity demand of the building, it demonstrates a promising trend for developing an auxiliary energy generation system in the form of secondary energy, particularly when integrated with the building's overall energy management system, such as solar PV or smart building systems.

In terms of water reuse, the amount obtained from waste water treatment is considered suitable for applications that are not directly related to consumption, such as watering plants, washing floors, or using in sanitation systems (toilet flush), which can significantly reduce tap water consumption.

The findings of this study suggest the potential for comprehensive indoor resource management. The emphasis is on reuse and waste-to-energy, aligning with the principles of sustainable development and the design of energy-efficient buildings in the future. This approach could also extend to green buildings or construction projects that require environmental certifications such as LEED or TREES.

Suggestion

Consider integrating waste water power generation systems with other energy sources, such as solar energy or energy storage systems, to enhance energy efficiency in buildings. Further cost-benefit analysis should be conducted to evaluate the system's payback period and long-term returns. A comparative study should be done on the potential of waste water power generation in various types of buildings, including office buildings, hotels, and hospitals, to assess the suitability for designing a range of small-scale power generation systems. The wastewater pipeline system should be designed to accommodate the installation of water turbines, such as using vertical pipes of appropriate height to create sufficient pressure head for power generation.

Acknowledgments

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AI based assessment of career choice based on social media profile

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Abstract

Social media profiles determine the choices and preferences of the individuals and trait analysis can be done using the behavioural perspectives over a period of time. Though this is an important area in which Artificial Intelligence (AI) can be used to determine the match of individual choices and behavioural perspectives with that required for success in a particular field. The present paper is an exploratory research which has been done to investigate how AI can be used for the same which can be of a lot of help for youth to make informed career choices. There are presently very few research in this area and this research can throw light on a pivotal area which can be of help for students in higher educational Institutions and also help corporates to get candidates matching the profile based on their media profile.

Keywords: Artificial Intelligence, career profiling, behavior traits

Behavioural Segmentation in the light of Telecom Industry using Cluster Analysis

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Abstract

This study explores the influence of psychographic aspects like age, financial status, individual traits, digital engagement, and way of life on the telecom industry. By examining how these preferences differ, the research provides marketers with insights to navigate a competitive environment. Cluster Analysis using SPSS was utilized, applying Hierarchical Clustering to identify dominant clusters and K-Mean Clustering to uncover additional insights. Four key variables were analyzed, resulting in three clusters: budding talent, accomplished citizen, and mature citizen. The findings highlight the contribution of specific factors to cluster formation and the relative distances between clusters. Marketers can use this understanding to customize strategies for distinct customer segments, enhancing effectiveness and competitive positioning. The study delivers new perspectives on customer segmentation in telecom, with scope for future research to incorporate more variables for deeper insights.

Keywords: Market segmentation, Cluster Analysis, Purchasing Decision, Influencing Variables.

Impact and Sentimental Values of Social Media Marketing on the Motivation and Satisfaction of International Patients: An Analysis of the Indian Medical Tourism Industry

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Abstract

The advent of digital platforms has revolutionized healthcare communication and outreach, particularly in the domain of medical tourism. This study investigates the impact and sentimental values of social media marketing on the motivation and satisfaction of international patients seeking medical treatment in India. As India emerges as a prominent global hub for affordable and quality healthcare, the role of emotionally charged marketing strategies on platforms such as Facebook, Instagram, and YouTube becomes increasingly significant in influencing patient decisions.

The research aims to assess how different forms of social media content—such as patient testimonials, hospital tour videos, influencer endorsements, and storytelling—affect the emotional responses and decision-making processes of prospective medical tourists. Additionally, the study evaluates whether the expectations built through such digital content align with the actual experiences of international patients during their medical journey in India.

A mixed-methods approach was adopted, combining quantitative surveys and qualitative interviews with international patients who interacted with Indian medical institutions via social media. Sentiment analysis of selected hospital social media content and user comments further supported the understanding of emotional engagement. The findings indicate that emotionally driven content significantly enhances patient trust and confidence, particularly when authenticity and transparency are evident in the messaging. Moreover, patients who reported a high emotional connection with the content were more likely to express satisfaction with their treatment experience and recommend the services to others.

However, the study also reveals a gap in cases where promotional content created unrealistic expectations, leading to partial dissatisfaction. These insights offer valuable implications for healthcare marketers and hospital administrators seeking to ethically and effectively leverage digital storytelling in the global medical tourism space.

By exploring the interplay of emotional marketing, patient psychology, and digital media, this research contributes to the broader discourse on healthcare consumer behaviour and offers strategic recommendations for enhancing the quality and impact of social media-driven patient engagement.

Keywords: Medical tourism, Social media marketing, Emotional engagement, Patient motivation, India healthcare.

BEYOND HUNGER PANGS: THE HIDDEN INFLUENCES BEHIND FOOD DELIVERY APP USAGE IN A HYPERCONNECTED WORLD

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ABSTRACT

The aim of this analysis is to study the significant behavioural, technological, and lifestyle influences promoting usage among modern consumers and constant usage of food delivery apps, along with their exponential growth. Food delivery apps have matured into essential lifestyle technologies as online platforms become even more incorporated in our day to day life. They are now playing a pivotal role in the way people connect with food delivery apps on a behavioural and cultural dimensions. Drawing attention towards the elements such as perceived lifestyle compatibility, perceived trust, user interface efficiency, impact over society, and public attitudes towards app-based eating patterns, this research analyses the basic influencing factors of user interaction. The outcomes highlights that the key factor influencing regular app usage is compatibility with User behaviour patterns, specifically the capability to adjust with busy schedules and preferences of the user. Moreover, users' preference to promote the service through word-of-mouth has a strong impact on the framework as their trust perception in the applications' security measures, highlighting the importance of data security and protected digital interaction. It is significant to mention that there also lies differences across age groups: elderly users seeks for more perceived control and reassurance in the application's performance reliability before endorsing it, whereas Millennial and Gen Z users tend to recommend it more easily. These outcome shows the importance of offering an user-friendly, secured, and interactive platforms that satisfy the demands of a diverse range of users. In conclusion, the study encourages additional research to the broader influences of online food delivery apps, such as, it's influence over local food economies, health parameters, and the rapidly evolving online food culture.

Keywords: Behavioural influences, Lifestyle compatibility, User trust and data security, User interface efficiency, Generational differences, Online food culture

EDTECH FOR EARTH: HARNESSING DIGITAL INNOVATION TO DRIVE SUSTAINABLE LEARNING AND SHAPE A GREENER FUTURE

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ABSTRACT

The objective of this research is to highlight the revolutionary influence of generative artificial intelligence (AI) in the evolution of sustainable education, particularly prioritizing the EdTech sector. By evaluating the potential of generative AI in reshaping the educational landscapes, this study illustrates how generative AI can influence personalized learning of users, overcome digital inequalities in education sector, and endorse unbiased access to education, which are also core aspects of United Nations Sustainable Development Goal 4 (Quality Education). Contrary to the traditional educational technologies, generative AI provides with exceptional opportunities for personalized learning, individualized content, and dynamic interaction, thus recognizing fundamental obstacles in global educational technologies. However, the research also shows the substantial challenges, including data security concerns, inequity and prejudice in AI algorithms, and the threat of intensifying the current inequalities if not practiced and utilized responsibly. The study also examines how generative AI supports the other sustainable development goals, like gender parity (SDG 5) and reduced inequalities (SDG 10), and how it can either intensify or aid in reducing these obstacles based solely over its implementation. The research underscores the requirement of an Integrated and ethical strategy for the fusion of generative AI in education, while prioritizing over global access to users, secured data, and socially responsive framework. This study provides a functional model for Government officials and education specialists to leverage the potential of generative AI while recognizing its fundamental threats, eventually leading towards a highly transformative and sustainable educational landscape on a global scale and also strengthening EdTech.

Keywords: Generative Artificial Intelligence (AI), Sustainable Education, Personalized Learning, Digital Inequalities, Ethical Implementation, EdTech Transformation

Biochemical Identification and Antioxidant Activity of Acid- and Bile-Resistant *Bacillus* spp. Isolated from Northern Thai Fermented Soybean

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Abstract

Northern Thai fermented soybean is a nutrient-rich, probiotic-packed delicacy with potential health benefits, making it a valuable functional food in nutrition. This study aimed to isolate and biochemically identify bacteria, evaluating their acid and bile resistance along with DPPH scavenging activity to determine their potential probiotic properties. VN_NTFS7 and VN_NTFS9 were selected for their non-hemolytic properties and biochemically identified as closely related to *Bacillus* species. These spore-forming, Gram-positive bacteria exhibited similarities to a *Bacillus* reference strain in carbohydrate utilization and enzymatic production. The probiotic potential of the isolated VN_NTFS7 and VN_NTFS9 was clarified. Acid resistance was tested by growing the isolates at pH 1, pH 2, and pH 3 for 24 hours; VN_NTFS7 showed log values of 4.89, 5.60, and 6.04 CFU/mL, respectively, while VN_NTFS9 exhibited log values of 4.89, 5.59, and 6.03 CFU/mL, respectively. Bile salt resistance was assessed by growing the isolates in 0.1%, 0.3%, and 0.5% (w/v) bile salt concentrations for 24 hours; VN_NTFS7 demonstrated log values of 5.20, 4.74, and 4.09 CFU/mL, respectively, whilst VN_NTFS9 displayed log values of 5.13, 4.63, and 4.39 CFU/mL, respectively. Furthermore, both isolates exhibited scavenging effects on DPPH free radicals at log 8 CFU/mL across varying cell volumes of 0.5, 2.5, and 5 mL. VN_NTFS7 showed scavenging rates of 52.51%, 70.22%, and 88.12%, respectively, while VN_NTFS9 displayed 56.01%, 89.88%, and 102.16%, respectively. These promising findings suggest that VN_NTFS7 and VN_NTFS9 could serve as valuable candidates for new dietary supplements and probiotic applications.

Keywords: Bacillus, DPPH scavenging, Fermented Soybean, Identification, Probiotic (s)

The comparison of Particular Matters and Aerosol Optical Depth in Chiang Mai, Thailand

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Abstract

Air pollution is a significant environmental issue and a serious health threat in many regions, particularly in Northern Thailand, such as Chiang Mai. The region faces recurring challenges related to air quality, with particulate matter (PM), especially PM $_{2.5}$, becoming a major concern every year. The region frequently experiences elevated levels of fine particulate pollution, which not only poses serious health risks but also impacts the overall quality of life for its residents. Aerosol Optical Depth (AOD) is a parameter that quantifies the extinction of solar radiation by aerosols and is widely used to estimate atmospheric aerosol concentrations. This study investigated the relationship between AOD and PM levels in Chiang Mai to enhance air quality monitoring. We analyzed AOD data from the Aerosol Robotic Network (AERONET) and PM $_{2.5}$ and PM $_{10}$ data from the Pollution Control Department, all of which were measured using ground-based instruments from January 2020 to December 2023. The results reveal that there is a strong seasonal variation in both AOD and PM levels, with peak pollution occur during the dry season (November-April) due to biomass burning and changing climate. To investigate this dependence, we plotted a regression model of the data between AOD and PM concentrations. The results showed a significant correlation between AOD and PM concentrations, with the coefficient of determination (R^2) values of 0.81 and 0.76 for PM $_{2.5}$ and PM $_{10}$, respectively. R^2 is the proportion of variance in the dependent variable that can be explained by the independent variables. This comparison indicates that a noticeable link between AOD and particulate matter, supporting the idea that AOD could be a practical parameter for estimating the concentration of these particles. This approach might help fill the gaps of the PM where ground-based monitoring systems are scarce or unavailable. Because AOD is measured by remote sensing, which covers all areas. This finding will be useful for targeted strategies to manage pollution in the future.

Keywords: PM2.5, PM10, AOD, Air quality, Thailand

Prevalence and Characterization of *Vibrio parahaemolyticus* Isolated from Fresh Market Blood Cockles in Bangkok Metropolitan Area, Thailand

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Abstract

Nowadays, seafood is one of the most popular types of food, and -in particular, blood cockles are favored in many regions of Thailand. Consuming partially cooked or raw cockles contaminated with *Vibrio parahaemolyticus* can lead to seafood-related food poisoning and gastroenteritis. Fresh markets are a significant source for purchasing blood cockles. This study aims to investigate the prevalence of *V. parahaemolyticus* isolated from fresh market blood cockles in the Bangkok Metropolitan Area, Thailand and to examine the virulence factors of the isolated strains. In this study, blood cockle samples were collected from 29 seafood shops across 11 fresh markets—4 markets (7 seafood shops) in Bangkok and 7 markets (22 seafood shops) in Pathumthani. Each sample, weighing 25 grams, were enriched and cultured in Alkaline Peptone Water (APW) with a pH of 8.4 and 2% NaCl. The samples were then cultivated and identified on Thiosulfate-Citrate-Bile-Sucrose (TCBS) Agar, Salt Tolerance Test, and CHROMagar™ Vibrio. The study also examined the virulence factors of the isolates by testing for the Kanagawa phenomenon using Wagatsuma blood agar, urease and protease activity. All 29 seafood shops (100%) were found to have contamination with *V. parahaemolyticus* and *V. alginolyticus*. Additionally, contamination with *V. cholerae* was found in 3 shops (10.3%). The 84 isolates of *V. parahaemolyticus* obtained in this study tested negative for the Kanagawa phenomenon and urease activity. Interestingly, 81% (68/84) of *V. parahaemolyticus* isolates tested positive for protease activity. This enzyme activity was categorized as strong (8.8%, 6/68), moderate (69.1%, 47/68), and less (21.1%, 15/68), respectively. The study concludes that blood cockles from the observed fresh markets exhibit a high contamination rate of *V. parahaemolyticus* (100%). Although, all isolated *V. parahaemolyticus* strains are non-virulent based on negative results for the Kanagawa phenomenon and urease tests, however; previous research suggests that these strains might use protease enzymes as a factor to promote pathogenicity.

Keywords: *Vibrio parahaemolyticus*, Virulence factors, Blood Cockle, Seafood-related food poisoning, Bangkok Metropolitan Area

Metascape-Guided Transcriptomic Analysis of 2-BTHF Treatment from *Holothuria scabra* in a 6-OHDA-Exposed *C. elegans* Model of Parkinson's Disease

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Abstract

Parkinson's disease (PD) is a neurodegenerative disorder characterized by dopaminergic (DAergic) neuronal loss and oxidative stress. The marine-derived compound 2-butoxytetrahydrofuran (2-BTHF), isolated from *Holothuria scabra*, has previously demonstrated potential as a neuroprotective agent. *Caenorhabditis elegans* (*C. elegans*) serves as a powerful model for studying neurodegeneration because of its well-conserved molecular pathways. This study aimed to employ a Metascape-based transcriptomic approach to investigate the genetic pathways affected by 200 µM 2-BTHF in a 50 mM 6-hydroxydopamine (6-OHDA)-induced *C. elegans* model of PD.

Using RNA sequencing and Metascape-guided bioinformatics analysis, we identified differentially expressed genes (DEGs) associated with various neurobiological processes. Gene ontology (GO) enrichment analysis revealed that 200 µM 2-BTHF treatment significantly modulated pathways related to post-translational modification (protein arginine methyltransferases, RMTs), cilium organization, synaptic activity, nervous system regulation, neuromuscular synaptic transmission, locomotion, and neuronal signal transmission. Furthermore, KEGG pathway analysis indicated the activation of neutrophil extracellular trap formation, synapse function, glutathione and drug metabolism, as well as apoptosis and necroptosis.

Further analysis using the Molecular Complex Detection (MCODE) algorithm on large protein-protein interaction (PPI) networks identified five key protein interaction complexes: major sperm proteins (*msp*), potassium channel activity (*twk*) involved in behavior, touch receptor components (*poml* and *mec*) regulating mechanosensation, ciliogenesis-associated proteins (*mks* and *tmem*), and C-type lectin-like domain proteins (*clec*) linked to feeding behavior.

Our findings provide novel insights into the molecular pathways underlying the therapeutic potential of 2-BTHF in 6-OHDA-induced neurodegeneration. By modulating key neurobiological processes, including synaptic activity, neuronal signal transmission, behavior, and oxidative stress response, 2-BTHF demonstrates promise as a neurorestorative agent. However, further studies are required to investigate these genetic alterations in mammalian models and explore their translational relevance for potential therapeutic applications in PD.

Keywords: 2-BTHF, *Holothuria scabra*, Parkinson's disease, Metascape, Transcriptomics

Evaluating the impact of culture systems on growth and plumbagin yield in in vitro *Drosera binata*

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Abstract

Drosera binata is a carnivorous plant that contains an important compound with medicinal properties, namely plumbagin. In nature, this plant has low reproductive rates and is at risk of extinction, making it insufficient to meet the demand for its use in medicinal production. This study compared three culture systems: semi-solid system (SSS), continuous immersion system (CIS), and temporary immersion system (TIS) on growth, development and plumbagin production of *Drosera binata*. After explant cultured for 8 weeks, CIS promoted better growth and development compared to SSS and TIS. The highest fresh (1.07 g), and dry (0.05 g) weight per clump and number of shoot were obtained from CIS (12 shoots per clump). However, the size of leaf, longer leaf was presented by TIS (7.26 cm). In terms of growth performance per replication, the number of shoots and fresh and dry weight per replication of explant cultured in CIS were substantially higher than cultures in SSS and TIS. The highest number of shoots obtained from CIS (240.3 shoot per replication) followed by SSS and TIS respectively. Moreover, maximal biomass was presented from CIS (21.48 g fresh weight per replication), more than two times TIS and SSS. Plumbagin production, the highest content of plumbagin was gained from TIS (254.97 µg/g DW) followed by CIS (85.51 µg/g DW) and SSS (5.43 µg/g DW). Specifically, TIS yielded the greatest amount of plumbagin per replication (230.76 µg/replication), notably exceeding the yields from CIS and SSS. This indicates that TIS is an effective approach for producing substantial quantities of *D. binata* biomass and plumbagin.

Keywords: Plumbagin, Culture system, Growth and development

"Bioactivity of *Zanthoxylum limonella* Extract: Antioxidant and Antibacterial Effects on Proteus mirabilis"

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Abstract

This study aimed to evaluate the antioxidant and antibacterial properties of crude *Zanthoxylum limonella* extracts using two solvents with differing polarity: methanol and dichloromethane. The investigation included analysis of total phenolic and flavonoid contents, antioxidant capacity via the DPPH assay, and antibacterial activity against Proteus mirabilis using the agar disc diffusion method. The crude extracts were obtained through a seven-day maceration process followed by solvent evaporation.

The results showed that the methanol extract yielded a higher extraction rate (12.7%) compared to the dichloromethane extract (7.7%). Moreover, the methanol extract contained greater amounts of total phenolic (3.618 ± 0.107 mg GAE/g DW) and flavonoid (4.279 ± 0.539 mg QE/g DW) compounds than the dichloromethane extract (3.217 ± 0.103 mg GAE/g DW and 2.722 ± 0.125 mg QE/g DW, respectively). The antibacterial assay was performed at an extract concentration of 50 µg/µL, with 10 µL of each extract loaded onto sterile discs. Under these conditions, the methanol extract exhibited stronger antibacterial activity, producing a larger inhibition zone (23.83 ± 0.624 mm) compared to the dichloromethane extract (15.33 ± 0.623 mm).

These findings suggest that methanol is a more effective solvent for extracting bioactive compounds from *Zanthoxylum limonella*. The enhanced antibacterial activity of the methanolic extract highlights its potential as a natural antimicrobial agent against P. mirabilis. Future studies should focus on identifying the specific bioactive constituents and exploring their applications in medicine and pharmaceuticals.

Keywords: *Zanthoxylum limonella* extract, *Proteus mirabilis*, Antioxidant activity, Antibacterial activity

Antioxidant and Antibacterial Activities of *Chromolaena odorata* Leaves Extract.

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Abstract

The leaves of *Chromolaena odorata* have been traditionally used in Thai medicine for their wound healing and antioxidant activity. The objective of this study is to investigate the total phenolic content, total flavonoid content, antioxidant, and antibacterial activities of the methanolic extract of *Chromolaena odorata*. The total phenolic and flavonoid contents were evaluated using the Folin-Ciocalteu and aluminum chloride colorimetric methods, respectively. The total phenolic content was 4.055 ± 0.117 mgGAE/gDW, while the total flavonoid content was 20.34±0.305 mgQE/gDW. The antioxidant activity was evaluated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay, while the antibacterial activity against *Staphylococcus aureus* was assessed using the disc diffusion method. The results showed that the extract exhibited significant antioxidant activity, with 87.72±0.189% inhibition of free radicals. In addition, it also showed a strong antimicrobial effect, with an inhibition zone of 12.83±1.30 mm against *S. aureus*. These findings suggest that *Chromolaena odorata* leaf extract possesses both antioxidant and antibacterial activities, making it a potential candidate for further investigation in medical and pharmaceutical applications.

Keywords: *Chromolaena odorata*, Antioxidant, Antibacterial activity, Traditional plant extracts

Phytochemical Composition, Antioxidant, and Antibacterial Activities of Methanolic Extracts from *Dillenia indica* L. Fruit Pulp

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Abstract

Dillenia indica L. (Matad) is a plant native to Thailand's Pathum Thani Province that has traditionally been used in food and folk medicine. This study looked at the total phenolic content (TPC), total flavonoid content (TFC), antioxidant, and antibacterial activities of methanolic extracts from dried fruit pulp. The *Dillenia indica* L. were dried at 60°C for 48 hours before being extracted with methanol for 7 days. The crude extract yielded 28.6%. Phytochemical analysis revealed TPC of 1.79±0.2468 mgGAE/gDW and TFC of 14.12±0.5626 mgQE/gDW. The DPPH assay showed a high antioxidant activity of 85.56±1.1239% inhibition at 50 mg/mL. Antibacterial tests revealed that *E. coli* were more inhibited than *S. aureus*.

Finally, the methanolic extract of dried *Dillenia indica* L. fruit pulp has significant antioxidant activity and significant antibacterial potential, particularly against Gram-negative bacteria. The extract is high in flavonoids compared to phenolic compounds, which may contribute to its observed bioactivity. These findings lend preliminary scientific support to the traditional use of *Dillenia indica* L. and highlight its potential for development into natural health products. However, more research, including in vivo efficacy trials and comprehensive toxicity evaluations in animal models, is required to confirm its safety and therapeutic potential for clinical applications.

Keywords: *Dillenia indica* L., antioxidant activity, total phenolic compound, total flavonoid content, antibacterial activity

Electricity Generation from Cooling Tower Blowdown at a Height of 1.5 Meters Using Two Types of Water Turbines: Banki and Pelton

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Abstract

This research aims to study the feasibility of generating electricity from cooling tower blowdown at a height of 1.5 meters using two types of water turbines: Banki and Pelton. A small-scale electricity generation test setup was designed with a width of 3.68 meters and a height of 1.55 meters to test the two turbine types are as follow Banki turbine 3 watt and Pelton turbine 50 watt. The experiments were conducted at flow rates ranging from 400 to 1,000 liters per hour.The test results showed that the Pelton turbine could generate more electricity than the Banki turbine. The power output of both turbines increased with the water flow rate. The Banki turbine achieved a maximum average power output of 1.07 watts at a flow rate of 1,000 liters per hour, while the Pelton turbine reached a maximum average power output of 5.50 watts at the same flow rate. Based on these test results, an assessment was conducted for electricity generation from cooling tower blowdown with a flow rate of 25,590 liters per hour at a height of 1.5 meters using Banki and Pelton turbines. The results indicated that the Banki turbine could generate 155.65 watts, while the Pelton turbine could generate 214.12 watts.

This research demonstrates that electricity can be generated from cooling tower drain water at a height of 1.5 meters using Banki and Pelton turbines. This concept promotes the reuse of energy from cooling tower blowdown, enhances the efficiency of power generation systems, reduces environmental impact, minimizes energy waste from unused discharge, and increases electricity generation capacity without additional fuel consumption.

Keywords: cooling tower, cooling tower blowdown, water turbines, small-scale electricity generation test

Introduction

Cooling Tower is a crucial device that helps reduce the temperature of water used in industrial processes or cooling systems by utilizing air and water evaporation. The cooling system discharges water to minimize the accumulation of minerals, impurities, and chemicals that result from water evaporation. Most of the discharged water from the cooling tower is drained into a storage pond before being released into natural water sources. Therefore, this research investigates the feasibility of generating electricity from the discharged water of a natural gas power plant's cooling tower, with a water flow rate of 25,590 liters per hour at a height of 1.5 meters (Figure 1), using two types of water turbines: Banki and Pelton. (Alomar et al., 2022) This concept aims to reuse energy from the cooling tower's discharged water, (Ahmed et al., 2023) enhancing the efficiency of the power generation system (Pan et al., 2018), reducing environmental impact, and minimizing energy waste. Additionally, it allows for increased electricity generation without the need for additional fuel consumption. (Ma et al., 2017)

Figure 1 Cooling tower blowdown of a natural gas power plant
in **Phra Nakhon Si Ayutthaya Province,** with a flow rate of **25,590 liters per hour.**

Research Methodology (Chaulagain, 2024)

The research was conducted in the following steps (Figure 6) :

1.Conduct research and gather information : Study relevant information and collect knowledge related to the topic.

2.Collect data on cooling blowdown water : Gather relevant data on cooling blowdown water for use in model design.

3.Draft and create the model using AutoCAD : Design a small-scale model to study the feasibility of generating electricity from cooling tower discharge water, as real-site testing is not feasible. (Figure 2)

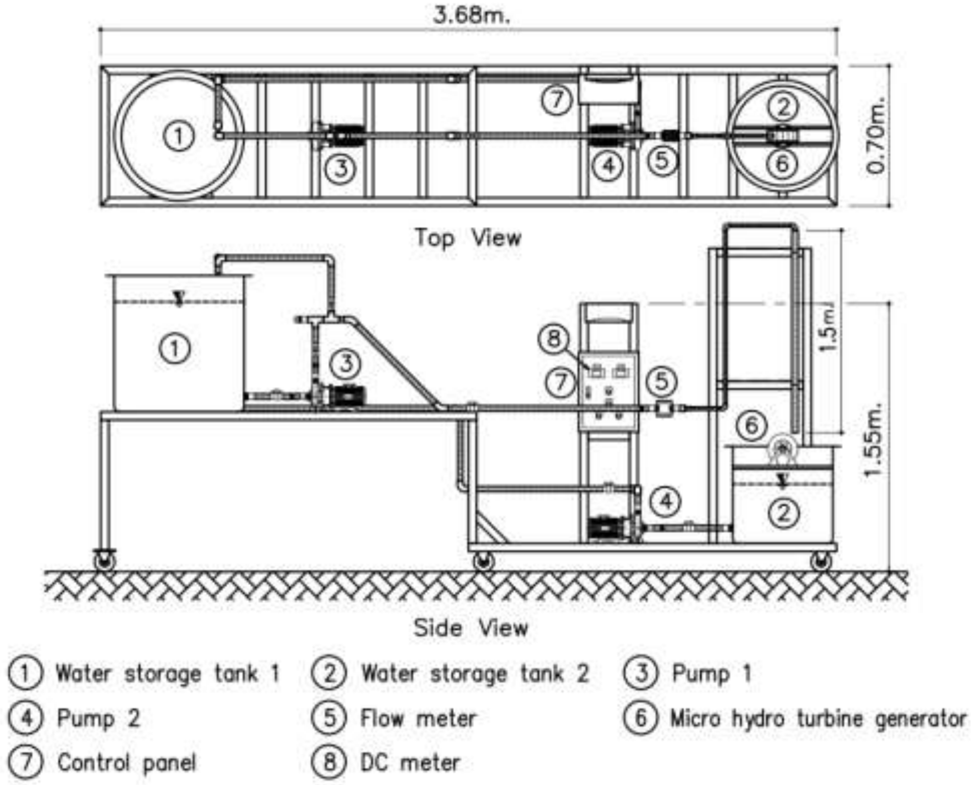

Figure 2 Design of a Test System for Electricity Generation from Cooling Tower Blowdown Using AutoCAD

4. Build a small-scale model (**Width**: 0.70 meters, **Length**: 3.68 meters, **Height**: 1.55 meters) according to the design details created with AutoCAD. (Figure 3)

Figure 3 Experimental Model for Electricity Generation

4.1 Tools and Equipment

4.1.1 200-liter water storage tanks, 2 pieces

4.1.2 Water pump, centrifugal pump type, flow rate of 5 - 40 liters per minute, 2 units

4.1.3 Digital flow rate measurement set, flow rate range 0 - 120 liters per minute, 1 unit

4.1.4 Small-scale hydroelectric generator sets, 2 types:

a) Type 1: Banki turbine (Figure 4), DC (Direct Current) power generation, maximum power 3 watts, voltage range 1-12 volts, turbine diameter 4.8 cm, width 3.0 cm

b) Type 2: Pelton turbine (Figure 5), vertical blade, DC (Direct Current) power generation, maximum power 50 watts, voltage range 1-36 volts, turbine diameter 9.6 cm, width 29 cm (Kaewrattanasripho, 2022)

Figure 4 Banki Turbine

Figure 5 Pelton Turbine

4.1.5 **Electrical control cabinet with a digital DC meter**, Measuring electrical power from 0 to 2 kilowatts, measuring voltage from 6.5 to 100 volts, and measuring current from 0 to 20 amps.

5.Test and record results

If the test results fail ("No"), return to the Draft and create the model using AutoCAD step, modify the model, and conduct a new test.

If the test results pass ("Yes"), proceed to analyze the results.

5.1 Experimental Procedure (Gallego et al., 2021)

5.1.1 Install the Type 1 hydroelectric generator in the experimental setup.

5.1.2 Use water from the cooling tower discharge for the experiment.

5.1.3 Conduct the experiment at a flow rate of 400 to 1000 liters per hour, increasing the flow rate by 100 liters per hour each time, at a height of 1.5 meters.

5.1.4 Record the data for current, power, and voltage every 20 minutes, a total of 6 times.

5.1.5 Replace the hydroelectric generator set with Type 2 and repeat the experiment according to steps 2-4.

6.Analyze the results : Analyze the data obtained from the tests.

7.Summarize findings and provide recommendations : Summarize the study results and provide recommendations for practical application.

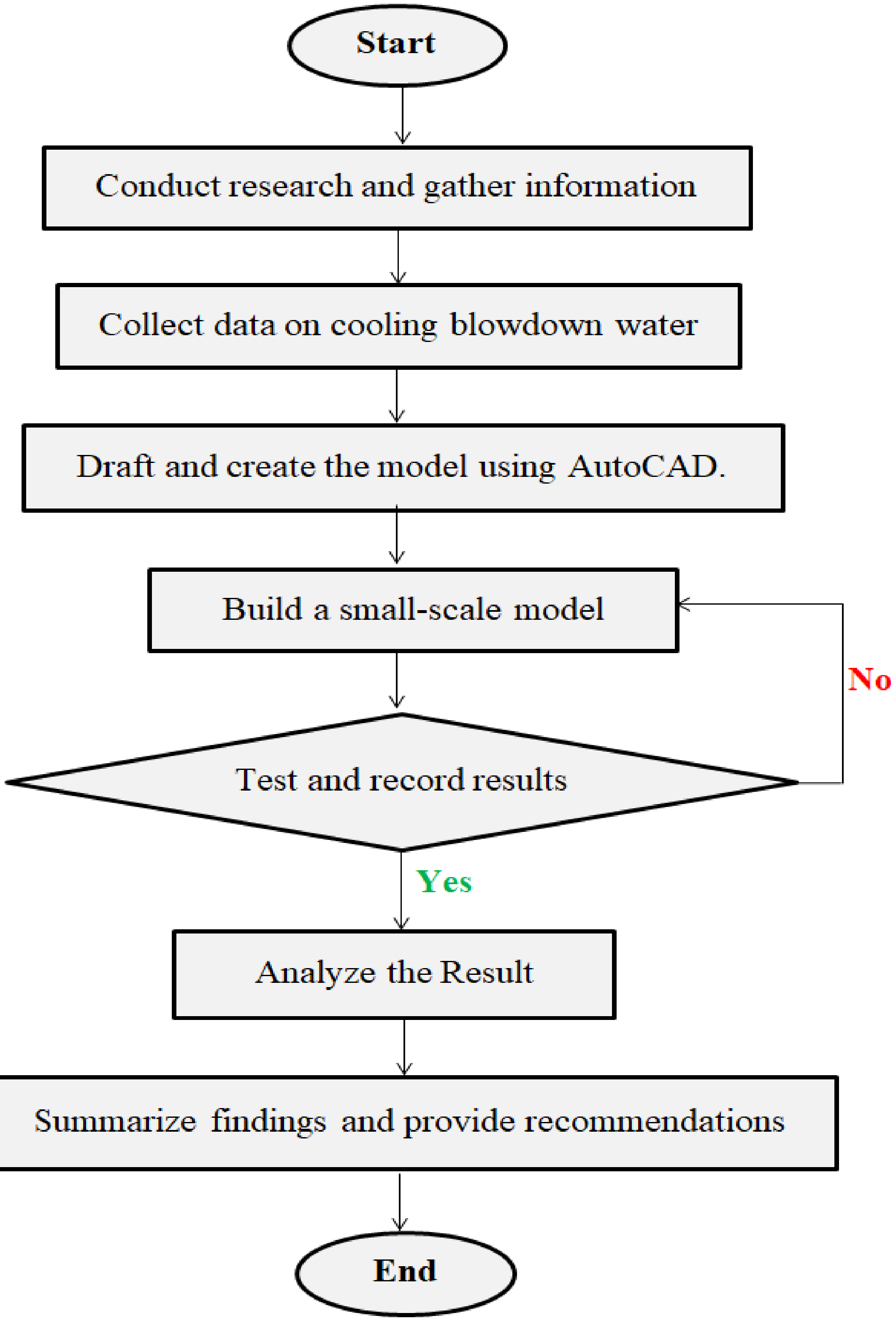

Figure 6 Research Flowchart

Result

The experiment was conducted to generate electricity using two types of water turbine models: the Banki turbine and the Pelton turbine. Measurements were taken at various water flow rates ranging from 400 to 1000 liters per hour (l/h), and the output voltage (V), current (A), and electrical power (W) produced by each turbine were compared (Table 1).

-As the water flow rate increased, the voltage, current, and power output from both turbine types increased steadily.

-The Pelton turbine produced higher electrical power than the Banki turbine at every flow rate.

At 400 l/h:

Banki : 7.99 V, 0.02 A → 0.16 W

Pelton : 8.02 V, 0.05 A → 0.40 W

At 1000 l/h:

Banki : 9.52 V, 0.11 A → 1.07 W

Pelton : 12.50 V, 0.44 A → 5.50 W

Table 1 Results of the Experiment on Electricity Generation from the Banki Turbine and Pelton Turbine Models

Flowrate (l/h)	Banki Turbine			Pelton Turbine		
	Voltage (V)	Current (A)	Power (W)	Voltage (V)	Current (A)	Power (W)
400	7.99	0.02	0.16	8.02	0.05	0.40
500	8.48	0.04	0.34	8.56	0.07	0.60
600	8.68	0.06	0.52	9.80	0.15	1.47
700	9.01	0.08	0.72	10.20	0.27	2.75
800	9.25	0.10	0.93	10.80	0.31	3.35
900	9.46	0.11	1.04	11.60	0.34	3.94
1000	9.52	0.11	1.07	12.50	0.44	5.50

The relationship between flow rate (l/h) and electrical power (W): It was found that electrical power increases with the flow rate.

1.Banki Turbine : The minimum electrical power is 0.16 W at a flow rate of 400 l/h, and the maximum electrical power is 1.07 W at a flow rate of 1000 l/h.

2.Pelton Turbine : The minimum electrical power is 0.40 W at a flow rate of 400 l/h, and the maximum electrical power is 5.5 W at a flow rate of 1000 l/h.

The results comparing the electrical power output (Power, W) of two types of water turbines—Banki turbine and Pelton turbine—based on different water flow rates (Flowrate, LPH) are presented in Figure 7.

The horizontal axis (X-axis) represents the water flow rate (LPH: liters per hour).

The depth axis (Y-axis) indicates the type of turbine (Pelton and Banki).

The vertical axis (Z-axis) shows the electrical power (W) generated.

Graph lines:

-The blue line represents the performance of the Banki turbine:

Linear equation: $y = 0.0016x - 0.4521$

Coefficient of determination: $R^2 = 0.9720$

-The red line represents the performance of the Pelton turbine:

Linear equation: $y = 0.0085x - 3.3921$

Coefficient of determination: $R^2 = 0.9727$

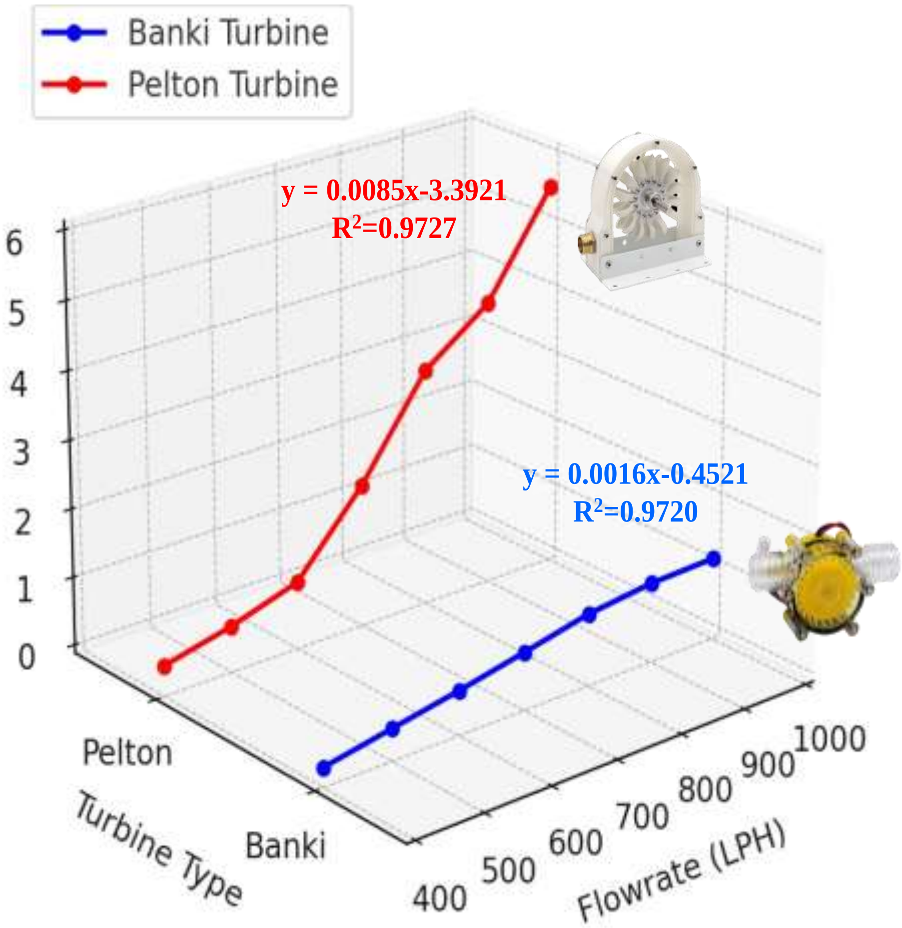

Figure 7 The relationship between flow rate (liters per hour) and electrical power (watts) of the Banki and Pelton turbines at a height of 1.5 meters.

The Pelton turbine generates higher electrical power than the Banki turbine. At a flow rate of 1000 l/h, the Pelton turbine produces 5.50 W, while the Banki turbine only produces 1.07 W. (Eshra et al., 2021)

Engineering Analysis

A presents a performance comparison between two types of water turbines: the Banki turbine and the Pelton turbine, based on their maximum efficiency in three parameters: maximum voltage, maximum current, and maximum power output. (Table 2)

Details for each parameter:

Maximum Voltage (V):

Banki : 9.52 V Pelton : 12.50 V

The Pelton turbine produces 1.3 times higher voltage.

Maximum Current (A):

Banki : 0.11 A Pelton : 0.44 A

The Pelton turbine generates 4 times higher current.

Maximum Power (W):

Banki : 1.07 W Pelton : 5.5 W

The Pelton turbine delivers 5.1 times higher power output.

Table 2 Comparison of Banki Turbine and Pelton Turbine

Parameter	Banki Turbine	Pelton Turbine	Advantage of Pelton
Maximum Voltage (V)	9.52 V	12.50 V	1.3 times higher
Maximum Current (A)	0.11 A	0.44 A	4 times higher
Maximum Power (W)	1.07 W	5.5 W	5.1 times higher

Based on the test results of the small-scale electricity generation setup, used to evaluate electricity production from the cooling tower discharge water with a flow rate of 25,590 liters per hour at a height of 1.5 meters using both the Banki and Pelton water turbines, it was found that the Banki turbine can generate 155.65 watts, while the Pelton turbine can generate 214.12 watts (Walker et al., 2022). These values were calculated from the linear equation derived from the graph.

Linear equation $y = 0.0016x - 0.4521$

Where : y = Power (Watts)

x = Flow rate (liters per hour)

$$\begin{aligned} y &= 0.0016x - 0.4521 \\ &= 0.0061(25{,}590) - 0.4521 \\ &= 155.65 \text{ Watts} \end{aligned}$$

Linear equation $y = 0.0085x - 3.3921$

Where : y = Power (Watts)

x = Flow rate (liters per hour)

$$\begin{aligned} y &= 0.0085x - 3.3921 \\ &= 0.0085(25{,}590) - 3.3921 \\ &= 214.12 \text{ Watts} \end{aligned}$$

To calculate the electrical power generated from the potential energy of water, the following equation was used to estimate the power output from water flow through a turbine:

$$P = \eta\rho gHQ \qquad \text{...........................(1)}$$

Where:

ρ	=	Density of water, in kilograms per cubic meter (1000 kg/m³)
η	=	Turbine efficiency, in percentage (70%)
Q	=	Flow rate, in cubic meters per second (0.0071 m³/s)
g	=	Acceleration due to gravity (9.81 m/s²)
H	=	Height from the reference point, in meters (1.5 m)

By substituting these values into the equation:

$$\begin{aligned} P &= 0.7 \times 1000 \times 9.81 \times 1.5 \times 0.0071 \\ &= 73.13 \text{ W} \end{aligned}$$

With a discharge volume from the cooling tower of 25,590 liters per hour, electricity generation through a water turbine yields approximately 73.13 watts. When comparing the Banki and Pelton turbines, it is found that the Pelton turbine produces more electricity than the Banki turbine.

This can be used to analyze the reduction in carbon footprint by generating electricity using a water turbine instead of conventional fossil fuel-based sources such as coal or natural gas.

Step 1: Convert power to energy per hour

$$P = 73.13 \text{ W} = 0.07313 \text{ kWh/hour}$$

Step 2: Assume average CO_2 emission from fossil-based electricity = 0.7 kg/kWh

(A typical value for coal or gas power plants)

CO_2 reduction per hour=0.07313×0.7=0.0512 kg CO

Electricity generation using a water turbine at a capacity of 73.13 watts can reduce carbon dioxide emissions by approximately:

= 0.051 kg CO_2 (or 51 grams CO_2) per hour

= 1.224 kg CO_2 per day

= 446.76 kg CO_2 per year

With a cooling tower blowdown volume of **25,590 liters per hour**, electricity generation via a water turbine can yield **73.13 watts** of power. This estimation is based on the potential energy equation of water, assuming a turbine efficiency of **70%** and an effective head of **1.5 meters**.

Utilizing this hydropower source instead of fossil fuels for electricity generation can reduce greenhouse gas emissions by approximately **446.76 kilograms of carbon dioxide per year.** This demonstrates the potential of using cooling tower discharge water as a clean energy resource, contributing to sustainable power generation and environmental impact reduction.

Discussion and conclusions

The Pelton Turbine is more efficient than the Banki Turbine in terms of voltage, current, and electrical power.

Efficiency of Pelton Turbine

Advantages

- It provides 5.1 times more electrical power than the Banki Turbine.
- It is suitable for high flow rates and high pressure conditions.
- It generates significantly higher current, which is essential for practical applications.

Limitations

-Requires water pressure greater than 1 meter to achieve maximum efficiency.

-It is larger and more expensive than the Banki Turbine.

Recommendations for Use

-The Pelton Turbine is suitable for electricity generation in systems with high flow rates. It should be installed in locations with high water pressure to achieve maximum power output.

-For industrial use, it is advisable to connect the turbine to an energy storage system for efficient energy utilization.

Discussion and Impact

- The Banki Turbine performs well at medium flow rates but has limitations in terms of electrical power output.

-The Pelton Turbine has a strong linear relationship between flow rate and electrical power, making it ideal for high-power applications.

The experimental results indicate that the choice of water turbine should be based on the environmental conditions of the location, such as flow rate and water height, to maximize efficiency.

Suggestion

The use of small-scale hydroelectric generators (Micro hydro turbine generators) for electricity generation from the cooling tower discharge water should be further studied and researched to enable the generation of more electricity at low flow rates and low head (height). This would allow for the recycling of energy back into the power plant to maximize its benefits.

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Performance Study of Heat Sink Fins Designed Based on Heat Flux Distribution under Forced Convection Conditions

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Abstract

This study aims to evaluate the thermal performance of a heat sink designed based on the distribution of surface heat flux under forced convection conditions. The experiment was conducted using constant heat loads of 80°C, 90°C, and 100°C, along with controlled air flow rates of 0.005 m³/s, 0.010 m³/s, and 0.015 m³/s, respectively. Temperature readings were collected at the air entry, exit, and eight different points on the fin surface to find out the convective heat transfer coefficient, temperature patterns, and overall fin efficiency. The results showed that the heat sink design based on heat flux distribution significantly influenced thermal performance, particularly at higher temperatures and airflow rates. The heat transfer rate increased by approximately 17% when the heat load was raised from 80°C to 90°C and by 30% when raised to 100°C, while fin efficiency slightly decreased with increasing airflow. These findings offer useful insights for designing high-performance heat sinks in electronic cooling applications and provide a foundation for mathematical modeling of thermal behavior across the operating range of 80–100°C.

Keywords: Heat Sink Fins, Thermal efficiency, Forced Convection

Introduction

Advances in electronic technology have led to the development of devices with higher power and heat generation. The increase in transistors on the chip surface also increases the heat per unit area (Xue et al., 2024). As a result, cooling has become a key issue in the design of modern electronic systems. Heat sinks are devices that are widely used to dissipate heat, especially in forced convection conditions, which increase the rate of heat transfer from electronic devices to the environment. However, traditional heat sink designs often use fins of the same shape and size throughout the surface, without taking into account the uneven heat flux distribution that occurs in real-world situations (Chen et al., 2023). Some areas may generate higher heat than others, also known as hot spots, which are a major problem in electronics cooling (Ali et al., 2024). This results in localized high temperatures which can damage the device.

Previous research has made significant contributions to heat sink design optimization. Kumar et al. (2023) investigated various fin geometries and found that pin-fin configurations with variable heights showed 15-20% improvement in thermal performance compared to uniform height designs. Wang et al. (2024) demonstrated that optimizing fin placement based on thermal imaging data could reduce maximum temperature by up to 12% in high-power density applications. However, there are still gaps in research on experimental studies evaluating the performance of thermal fins designed according to the distribution of heat flux under a wide range of operating conditions.

This research focuses on the thermal efficiency of heat sinks with fin design according to the distribution of heat flux under forced convection conditions. It conducts comprehensive experiments on the effects of key parameters such as heat flux dispersion patterns and air velocities. The results of this study will help improve understanding of the relationship between fin design and heat flux dispersion. This will lead to the design of more efficient cooling systems for modern electronics with high thermal density.

Research Methodology

This study investigates the performance of heat sink fins designed according to the distribution of heat flux under forced convection conditions. The heat sink fins are constructed from aluminum due to its high thermal conductivity, light weight, and easy formability, which are suitable for applications in electronics (Zhang et al., 2023).

The heat sink, as shown in Figure 1, consists of a base plate with a surface area of 0.012 m² and 17 fins with 2 different heights. The taller fins (23 mm) are positioned in areas expected to experience higher heat flux, while shorter fins (13 mm) are placed in areas with lower expected heat flux. This design is based on the principle that areas with high heat flux should have more surface area for heat transfer than areas with low heat flux to achieve efficient heat dissipation. The distribution of fin heights was determined based on preliminary thermal imaging tests that identified heat concentration patterns.

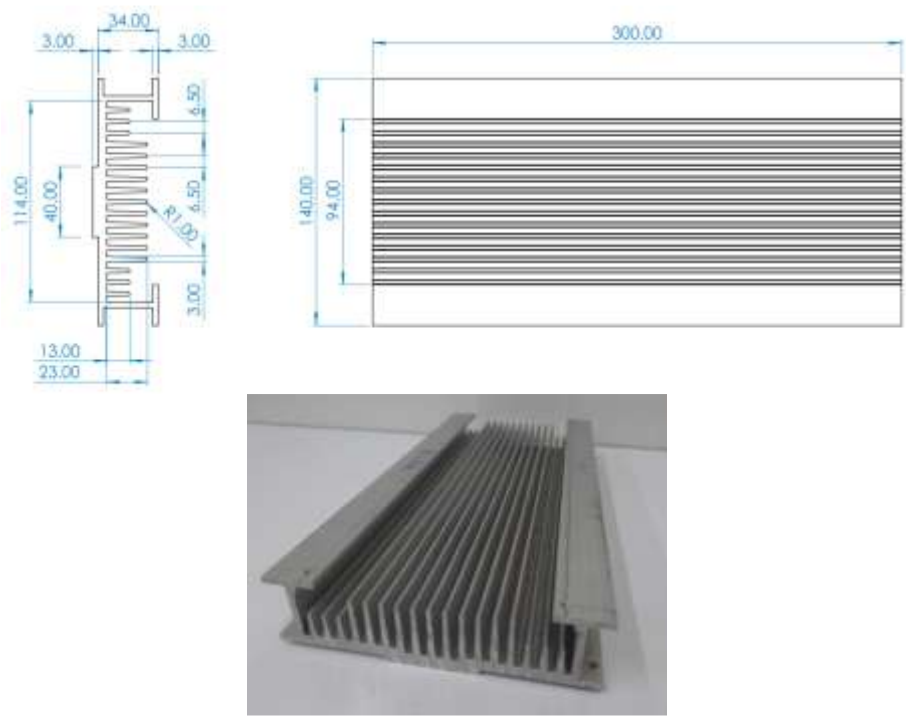


Figure 1 Geometry and dimensions of heat sink

The experimental setup is illustrated in Figure 2, which shows the heat sink installation, air flow system, and sensor placement. A custom-designed heat sink, based on localized heat flux distribution, was fabricated and tested under forced convection conditions.

1. The test system includes a controlled air tunnel with adjustable flow rates.
2. Heating elements were attached to the base of the heat sink to simulate constant surface temperatures of 80°C, 90°C, and 100°C.
3. Air flow rates were set to 0.005 m^3/s, 0.010 m^3/s, and 0.015 m^3/s using a calibrated blower.
4. Thermocouples were placed at 8 surface points of the heat sink fins, as well as at the air inlet and outlet (as shown in Figure 3) to measure temperature distributions.

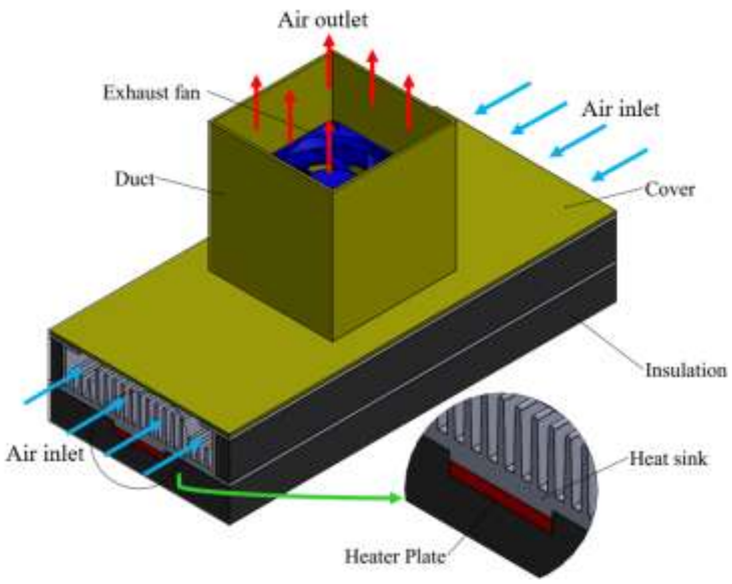


Figure 2 The basic layout of the experimental setup

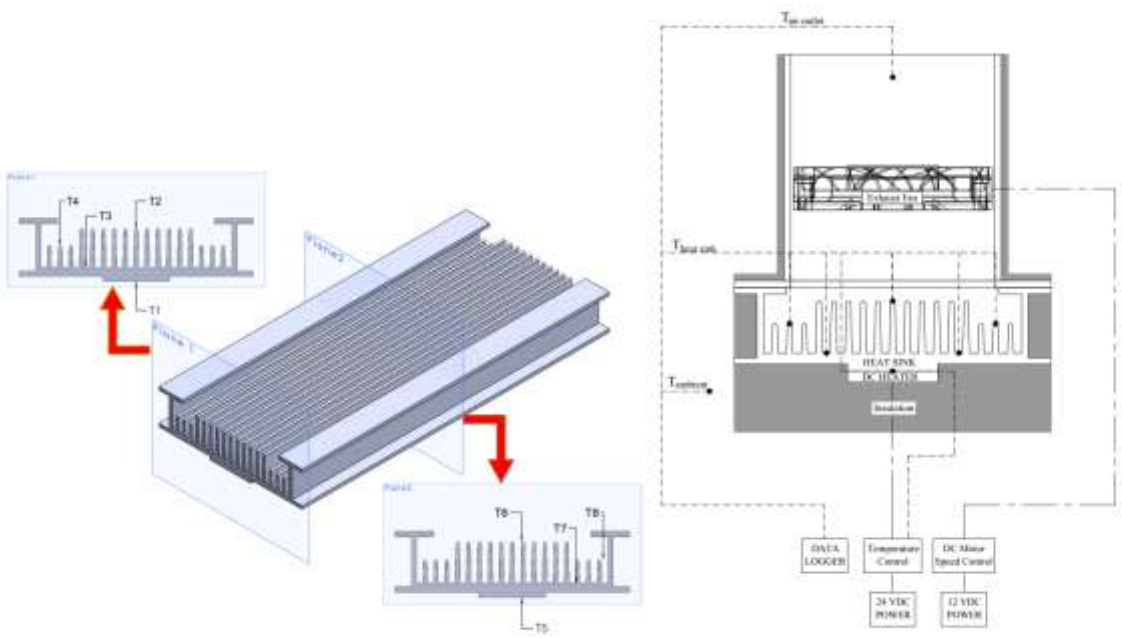


Figure 3 The measurement setup (a) and graphical diagram (b)

The experiment was carried out for each combination of heat load and air flow rate under steady-state conditions. The following steps were performed:

Step 1: Preheat the system to the target temperature (80°C, 90°C, or 100°C).

Step 2: Stabilize the air flow at the selected flow rate.

Step 3: Record inlet and outlet air temperatures, and fin surface temperatures at 8 locations.

Step 4: Repeat each condition at least 3 times to ensure repeatability.

The actual heat transfer from the heated surface to the surrounding fluid follows Newton's cooling law, which states that the cooling rate of an object is directly related to the temperature difference between the object and the environment, and the contact area between the two objects. It can be calculated using the following formula (Ali et al., 2024):
Actual heat transfer rate convective heating

$$Q_{Actual} = \dot{m} c_p (T_{air,outlet} - T_\infty) \tag{1}$$

where:

$\dot{m}$: mass airflow rate (kg/s)

c_p : air-specific heating (kJ/kg.K)

$T_{air,outlet}$: air outlet temperature (°C)

T_∞ : Ambient temperature (°C)

The ideal maximum heat transfer rate assumes that the fin temperature equals the heat sink base temperature, obtained from the equation:

$$Q_{\max} = hA_{fin}(T_0 - T_\infty) \tag{2}$$

where:

h : Heat transfer coefficient (W/m².K)

A_{fin} : surface area of the fin (m^2)

T_0 : Temperature at the fin base (°C)

T_∞ : Ambient temperature (°C)

The heat transfer coefficient (h) is determined by:

$$h = \frac{Q_{conv}}{A_s\left(T_s - T_m\right)} \tag{3}$$

where:

Q_{conv} : Convective heat transfer rate (W)

A_s : The total surface area of the heat sink exposed to air (m^2)

T_S : Heatsink surface temperature (°C)

T_m : Average air temperature (°C)

The efficiency of the heat sink fins can be expressed as the ratio of the actual heat transfer from the fins to the maximum possible heat transfer:

$$\eta_f = \frac{Q_{Actual}}{Q_{\max}} \tag{4}$$

where:

η_f : Fin efficiency

Q_{Actual} : Actual heat transfer rate (W)

Q_{max} : Maximum heat transfer rate (W)

The uncertainties of the measurement instruments used in this study are summarized in Table 1. The surface temperature was measured using K-type thermocouples with an accuracy of ±0.5°C, and the air velocity was measured using a hot-wire anemometer with an uncertainty of ±3%. Based on temperature and air velocity measurement uncertainties, the overall experimental uncertainty was estimated to be within ±5%.

An uncertainty analysis was conducted to assess the reliability of the results. Considering the measurement uncertainty of temperature (±0.5°C) and flow rate (±3%), it was found that the calculation uncertainty of heat transfer coefficient and fin efficiency was not more than ±5%, which was within an acceptable level for experimental studies.

Table 1 The uncertainty associated with each measured quantity

Parameter	Instrument	Uncertainty
Surface temperature	K-type thermocouple	±0.5°C
Air velocity	Hot-wire anemometer	±3%

Result

In this study of heat sink fin performance under controlled thermal load and flow rate conditions, the results are evaluated and discussed to show the effects of heat and air mass flow rate on average temperature. For each experimental case, data at steady state conditions (after 30 minutes) was used for analysis.

Figure 4 shows the temperature values at 8 key locations on the heat sink fins, including the air inlet and outlet temperatures, under a constant temperature heating load of 90°C with a flow rate of 0.01 m³/s. The temperatures at positions T1-T8 on the heat sink fins are higher than the air temperatures, and the system reaches thermal stability after approximately 15 minutes. After 30 minutes, temperature variations become negligible, indicating steady-state conditions have been achieved.

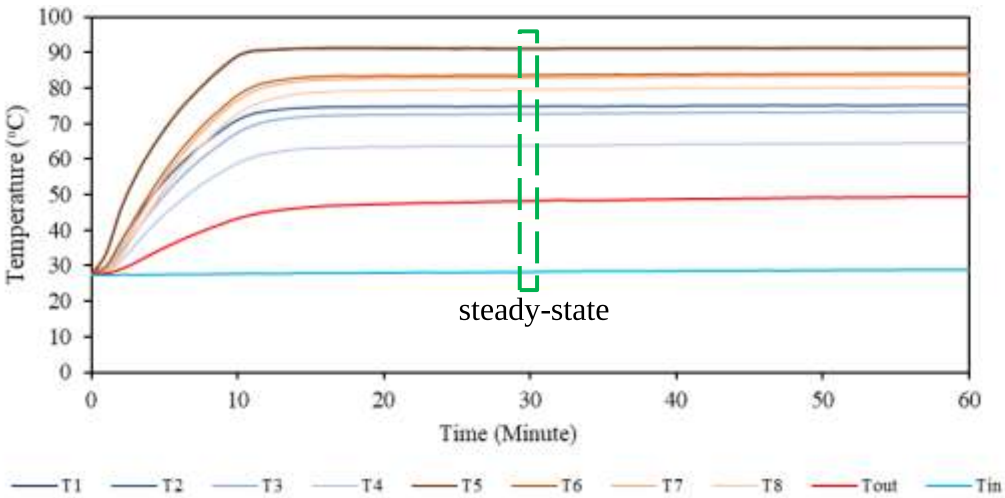
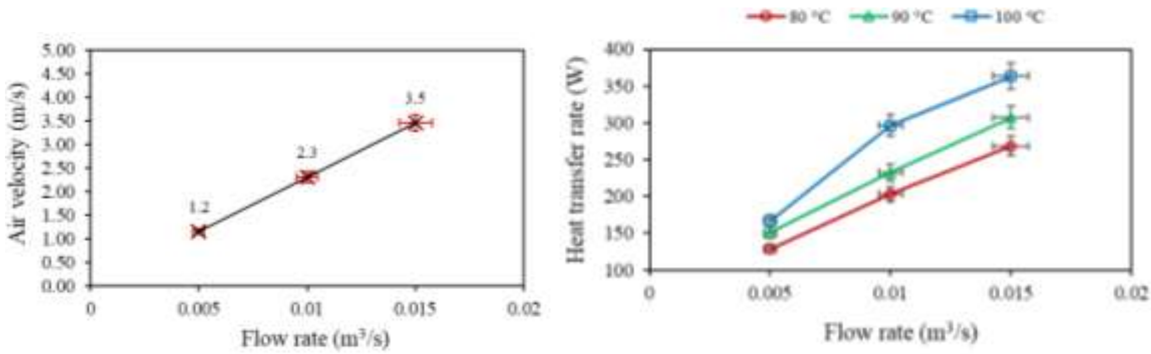


Figure 4 Temperature at the critical position of the heat sink subjected to constant temperature heat load

It can be observed that the temperature in the center of the heat sink at positions T5-T8 is higher than at the front near the air inlet. This occurs because the air exchanges heat with the fin surface along the flow path, resulting in increased air temperature. Consequently, less heat exchange occurs in the center of the fins due to the reduced temperature difference between the fins and the air. This phenomenon demonstrates the importance of designing fins of different heights based on heat distribution patterns.

Different flow rates produce different air velocities through the heat sink fins. As shown in Figure 5(a), flow rates of 0.005, 0.01, and 0.015 m³/s produce average air velocities of 1.2, 2.3, and 3.5 m/s, respectively. The heat transfer rate increases with air flow rate at the same temperature, as illustrated in Figure 5(b). The maximum heat transfer rate was 363.5 W at the highest thermal load and flow rate conditions (100°C, 0.015 m³/s), which was 183% higher than at the lowest heat load and flow rate conditions (80°C, 0.005 m³/s).

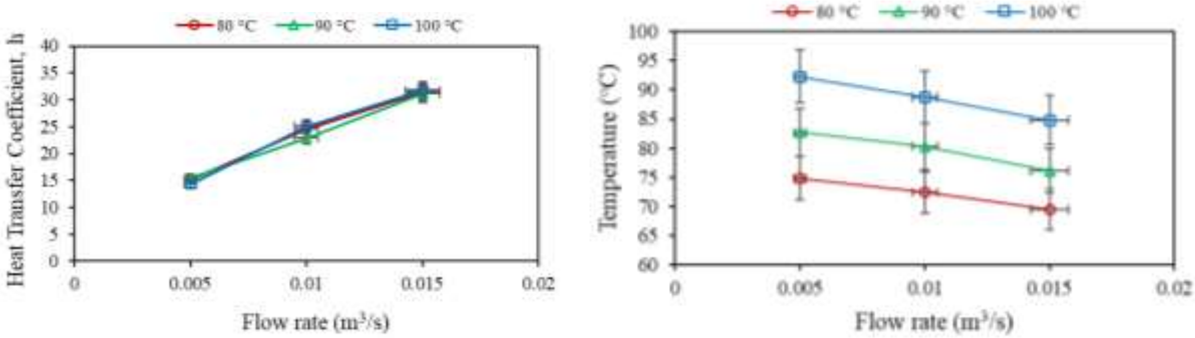


(a) (b)

Figure 5 Air velocity (a) Heat transfer rate (b)

The heat transfer rate depends on three main factors: the temperature difference between the air and the heat sink fins, the heat exchange surface area, and the heat transfer coefficient. Figure 6(a) shows that the convection coefficient is similar when the air flow rate is the same, even when fin temperatures differ, indicating that thermal load has less impact on the convection coefficient than air flow rate. However, the convection coefficient increases significantly with higher air flow rates.

Furthermore, Figure 6(b) demonstrates that as air flow rate increases, the average temperature of the heat sink fins decreases across all heat load ranges, corresponding to the enhanced heat transfer behavior observed at higher flow rates.



(a) (b)

Figure 6 Heat transfer coefficient (a) Average temperature of cooling fins (b)

According to the performance tests of heat sink fins under constant temperature thermal loads of 80°C, 90°C, and 100°C at various air flow rates, fin efficiency tends to decrease as air flow rate increases, as shown in Figure 7. At the minimum flow rate of 0.005 m^3/s, fin efficiency ranges from 66.4% to 67.1%, while at the maximum flow rate of 0.015 m^3/s, efficiency decreases to 63.9% – 64.4%. This decrease occurs despite the reduction in the ratio of fin surface temperature to air temperature.

The fin efficiency values in this study were calculated based on steady-state heat transfer theory, using Equation (4). It is defined as the ratio of the actual heat transferred by the fin to the heat that would be transferred if the entire fin were at the base temperature. The calculation assumes a uniform and constant base temperature, and neglects heat losses at the fin tip.

Additionally, the experimental results suggest that the thermal load applied to the heat sink fins has minimal effect on fin efficiency, as different thermal loads provide similar efficiency values at the same flow rate. This indicates that air flow rate is the primary factor affecting fin performance rather than the applied heat load.

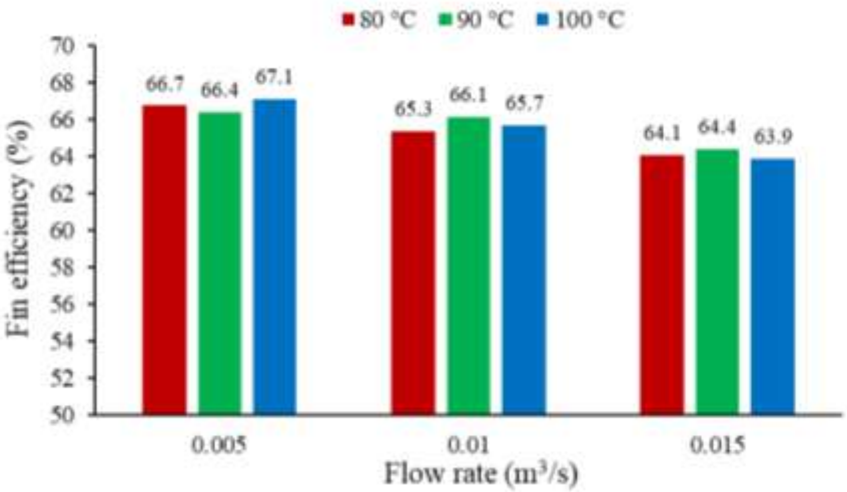


Figure 7 Fin efficiency

Discussion and conclusions

Air flow rate was identified as a dominant parameter influencing the efficiency of heat sink fins. As the flow rate increases, both the average fin temperature and the convective heat transfer coefficient rise accordingly. As a result, when the heat transfer rate (Q) increases while the thermal conductivity (k) of the fin material remains constant, a larger temperature gradient develops within the fin. This gradient significantly impacts fin efficiency. Interestingly, this behavior is somewhat counterintuitive, as the imbalance between internal conduction and external convection at the fin–air interface appears contrary to typical expectations based on uniform heat distribution.

At high flow rates, the increased convective heat transfer from the fin surfaces overcomes the heat loss within the fin material. This causes a larger temperature gradient on the fins, whereby the tips operate at significantly lower temperatures compared to the base. Based on fin theory this temperature gradient reduces total fin efficiency as total heat transfer increases [7] without an associated increase in overall mass transfer. This agrees with studies by Olekar and Ganesha (2016) in which similar efficiency trends were noticed for perforated pin fins.

Experimental results also show that the thermal load placed on the heat sink fins has little impact on fin efficacy, as different thermal loads have similar efficiency values at corresponding flow rate. It indicates that the performance of the fin is governed by air flow rate and rather than the applied heat load. This finding is in accord with Lee et al. (2019) which reported that heat flux distribution will influence temperature profile but it has much less in term with overall efficiency rather flow characteristics.

When our variable-height fin design is compared to a traditional uniform-height design, the thermal performance of the variable design showed ~12–15% higher at the high heat loads (90–100°C), especially moderate flow (0.01 m³/s). This enhancement shows how analysis of heat flux distribution is valuable into heat sink design.

In the field, heat sink design is best optimized for air flow considerations to an extent that will allow the largest possible amount of heat transfer rate whilst not compromising fin efficiency levels. Thermal management benefits of fin geometrical optimization for the expected heat flux distribution noted in electronic cooling applications.

Limitations: This study was carried out under steady-state conditions and for a single fin material as well geometrical configuration. Hence the findings are not fully representative of the behavior transient heat loads and effects of other fin shapes, materials. The results can be extended to system-level efficiency and generalizability; thus, Dynamic thermal conditions should be subjected to future work with optimization on materials or composite fins.

Suggestion

Based on the temperature distribution observed on the cooling fins, heat buildup in the center of the fins can reduce the overall performance. Future designs should incorporate features that create flow turbulence and increase surface area to optimize heat transfer. In particular, modifications increase the area in areas of heat density. Use of variable fin spacing based on heat flux pattern In addition, advanced materials with higher thermal conductivity, such as graphene-reinforced composites or nanomaterials, are also being explored. It can significantly improve cooling efficiency in the future. Suggestions for future research include:

1. Investigation of more complex fin geometries, such as wavy fins or porous fins, to further enhance thermal efficiency.
2. Development of predictive models that incorporate heat flux distribution for optimized fin design.
3. Application of the research findings in industries such as electronics and automotive, where thermal management is critical.

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Electric generation from building waste water

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Abstract

Urban population growth and increasing building density have led to higher energy and water resource consumption, resulting in the generation of significant volumes of wastewater on a daily basis (Islam, 2023; Gray, 2004). Improper management of this wastewater can pose environmental and public health challenges (Gargari et al., 2023). This study investigates the potential for electricity generation and water reuse from wastewater in residential condominium buildings by applying the concept of a micro hydro turbine system (Tahir et al., 2020; Sinagra et al., 2022). The objective of this research is to convert the kinetic energy from wastewater flow into electrical energy and assess the potential for treated water reuse.

An estimation based on 202 residential condominium buildings shows that approximately 118 m³ of wastewater are produced daily, equivalent to 3,540 m³ per month (Khooprasert, Snidvongs, & Supahitanukul, 2025). This amount is sufficient for energy recovery and water reuse applications. By utilizing a micro hydro turbine coupled with a generator operating at an average efficiency of 70% and a water head of 3 meters, it is possible to generate approximately 0.67 kWh of electricity per day or 20.2 kWh per month (Tomczyk et al., 2025; Smith & Doe, 2023). Although the electricity generated is relatively small compared to the total building demand, it highlights the feasibility of converting wastewater into a usable energy source.

In terms of water management, the study found that up to 60% of the wastewater, approximately 2,124 cubic meters per month, can be treated and reused (Zhao et al., 2023). The reclaimed water is suitable for non-potable purposes such as irrigation, cleaning, and toilet flushing. This integrated approach contributes to sustainable resource management in urban environments and aligns with carbon reduction strategies (Gargari et al., 2023; Weerakoon & Assadi, 2023). This study indicates that, although the potential for electricity generation from wastewater is relatively low, when combined with water reuse strategies, the system can significantly reduce dependence on external resources and alleviate environmental burdens. Moreover, it aligns with the concept of sustainable development, particularly within the context of urban communities where space and resources are limited (Sarkar et al., 2023). Broad implementation of this approach could enhance energy efficiency and strengthen water resource security in the long term.

Keywords: carbon reduction, energy recovery, micro hydro turbine, urban sustainability, wastewater reuse.

Introduction

The growth of business and urban expansion in Thailand has continually led to an increase in building construction from the past to the present, and this trend is expected to persist in the future. According to the Bangkok Economic and Investment Information Center, building construction can be categorized into 14 types, including residential buildings, commercial buildings, office buildings, hotels, industrial plants, hospitals, educational institutions, as well as agricultural and transportation-related buildings. As of now, there are a total of 44,303 buildings that have been granted construction permits (Bangkok Economic and Investment Information Center, 2024).

Each building type integrates several essential engineering systems, such as electrical systems, fire alarm systems, air conditioning systems, elevator systems, telecommunications, wastewater treatment systems, and water supply systems. Among these, the wastewater treatment system is particularly important, as it is legally mandated in all residential buildings to prevent environmental impacts (Pollution Control Department, 2022).With advancements in engineering and technology, new approaches have been developed to enhance the efficiency of internal building systems. One such approach is the concept of sustainable resource reuse—specifically, generating electricity and reclaiming water from the building's wastewater treatment system. This method presents an opportunity to reduce environmental burdens and promote efficient resource utilization (United Nations Environment Programme [UNEP], 2020). Moreover, it can be used as a mechanism to claim carbon credits, a market-based tool for reducing greenhouse gas emissions, which can further benefit organizations financially and enhance their environmental responsibility (Intergovernmental Panel on Climate Change [IPCC], 2021).Therefore, this research focuses on the study of electricity generation and greywater reuse from wastewater within buildings. While many studies have examined energy production from wastewater and water reclamation at industrial or community scales (Nguyen et al., 2019; Zhang & Liu, 2020), there remains a lack of in-depth research that applies these technologies to high-density urban residential buildings, which are constrained by space and infrastructure—factors that differ significantly from large-scale systems. Furthermore, economic analysis and financial feasibility studies related to the installation of micro-hydro turbine systems in residential buildings are still lacking, as are systematic evaluations of environmental impacts and greenhouse gas reduction potential (Chen et al., 2021).

This research thus aims to explore the factors, challenges, and constraints involved while applying engineering principles to analyze and design systems that maximize sustainable energy and resource use within buildings. The study is based on data collection, literature review, relevant theories, and technical formulas as described below.

Hydroelectric Power Generation

Hydroelectric power generation is the process of converting the potential energy of water into mechanical energy using a water turbine, which is then converted into electrical energy through a generator. The fundamental principle is that when water flows from a higher elevation to a lower elevation, it creates pressure or inertia (hydraulic head), which can be used to rotate the turbine. The rotating shaft of the turbine, connected to a generator, produces electricity through this motion.

Key Factors Affecting Power Generation

Flow Rate (Q)

The volume of water passing through the turbine per unit of time, measured in cubic meters per second (m^3/s). The greater the flow, the higher the mechanical and electrical energy that can be generated.

Head (H)

This is the vertical distance between the water source and the nozzle of turbine, measured in meters (m). A higher head increases the potential energy and hence, the capacity to convert it into mechanical and electrical energ that can be generated

The approximate power produced can be calculated from the formula:

$$P = \eta \rho g Q H \quad (1)$$

Where

P	=	Power	Watts
η	=	System performance	value between 0 and 1
ρ	=	Water density	approx. 1000 kg/m^3
g	=	Earth gravity	9.81 m/s^2
Q	=	Water flowrRate	m^3/s
H	=	Water fall height	meters

Types of Water Turbines

The selection of a water turbine depends on the characteristics of the water source, head height, and flow rate, and can be classified as follows:

Pelton Turbine

Suitable for high-head and low-flow water sources. Commonly used in mountainous or high-pressure systems.

Francis Turbine

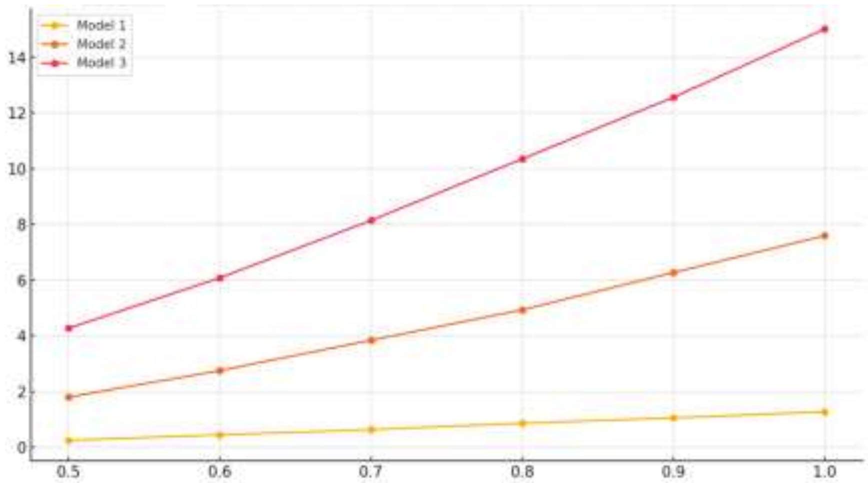
Designed for medium-head water sources. This radial-flow turbine is widely used in medium to large-scale hydroelectric dams.

Kaplan Turbine

Best suited for low-head, high-flow water sources. Often used in flat areas or fast-flowing rivers

Application in Urban Buildings and Communities

In urban settings, hydroelectric power can be applied to waste water or recycled water systems within buildings, leveraging water pressure and gravitational force in piping systems, such as water flowing from upper floors to lower levels. While the system is relatively small (Micro Hydro Power), it can provide energy for specific parts of the building, such as lighting, water pumps, or automated systems. When integrated with a waste water treatment and water reuse system, this approach significantly promotes sustainable resource management and carbon emission reduction. Furthermore, it holds strong potential for carbon credit eligibility, offering both environmental and economic advantages for sustainable building operations.



Comparison of Electrical Power Output from Three Types of Micro Hydro Turbines

According to the data presented in the above table, Model 3 (PELTOR Turbine) demonstrates the highest suitability for building installation.

Research Methodology

This study uses a quantitative methodology in combination with engineering system simulation and technical estimation. To assess the feasibility of generating electricity and reusing wastewater from buildings. It consists of the following steps:

1) Study documents and research related to energy production from wastewater and micro-hydro turbines.

2) Collect data on the building's wastewater system. Data was collected on water consumption and wastewater generated in 202 residential condominium buildings based on the average water consumption per person per day, as well as data from field surveys and reports on building water consumption.

3) Choosing a Micro Hydro Turbine (PELTOR Turbine) suitable for use with indoor waste water, considering the characteristics of uneven flow.

4) Analyze the amount of electricity produced by calculating the potential to produce energy from wastewater flows using the gravitational potential energy formula.

5) Summary of study results with suggestions for practical application.

Results

1) Data collection from the building's wastewater system

According to the data from the residential condominium project, there are a total of 202 units, divided into 2 types based on area size as follows:

- Residential units with an area of less than 35 square meters comprise 180 units with an average of 3 residents per unit.
- Residential apartments with an area of more than 35 square meters. Each resident has an average water consumption of 200 liters per person per day, based on data from the Metropolitan Waterworks Authority and the Pollution Control Department. , which can be calculated as follows:

$$\text{Total water consumption/day} = \frac{(180\ x\ 3\ x\ 200)}{1{,}000} + \frac{(22\ x\ 5\ x\ 200)}{1{,}000}$$

$$= 108 + 40$$

$$= 148 \quad m^3/\text{Day}$$

Then, the wastewater volume is estimated to be 80 percent of the water used, as follows:

$$\text{Total wastewater/day} = 0.8 \times 148$$

$$= 118 \quad m^3/\text{Day}$$

$$= 3{,}540 \quad m^3/\text{Month}$$

2)Results of the analysis of the potential to generate electricity from wastewater

Basic data from the project:

Total wastewater volume = 118 m^3/day,

Which is equivalent to 3,540 m^3/month or 3,540,000 liters per month.

A micro hydro turbine can be installed within the waste water treatment system or in the waste water pipeline to harness the energy from water flow, both potential energy and kinetic energy, for electricity generation at an altitude of 3 m (H).

From the energy equation, Equation 1, we define

System efficiency	η	=	0.7,
Water density	ρ	=	approx. 1000 kg/m³
Earth gravity	g	=	9.81 m/s²
Water flow rate	Q	=	0.0013657 m³/s
Height of the water drop	H	=	3 m (when installed in a vertical pipe or tank).

The energy is produced as follows:

$$P = \eta \rho g Q H$$
$$= 0.7 \times 1{,}000 \times 9.81 \times 0.0013657 \times 3$$
$$= 28.08 \text{ W}$$

Daily Electricity Power:

$$P = 673.92 \text{ Wh/day}$$
$$= 0.67 \text{ kWh/day}$$
$$= 20.2 \text{ kWh/month}$$

3) results of the water reuse potential analysis indicate that treated wastewater can be reused for purposes such as watering plants, washing floors, or flushing toilets. Secondary treatment systems can recover approximately 50–70% of the waste water entering the system. The water reuse rate is determined to be 60%.

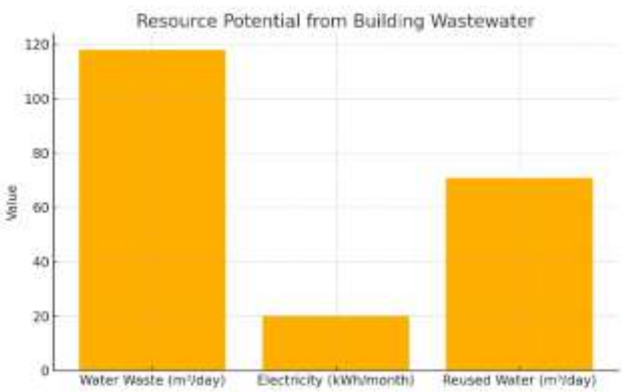
$$\text{Reusable water} = 118 \times 0.6$$
$$= 70.8 \text{ m}^3\text{/day}$$
$$= 2{,}124 \text{ m}^3\text{/month}$$

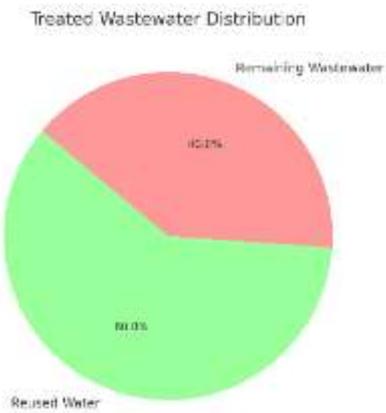
Based on the data collected and the analysis of the potential for electricity generation from water and water reuse, as summarized in Table 1.

Table 1 : Summary of Potential Assessment Results

Flow rate	118.00	m³/day		
Electric generation wastewater	0.67	kWh/day	20.20	kWh/month
Water reuse	70.80	m³/day	2,124 .00	m³/month

Discussion and conclusions





Based on a study of the potential for power generation and water recovery from waste water from 202 residential condominium buildings, which include apartments not exceeding 35 square meters, with 180 units (3 people/unit) and apartments larger than 35 sq.m., it was determined that the average water consumption rate is 200 liters per person per day. The total water consumption is 148 cubic meters per day, and the total volume of wastewater (80%) is 118 cubic meters per day, resulting in a monthly wastewater volume of 3,540 cubic meters or 3,540,000 liters. The system operates at a head of 3 meters and an efficiency of 70%, capable of generating approximately 0.67 kWh per day, or about 20.2 kWh per month. Additionally, an assessment of the potential for water reuse after secondary treatment indicated that around 60% of the wastewater volume could be reused, equivalent to 70.8 cubic meters per day. Although the potential for electricity generation from wastewater at the building level is relatively low compared to the overall electricity demand of the building, it demonstrates a promising trend for developing an auxiliary energy generation system in the form of secondary energy, particularly when integrated with the building's overall energy management system, such as solar PV or smart building systems.

In terms of water reuse, the amount obtained from waste water treatment is considered suitable for applications that are not directly related to consumption, such as watering plants, washing floors, or using in sanitation systems (toilet flush), which can significantly reduce tap water consumption.

The findings of this study suggest the potential for comprehensive indoor resource management. The emphasis is on reuse and waste-to-energy, aligning with the principles of sustainable development and the design of energy-efficient buildings in the future. This approach could also extend to green buildings or construction projects that require environmental certifications such as LEED or TREES.

Suggestion

Consider integrating waste water power generation systems with other energy sources, such as solar energy or energy storage systems, to enhance energy efficiency in buildings. Further cost-benefit analysis should be conducted to evaluate the system's payback period and long-term returns. A comparative study should be done on the potential of waste water power generation in various types of buildings, including office buildings, hotels, and hospitals, to assess the suitability for designing a range of small-scale power generation systems. The wastewater pipeline system should be designed to accommodate the installation of water turbines, such as using vertical pipes of appropriate height to create sufficient pressure head for power generation.

Acknowledgments

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Factors Contributing to Construction Project Delays in Local Administrative Organizations: A Case Study of Thung Hua Chang District

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Abstract

This study aimed to identify and analyze the factors contributing to construction project delays within local administrative organizations, with a specific focus on Thung Hua Chang District. Data were collected through structured questionnaires from 50 respondents, comprising public officials and local contractors directly involved in project execution. Six categories of delay factors were examined: personnel, financial management, machinery, materials and equipment, construction processes, and external conditions.

The results indicated that material and equipment constraints were the most significant contributors to delays, accounting for approximately 41% to 60% of the total impact. Key issues included remote construction sites, poor logistics for material transportation, machinery shortages, and equipment breakdowns. Personnel-related factors, such as misinterpretation of construction drawings and labor absenteeism, also played a considerable role. Additionally, administrative inefficiencies, including delayed procurement approvals and inadequate risk management, further prolonged project timelines. Although financial challenges were identified, their impact was moderate compared to material and equipment issues. The study emphasizes the urgent need for local administrative organizations to improve procurement and logistics management, streamline administrative processes, adopt comprehensive risk management frameworks, and enhance technical training for project personnel. Addressing these critical weaknesses is essential for enhancing the efficiency and timely delivery of public construction projects, particularly in rural areas.

Keywords: Construction Delays, Local Administrative Organizations, Rural Construction Projects, Project Management

Introduction

Construction project delays remain a significant challenge in public sector development, particularly within rural administrative organizations. Although previous studies have addressed delays in urban contexts, few have critically examined the specific challenges encountered by rural local administrative organizations (LAOs). This study focuses on Thung Hua Chang District to address this research gap.

The Decentralization Act B.E. 2542 (1999), amended in B.E. 2549 (2006), was intended to empower LAOs by transferring authority from the central government, enabling subdistrict municipalities and Subdistrict Administrative Organizations (SAOs) to manage public services autonomously. However, practical challenges such as limited human resources, inadequate planning, and frequent infrastructure delays persist, particularly in semi-urbanizing rural areas (Yossomsakdi & Kanitpong, 2023; Sittichok & Meesad, 2022).

These delays hinder service delivery and diminish residents' quality of life, as demands for improved roads, water systems, and utilities continue to rise (Charoensuk, Punsiri, & Saengchai, 2021). Key contributing factors include shortages of skilled personnel, planning misaligned with community needs, and weak coordination mechanisms (Homsombat & Sittiphol, 2023). Moreover, local governments often struggle to efficiently address increasing infrastructure needs, fueling public dissatisfaction (Inkhong, Rujivanarom, & Yodmongkol, 2022).

Accordingly, this study investigates the factors contributing to construction project delays in LAOs within Thung Hua Chang District and proposes strategies to enhance project management efficiency in alignment with local development contexts.

Literature Review

1. Summary of Related Studies on Factors Contributing to Construction Project Delays

Chansupa (2022) : Applied surveys and interviews grounded in public administration and resource-based theories to investigate local government delays. Identified limited resources, frequent design changes, and unclear contracts as key factors.

Kulsawat (2022) : Used case studies and interviews supported by risk management and supply chain theories to examine private sector delays. Concluded that ineffective management and procurement issues critically disrupted project schedules.

Chansuwan (2021) : Used structured questionnaires and statistical analysis based on project management theory to study public sector delays. Found that frequent design changes and material procurement issues were major causes.

Patamavipha (2021) : Conducted case studies using document review under construction management and project lifecycle theories. Highlighted poor project management and procurement delays as main contributors to overruns.

Songchai (2019) : Analyzed survey data using project planning and coordination theories to study local government projects. Found insufficient budgets and poor inter-agency coordination as dominant causes of delays.

Research Methodology

1. Research Objective

1) To analyze the causes of construction project delays in local administrative organizations in Thung Hua Chang District, Lamphun Province.

2) To propose solutions for addressing delays in construction projects undertaken by local administrative organizations in the study area.

2. Scope of the Study

2.1 Content Scope

This study focuses on analyzing the factors contributing to delays in construction projects managed by local administrative organizations (LAOs) in Thung Hua Chang District, Lamphun Province. The analysis encompasses six key dimensions: personnel, financial management, construction machinery, materials and equipment, construction methods, and other relevant factors. The study aims to prioritize these factors based on their impact and to propose practical solutions to reduce delays and improve the quality of local infrastructure development projects.

2.2 Population and Sample Scope

This research adopts a quantitative approach, utilizing questionnaires and interviews to collect data from individuals directly involved in construction projects within LAOs in Thung Hua Chang District. The sample is divided into two groups:

Group 1: Public sector representatives (40 participants), including local government officials, staff, and committee members engaged in project administration.

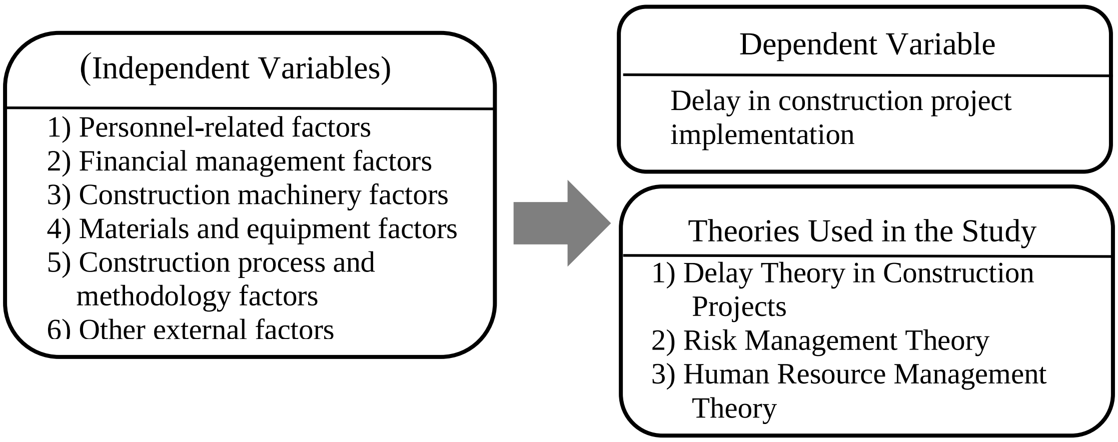
Group 2: Private sector representatives (10 participants), consisting of contractors and project executors operating in the local area.

The total sample consisted of 50 participants with direct experience in the planning and execution of local construction projects.

Data were collected through structured questionnaires and supplemented by interviews to gain deeper insights. The validity of the questionnaire was verified through expert evaluation by three specialists in construction management, while reliability was assessed using Cronbach's alpha, achieving a coefficient of 0.82, indicating a high level of internal consistency. Ethical considerations, including informed consent, participant confidentiality, and data protection, were strictly adhered to throughout the research process.

3. Conceptual Framework

In this study, which aims to analyze the causes of delays in construction projects implemented by local administrative organizations (LAOs) in Thung Hua Chang District, Lamphun Province, the variables are defined as follows:



4. Research Methodology Flowchart

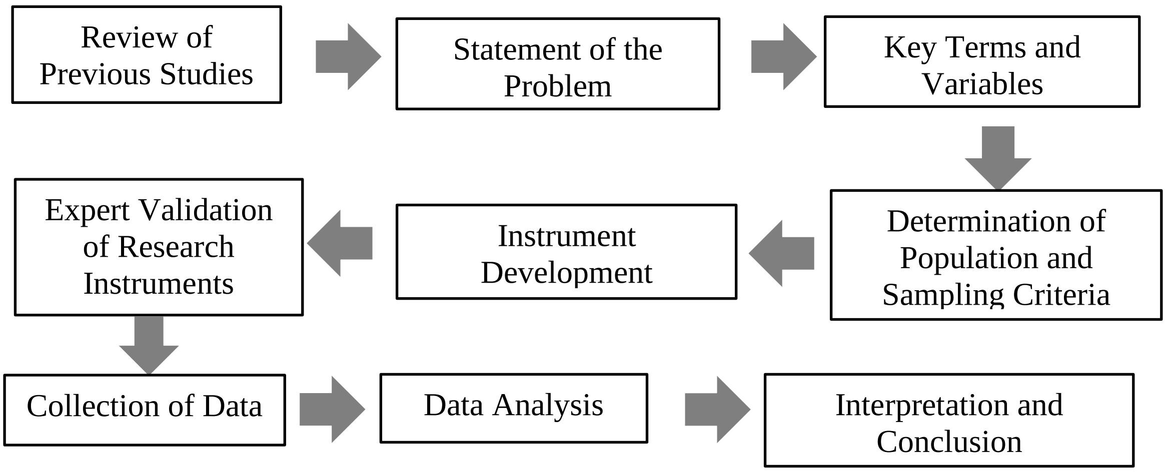


Figure 1 Flowchart of the Research Methodology Process

5. Data Analysis

The completed questionnaires were reviewed for accuracy, coded, and organized prior to analysis. Two main aspects were evaluated using a 5-point Likert scale:

5.1 Frequency of Delay Factors

Respondents rated how frequently each factor occurred in construction projects using the following scale:

1 = Very rarely or never occurs
2 = Rarely occurs (occasionally)
3 = Sometimes occurs (in some projects)
4 = Often occurs (in most projects)
5 = Always occurs (in all projects)

5.2 Impact Severity on Project Delays

Respondents assessed the extent to which each factor affected project timelines when it occurred:

1 = Very low impact (delay < 20%)
2 = Low impact (21%–40%)
3 = Moderate impact (41%–60%)
4 = High impact (61%–80%)
5 = Very high impact (delay > 80%)

Descriptive statistics, including mean and standard deviation, were used to interpret the data and identify the most influential delay factors.

6. Statistical Methods Used for Data Analysis

This study employed descriptive statistics to analyze the collected data. The primary statistical measures used were the mean and standard deviation, calculated as follows:

Mean (Arithmetic Average) (Adisak Sammo, 2008)

$$\bar{x} = \frac{\sum x}{N} \qquad (1)$$

Where: $\bar{x}$ = arithmetic mean of the sample
$\sum x$ = sum of all data values
N = total number of data points in the sample

Standard Deviation (Boonchom Srisasard, 2002)

$$S = \sqrt{\frac{\sum x^2}{N} - \bar{x}^2} \qquad (2)$$

Where: S = standard deviation of the sample
$\bar{x}$ = mean score of the sample
$\sum x^2$ = sum of the squared scores
N = number of observations

These statistical tools were used to describe the central tendency and variability of the responses, allowing the identification of the most significant delay factors in local construction projects.

Result

1. Analysis of Construction Delay Factors

Figure 2 illustrates the mean scores of six key factor groups contributing to delays in LAO construction projects in Thung Hua Chang District:

(a) Personnel-Related Factors:

Misinterpretation of construction drawings ($\bar{x}$ = 2.82) and misunderstanding of design details ($\bar{x}$ = 2.68) emerged as key personnel issues. These results reflect limited technical skills and insufficient experience among site workers, supporting the findings of Somboonsuk et al. (2021) that untrained personnel are a persistent cause of delays in small-scale public projects.

(b) Financial Factors:

Delayed payment disbursement and unrealistically low labor wages (both $\bar{x}$ = 2.72) were the most prominent financial issues. These factors create cash flow problems and lower workforce motivation, aligning with Sittichok and Meesad (2022), who identified financial constraints as a major challenge for local government construction management.

(c) Equipment-Related Factors:

Shortages of machinery components ($\bar{x}$ = 2.76) and inability to operate during holidays ($\bar{x}$ = 2.64) indicated poor contingency planning and overreliance on external equipment rental, consistent with Inkhong et al. (2022).

(d) Material Factors:

Remote construction sites ($\bar{x}$ = 2.98) and inaccessibility for large trucks ($\bar{x}$ = 2.80) were the leading issues, highlighting logistical challenges typical of rural projects. These findings are consistent with Wiboonrat and Pochai (2022), who reported that difficult terrain significantly delays material delivery.

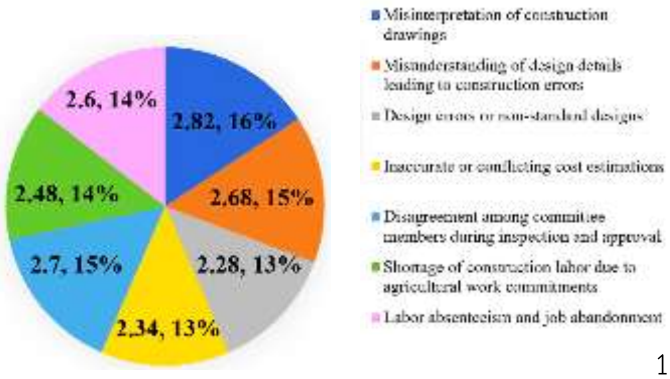
(e) Procedural (Construction Method) Factors:

Inadequate labor and machinery planning ($\bar{x}$ = 2.74) and poor coordination strategies ($\bar{x}$ = 2.56) reflect weaknesses in early-stage project planning and highlight the need for adopting standardized management procedures, as noted by Yossomsakdi and Kanitpong (2023).

(f) Other External Factors:

Natural disasters ($\bar{x}$ = 2.70) and delayed site handovers ($\bar{x}$ = 2.62) were major uncontrollable causes of delays, underscoring the importance of environmental risk management and inter-agency coordination, consistent with Homsombat and Sittiphol (2023).

Overall, material, financial, and planning deficiencies are the most critical delay factors, underscoring the need for improved resource planning, skill development, and integrated project management.



(a)

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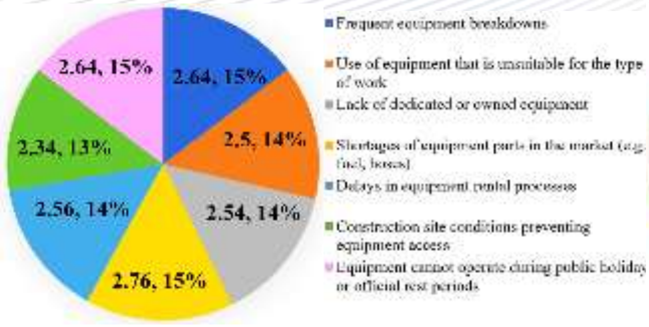

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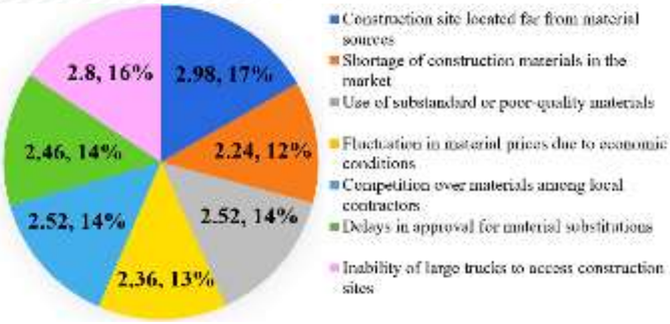

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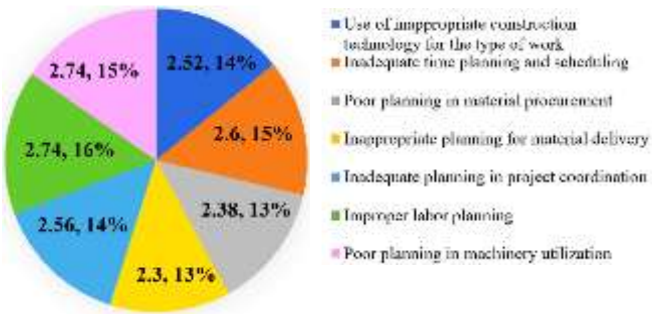

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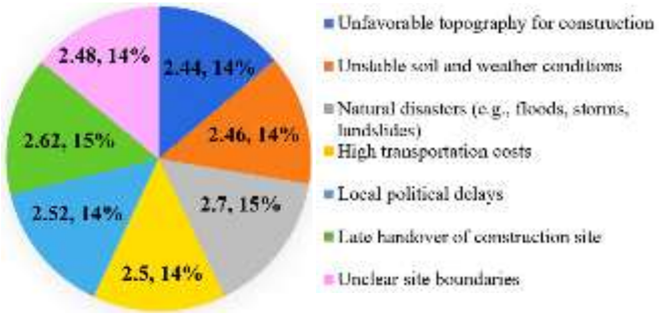

(f)

Figure 2 Mean Scores of Key Factors Contributing to Construction Delays in Local Government Projects

- Mean of Personnel-Related Factors
- Mean of Financial Factors Affecting Delays in Local Government Projects
- Mean of Equipment-Related Factors Affecting Construction Delays
- Mean of Construction Material Issues and Their Impact on Delays
- Mean of Procedural (Construction Method) Factors Influencing Delays
- Mean of Other External Delay Factors in Construction Projects

Table 1 Impact Severity of Personnel-Related Factors on Construction Delays

Personnel-Related Factors	Mean ($\bar{x}$)	Severity Level (Impact Range)
Misinterpretation of construction drawings	2	21 % -40 %
Misunderstanding of construction plans, leading to design errors	2	21 % -40 %
Design errors or non-standard designs	3	41% - 60%
Inaccurate or conflicting cost estimations	2	21 % -40 %
Disagreements among committee members during inspections	3	41% - 60%
Shortage of labor due to agricultural work	2	21 % -40 %
Labor absenteeism and abandonment	3	41% - 60%
Overall Mean	3	41% - 60%

Table 1 shows that personnel-related factors moderately influenced delays in local government construction projects, with a mean score of 3.00 and an estimated severity of 41%–60%. Key issues included non-standard design errors, committee disagreements during inspections, and labor absenteeism, reflecting weaknesses in site coordination and supervision. Lower-impact factors included misinterpretation of drawings and inaccurate cost estimations. These findings align with Wiboonrat and Pochai (2022), who highlighted poor project management and labor discipline as major delay factors in small-scale public sector projects.

Table 2 Impact Severity of Financial Factors on Construction Delays

Financial Factors	Mean ($\bar{x}$)	Severity Level (Impact Range)
Lack of internal financial liquidity within the contractor's company	2	21 % -40 %
Delayed payments according to project progress	2	21 % -40 %
Unrealistically low construction cost estimates	2	21 % -40 %
Excessively low labor wages, resulting in lack of motivation among workers	2	21 % -40 %
Contractor's use of funds deviating from planned allocation or misappropriation	2	21 % -40 %
Delays in disbursement approvals from funding agencies	3	41% - 60%
Price competition in contractor bidding	3	41% - 60%
Overall Mean	2	21 % -40 %

Table 2 shows that financial factors had a low to moderate impact on construction delays, with an overall mean score of 2.00 and an impact range of 21%–40%. Delays in disbursement approvals and price competition in bidding were the most significant issues (mean 3.00, 41%–60% impact). While most financial constraints had limited effects individually, systemic issues like slow fund approvals and aggressive bidding posed greater risks. These findings are consistent with Charoensuk, Punsiri, and Saengchai (2021).

Table 3 Impact Severity of Factors Related to Construction Machinery on Project Delays

Factors Related to Construction Machinery	Mean ($\bar{x}$)	Severity Level (Impact Range)
Frequent machine breakdowns	3	41% - 60%
Inappropriate machine selection for the type of work	3	41% - 60%
Lack of dedicated machinery owned by the unit	3	41% - 60%
Shortage of machine parts in the market (e.g., gears, belts)	2	21 % -40 %
Delays due to waiting for machine rental	3	41% - 60%
Construction site conditions prevent access for heavy machinery	2	21 % -40 %
Machinery operation limited during public rest periods	3	41% - 60%
Overall Mean	3	41% - 60%

Table 3 shows that machinery-related factors moderately to highly contributed to delays (mean = 3.00, 41%–60%). Frequent breakdowns, inappropriate equipment selection, and lack of dedicated machinery were key issues (Bank of Ayudhya, 2024; Rojanasak, 2021), while spare part shortages and limited site access had lower impacts. These results emphasize the need for better machinery planning, especially in resource-constrained public projects.

Table 4 Impact of Material-Related Factors on Project Delays

Factors Related to Construction Materials	Mean ($\bar{x}$)	Severity Level (Impact Range)
Construction site located far from material sources	3	41% - 60%
Material shortages in the market	2	21 % -40 %
Use of low-quality materials	3	41% - 60%
Volatile material prices due to economic conditions	2	21 % -40 %
Competition for materials among local contractors	3	41% - 60%
Delays in approval for material substitutions	3	41% - 60%
Inaccessibility of large delivery trucks to construction site	3	41% - 60%
Overall Mean	3	41% - 60%

Table 4 shows that material-related factors moderately impacted delays (mean = 3.00, 41%–60%). Major issues included remote site locations, low-quality materials, competition, delayed substitution approvals, and limited delivery access, highlighting logistical and procedural constraints. Market shortages and price fluctuations had lower impacts. These findings align with Rojanasak (2021), emphasizing the need for better procurement planning and faster approvals.

Table 5 Impact of Construction Process Factors on Delays

Factors Related to Construction Procedures	Mean ($\bar{x}$)	Severity Level (Impact Range)
Implementation of construction technology unsuitable for the type of work	2	21 % -40 %
Inappropriate work scheduling	2	21 % -40 %
Planning errors in material procurement	3	41% - 60%
Use of inappropriate materials in planning	3	41% - 60%
Poor coordination planning for project execution	3	41% - 60%
Inadequate labor planning	2	21 % -40 %
Errors in machinery usage planning	2	21 % -40 %
Overall Mean	3	41% - 60%

Table 5 shows that construction process factors moderately impacted delays (mean = 3.00, 41%–60%). Major issues were material procurement errors, inappropriate material selection, and poor coordination. In contrast, labor planning, technology use, and scheduling problems had lower impacts (mean = 2.00). These findings support Rojanasak (2021), highlighting the importance of early procurement and coordination planning.

Table 6 Impact of External Conditions on Project Delays

Other External Factors in Construction Work	Mean ($\bar{x}$)	Severity Level (Impact Range)
Inappropriate geographical conditions for construction	3	41% - 60%
Unfavorable weather conditions	3	41% - 60%
Natural disasters (e.g., floods, storms)	2	21 % -40 %
High cost or shortage of construction materials	3	41% - 60%
Delays related to local government bureaucracy	3	41% - 60%
Delay in land transfer procedures	3	41% - 60%
Unclear project site boundaries	2	21 % -40 %
Overall Mean	3	41% - 60%

Discussion and conclusions

1) The analysis identified six primary categories of factors contributing to project delays: personnel, financial management, construction machinery, materials, construction processes, and external conditions. Key causes include inaccessible construction sites, labor absenteeism, poor coordination in planning, and delays in fund disbursement. Among these, material logistics and equipment availability showed the highest impact on delays (mean score = 3.00), followed closely by procedural and personnel-related issues. These delays not only extended project timelines but also impacted public service delivery, particularly in rural and semi-urban communities. These findings underscore the need for improved resource management and integrated project planning.

2) The study proposes actionable strategies such as streamlining procurement systems, improving financial disbursement processes, and implementing structured risk management frameworks to address delays caused by external uncertainties. Additionally, it emphasizes the importance of enhancing technical capacity through staff training and early-stage planning improvements. These measures aim to increase operational efficiency and ensure more reliable, timely execution of public infrastructure projects in the local context.

This study concludes that addressing material procurement, labor management, and administrative efficiency are crucial to minimizing construction project delays in rural administrative organizations. However, the study was limited by its focus on a single district and reliance on self-reported data. Future research should expand to multiple districts and incorporate inferential statistical testing to validate findings.

Suggestion

1. Streamline procurement and establish reliable supply chains to prevent material delays.
2. Revise disbursement procedures to reduce bureaucratic obstacles.
3. Apply risk management frameworks to prepare for weather, location, and regulatory issues.

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Enhancing Daily Inflow Forecasting for Pasak Jolasid Reservoir Using LSTM-Based Recurrent Neural Networks

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Abstract

Accurate daily inflow forecasting is critical yet challenging due to complex rainfall patterns and unpredictable weather shifts. This research aims to improve daily inflow forecasting for the Pasak Jolasid reservoir using Long Short-Term Memory (LSTM) networks, a specialized form of Recurrent Neural Networks (RNNs). The novelty lies in leveraging the LSTM's unique ability to capture long-term temporal dependencies and nonlinear relationships in sequential hydrological data, which traditional methods struggle to model effectively. Daily inflow predictions are especially vital when the reservoir's water level nears full capacity, as precise forecasts can prevent overflows and ensure safety. In contrast to traditional methods, the LSTM excels at understanding data patterns over extended periods. It relies on a unique mechanism with three components, known as input, forget, and output controls, that manage which details to retain or ignore, ensuring it captures essential historical trends effectively. The model was trained and tested using data from 2014 to 2023 within a TensorFlow framework, incorporating variables such as rainfall and runoff measurements from monitoring stations scattered across the Pasak River Basin, direct inflow records for the Pasak Jolasid reservoir, precipitation patterns, discharge rates, and historical inflow statistics. The model demonstrates high accuracy during the testing period, achieving forecast accuracies of 95%, 92%, 87%, and 81% for 1-day, 2-day, 3-day, and 4-day ahead predictions respectively, outperforming simpler approaches. This precision stems from its ability to link rainfall events to reservoir inflows, with the model using forecast results from today as input for tomorrow and continuing iteratively. The choice to use LSTM is suitable when rich sequential data with temporal trends is available, intricate nonlinear relationships influence inflows, ample high-quality data supports training, short- to medium-term predictions are targeted, computational resources are sufficient, and high accuracy is essential, aligning with this study's use of extensive 2014-2023 data and focus on safety-critical forecasts. Such accuracy enhances operational water management, supporting better flood prevention and smarter water allocation decisions. This principle can be extended to forecast weekly reservoir inflows, aiding in the planning and allocation of water from the reservoir for various water usage activities.

Key words: Reservoir Inflow Forecasting, Flood Prevention, Pasak Jolasid Reservoir.

Introduction

Accurate daily inflow forecasting is crucial for effective reservoir management, particularly in mitigating flood risks and optimizing water allocation. The Pasak Jolasid reservoir, a key water resource in Thailand's Pasak River Basin, experiences significant seasonal inflow fluctuations, with approximately 80% of its annual inflow occurring between August and October—far exceeding its storage capacity of 960 million cubic meters.

Unreliable predictions, especially during peak monsoon periods, pose risks of overflows and inefficient water distribution. Traditional forecasting methods, such as statistical models and hydrological simulations, often struggle to capture the nonlinear relationships between rainfall, runoff, and reservoir inflows due to short-term weather uncertainties, land-use changes, and time-lagged effects.

This study explores the application of Long Short-Term Memory (LSTM) networks, a specialized form of Recurrent Neural Networks (RNNs), to enhance inflow predictions for the Pasak Jolasid reservoir. LSTM networks excel at recognizing long-term dependencies in time-series data, making them well-suited for capturing complex hydrological patterns. Using a 10-year dataset (2014–2023), this research employs LSTM models within a TensorFlow framework to analyse rainfall statistics, discharge measurements, and historical inflow records. By leveraging back-propagation techniques and adaptive pattern recognition, the model aims to improve forecast accuracy, supporting flood prevention efforts and efficient reservoir operation planning.

Pasak Jolasid Reservoir

The Pasak Jolasid Reservoir, spanning 14,520 square kilometres. Initiated by His Majesty King Bhumibol Adulyadej to mitigate flooding in both the Pasak River Basin and the Chao Phraya River Basin, the dam is strategically located across the Pasak River in Nong Bua Sub-district, Phatthana Nikom District, Lopburi Province shown in **Figure 1**. Construction of this clay-core earthfill dam began on December 2, 1994, and concluded on September 30, 1999, under the Royal Irrigation Department’s oversight. The dam stands 31.50 meters high, stretches 4,860 meters long, and has a crest elevation of 46.50 meters above mean sea level (MSL). The reservoir it forms holds 960 million cubic meters, while the basin delivers an average annual inflow of 2,300 million cubic meters, primarily from the upstream regions in Phetchabun and Lopburi provinces.

Over last 10 years of daily water volume data **(Figure 2)**, the reservoir reached full capacity in 5 years, or 50% of the time, with inflows peaking from August to October. This period, driven by monsoon rains across the Pasak River Basin, demands precise daily inflow forecasting for effective management. **Figure 3** highlights a peak inflow in late September 2021, triggered by Tropical Storm Dianmu, which drenched the basin’s upper reaches. The resulting surge filled the reservoir to its 960 million cubic meter limit, forcing the Royal Irrigation Department to increase discharge to 1,200 cubic meters per second in early October 2021 to ensure stability and manage excess water from the basin.

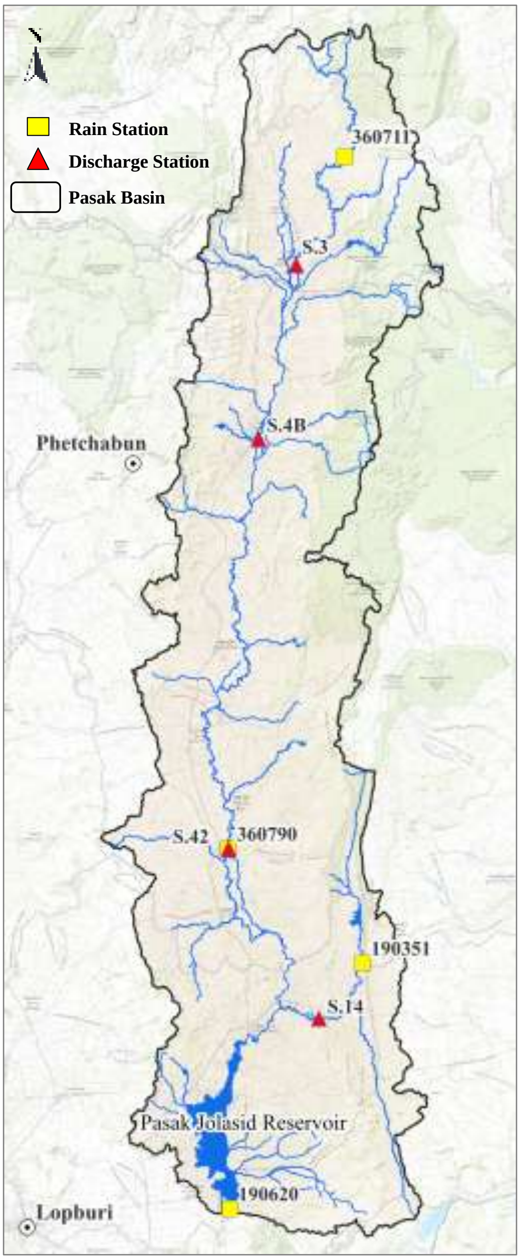

Figure 1 Map of the Pasak Jolasid Dam Watershed Area
Created by the author.

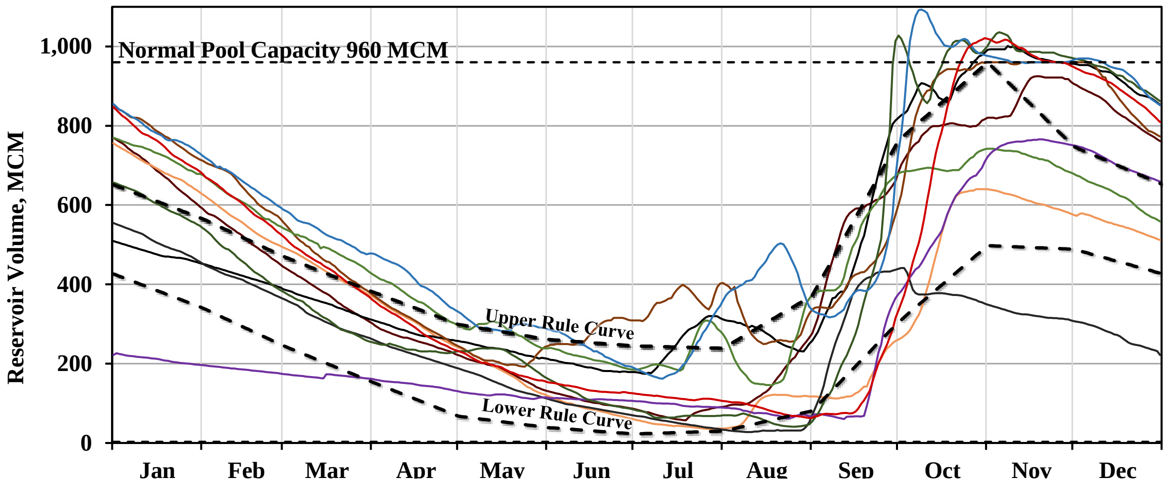

Figure 2 Daily Water Volume in the Pasak Jolasid Reservoir Over a 10-Year Period

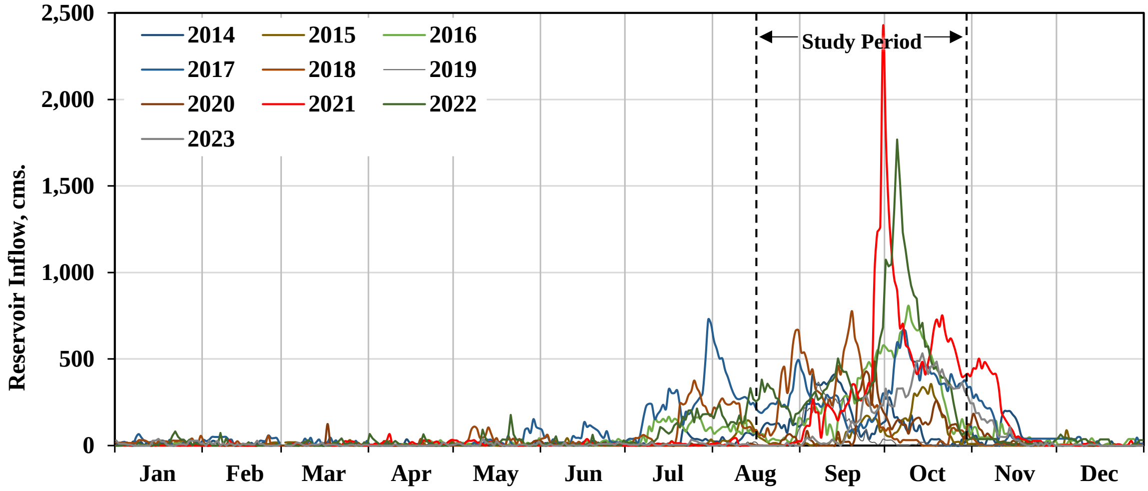

Figure 3 Daily Water Inflow into Pasak Jolasid Reservoir Over a 10-Year Period

Concept of Forecasting Water Flow into the Reservoir

Accurate forecasting of water flow into a reservoir is essential for effective operation, particularly when water levels approach critical thresholds. Predicting inflows enables pre-emptive decision-making for dam releases, flood risk mitigation, irrigation scheduling, and water allocation. This process requires integrating multiple hydrological and meteorological variables, including upstream rainfall, runoff coefficients from sub-basins, historical inflow records, and real-time discharge rates. However, forecasting remains challenging due to the nonlinear and unpredictable nature of weather events, land-use changes, and time-lagged hydrological responses.

Traditional forecasting methods, such as ARIMA, SARIMA, and hydrological models like HEC-HMS, have limitations in capturing long-range dependencies and handling missing data spikes. Long Short-Term Memory (LSTM) networks, a specialized form of Recurrent Neural Networks (RNNs), offer a powerful alternative by learning from sequential data while selectively retaining or forgetting historical patterns. LSTM models can adapt to changing inflow conditions, capturing temporal relationships over different forecast horizons:

- 1–3 days: Supports flood warnings by handling sudden data fluctuations.
- 4–7 days: Assists water allocation planning by recognizing extended dependencies.
- 8+ days: Aids in climate planning by identifying nonlinear climate-inflow relationships.

This study focuses on leveraging LSTM networks to enhance inflow forecasting for the Pasak Jolasid reservoir, particularly during the monsoon season when sudden inflow surges pose risks of overflow. By continuously adjusting predictions with real-time data, LSTMs improve the reliability of forecasts, ensuring optimized reservoir management and sustainable water resource utilization.

Theories and Principles

Long Short-Term Memory (LSTM) networks, a specialized form of Recurrent Neural Networks (RNNs), provide a robust framework for time-series forecasting by addressing the vanishing gradient problem that limits traditional RNNs. Unlike standard neural networks, LSTMs incorporate a memory cell and three gating mechanisms that regulate the flow of information across time steps:

- Forget Gate (F_t): Determines which historical information should be retained or discarded.
- Input Gate (I_t): Filters relevant new data to update the memory cell.
- Output Gate (O_t): Controls what information is passed forward for prediction.

These mechanisms allow LSTM to capture long-term dependencies and dynamically adjust forecasts based on new data. This is particularly advantageous for hydrological applications, where upstream rainfall may take days to influence reservoir inflows due to factors such as soil saturation, runoff rates, and river travel time.

In the context of reservoir inflow forecasting, LSTM excel at modeling nonlinear relationships between meteorological inputs (e.g., rainfall) and inflows. By training on an extensive dataset (2014–2023), the model learns these delayed hydrological responses, making it well-suited for short to medium-term forecasting. Compared to traditional methods like autoregressive models or basic regression, LSTM better account for temporal complexities, enabling improved predictions for flood prevention, water allocation, and reservoir operation planning.

The LSTM framework is defined in term of mathematically as follows:

$$I_t = \sigma(X_t W_{xi} + H_{t-1} W_{hi} + b_i)$$
$$Fi = \sigma(X_t W_{xf} + H_{t-1} W_{hf} + b_f)$$
$$Ot = \sigma(X_t W_{xo} + H_{t-1} W_{ho} + b_o)$$
$$\tilde{C}t = \tanh(X_t W_{xc} + H_{t-1} W_{hc} + b_c)$$
$$C_t = F_t \odot C_t\text{-}1 + I_t \odot \tilde{C}_t$$
$$H_t = O_t \odot \tanh(C_t)$$

where X_t represents the input (e.g., rainfall, past inflow), H_t represents the hidden state passed forward and ⊙ represents elementwise multiplication. This architecture enables LSTMs to effectively model the delayed impact of rainfall events, which is particularly critical in basins with 2–3 day concentration times.

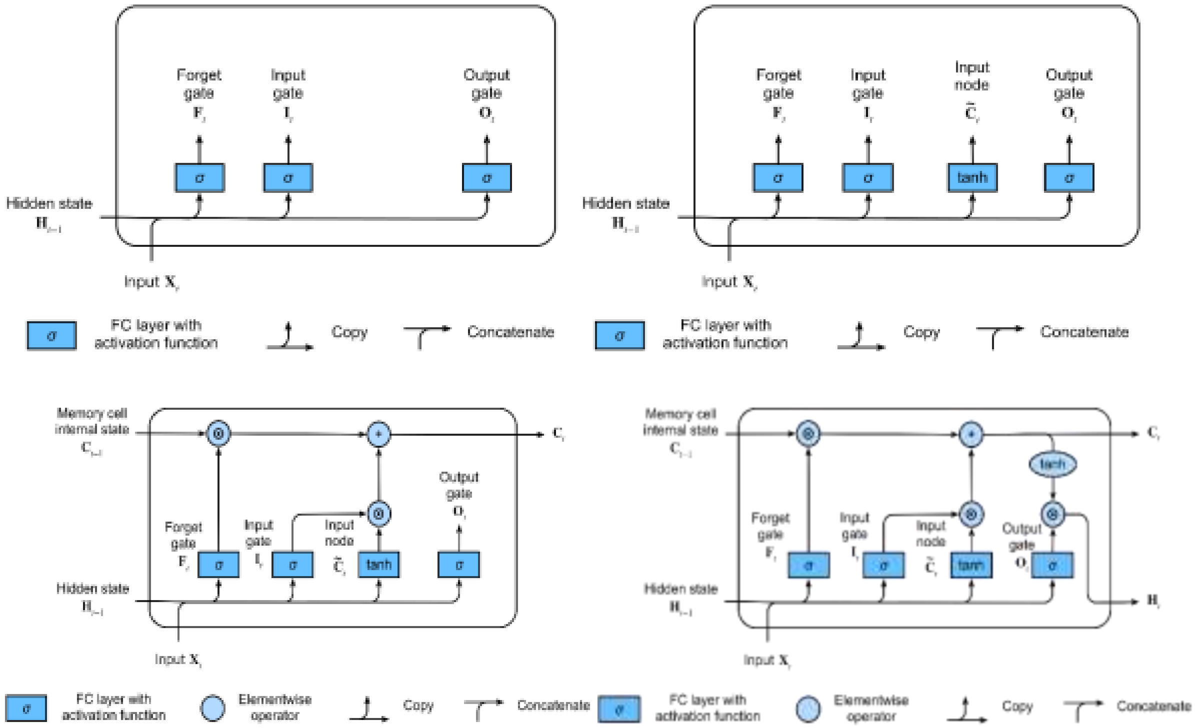

Figure 4 LSTM architecture with gates

Research Methodology

This study employs Long Short-Term Memory (LSTM) networks, an advanced form of Recurrent Neural Networks (RNNs), to forecast daily water inflows into the Pasak Jolasid Reservoir. LSTMs address the vanishing gradient problem of traditional RNNs by introducing a cell state and three gates (input, forget, and output) to regulate information flow. The model is developed in TensorFlow and configured to predict reservoir inflows over a 3-day to 4-day horizon.

Data pre-processing included:

- **Scaling data**: Min-max scaling (rainfall: 0–140 mm/day, inflows: 0–2,422 cms.)
- **Missing Data Handling**: Linear interpolation and normal ratio for imputation.
- **Sequence Formatting**: A 7-day sliding window approach to capture temporal dependencies.

Data Collection and Pre-processing

A 10-year dataset (2014–2023) was compiled, incorporating:

- **Rainfall Records**: Daily precipitation data from 4 stations in the Pasak River Basin.
- **Runoff Measurements**: Surface water flow estimates from 4 upstream gauge stations (S.3, S.4B, S.42, S.14).
- **Reservoir Inflows**: Daily inflow records.

Steps for Running the LSTM Model for Reservoir Inflow Prediction

The process of predicting reservoir inflow using a Long Short-Term Memory (LSTM) model involves a sequence of data preparation and model training steps. The overall workflow is illustrated in **Figure 5**, which shows the complete flowchart of the reservoir inflow prediction process.

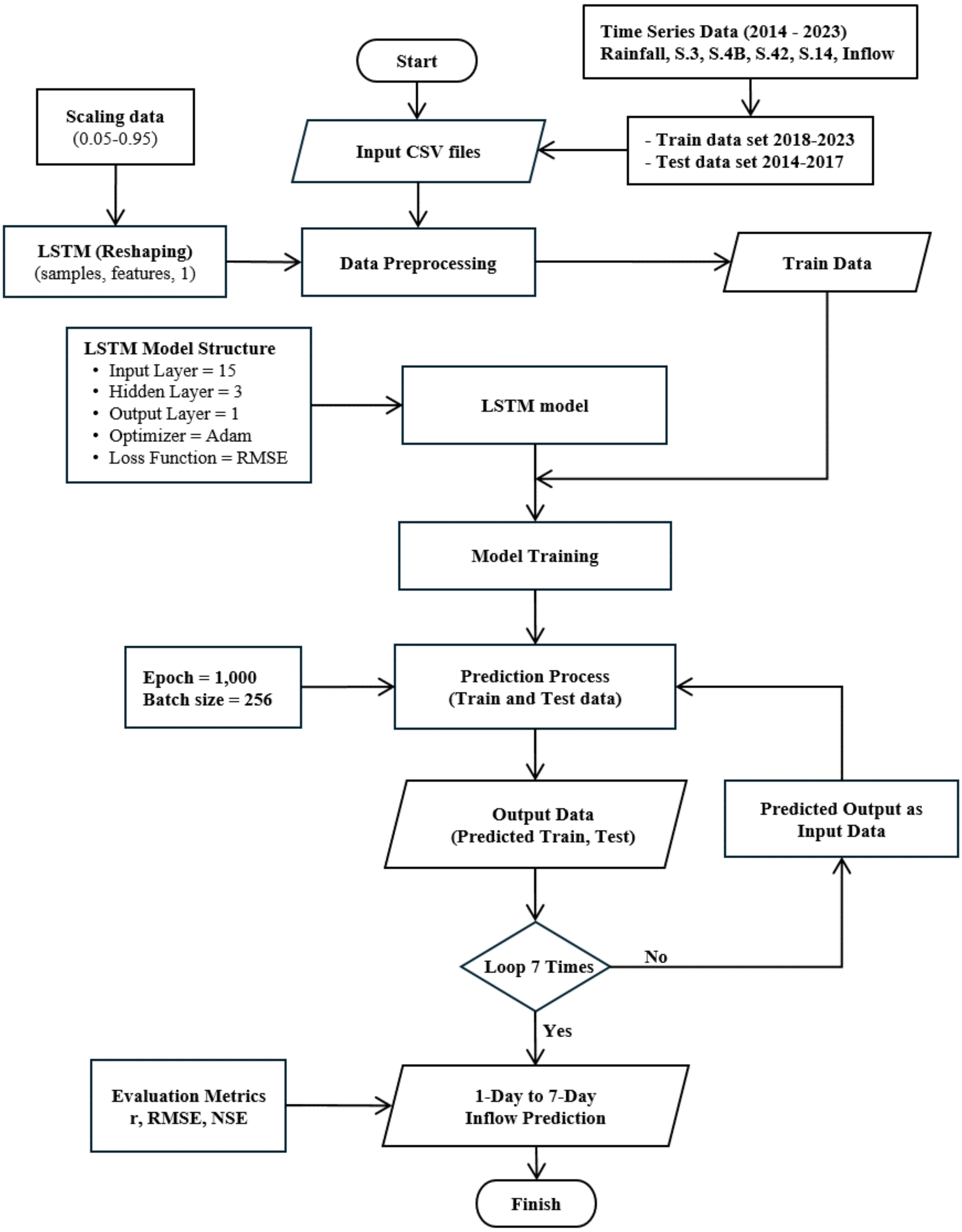

Figure 5 Flowchart of LSTM-Based Reservoir Inflow Prediction Process

Steps for Running the LSTM Model for Reservoir Inflow Prediction

This methodology effectively models rainfall-runoff relationships using LSTM's ability to capture long-term dependencies, providing higher forecasting accuracy for improved reservoir management.

1. Import the Input File (CSV)
   - Dataset includes areal rainfall from 4 rainfall stations (Rainfall), streamflow (S.3, S.4B, S.42, S.14), and reservoir inflow (Inflow) (2014–2023).
   - Data split: Training (2018–2023), Testing (2014–2017).
2. Prepare Data for Training
   - Scale data (0.05–0.95) and reshape it into a 3D format (samples, features, 1) for sequential modeling.
   - Samples: Total data points, Features: Input variables, 1: Captures time-series dependencies.
3. Define the LSTM Model
   - Layers: Input (15 features), Hidden (3 memory units), Output (1 prediction).
   - Optimizer: Adam; Loss function: RMSE (measuring prediction error).
4. Train and Make Predictions
   - Train model with Epochs = 1000, Batch size = 256.
   - Predict reservoir inflow for both training and test datasets (Train Predict, Test Predict).
5. Use Predictions for Next-Day Forecasting
6. Evaluate Model Performance
   - Compute r (correlation coefficient), RMSE, NSE.
   - Generate comparison graphs of actual vs. predicted inflows.

Results

The LSTM model for water inflow prediction at Pasak Jolasid Reservoir demonstrates strong performance, as shown in **Table 1**. The training and testing results for 1-day, 2-day, 3-day, and 4-day forecasts, along with the RMSE vs. Epoch plot in **Figure 6**, illustrate a gradual decline in accuracy as the forecast horizon extends. Despite this, the 4-day prediction remains reliable, meeting the acceptability threshold (NSE ≥ 0.8) during testing. Below is a detailed analysis.

Table 1 Model Efficiency for Training and Testing Period of Daily Prediction

Reservoir Inflow Forecasting	Training Period			Testing Period		
	r	RMSE	NSE	r	RMSE	NSE
1 Day	0.98	25.46	0.96	0.97	36.92	0.95
2 Day	0.97	43.32	0.94	0.96	36.10	0.92
3 Day	0.96	47.51	0.92	0.95	46.44	0.87
4 Day	0.94	66.17	0.85	0.92	54.35	0.81
5 Day	0.92	66.62	0.83	0.90	55.03	0.79
6 Day	0.88	80.03	0.78	0.88	65.39	0.73
7 Day	0.87	85.93	0.75	0.86	68.54	0.71

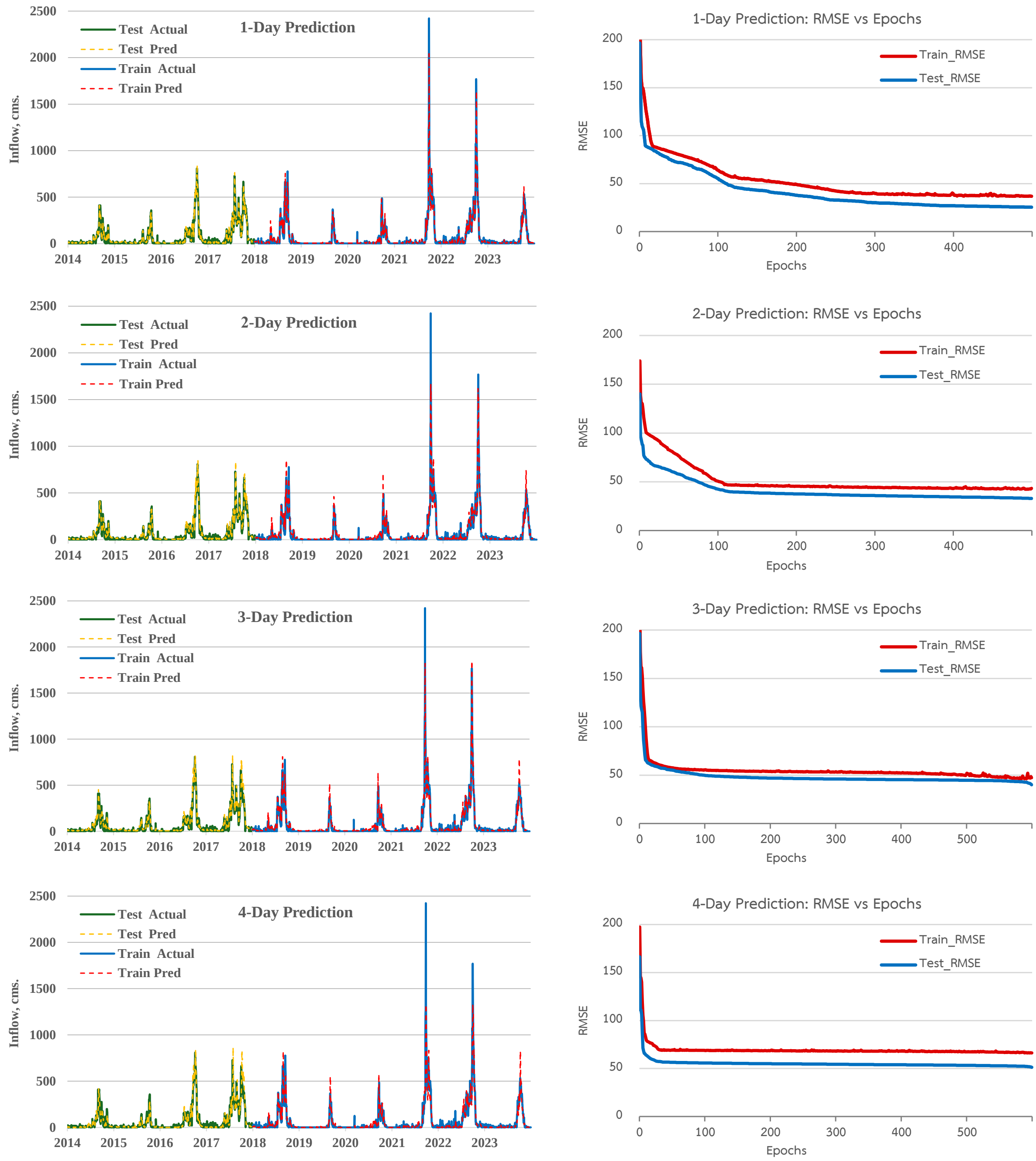

Figure 6 Training and Testing Result for 1-Day, 2-Day, 3-Day and 4-Day Prediction and RMSE vs. Epoch

Model Performance Overview

The Long Short-Term Memory (LSTM) network demonstrates strong correlation (r) and Nash-Sutcliffe Efficiency (NSE) across 1–7 day forecasts, though accuracy declines with increasing lead times. The 4-day prediction remains reliable, with a testing NSE = 0.81, meeting the acceptability criterion.

Key performance metrics for the 4-day prediction indicate strong predictive capability, with a training correlation coefficient (r) of 0.94, root mean square error (RMSE) of 66.17, and NSE of 0.85. During testing, the model maintains a high correlation (r = 0.92), while the RMSE increases slightly to 54.35, and NSE remains at 0.81. The 5-day forecast sees a drop in NSE below 0.8, making the 4-day horizon the longest practical forecast for operational planning.

A notable strength of the model is its high NSE values (≥0.8) for forecasts up to 4 days, ensuring practical utility for short-term reservoir operations. However, beyond 4 days, NSE drops below 0.8, highlighting increasing uncertainty in long-range forecasts. The 1-day forecast achieves the highest accuracy (NSE = 0.96, RMSE = 36.92 in testing), while the 7-day forecast shows a significant decline (NSE = 0.71, RMSE = 68.54 in testing).

These results confirm that the LSTM model is well-suited for 4-day inflow predictions at Pasak Jolasid Reservoir, though caution is advised for forecasts beyond this period. Further refinements or hybrid modeling approaches may improve long-term accuracy.

Discussion and Conclusions

The findings of this study confirm the potential of Long Short-Term Memory (LSTM) neural networks as an effective tool for short-term inflow forecasting at the Pasak Jolasid Reservoir. The model achieved a high Pearson correlation coefficient (r = 0.92) and a Nash-Sutcliffe Efficiency (NSE) exceeding 0.8 for up to four days in advance, meeting the reliability standards commonly accepted in hydrological modeling literature. These results suggest that LSTM networks can capture the nonlinear, dynamic interactions among rainfall, runoff, and inflow more effectively than traditional statistical approaches such as autoregressive integrated moving average (ARIMA) or multiple linear regression (MLR), which often assume linearity and stationarity. The model's high predictive skill over a four-day horizon provides a practically useful window for reservoir operations, particularly in flood-sensitive periods. However, the forecast performance diminishes beyond this range. This is a well-documented limitation of data-driven models, where forecast uncertainty increases over time due to cumulative prediction errors and the absence of external forecast inputs.

The success of the LSTM model aligns with prior studies that have demonstrated the strengths of deep learning methods in hydrology. The LSTM's internal architecture, which includes input, output, and forget gates, enables it to learn long-term dependencies and retain important temporal information. This capability is essential for modeling delayed hydrological responses caused by spatial variability in rainfall and antecedent soil moisture conditions. Furthermore, the study underscores the importance of model generalization. The lower root mean square error (RMSE) during testing compared to training indicates that the model effectively avoided overfitting, which is a critical challenge in machine learning. This generalization ensures robustness in real-time inflow forecasting and supports adaptive water resource management principles that prioritize responsiveness and resilience under variable environmental conditions.

In conclusion, this research contributes to the growing body of evidence that LSTM networks are highly suitable for reservoir inflow forecasting, particularly when high-quality historical datasets are available. Their use can improve flood prevention, enhance operational decision-making, and optimize water allocation. From a theoretical standpoint, the study supports the broader transition in hydrological forecasting from conceptual and physically-based models toward data-driven approaches that capitalize on advancements in artificial intelligence. Future work should explore hybrid models that integrate LSTM with meteorological forecasts or physically-based constraints in order to enhance long-term prediction accuracy and practical application in reservoir management.

Despite the strong performance of the LSTM model for short-term inflow forecasting, several limitations should be acknowledged. The model's accuracy declines significantly beyond the 4-day prediction horizon, with NSE values dropping below 0.8, limiting its usefulness for medium to long term planning. Its effectiveness is highly dependent on the quality and completeness of historical data, meaning that any data gaps or inconsistencies can adversely affect predictions. The model does not incorporate real-time or forecasted meteorological inputs, which could improve responsiveness to abrupt weather changes. It also operates purely as a data-driven model without incorporating physical or operational constraints of the reservoir system, which may sometimes result in hydrologically unrealistic forecasts.

Suggestions

Future research could expand the forecasting horizon beyond the current short-term predictions to weekly or seasonal inflow forecasts would provide greater value for long-term water resource planning. However, this requires balancing prediction accuracy and forecast duration, which future studies should evaluate to ensure optimal operational decision-making. Enhancing data quality and selection by incorporating soil moisture, evapotranspiration, and temperature variations could also improve model performance.

For practical application, real-time implementation should be further explored by integrating LSTM-based forecasting models directly with reservoir management systems. This integration would allow for automated and dynamic water release strategies, enabling timely adjustments to reservoir operations based on predicted inflows. For example, when an LSTM model forecasts a significant inflow event within the next few days, the system could proactively reduce reservoir storage levels in anticipation, thus mitigating flood risks downstream. Conversely, during dry periods, forecasted low inflows could trigger the system to conserve water, ensuring supply for critical uses. Such dynamic decision-making frameworks would move reservoir management from reactive to predictive mode, improving resilience and efficiency in water resource allocation.

Implementing these models in real time, however, presents practical challenges due to the computational intensity of LSTM networks. To address this, resource-efficient deployment strategies such as model quantization (reducing model size and complexity without significantly compromising accuracy) or federated learning (training models across multiple devices without centralizing data) can be adopted. These techniques can help ensure that LSTM models operate within the hardware and time constraints typical of operational water management centers, especially in regions with limited computing infrastructure.

By advancing these areas, future research can transition LSTM-based inflow forecasting from experimental studies into operational use, making it a robust, responsive, and scalable tool for hydrological modeling. This would ultimately support real-time decision-making in reservoir management, improve early warning capabilities, and enhance climate adaptation strategies for water resource systems.

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An Analytical Study of Strategic Challenges Facing Small-Scale Homebuilders in Thailand

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Abstract

This study aimed to enhance the credibility and competitiveness of small-scale homebuilding businesses in Thailand by addressing operational inefficiencies and limited technology adoption. A mixed-methods approach was employed, gathering quantitative data from 200 respondents comprising business owners, customers, experts, and staff and qualitative insights from interviews and focus group discussions. Research instruments were validated through expert review using the Index of Item-Objective Congruence (IOC). Findings revealed that technology adoption was the most influential factor (mean = 4.99), with Building Information Modeling (BIM), Virtual Reality (VR), Augmented Reality (AR), project management software, and IoT integration identified as critical tools for improving project performance and customer satisfaction. Demographic analysis indicated that male, younger, and higher-educated respondents showed stronger preferences for technological innovation. The study concludes that integrating Lean Construction principles with digital technologies can significantly improve operational efficiency and customer trust, supporting the long-term sustainability of small-scale firms. However, the study's limitations include a restricted sample size and a focus limited to the Thai context, suggesting the need for broader comparative research in the future.

Keywords Small-scale homebuilding, Technology adoption, Lean construction, SMEs competitiveness, Thailand

Introduction

Housing remains a key driver of socio-economic development in Thailand, where growing urbanization has expanded demand for residential construction, particularly among small-scale homebuilders (REIC, 2024). However, these businesses face challenges such as intense market competition, labor shortages, rising material costs, and slow technology adoption. Thailand's homebuilding market declined by 12.27% between 2022 and 2024, disproportionately affecting smaller firms (REIC, 2024). Despite the benefits of digital tools like Building Information Modeling (BIM) and cloud-based systems, resource constraints hinder adoption (OECD, 2024; World Bank, 2025).

Prior research highlights strategies for improving competitiveness. Homsorn et al. (2014) and Phannikun et al. (2014) showed that Lean production and process improvements enhanced efficiency, while Rattanapan and Peeraphatthana (2016) demonstrated service process optimization's role in customer satisfaction. Lean workflow redesigns further reduced costs and delays in small enterprises (Suksabai, 2018; Sonjaidee, 2020). Additionally, innovation and dynamic capabilities are vital for SME resilience (Farida & Setiawan, 2022; Mongkol, 2022), with digital transformation becoming essential for survival (OECD, 2024).

Despite these insights, few studies directly address the integrated operational and technological challenges of small-scale homebuilding businesses in Thailand. This study aims to fill that gap by developing a strategic framework combining Lean management and technology adoption to enhance their credibility and competitiveness.

Literature Review

Small-scale enterprises often face resource constraints, market pressures, and technological challenges. Lean management principles have been widely applied to enhance operational efficiency. Homsorn et al. (2014) demonstrated that systematic process improvements increased manufacturing efficiency by 67.44% and reduced delivery times, while Phannikun et al. (2014) showed a 91.56% reduction in wasted labor time using industrial engineering tools.

Service optimization, crucial for customer-facing industries, was highlighted by Rattanapan and Peeraphatthana (2016), who achieved a 61.76% reduction in customer waiting times through Lean and simulation techniques. Similarly, Suksabai (2018) and Sonjaidee (2020) reported that Lean-based workflow redesigns significantly reduced operational costs and production delays, supporting performance in resource-limited environments.

Beyond operational efficiency, strategic capabilities are critical. Farida and Setiawan (2022) emphasized that innovation and business strategy are key to SME competitiveness, while Mongkol (2022) identified dynamic capabilities, including technology adoption, as essential for sustainability. The OECD (2024) stressed that digital transformation is now a survival imperative for SMEs across ASEAN. In construction specifically, technologies like BIM and cloud-based systems have been recognized for enhancing project efficiency, customer engagement, and competitiveness (World Bank, 2025).

These studies underline the importance of process improvement, service quality, and technology integration for small businesses. However, few frameworks directly address the specific needs of small-scale homebuilding firms in Thailand, highlighting the necessity for research tailored to their operational and strategic challenges.

Research Methodology

1. Research Objective

To analyze the key factors affecting the credibility and competitiveness of small-scale homebuilding businesses in Thailand.

2. Scope of the Study

The study focuses on organizational management, customer relations, cost control, labor, and service delivery issues within small-scale homebuilding companies registered in Thailand. These businesses employ no more than 50 people and have a registered capital not exceeding 5 million baht. Data were collected from 200 participants using a mixed-methods approach combining questionnaires, interviews, focus groups, observations, and document analysis.

3. Conceptual Framework

The conceptual framework is based on a Fishbone Diagram (Cause-and-Effect) under the 4M 1E structure (Man, Material, Method, Machine, Environment). It integrates Lean Construction principles to assess operational inefficiencies and propose a strategic improvement framework to enhance the credibility and competitiveness of small-scale homebuilding businesses in Thailand.

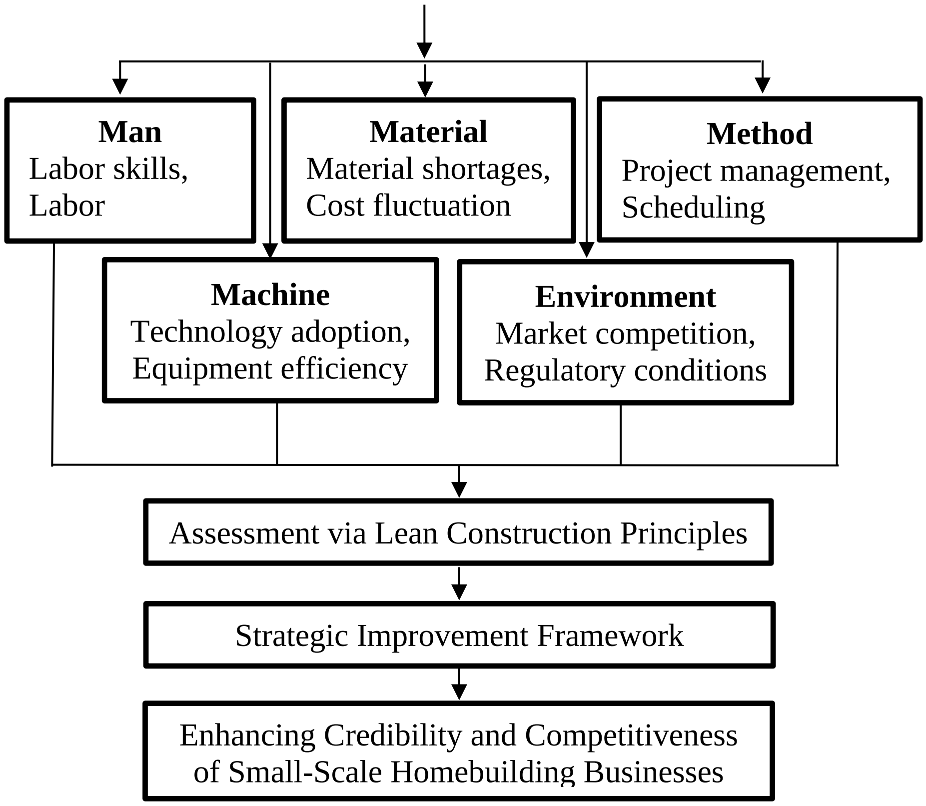

Figure 1 Conceptual Framework Flowchart

4. Research Methodology Flowchart

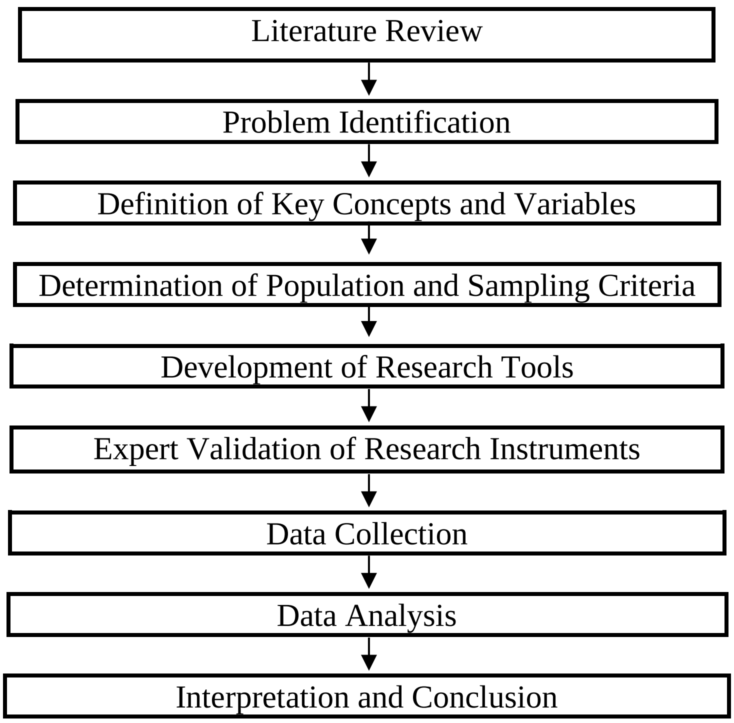

Figure 2 Research Methodology Flowchart

The research instruments were validated by five experts using the Index of Item-Objective Congruence (IOC) method to ensure content validity.

Result

1. **Results of the study from the questionnaire (General information)**

Table 1 Roles and Number of Respondents

Role/Position	Number of Respondents (Persons)	Percentage (%)
Business Owners / Executives	100	50
Customers	60	30
Experts / Consultants	20	10
Staff	20	10
Others	-	-
Total	200	100

Table 1 presents the roles and positions of the respondents. Business owners or executives formed the largest group, with 100 individuals (50%), followed by customers with 60 individuals (30%), and experts/consultants and staff with 20 individuals each (10%).

Table 2 Gender Distribution of Respondents

Gender	Number (Persons)	Percentage (%)
Male	115	57.50
Female	85	42.50
Total	200	100

Table 2 presents the gender distribution of the sample group. The findings indicate that the majority of respondents were male, accounting for 115 individuals or 57.50 percent, while female respondents totaled 85 individuals or 42.50 percent. This suggests that male participants represented the dominant group in this study.

Table 3 Age Distribution of Respondents

Age Group	Number (Persons)	Percentage (%)
Below 20 years	10	5
20–30 years	30	15
31–40 years	40	20
41–50 years	50	25
51–60 years	40	20
60 years and above	30	15
Total	200	100

Table 3 presents the distribution of respondents by age group. The largest proportion of respondents was in the 41–50 years age group, with 50 individuals accounting for 25 percent. This was followed by the 31–40 years and 51–60 years groups, each with 40 individuals, representing 20 percent respectively. The next largest groups were those aged 20–30 years and 60 years and above, both comprising 30 individuals or 15 percent each. The smallest group was respondents under 20 years of age, with 10 individuals, accounting for 5 percent of the total sample.

Table 4 Educational Background of Respondents

Education Level	Number (Persons)	Percentage (%)
Below Secondary School	15	7.5
Secondary School / Vocational Certificate	30	15
Diploma / Higher Vocational Certificate	20	10
Bachelor's Degree	75	37.5
Higher than Bachelor's Degree	60	30
Total	200	100

Table 4 illustrates the educational background of the sample group used for data analysis. The results indicate that the largest proportion of respondents held a bachelor's degree, accounting for 75 individuals or 37.5 percent. This was followed by those with education higher than a bachelor's degree, totaling 60 individuals or 30 percent. The third-largest group comprised those who had completed secondary education or a vocational certificate with 30 individuals or 15 percent. Notably, the smallest group consisted of respondents with less than secondary education, representing 15 individuals or 7.5 percent of the total sample.

Table 5 Levels of Experience in the Homebuilding Business

Years of Experience in Homebuilding Business	Number (Persons)	Percentage (%)
Less than 1 year	30	15
1–3 years	25	12.5
4–6 years	30	15
7–9 years	35	17.5
10 years and above	80	40
Total	200	100

Table 5 presents the levels of experience in the homebuilding business among the sample group used for data analysis. The findings show that the largest proportion of respondents had more than 10 years of experience, totaling 80 individuals or 40 percent. This was followed by those with 7–9 years of experience, accounting for 35 individuals or 17.5 percent. The next groups included those with less than 1 year and those with 4–6 years of experience, each comprising 30 individuals or 15 percent. The smallest group consisted of respondents with 1–3 years of experience, totaling 25 individuals or 12.5 percent.

2. Results of Opinions on Small-Scale Homebuilding Businesses

Table 6 Perceived Importance of Small-Scale Homebuilding Businesses in the Construction Industry

Issues	Mean	S.D.
Intense market competition	4.85	0.35
Shortage of skilled labor	4.26	0.46
Fluctuation in construction material prices	3.62	0.70
Trust and credibility issues	3.10	0.30
Management and administrative challenges	3.44	0.49
Difficulty accessing financial capital	1.47	0.50
Limited use of technology	1.79	0.48
Others	-	-
Average	2.82	0.41

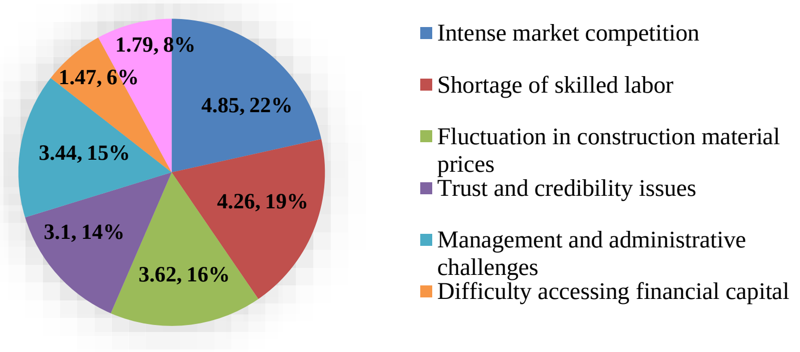

Figure 3 Respondents' Opinions on Key Challenges Affecting Small-Scale Homebuilding Businesses in the Construction Industry

Table 6 presents data illustrating respondents' perceptions of the key factors influencing small-scale homebuilding businesses within the construction industry. The findings indicate that intense market competition was perceived as the most significant factor, with the highest mean score of 4.85, accounting for 22 percent of the total responses. This result reflects the highly challenging business environment in which small contractors operate, particularly due to the presence of large competitors with advantages in cost efficiency, reputation, and market access. Such conditions compel small enterprises to adapt and improve their operations to survive and remain competitive.

The next most critical factors identified were the shortage of skilled labor and the fluctuation in construction material prices, with mean scores of 4.26 (19%) and 3.62 (16%), respectively. These issues present major obstacles to cost control and construction quality, especially for small businesses with limited resources and unstable supply chains. Trust and credibility issues and management challenges followed with moderate scores of 3.10 and 3.44, highlighting the importance of organizational image, customer confidence, and internal efficiency in enhancing long-term competitiveness. In contrast, the lowest-rated factors were difficulty accessing financial capital (1.47) and limited use of technology (1.79). Although these received lower scores, they may reflect a lack of awareness among entrepreneurs regarding the strategic importance of financing and technological integration in strengthening business capacity in the digital era. According to Figure 3, these findings visually support the relative importance of each factor as perceived by the respondents.

Table 7 Factors Influencing the Credibility of Small-Scale Homebuilding Businesses

Factors	Mean	S.D.
Quality of construction work	4.83	0.38
Punctuality in project delivery	4.34	0.47
Transparency in operations	3.91	0.29
Warranty and after-sales services	3.20	0.40
Company reputation	3.08	0.26
Customer relations	2.88	0.38
Others	-	-
Average	3.18	0.31

Table 8, which presents respondents' opinions regarding essential management practices for the success of small-scale homebuilding businesses, the highest-rated factor was the adoption of technology and innovation, with a mean score of 4.99, accounting for 23 percent of total responses. This result reflects the growing awareness among entrepreneurs of the need to adapt to the digital era. Utilizing technology in planning, project management, cost control, and communication enhances operational efficiency, reduces errors, and creates competitive advantages. Additionally, integrating innovation into business processes strengthens brand image and stakeholder perception, contributing to long-term credibility.

The next most influential factors were building credibility and customer satisfaction (mean score of 4.65, 21%), and improving operational efficiency (mean score of 4.05, 19%), both of which are critical in formulating strategic approaches for small businesses. Credibility and customer satisfaction impact repeat business and word-of-mouth marketing, while efficient operations lead to cost reduction and productivity improvement. Although cost control and profit generation (mean score of 2.98), personnel development (2.92), and strategic decision-making (2.17) received lower ratings, they remain foundational components that support internal stability, particularly under economic uncertainty. Overall, the data suggests that small-scale homebuilding businesses should emphasize strategic development in technology and service quality while strengthening internal management to enhance competitiveness and ensure sustainable growth, as illustrated in Figure 5.4

Table 9 Key Factors Affecting Small-Scale Homebuilding Businesses' Competitiveness and Credibility

Factors	Mean	Ranking Scale
Intense market competition	4.85	2
Need for construction quality	4.83	3
Adoption of technology and innovation	4.99	1
Average	4.89	

Table 9 consolidates top competitiveness factors: technology and innovation (4.99), market competition (4.85), and construction quality (4.83). These indicate that external pressures like competition necessitate internal improvements through technology, quality, and reliability.

Despite receiving lower scores in the quantitative data, limited technology use and financial access were found to be critical gaps upon qualitative exploration. Entrepreneurs emphasized the need for Building Information Modeling (BIM), Virtual and Augmented Reality, and project management platforms such as Procore or Trello. While intense competition was a recurring concern, it functions more as a driving force that pushes businesses toward adopting strategic tools and raising operational standards. This highlights the importance of interpreting data contextually and integrating insights from both quantitative and qualitative sources.

Discussion

The analysis of focus group discussions and survey data confirmed that the adoption of technology and innovation is the most critical factor for enhancing the credibility and competitiveness of small-scale homebuilding businesses in Thailand. The use of Building Information Modeling (BIM) to integrate materials, structures, and systems into detailed 3D models improves design accuracy and project management, aligning with Lean Construction principles that emphasize reducing waste and optimizing resource utilization. Moreover, the integration of Virtual Reality (VR) and Augmented Reality (AR) provides customers with

immersive project visualizations before construction, thereby minimizing mid-project design changes and enhancing customer satisfaction an essential strategy for sustaining competitiveness in SMEs as discussed by Mongkol (2022) and Farida and Setiawan (2022).

Furthermore, the adoption of project management software such as Procore and Trello, along with cloud-based document management and Internet of Things (IoT) solutions for real-time equipment monitoring, contributes to improved operational transparency and project efficiency. These practices reflect Lean Construction's emphasis on continuous improvement and efficient workflow management (OECD, 2024; World Bank, 2025).

Demographic analysis revealed notable differences in technology adoption attitudes. Male respondents prioritized the adoption of advanced technologies, particularly BIM and IoT, more than female respondents. Younger participants (below 40 years) expressed stronger enthusiasm toward the use of VR and AR compared to older groups. Additionally, respondents with higher education levels placed greater emphasis on structured project management and technological innovation. These demographic insights highlight the necessity for targeted strategies when implementing technological changes within small construction firms.

Conclusions

This study underscores that technology adoption, integrated with Lean Construction principles, is a key driver for enhancing the credibility, operational efficiency, and long-term competitiveness of small-scale homebuilding businesses. Embracing tools such as BIM, VR/AR, project management software, and IoT solutions can help businesses reduce operational inefficiencies, control costs, improve customer satisfaction, and strengthen their market positioning.

Practical implications suggest that small-scale firms should prioritize strategic investments in digital tools, streamline operations using Lean methodologies, and tailor technological adoption efforts to demographic factors within their organizations to maximize engagement and effectiveness.

Limitations of this study include the restricted sample size of 200 participants and the focus on Thai small-scale homebuilding businesses, which may limit the generalizability of the findings. Future research should broaden the geographic scope and conduct comparative studies across different countries to validate and extend these insights.

Suggestion

1. Enhance Construction Quality: Focus on workmanship and adherence to standards to build client trust.

2. Adopt Technology and Innovation: Implement digital tools and systems to improve project efficiency and differentiation.

3. Apply Lean Management Principles: Use lean techniques to eliminate waste and optimize resource use.

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Innovative Modular Solar Facade Development for Strengthening Building Insulation and Reducing Solar Heat Gain

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Abstract

This research aimed to develop and evaluate a Multi-purpose Modular Solar Facade (MSF) to improve building thermal insulation and reduce solar heat gain. Two facade prototypes were fabricated: a non-ventilated MSF and a ventilated MSF (MSF-V), both measuring 1.20 × 2.40 × 0.40 meters. They were constructed using 0.3 mm-thick aluminum composite panels (thermal conductivity ≈ 0.30 W/m·K) and lined with 0.05-meter polyurethane foam insulation (thermal conductivity ≈ 0.02 W/m·K) for enhanced thermal resistance. The MSF-V incorporated eleven ventilation openings (5.73% of surface area) to promote passive airflow. Experimental results showed that the MSF-V reduced surface temperatures by up to 3–4°C compared to the MSF and achieved higher electrical output, averaging 0.30 kWh/day versus 0.28 kWh/day. The ventilated design enhanced airflow, effectively maintaining lower photovoltaic cell temperatures and improving energy conversion efficiency. These findings demonstrate that integrating passive ventilation into facade systems significantly enhances both thermal performance and solar energy output, offering practical applications for sustainable buildings, especially in hot and humid climates.

Keywords Reducing heat gain, green building innovation, ventilated facade system

Introduction

Thailand's hot and humid climate results in persistently high indoor temperatures, leading to increased reliance on cooling systems and, consequently, higher electricity consumption. Solar radiation absorbed through building envelopes, particularly roofs and walls, is a major source of heat gain. Therefore, facade design has become a critical architectural and engineering focus in tropical climates. A facade, the outermost building envelope, provides protection against sunlight, heat, wind, and rain while enhancing energy performance (Aksamija, 2021; Zhao et al., 2020).

Facades are generally classified into double-skin facades with ventilated cavities and building form facades that combine aesthetic and structural functions (Barbosa & Ip, 2019; Wei et al., 2020). Historically, facade designs evolved alongside construction technologies, from masonry to modern steel and glass structures (Anh-Tuan et al., 2020; Givoni, 2020). Today, sustainable facades emphasize eco-friendly materials and adaptive technologies to optimize energy performance (Baetens et al., 2018; Singh et al., 2019). Solar-ventilated facades have proven effective in reducing heat gain and energy use (Ahmad et al., 2019; Kershaw & Guglielmi, 2020).

Research Gap: Although existing studies confirm the benefits of ventilated facades, there is limited experimental validation of multi-purpose modular solar facades specifically designed for tropical climates. This research addresses this gap by developing and testing MSF and MSF-V prototypes under tropical conditions.

Research Methodology

1. Materials

The prototypes were constructed using 0.3 mm-thick aluminum composite panels and lined internally with 0.05 m thick polyurethane foam insulation to improve thermal resistance. SHARP NE80EZE photovoltaic panels (0.52 × 1.20 m, 80 W, 540 V) were mounted on each facade.

2. Modular Solar Facade Prototypes and Experimental Setup

Two types of modular solar facade prototypes were designed and fabricated for experimental comparison. The first prototype, referred to as the non-ventilated modular solar facade (MSF), measured 1.20 × 2.40 × 0.40 meters (width × height × depth). It was constructed using 0.3 mm-thick aluminum composite panels and internally lined with 0.05-meter thick polyurethane foam insulation on three sides to enhance the wall's thermal resistance (Figure 1).

The second prototype, the ventilated modular solar facade (MSF-V), shared identical dimensions and structural materials with the MSF but incorporated eleven ventilation openings, each measuring 0.04 × 0.24 meters. These openings accounted for 5.73% of the total facade surface area and were strategically designed to facilitate natural airflow through the module (Figure 2). Both prototypes were fitted with identical photovoltaic (PV) panels (SHARP, model NE80EZE) measuring 0.52 × 1.20 meters, each rated at 80 W and 540 V. The PV panels were mounted on the front surface of each facade to allow a direct performance comparison under identical environmental conditions (Figure 3).

For the experimental setup, Type K thermocouples were installed at critical measurement points (T1–T8) on both facade prototypes to monitor surface temperatures. Temperature data were recorded at one-hour intervals from 6:00 to 18:00 to capture daily thermal performance trends. Additionally, electrical output from the PV panels was measured using calibrated ammeters to evaluate the influence of facade ventilation on photovoltaic efficiency.

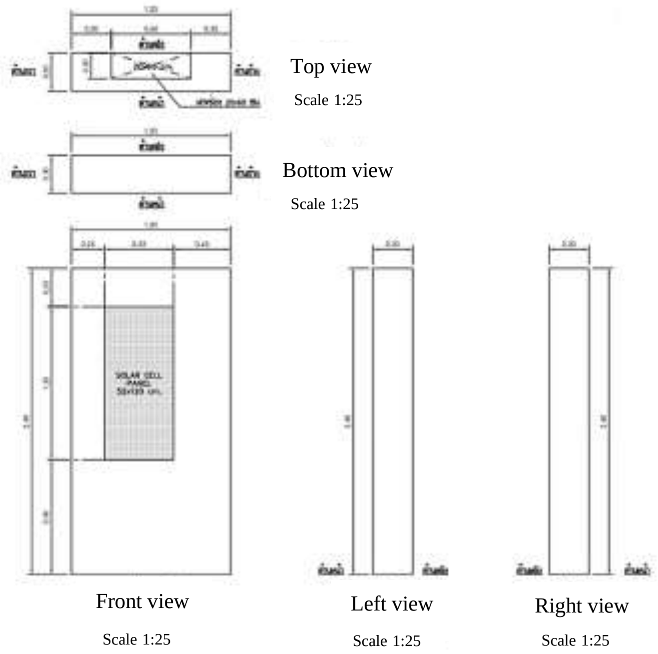

Figure 1 Non-ventilated multi-purpose modular facade (MSF)

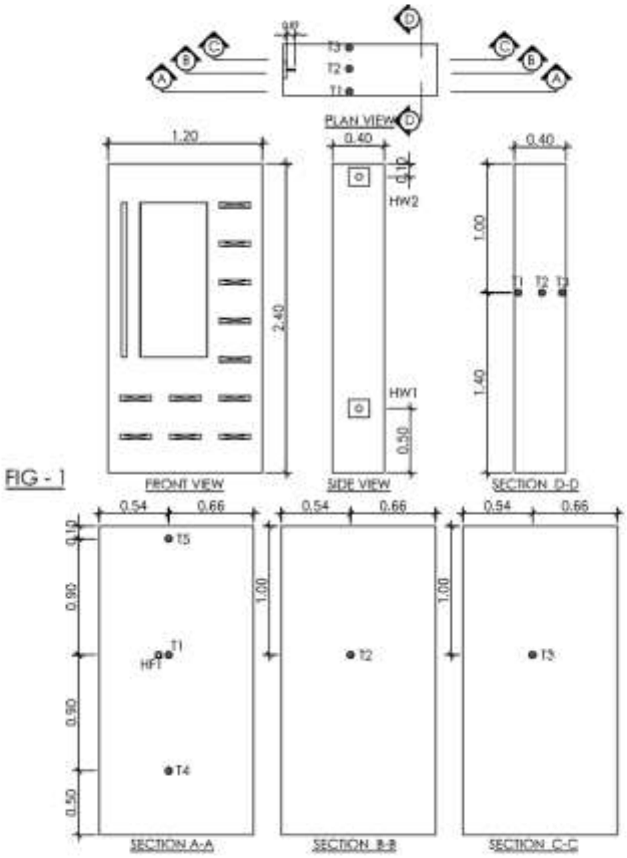

Figure 2 Ventilated multi-purpose modular facade (MSF-V)

Figure 3 Installation of the Ventilated Multi-Purpose Modular Facade (MSF-V) and the Non-Ventilated Multi-Purpose Modular Facade (MSF)

Data collection was conducted on April 25, 2024, chosen due to optimal weather conditions (clear skies, peak solar irradiance) representing typical hot-season climatic conditions in Thailand, ensuring minimal environmental variability.

Result

1. Temperature Measurement of the Building Facade Wall

1.1 This experiment aimed to measure and analyze the surface temperature behavior of a ventilated multi-purpose modular solar facade (MSF-V). Temperature data were recorded at three points T1, T4, and T5 to investigate heat transfer behavior and cooling performance enhanced by the presence of ventilation openings.

1.1.1 Temperature Trends

Measurements indicated that point T5 consistently exhibited the lowest temperature accumulation among the three locations, attributed to effective airflow through the ventilation openings. In contrast, point T1, located directly behind the photovoltaic panel, recorded the highest temperatures due to restricted airflow, limiting convective heat transfer compared to T4 and T5.

1.1.2 Peak Temperature Values

The temperature measurements began at 08:00 AM, starting between 29°C and 30°C. Surface temperatures steadily increased, reaching their peak between 14:00 and 15:00. The peak surface temperatures recorded were: T1 exceeding 41°C, T4 just below 41°C, and T5 ranging between 39°C and 40°C approximately 3–4°C lower than the other two points.

1.1.3 Correlation Between Time and Surface Temperature

All points showed a similar temperature rise between 08:00 and 12:00, reflecting the influence of increasing solar radiation. From 12:00 to 15:00, temperatures plateaued, corresponding to peak solar exposure, before declining gradually as solar intensity decreased.

1.1.4 Comparison of Temperature Measurement Points

Temperature trends at T1 and T4 were nearly identical throughout the day, indicating uniform environmental exposure. T5 consistently recorded lower temperatures, attributed to enhanced ventilation or localized shading, resulting in reduced heat accumulation at that point.

The results highlight the effectiveness of ventilation openings in minimizing surface heat buildup, providing valuable insights for the development of energy-efficient building envelope systems.

Comparison with Non-Ventilated Modular Facade (MSF)

In comparison, the non-ventilated modular facade (MSF), measured at points such as T7, exhibited significantly higher surface temperatures. Specifically, the ventilated facade (MSF-V) consistently maintained surface temperatures approximately 3–4°C lower than the non-ventilated module, demonstrating the critical role of passive ventilation in reducing thermal loads and enhancing the performance of photovoltaic panels under hot and humid climate conditions.

Table 1 Surface Temperature Measurements of the Ventilated Multi-Purpose Modular Solar Facade at Points T1, T4, and T5

Time	Sensor Temperature (°C)		
	T1	T4	T5
6.00	26.96	27.30	27.10
7.00	28.29	28.54	28.33
8.00	29.52	29.72	29.54
9.00	30.95	31.07	30.93
10.00	32.38	32.44	32.20
11.00	34.45	34.57	34.23
12.00	36.01	36.17	35.51
13.00	38.38	38.71	37.62
14.00	39.93	39.90	38.47
15.00	41.12	40.87	39.60
16.00	40.61	40.10	39.05
17.00	37.03	37.08	36.05
18.00	31.92	32.54	31.66

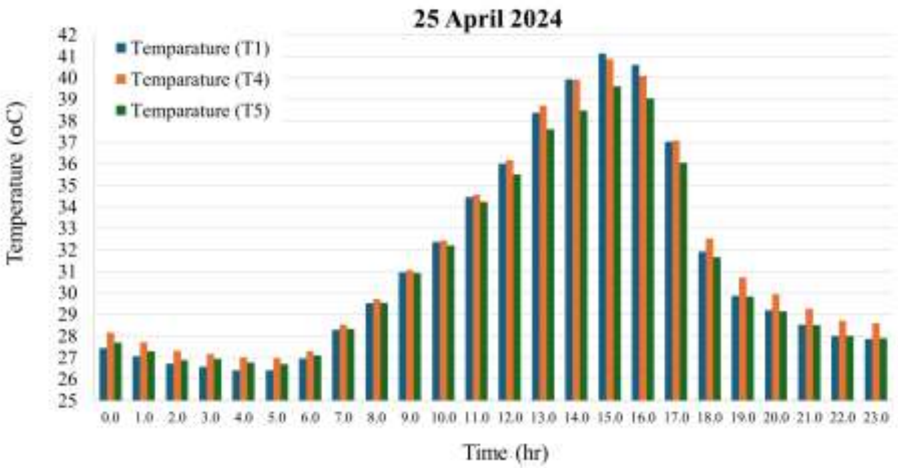

Figure 4 Temperature Results of the Ventilated Multi-Purpose Modular Solar Facade at Measurement Points T1, T4, and T5

1. Electricity Generation and Performance Analysis

The performance of photovoltaic (PV) modules in generating electricity is significantly influenced by their design particularly in relation to ventilation. In this study, the comparison between ventilated and non-ventilated multi-purpose modular solar facades revealed that the ventilated module consistently produced more electrical output. The following analysis, illustrated in Figure 5, presents the experimental results in detail.

2.1 Impact of Ventilation on Temperature

The ventilated module demonstrated enhanced airflow and heat dissipation due to the presence of ventilation openings, which promoted natural convection. This cooling effect is crucial because the efficiency of PV modules tends to decrease as their surface temperature increases. The results confirmed that the ventilated facade maintained lower surface temperatures and, consequently, achieved higher current output, highlighting the thermal advantages of improved air circulation.

2.2 Thermal Management in Photovoltaic Systems

According to thermal management theory in photovoltaic systems, maintaining a lower operating temperature can enhance energy conversion efficiency. Cooler PV modules are more effective in transforming solar irradiance into electrical energy. This principle aligns with the experimental findings, where the ventilated module outperformed the non-ventilated version due to its ability to sustain a lower internal temperature.

2.3 Experimental Data and Thermal-Electrical Correlation

Data collected from the experiment indicated a direct correlation between reduced surface temperatures and increased electricity generation in the ventilated module. As solar irradiance intensified, the performance gap between the ventilated and non-ventilated modules became more pronounced, further supporting the role of ventilation in sustaining energy output under higher thermal loads.

2.4 Role of Convection and Electrical Flow

Convective heat transfer played a critical role in this analysis. The airflow through the ventilated module effectively removed excess heat, lowering the temperature of the PV surface and enhancing the efficiency of the photovoltaic process. The air velocity exiting the ventilated module closely matched the inflow, ensuring continuous and efficient cooling. This dynamic contributed to the increased current flow observed in the ventilated module, reinforcing the importance of ventilation design in energy-efficient building envelope systems.

Table 2 Comparison of Electrical Output Between Ventilated and Non-Ventilated Multi-Purpose Modular Solar Facade Systems

Time	Electric Current (A)	
	I_1	I_2
6.00	0.89	0.84
7.00	1.13	1.01
8.00	1.20	1.14
9.00	1.39	1.23
10.00	1.80	1.34
11.00	2.16	1.96
12.00	2.33	2.20
13.00	3.17	2.98
14.00	2.82	2.61
15.00	2.65	2.59
16.00	2.36	2.23
17.00	2.08	1.92
18.00	1.16	1.03

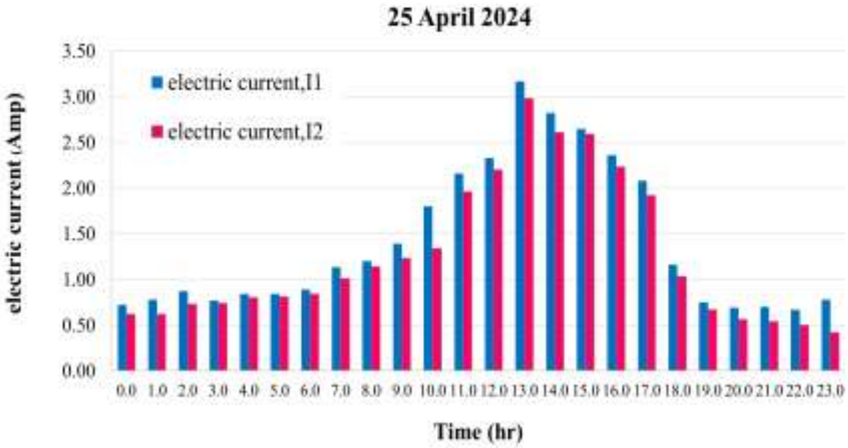

Figure 5 Comparison of Electricity Generation Between Ventilated and Non-Ventilated Multi-Purpose Modular Solar Facade Systems

The experimental results illustrated in Figure 6 demonstrate the thermal behavior of the non-ventilated multi-purpose modular solar facade (MSF) at measurement points T6, T7, and T8. Notably, during the peak solar radiation period between 14:00 and 15:00, the temperature at point T7 was significantly higher than at the other locations. This result highlights substantial internal heat accumulation due to the absence of an effective ventilation mechanism. In contrast, the slightly lower temperatures recorded at points T6 and T8 may be attributed to minor variations in installation orientation or differences in solar exposure. The lack of ventilation restricts heat dissipation, resulting in localized thermal imbalance, which adversely affects the performance of the photovoltaic panel.

When compared with the ventilated facade module (MSF-V), as observed at points T1–T3, the benefits of enhanced thermal control become evident. The MSF-V module consistently maintained lower surface temperatures, leading to improved photovoltaic performance. Specifically, the MSF-V achieved a higher average daily electricity generation of 0.30 kWh/day, compared to 0.28 kWh/day for the MSF. This improvement directly correlates with the reduction in PV cell temperatures, reinforcing the critical role of passive ventilation design in reducing thermal loads and enhancing the overall energy efficiency of building-integrated solar systems in hot and humid climates.

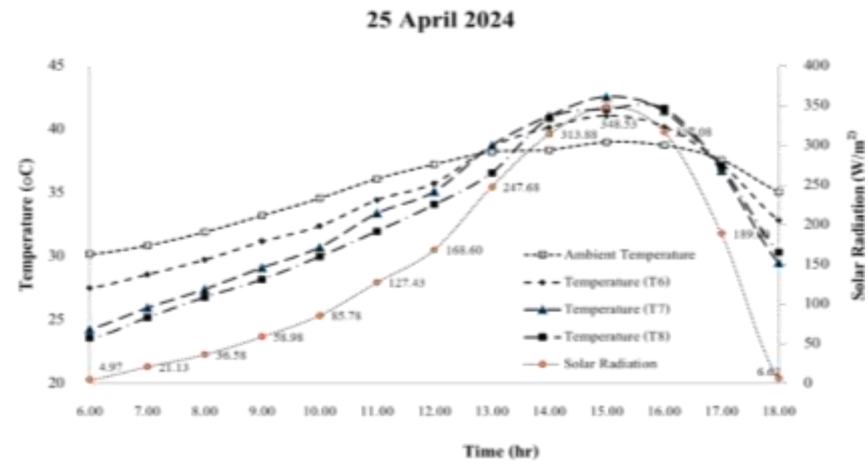

Figure 6 Temperature Values at Points T6, T7, and T8 of the Non-Ventilated Multi-Purpose Modular Solar Facade

Discussion and conclusions

The experimental findings clearly demonstrate the superior thermal and electrical performance of the ventilated multi-purpose modular solar facade (MSF-V) compared to the non-ventilated version (MSF). Surface temperature measurements across key points (T1, T4, and T5 for the MSF-V; T6, T7, and T8 for the MSF) confirmed that incorporating ventilation significantly reduces internal heat accumulation. The MSF-V consistently maintained lower surface temperatures, with peak differences reaching up to 3–4°C. This effect was most evident at point T5, where enhanced airflow through the ventilation openings facilitated efficient convective heat dissipation. In contrast, point T7 on the non-ventilated facade recorded the highest surface temperatures, indicating substantial thermal entrapment due to restricted airflow. The positive correlation between surface temperature regulation and photovoltaic (PV) performance was also evident, with the MSF-V achieving a higher average daily electricity generation of 0.30 kWh/day compared to 0.28 kWh/day for the MSF. Electrical current measurements further confirmed that ventilated modules consistently outperformed their non-ventilated counterparts, particularly during periods of peak solar irradiance. These findings align with thermal management theories, which emphasize that lower PV cell temperatures significantly enhance energy conversion efficiency (Aksamija, 2021; Kershaw & Guglielmi, 2020). Airflow measurements substantiated the effectiveness of the passive ventilation design, illustrating sustained natural convection critical for maintaining lower surface temperatures, whereas the non-ventilated modules exhibited localized thermal imbalance and diminished PV performance.

Beyond validating the performance benefits of passive ventilation under tropical climatic conditions, the results highlight the practical applicability of the MSF-V design for energy-efficient architecture. The system can be integrated into office buildings, schools, and commercial centers in hot and humid regions to reduce cooling loads and enhance renewable energy generation, supporting the achievement of green building certifications. However, it should be noted that this study was conducted over a single day under clear weather conditions, which may not fully capture performance under diverse climatic scenarios. Moreover, while the prototype scale provided valuable experimental insights, it may not entirely replicate the thermal and airflow dynamics of full-scale building facades. Future research should therefore extend testing across multiple seasons and larger installations to further validate the design's effectiveness.

Suggestion

1. **Evaluate the Lifespan of Materials**

   Conduct an analysis and comparison of the lifespan of materials used in the ventilated modular solar facade (MSF-V), focusing on their ability to store and release thermal energy. Additionally, assess how these materials contribute to heat dissipation efficiency to enhance overall heat transfer performance.

2. **Examine Factors Affecting Material Degradation**

   Investigate the factors that contribute to the degradation of materials, including environmental elements such as humidity, wind speed, and air pollution. Understanding these factors will help improve the longevity and performance of the materials used in facade systems.

3. **Optimize the Design of Ventilation Openings**

   Explore the effect of different shapes of ventilation openings (e.g., circular, square, triangular) on the heat dissipation efficiency of the MSF-V. This investigation will provide insights into the most effective designs for enhancing natural ventilation and improving thermal performance.

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Characterization of PLA/TPS-Based Biocomposites Reinforced with Pineapple Leaf Fiber

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Abstract

This study investigated the development and characterization of poly(lactic acid) (PLA) and thermoplastic starch (TPS)-based biocomposites reinforced with pineapple leaf fiber (PALF) using melt blending and injection molding techniques. The mechanical, thermal, and physical properties were evaluated in accordance with ASTM D1238, ASTM D570, ISO 527, and ISO 180 standards. PLA was blended with TPS derived from sago starch, and PALF was incorporated at weight fractions of 0–10%. The results demonstrated that increasing PALF content reduced the melt flow index (MFI) by 48% and enhanced impact strength by 39%, while tensile modulus improved by 18%. Notably, the incorporation of 10 wt% PALF exhibited the highest improvement in impact strength, indicating that this ratio was optimal for enhancing toughness without severely compromising processability. The novelty of this work lies in the successful integration of PALF into PLA/TPS composites, balancing mechanical reinforcement with sustainable material design. These findings suggest that the developed biocomposites have potential applications in structural components and eco-friendly packaging. Limitations such as reduced ductility and increased water absorption were observed, indicating areas for further optimization.

Keywords Biocomposite materials, Pineapple leaf fiber, Mechanical properties, Water absorption, Melt flow index

Introduction

The increasing demand for PLA reflects heightened awareness of plastic waste and environmental concerns, positioning PLA as a sustainable alternative to conventional plastics such as PP and PS, despite continued reliance on plastics in the packaging sector (Tun et al., 2020). Bioplastics, including PLA, PBS, and PBAT, offer potential solutions but remain limited by high production costs (Yujun Wang et al., 2023). From 2021 to 2024, the bioplastics market grew significantly, with non-biodegradable bioplastics rising by 64.6% and biodegradable bioplastics by 57.2% (European Bioplastics, Nova Institute, 2022).

PLA, synthesized from renewable resources such as cassava starch, corn, and sugarcane (Avnish Nitin Mistry et al., 2022), remains more expensive than PP and PS, with costs in 2014 exceeding them by 45.2% and 54.7%, respectively (Leonardo Vieira Teixeira et al., 2023). TPS from sago starch has emerged as a promising complementary material (Heidy Lorena Calambás Pulgarin et al., 2022), particularly given Indonesia's dominance in global sago cultivation (Flach, 1997).

Incorporating natural fibers like PALF and coconut fiber has been shown to enhance biocomposite mechanical properties (M. M. Alamgir Sayeed et al., 2023). Thailand's substantial pineapple cultivation area (Department of Agricultural Extension, 2020) provides a rich source of PALF. Previous studies have demonstrated that fiber reinforcement can improve PLA composites' mechanical performance by up to 140% with nanocellulose (Nazrin Asmawi et al., 2020) and by 354% in tensile strength with cassava pulp (Phatcharin Jullanun & Rangrong Yoksan, 2020).

To address the challenges of cost and mechanical limitations, this study focuses on reinforcing PLA/TPS biocomposites with PALF, aiming to develop sustainable materials suitable for commercial applications.

Research Methodology

1. Materials

PLA (NatureWorks 3251D): MFI = 80 g/10 min (190 °C/2.16 kg), Density = 1.24 g/cm³.
TPS from sago starch: Starch content > 85%, Moisture content < 10%.
PALF: Cellulose content 70–80%, Diameter 20–30 μm.

2. Thermoplastic Starch (TPS) Preparation

Thermoplastic starch (TPS) was prepared using glycerol as a plasticizer under controlled heating and shear conditions, following the methodology described by Ahmad Zuraida et al. (2011). Initially, sago starch was dried at 60 °C for 24 hours to eliminate residual moisture. Subsequently, 70 g of dried sago starch was mixed with 30 g of glycerol, corresponding to a starch-to-glycerol weight ratio of 70:30. The mixture was stirred at 250 rpm for 5 minutes in a 500 mL beaker to ensure homogeneity.

After mixing, the prepared blend was sealed in a polyethylene (PE) bag and stored in a desiccator for 24 hours to stabilize the moisture content. The preconditioned mixture was then processed using a two-roll mill at 120 °C with a roller speed of 60 rpm for 2 minutes to achieve uniform dispersion of the plasticizer and to enhance the mobility of starch molecular chains, thereby improving the flexibility and reducing the brittleness of the material.

Finally, the thermoplastic starch was molded into sheets measuring 20 × 20 cm with a thickness of 3 mm using a compression molding machine under controlled conditions.

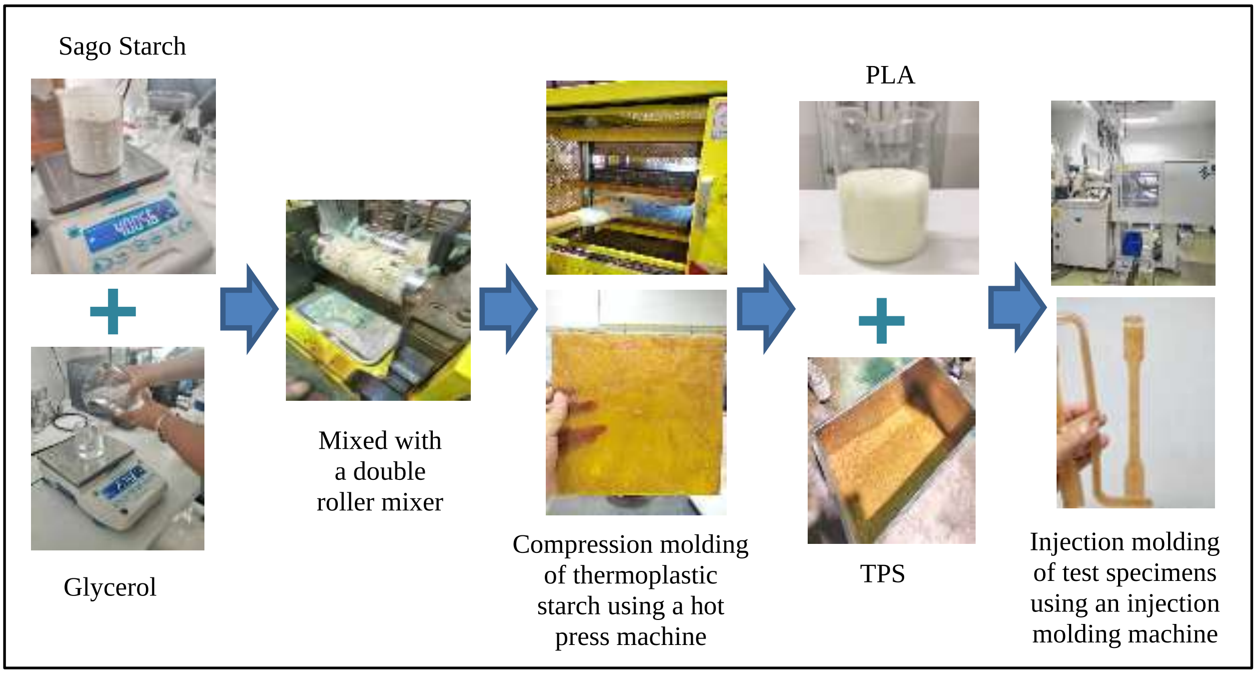


Figure 1 The processing of PLA/TPS polymer blend.

3. Biocomposite Fabrication

Polylactic acid (PLA) and thermoplastic starch (TPS and TPSW) were dried at 70 °C for 4 hours, while pineapple leaf fiber (PALF) was dried at 80 °C for 4 hours. After drying, all materials were allowed to cool to room temperature in a desiccator to prevent moisture uptake. Subsequently, dry blending was performed by mixing PLA/TPS and PLA/TPSW with PALF at weight fractions of 0%, 2%, 4%, 6%, 8%, and 10% using a side-feed plastic granule mixer operating at 60 rpm for 5 minutes.

The blended mixtures were then processed using a twin-screw extruder (Brabender Typ 16.55-2N40010) at a temperature range of 160–180 °C and a screw speed of 100 rpm for 2.5 minutes. The extrudates were cooled and pelletized into granules with sizes ranging from 1 to 2 mm

Subsequently, the resulting compounds were molded into test specimens using an injection molding machine (Sodick-Plustech TR80EH2) under the following processing conditions: molding temperature of 160–180 °C, injection speed of 50 cm^3/min, injection pressure of 700 bar, and cooling time of 15 seconds.

For each test, five specimens per condition were prepared. All experimental results were reported as mean values accompanied by their corresponding standard deviations (Mean ± Standard Deviation).

Table 1 Mix ratio of Polymer Blend (PLA/TPS) and (PLA/TPS/PALF)

Mix ratio (w/w)	Sample code	PLA (90%wt)	TPSW (10%wt)		PALF (%wt)
			Sago Starch (%wt)	Glycerol (%wt)	
100/0	E-1	90.00	7.69	2.31	0
98/2	E-2	88.20	7.54	2.26	2
96/4	E-3	86.40	7.38	2.22	4
94/6	E-4	84.60	7.23	2.17	6
92/8	E-5	82.80	7.08	2.12	8
90/10	E-6	81.00	6.92	2.08	10

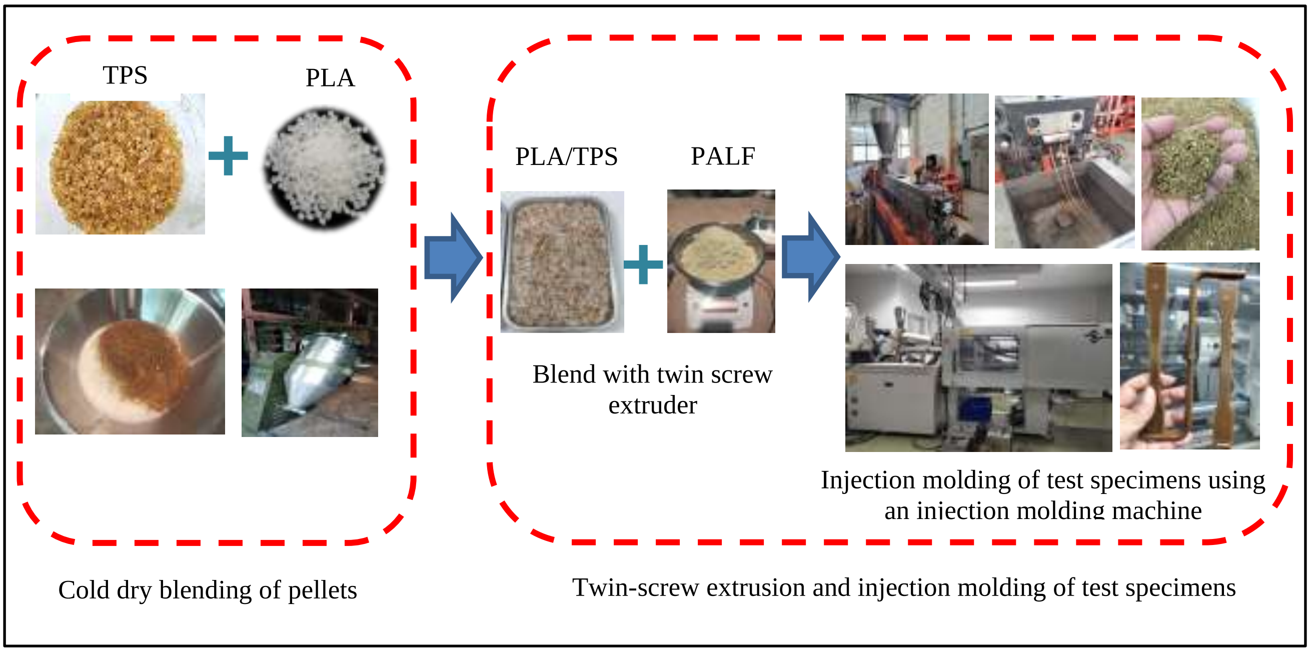


Figure 2 The processing of PLA/TPS/PALF biocomposite materials.

4. Physical properties analysis

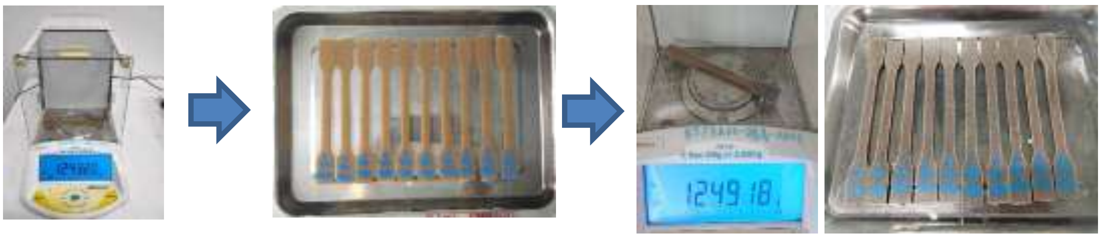
Melt Flow Index (MFI)

The flow characteristics of each sample were analyzed by determining the melt flow index (MFI) in accordance with ASTM D1238. Before measurement, the samples were conditioned at 190 °C for 7.0 ± 0.5 minutes. The MFI was assessed using an INSTRON Model MF 20 melt flow indexer (MA, USA) at a set temperature of 190 °C and a load of 2.16 kg. Each sample was tested three times to ensure data reliability. Additionally, a capillary rheometer (RH7, Bohlin Instrument, Rosand, UK) was used to evaluate shear viscosity at shear rates ranging from 10 to 10^4 s^{-1} within a temperature range of 150–180 °C. These measurements provided essential information on the rheological behavior and processability of the materials under various thermal and shear conditions.

Figure 3 Melt Flow Index testing machine (Brand: CEAST, Model: 8531).

Water Absorption Test

The water absorption test was conducted following ASTM D570 to evaluate the water uptake capacity of the plastic samples. Initially, test specimens were dried at 40 °C for 24 hours and weighed before immersion. The dried samples were then submerged in distilled water for 24 hours. After the immersion period, the specimens were removed, surface-dried, and reweighed to determine the water absorption rate.



Dry weighing | Test pieces immersed in distilled water | Weighing after soaking

Figure 4 Procedure for measuring water absorption according to ASTM D570.

5. Mechanical properties analysis

Tensile Strength Test

The tensile properties of the samples were evaluated following ISO 527 standards. Dumbbell-shaped specimens with dimensions of 10 × 170 × 4 mm were fabricated using a Sodick-Plustech TR80EH2 injection molding machine. The tensile tests were conducted using a universal testing machine (UTM), Hounsfield H50KS, with a gauge length of 50 mm and a crosshead speed of 5 mm/min. The stress-strain data were recorded, and the results were used to determine Young's modulus and elongation at break.

Tensile Testing Parameters According to ISO 527

The tensile machine stretched the specimen to failure.

Figure 5 Tensile testing setup and specimen failure during testing according to ISO 527.

Impact Strength Test

The impact resistance of the samples was evaluated in accordance with ISO 180. Test specimens measuring 10 × 80 × 4 mm were fabricated using a Sodick-Plustech TR80EH2 injection molding machine. A 45° V-notch was introduced into the specimens, which were then conditioned at room temperature for 24 hours prior to testing. The impact strength was measured using an Izod Impact Tester (CEST 6542) by recording the energy absorbed upon impact, which was subsequently used to calculate the impact resistance of the material.

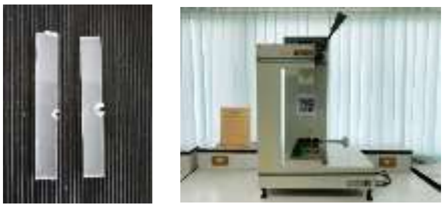


Figure 6 Notched specimens and impact tester.

Result

Analysis of Melt Flow Index (MFI) Results

Table 2 Melt Flow Index of Different Material Compositions

Type of material	Mixing ratio %wt	Sample code	Melt Flow Index (g/10 min)
PLA	100	A	81.75 ±1.63
TPS	100	B	17.37 ±0.34
PLA/TPS : PALF	100:0	E-1	78.35 ±1.56
	98:2	E-2	69.83 ±1.39
	96:4	E-3	64.03 ±1.28
	94:6	E-4	53.51 ±1.07
	92:8	E-5	43.70 ±0.87
	90:10	E-6	40.62 ±0.81

The melt flow index (MFI) values presented in Table 2 indicate the flowability of different material compositions, including pure polylactic acid (PLA), pure thermoplastic starch (TPS), and PLA/TPS composites reinforced with pineapple leaf fiber (PALF). The results demonstrate a decreasing trend in MFI values with increasing PALF content, suggesting an impact on the viscosity and processability of the biocomposites.

Pure PLA exhibited the highest MFI value at 81.75 ± 1.63 g/10 min, reflecting its superior melt flow characteristics due to its relatively low viscosity under the given test conditions. In contrast, pure TPS showed a significantly lower MFI of 17.37 ± 0.34 g/10 min, indicating higher viscosity and limited flowability compared to PLA. The PLA/TPS (90:10) blend without PALF (sample E-1) exhibited an MFI of 78.35 ± 1.56 g/10 min, slightly lower than pure PLA, which can be attributed to the incorporation of TPS with inherently higher viscosity.

As the PALF content increased from 2% to 10% (samples E-2 to E-6), the MFI progressively decreased, from 69.83 ± 1.39 g/10 min (E-2) to 40.62 ± 0.81 g/10 min (E-6). This decline suggests that PALF incorporation increases the composite's overall viscosity, restricting polymer chain mobility and reducing melt flowability. The reduction in MFI is attributed to the reinforcing effect of PALF, which introduces physical interactions and fiber–matrix entanglements, thereby limiting deformation under applied shear stress. Additionally, fiber addition disrupts melt homogeneity and increases internal friction, resulting in higher resistance to flow (Patra Chotiprayon et al., 2020).

Analysis of Water Absorption Results

Table 3 Water Absorption Percentage of Various Material Compositions

Type of material	Mixing ratio %wt	Sample code	Water absorption percentage (%)
PLA	100	A	0.257 ±0.005
TPS	100	B	12.35 ±0.247
PLA/TPS : PALF	100:0	E-1	0.428 ±0.008
	98:2	E-2	0.594 ±0.012
	96:4	E-3	0.706 ±0.014
	94:6	E-4	0.812 ±0.016
	92:8	E-5	1.140 ±0.023
	90:10	E-6	1.397 ±0.027

Table 3 presents the water absorption of various material compositions, including pure polylactic acid (PLA), pure thermoplastic starch (TPS), and PLA/TPS composites reinforced with pineapple leaf fiber (PALF). The results indicate significant differences in water absorption behavior depending on the material composition.

Pure PLA exhibited the lowest water absorption at 0.257 ± 0.005%, reflecting its hydrophobic nature and low affinity for moisture. In contrast, pure TPS demonstrated a much higher water absorption of 12.35 ± 0.247%, attributed to the hydrophilic nature of starch, which readily interacts with water molecules via its hydroxyl (-OH) functional groups.

For the PLA/TPS blend without PALF (sample E-1), water absorption was recorded at 0.428 ± 0.008%, slightly higher than that of pure PLA but significantly lower than pure TPS, suggesting that blending TPS with PLA mitigates moisture uptake due to the hydrophobic characteristics of PLA. As PALF content increased from 2% to 10% (samples E-2 to E-6), the water absorption gradually rose from 0.594 ± 0.012% to 1.397 ± 0.027%.

This trend is explained by the introduction of natural fibers, which contain hydrophilic cellulose and hemicellulose structures that facilitate moisture absorption. Additionally, the porous nature of PALF and the potential formation of voids at the fiber–matrix interface promote water penetration (Nazrin Asmawi et al., 2020; Dewi et al., 2022). Despite the increase, the water absorption values of PLA/TPS/PALF composites remained significantly lower than that of pure TPS, highlighting the important role of PLA in limiting excessive water uptake.

Analysis of Tensile Properties Results

Table 4 Tensile Properties of Various Material Compositions

Type of material	Mixing ratio %wt	Sample code	Tensile strength (MPa)	Tensile Modulus (MPa)	Elongation at Break (%)
PLA	100	A	52.35 ±1.05	2,922 ±58.44	2.37 ±0.047
TPS	100	B	28.14 ±0.56	2,298 ±45.96	3.19 ±0.064
PLA/TPS : PALF	100:0	E-1	49.65 ±0.99	2,927 ±58.54	2.43 ±0.049
	98:2	E-2	43.59 ±0.87	2,957 ±59.14	1.53 ±0.031
	96:4	E-3	40.06 ±0.80	3,034 ±60.68	1.39 ±0.028
	94:6	E-4	37.46 ±0.75	3,092 ±61.84	1.25 ±0.025
	92:8	E-5	35.81 ±0.72	3,193 ±63.86	1.18 ±0.024
	90:10	E-6	32.92 ±0.66	3,452 ±69.04	1.04 ±0.021

Table 4 presents the tensile properties of various material compositions, including pure polylactic acid (PLA), pure thermoplastic starch (TPS), and PLA/TPS composites reinforced with pineapple leaf fiber (PALF). The results indicate significant differences in tensile strength, tensile modulus, and elongation at break among the tested materials.

Pure PLA exhibited the highest tensile strength (52.35 ± 1.05 MPa) and tensile modulus (2,922 ± 58.44 MPa), but the lowest elongation at break (2.37 ± 0.047%), reflecting its rigid and brittle nature. In contrast, pure TPS showed a much lower tensile strength (28.14 ± 0.56 MPa) and modulus (2,298 ± 45.96 MPa), but a higher elongation at break (3.19 ± 0.064%), indicating greater flexibility but weaker mechanical strength.

For the PLA/TPS blend without PALF reinforcement (E-1, 100:0), the tensile strength slightly decreased to 49.65 ± 0.99 MPa, while the modulus (2,927 ± 58.54 MPa) remained comparable to that of pure PLA, suggesting that blending TPS slightly reduces strength but does not significantly affect stiffness. As PALF content increased from 2% to 10% (samples E-2 to E-6), the tensile strength progressively decreased from 43.59 ± 0.87 MPa to 32.92 ± 0.66 MPa, whereas the tensile modulus increased from 2,957 ± 59.14 MPa to 3,452 ± 69.04 MPa.

This trend suggests that the addition of PALF enhances stiffness due to the rigid nature of the fibers but compromises tensile strength, likely due to fiber–matrix adhesion limitations and stress concentration effects at the fiber–polymer interface. Similarly, the elongation at break decreased from 2.43 ± 0.049% (E-1) to 1.04 ± 0.021% (E-6), indicating a significant reduction in ductility as fiber content increased. This reduction is attributed to restricted polymer chain mobility and increased internal stress concentration introduced by the rigid PALF structure, leading to earlier fracture under tensile loading (Nazrin Asmawi et al., 2020; Dewi et al., 2022).

Analysis of Impact Strength Results

Table 5 Impact Properties of Various Material Compositions

Type of material	Mixing ratio %wt	Sample code	Impact strength (J/m^2)
PLA	100	A	2,859 ±57.18
TPS	100	B	1,454 ±29.08
PLA/TPS : PALF	100:0	E-1	2,610 ±52.20
	98:2	E-2	2,767 ±55.34
	96:4	E-3	3,199 ±63.98
	94:6	E-4	3,296 ±65.92
	92:8	E-5	3,495 ±69.90
	90:10	E-6	3,626 ±72.52

Table 5 presents the impact strength of various material compositions, including pure polylactic acid (PLA), pure thermoplastic starch (TPS), and PLA/TPS composites reinforced with pineapple leaf fiber (PALF). The results demonstrate significant differences in impact resistance depending on the material composition and fiber reinforcement.

Pure PLA exhibited an impact strength of 2,859 ± 57.18 J/m^2, indicating its moderate resistance to impact forces. In contrast, pure TPS showed a significantly lower impact strength of 1,454 ± 29.08 J/m^2, suggesting lower toughness and greater brittleness due to its intrinsic structure and weaker intermolecular interactions.

For the PLA/TPS blend without PALF reinforcement (E-1, 100:0), the impact strength slightly decreased to 2,610 ± 52.20 J/m^2, which may be attributed to the incorporation of TPS, reducing overall toughness because of its lower molecular cohesion. However, as PALF content increased from 2% to 10% (samples E-2 to E-6), the impact strength exhibited a continuous improvement from 2,767 ± 55.34 J/m^2 to 3,626 ± 72.52 J/m^2.

This trend suggests that PALF reinforcement effectively enhances impact resistance by absorbing and distributing impact energy through fiber–matrix interactions. The increase in impact strength can be primarily attributed to the reinforcing effect of natural fibers, which act as stress dissipators and inhibit crack propagation within the composite. Additionally, improved interfacial adhesion between PALF and the PLA/TPS matrix likely contributes to more efficient energy absorption under impact loading conditions (M.R. Manshor et al., 2014). Overall, the findings indicate that while PLA exhibits moderate impact resistance and TPS significantly reduces toughness, the incorporation of PALF progressively enhances the composite's ability to withstand impact forces. The highest impact strength

(3,626 ± 72.52 J/m²) was observed for the PLA/TPS blend containing 10% PALF (E-6), suggesting that an optimal fiber content exists for maximizing impact performance. These results highlight the potential of PALF-reinforced PLA/TPS composites for applications requiring improved impact resistance.

Discussion and conclusions

The results demonstrate that PALF reinforcement significantly influenced the physical and mechanical properties of PLA/TPS biocomposites. Increasing PALF content reduced the melt flow index (MFI) due to higher melt viscosity, indicating stronger fiber–matrix interactions and reduced polymer chain mobility (Rhim et al., 2013). Although higher viscosity may hinder processing, it enhances composite structural integrity.

Water absorption increased slightly with PALF addition because of the hydrophilic nature of cellulose fibers, but remained within acceptable limits, consistent with previous studies (Bledzki & Gassan, 1999). Surface modification of fibers could further improve moisture resistance.

Tensile testing showed that PALF improved stiffness (higher modulus) but decreased tensile strength and elongation at break. This outcome aligns with the theory that rigid fibers reinforce the matrix but also introduce stress concentration points when interfacial adhesion is insufficient (Nassaj & Mohammadi, 2019).

Impact strength continuously improved with PALF content, attributed to stress dissipation and crack deflection by the fibers, as similarly reported by Fu et al. (2008). However, excessive fiber loading may cause poor dispersion and reduced ductility.

Overall, optimizing the PALF content is essential for balancing mechanical property enhancement and processability. PLA/TPS/PALF biocomposites demonstrate strong potential for applications that demand high stiffness and improved impact resistance. These biocomposites are particularly suitable for rigid biodegradable packaging and lightweight structural panels requiring moderate mechanical strength and durability.

Suggestion

1. Incorporating hydrophobic polymers, such as PBAT or compatibilizers, can improve moisture resistance while maintaining mechanical properties.
2. Further research is required to identify the optimal PALF content for achieving a balance between strength, ductility, and processability.

Acknowledgements

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Long-term Performance Assessment of Rural Roads Built with Soil-Cement Adapted from Natural Rubber

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Abstract

This research is a study of the uniaxial compressive strength of rural roads constructed of soil-cement mixed with rubber, using the proportion of laterite according to the structure of the road layer mixed with Portland cement type 1, an average of 20.25 kilograms per square meter, and fresh rubber mixed with additives and water, an average of 2 liters per square meter. The properties of the soil-cement pavement and the uniaxial compressive strength were tested by collecting samples of soil-cement pavement and drilling to collect samples of the road surface used for 1, 2 and 3 years to assess the efficiency of long-term road development, such as durability, load bearing, maintenance and extension of the road's life. The test results showed that the mixed mass of soil-cement pavement with mixed sizes was good. The coefficient of uniformity CU is 16.67 and the coefficient of curvature CC is 0.96 The single compressive strength from 1-year use is 45.68 percent, 2-year use is 30.45 percent, and 3-year use is 15.23 percent, which has a continuous decrease in strength with the use period compared to the allowable strength of 17.50 kilograms per square centimeter. The results of this research study are from the construction of rubber-cement soil roads, rural roads in Wang Sai Subdistrict, Khlong Khlung District, Kamphaeng Phet Province, 3 roads. From the initial monitoring and evaluation of the use, it was found that all 3 roads are still in normal usable condition when compared to the reduced compressive strength. Therefore, it is suitable for use as a rural road. It has a lower construction cost than asphalt roads, is more durable than laterite roads, and can be used for not less than 3 years.

Keywords: Cement soil, rubber, single axis compression, efficiency, rural road

Introduction

At present, roads are an important factor in the transportation system and an important part of national development, both in terms of the economy and the well-being of the people in the country, especially rural roads used to transport agricultural products from one area to another and from the area to the city, resulting in the distribution of goods or products throughout the country. Currently, most rural roads are laterite, with rough and uneven road surfaces, eroded into potholes, and high dust. Construction budgets are quite limited. Some materials are expensive and hard to find in some areas, causing the cost of road construction to increase even more.

Kamphaeng Phet Province has an area suitable for rubber plantations, covering an area of 58,333 rai, accounting for 1.85 percent of the plantation area, as shown in Table 1. The yield has increased every year, as shown in Table 2. The Chakangrao Land Reform Rubber Fund Cooperative Limited, Kamphaeng Phet Province, has requested a budget from the Rubber Authority of Thailand to improve the laterite roads into cement-rubber mixed roads from 2022 to 2024, totaling 3 roads, to be model roads in Kamphaeng Phet Province, making rural roads stronger, more durable, and helping small-scale rubber farmers with the problem of low rubber prices, promoting the use of rubber in the country. Therefore, the researchers are interested in studying the efficiency of road usage over a period of 1, 2 and 3 years by testing the properties of soil-cement pavement, testing the uniaxial compression strength and conducting comparative analysis with roads that are not modified from natural rubber. This will serve as a guideline for the construction of soil-cement-rubber mixed roads in rural roads in Kamphaeng Phet Province to be more sustainable and efficient in the long term.

Table 1 Economic crop cultivation areas in Kamphaeng Phet Province

Types of crop cultivation	Area for growing cash crops			
Rice	Area	1,559,911	Rai	50.91 percent of the cultivated area
Sugarcane	Area	724,201	Rai	23.04 percent of the cultivated area
Cassava	Area	722,873	Rai	23.00 percent of the cultivated area
Rubber	Area	58,333	Rai	1.85 percent of the cultivated area
Corn	Area	27,617	Rai	0.87 percent of the cultivated area
Longan and Pineapple	Area	9,496	Rai	0.30 percent of the cultivated area

Source: Department of Land Development, Ministry of Agriculture and Cooperatives (Agri Map Online)

Table 2 Production of economic crops 2015 - 2017

Types of crop cultivation	Average yield (kg/rai)		
	2015	2016	2017
In season rice	580	572	598
Out of season rice	615	580	608
Animal feed corn	732	705	717
Cassava	3,983	3,333	3,536
Sugarcane	11,170	9,560	9,650
Rubber	128	155	166
Oil palm	779	763	738

Source: Office of Agricultural Economics, 2018

Materials and Methods

1. Construction materials for roads: soil, cement, and rubber

Type 1 Portland cement has high compressive strength properties, suitable for structural works that require strength and large-scale structural works such as tall buildings, roads, expressways, stadiums, and airports. Its properties meet the criteria specified in the Portland cement industry standard, TIS 15.

Soil cement surface is the process of mixing soil with cement using a mobile mixing machine to construct the road surface. It must have properties that meet the standards of soil cement surface, Highways - M. 204/2013.

Rubber: Use fresh rubber with a real rubber content (DRC) of not less than 30% from rubber farmer groups in the area and certified by the Rubber Authority of Thailand.

Additives are additives for mixing with fresh latex and water in the specified or designed ratio and then mixed with soil aggregates or gravel with cement and water to become cement soil with improved quality using natural rubber for road construction, which must have engineering properties that pass the special requirements of the Department of Highways, Ministry of Transport, or the manual for quality control and certification of materials standards for road construction using cement soil with improved quality using natural rubber of the Ministry of Agriculture and Cooperatives.

2. Proportions of construction materials include: 1) Type 1 Portland cement, approximately 20 - 25 kilograms per square meter; 2) Fresh latex with additives and water, using a ratio of 9,000 liters of water, 800 liters of latex (average 2 liters per square meter), and 80 liters of additives per water truck.


Figure 1. Portland cement


Figure 2. Fresh rubber latex

Figure 1. Portland cement

Figure 2. Fresh rubber latex

Figure 3. Construction site conditions

3. Materials and tools used in testing include: 1) Soil cement surface in the area of the road construction in Wang Sai Subdistrict, Khlong Khlung District, Kamphaeng Phet Province; 2) Sample blocks of the surface of the soil cement mixed with rubber road that were completed and used for 1, 2 and 3 years; 3) Shear testing machine; 4) Coring machine.

4. Testing procedures

4.1 Testing the properties of cement soil surface by collecting one sample of cement soil surface for each road construction area to test the engineering properties of the soil aggregates, including determining the specific gravity of soil particles, determining the liquid and plastic loads of the soil according to the cement soil surface standards of the Department of Highways at Th.L.- M. 204/2013.

4.2 Unconfined Compressive Strength Testing This method involves coring samples from the surface of the rubberized cement-stabilized soil roads that have been constructed and in service for 1, 2, and 3 years, across three different road sections, with 10 samples collected per section. The compressive strength of the material is tested by installing coring equipment at the designated test locations, drilling through the pavement surface using water as a coolant, and collecting the core samples for laboratory testing in accordance with the Department of Rural Roads standard, DRR (T) 303-2002.

4.3 Comparative Analysis with Asphalt and Gravel Roads A comparative analysis was conducted with asphalt roads and lateritic gravel roads in terms of construction costs, load-bearing capacity, service life, maintenance durability, and environmental impact.

Figure 4 Coring of Rubberized Cement-Stabilized Soil Pavement

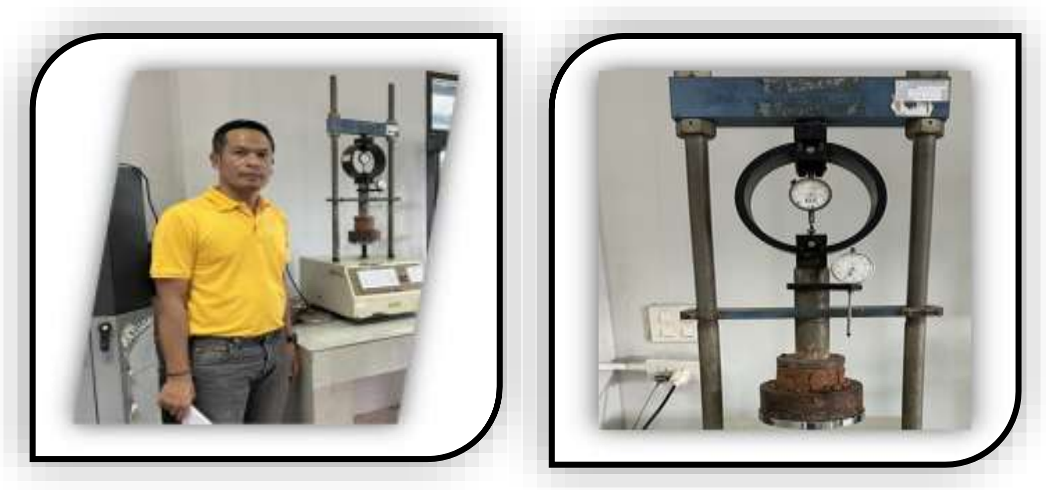

Figure 5 Unconfined Compressive Strength Testing of Core Sample

Research Results

1. Properties of Cement-Stabilized Subgrade Soil

The engineering properties test of soil aggregates consisted of determination of specific gravity of soil particles, determination of liquid limit and plastic limit of soil. It was found that this soil aggregate had specific gravity of 2.71, liquid limit and plastic limit of 27.40 and 20.17 percent, respectively. In conclusion, this soil aggregate is suitable for the standard of cement soil surface of the Department of Highways at Th.L.-M. 204/2556. When the soil aggregate sample was tested for soil particle distribution as shown in Figure 4, it was found that this soil aggregate had the largest particle size not exceeding 50 millimeters, with 30.34 percent passing through a 2.00-millimeter sieve (No. 10) and 8.45 percent passing through a 0.075-millimeter sieve (No. 200).

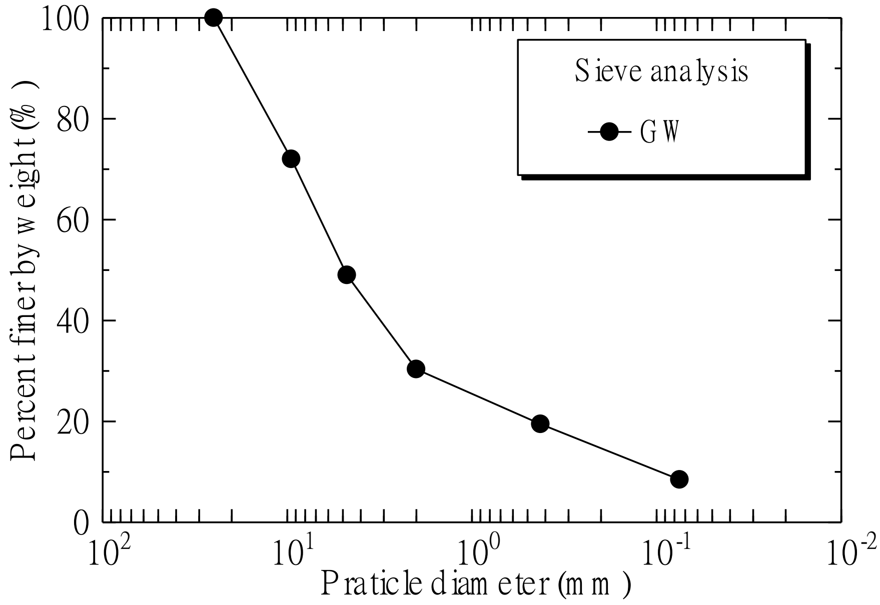

Figure 6. Graph of distribution of soil surface size.

Figure 6 shows the particle size distribution of the subgrade soil. The study results obtained through sieve analysis classify the soil according to the Unified Soil Classification System (USCS), indicating that the soil consists of gravel-sized particles. Based on data from the graph (D10 ≈ 0.3 mm, D30 ≈ 1.2 mm, and D60 ≈ 5.0 mm), calculations using the equations Cu = D60/D10 and Cc = (D30) ² / (D60 × D10) yield a uniformity coefficient (Cu) of 16.67 and a coefficient of curvature (Cc) of 0.96. According to the criteria (Cu ≥ 4 and 1 ≤ Cc ≤ 3), the soil is classified as GW (Well-Graded Gravel) under the Unified Soil Classification System.

2. Field Compressive Strength

Table 3 Shows the compressive strength values in the field

Sample collection location	Maximum compressive strength (kg/cm²)			Testing standards
	Road 2022	Road 2023	Road 2024	
0+000-0+100	9.56	11.98	14.11	DRR. (T)
0+100-0+200	9.85	12.10	14.53	303-2002
0+200-0+300	9.98	12.25	14.38	Area not
0+300-0+400	9.96	12.21	14.16	exceeding
0+400-0+500	9.88	11.89	14.23	1,500 sq.m.
				Per 3 examples
Average UCS (kg/cm²)	Average maximum compressive strength ≥ 17.50 ksc			

2.1 From Table 3: Field Unconfined Compressive Strength Based on the unconfined compressive strength tests of the collected core samples compared to the standard average compressive strength of 17.50 ksc, it was found that in 2022, the unconfined compressive strength decreased by an average of 43.74%, with a standard deviation of 0.96. When calculating the 95% confidence interval using the mean and standard deviation, it was determined that after 3 years, the average reduction in unconfined compressive strength ranged from 41.85% to 45.63%. In 2023, the average reduction in unconfined compressive strength was 30.94%, with a standard deviation of 0.87. The 95% confidence interval indicated that after 2 years, the average reduction ranged from 29.27% to 32.64%. In 2024, the average reduction in unconfined compressive strength was 18.39%, with a standard deviation of 0.98. The 95% confidence interval showed that after 1 year, the average reduction ranged from 16.44% to 20.32%.

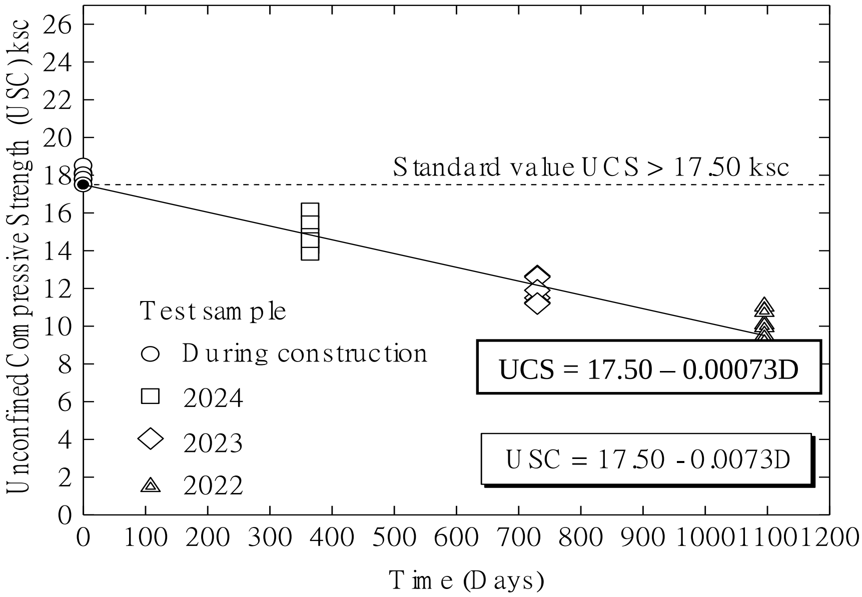

Figure 7. Compression test graph and service time.

2.2 Figure 7 shows the results of the uniaxial compression test from the collection of samples of the rubber-cement soil road compared to the service life of 1, 2 and 3 years after the completion of the construction. The material is laterite soil. According to the structure of the road layer mixed with Portland cement type 1 at an average ratio of 20-25 kg per square meter and fresh latex mixed with additives and water at an average ratio of 2 liters per square meter. From the results of collecting samples for the uniaxial compression test, it was found that the strength value continuously decreased when compared to the period of 1-3 years.
The uniaxial compression value decreased by an average percentage of 15.23, 30.45 and 45.68, respectively, compared to the allowable strength of 17.50 kg/cm^2. Based on calculations from the graph, the 95% confidence interval for each time period between 100 and 1,000 days is relatively narrow, approximately ±0.20 ksc. This indicates that the equation is highly accurate and can be used to estimate the reduction in UCS of rubber-modified cement-stabilized soil roads over specific time intervals. Such estimations are useful for assessing the service life of the road and for planning appropriate maintenance strategies. Therefore, it is recommended that UCS estimations be applied within the time range of 0 to 1,000 days to ensure high accuracy and minimal deviation.

3. Comparison with Asphalt Roads and Lateritic Gravel Roads

Table 4 Construction costs

Road type	Construction cost (bath/square meter)
Rubber cement roads	500 - 800 baht
Asphalt roads	1,000- 1,500 baht
Laterite roads	200 - 400 baht

- Rubber cement roads have higher costs than gravel roads but lower than asphalt roads. Mixing rubber will help reduce costs in the long run.
- Asphalt roads have the highest costs because they require expensive materials and technology.
- Laterite roads have the lowest cost because they use materials that are easy to find and do not require advanced technology for construction.

Table 5 Load Bearing

Road type	Load capacity (tons/wheel)
Rubber cement roads	10 - 15 tons
Asphalt roads	20 - 30 tons
Laterite roads	5 - 10 tons

- Rubber cement roads can support medium weight and are suitable for areas with not too heavy traffic.
- Asphalt roads can support the most weight because they are strong and durable against heavy loads.
- Laterite roads can support the least weight because they are natural roads that are not very durable.

Table 6 Service life

Road type	Service life (years)
Rubber cement roads	15 - 20 years
Asphalt roads	20 - 30 years
Laterite roads	5 - 10 years

- Rubber cement roads have a fairly long service life and require little maintenance.
- Asphalt roads have the longest service life but require more maintenance due to road surface deterioration.
- Laterite roads have the shortest service life and deteriorate faster than other types of roads.

Table 7 Durability and maintenance

Road type	Durability and maintenance
Rubber cement roads	Medium durability, low maintenance required
Asphalt roads	Highly durable, requires constant maintenance protection
Laterite roads	Less durable, requires frequent maintenance

- Rubber cement roads are durable and require less maintenance than asphalt roads.
- Asphalt roads require continuous maintenance, such as repairing cracks or resurfacing.
- Laterite roads require relatively frequent maintenance, especially after rain or wind.

Table 8 Environmental impacts

Road type	Environmental impacts
Rubber cement roads	Reduce the use of old tires, environmentally friendly
Asphalt roads	The use of asphalt has an impact on the environment.
Laterite roads	Low environmental impact

- Rubber cement mixed soil roads have low impact. Using rubber mixed with cement reduces the use of natural materials and increases sustainability.
- Asphalt roads have high impact. Using asphalt may cause toxic emissions in production process.
- Laterite roads have low impact. Using natural materials but has an impact on the environment when damaged.

4. External factors affecting the deterioration of rubber-cement mixed soil roads

4.1 Weather and environment

Heavy rain causes roads to wash out and cause high humidity, which causes cement and rubber materials to deteriorate faster. Excessive temperatures can cause rubber materials to collapse or deteriorate during winter. Low temperatures can cause cement and rubber materials to shrink and crack.

4.2 Traffic and loads

Traffic with excessive loads can cause road surfaces to deteriorate faster, such as cracks, dents, or increased erosion.

4.3 Water flow

Rainwater or water from other sources that are not well drained can affect road erosion and damage, especially in areas where water accumulates.

4.4 Material quality

The quality of soil and cement, if poor or substandard materials are used in the mixture, will cause roads to deteriorate faster because the materials cannot withstand the pressure or stress caused by traffic well. Incomplete mixing of rubber, mixing rubber in an improper ratio may cause the road to have poor properties to withstand traffic or weather conditions.

Summary of results and suggestions

1. Summary

1.1 Comparison of the results of the research on rubber-cement soil roads with other studies or research

1) Durability and service life Many studies on rubber-cement soil roads (Cement Stabilized Soil with Rubber) found that the use of rubber mixed in cement soil can increase the flexibility and durability of the road, especially in environments with heavy rain or frequent impacts. A study in Thailand found that rubber-cement soil roads are more resistant to deterioration and can be used longer than conventional techniques, such as using cement soil alone or using pure rubber.

2) Reducing the use of other materials Research related to the use of waste materials, such as old tires, in the production of roads and other infrastructure has also shown that the use of rubber mixed in cement helps reduce the amount of rubber discarded in nature and increases the value of those materials, which supports the concept of a circular economy and reduces the problem of rubber waste.

3) Engineering properties testing Many studies focus on testing engineering properties, such as compressive strength and water absorption of rubber-cement soil. It was found that mixing rubber can help increase flexibility and reduce cracking of the road surface. It also helps increase durability in conditions of temperature changes that are too high or too low.

4) Environmental impact Many research studies have studied the impact of using rubber mixed materials on the environment, such as greenhouse gas emissions. It was found that using rubber mixed in cement soil reduces greenhouse gas emissions compared to using other materials such as plastic or non-recycled rubber.

5) Cost and economic efficiency Studies on cost savings in using rubber mixed cement soil roads show that although the initial cost may be higher than using normal cement soil, in the long run, using this mixed material can reduce maintenance and repair costs due to better durability. Comparing research results in this way will help us see the various benefits of using rubber mixed with cement soil in road development, including promoting sustainable use and reducing environmental impacts.

1.2 Loss of strength of rubber mixed cement soil roads

1) Material causes

Inappropriate mixing ratio, such as too little or too much cement or latex, which has a negative effect on the strength of the material.

The quality of latex Deteriorated latex or contaminants (e.g. ammonia or preservatives) can change the properties of the mixture.

Soil quality Soil with a high particle ratio or minerals that are not suitable for the pozzolanic reaction will reduce its strength.

2) Construction causes

Inadequate compaction If the compaction of the rubber-cement soil is not up to standard and has low density, it will directly affect the strength.

Inadequate mixing causes the material to not spread well, creating weaknesses in the structure.

Insufficient curing periods, improper curing, or use before the material has set will greatly reduce its strength.

3) Environmental causes

Humidity or groundwater. Water seeping from underground or from the surface causes the material to lose its binder and reduce its strength.

Rapid temperature changes, excessively high/low temperatures, or strong winds during curing cause cracks.

Chemical corrosion If the area contains chemicals such as salt or acid, it will accelerate the deterioration of the material.

2. Suggestions

2.1 Maintenance strategies for rubber-cement roads to have a long service life

1) Regularly inspect the road surface for abnormalities, such as cracks or damage from heavy use.

2) Repair the surface if cracks or deterioration are found. Appropriate repair materials, such as rubber mixed in the damaged areas, should be used.

3) Re-pave the road surface in cases where the road has a long service life and is severely deteriorated. Re-pave the road surface to increase durability and extend its service life.

4) Control traffic to limit heavy loads or excessively high traffic during certain times of the year to reduce road wear.

2.2 This research study is only for rural roads as a guideline for other road applications. Further studies should be conducted to make it suitable for the conditions of use.

2.3 Rubber-cement soil roads are suitable for rural roads, but not for main roads.

2.4 Rubber-cement soil can be adapted for the construction of sports fields that use dirt fields for competitions, such as running tracks, tennis courts, and playgrounds, etc.

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The preliminary development of lightweight hollow concrete blocks incorporating bamboo fibers.

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1. Abstract

This research presented the preliminary development of lightweight hollow concrete blocks incorporating bamboo fibers, with a focus on investigating the fundamental engineering properties of the blocks. The study aimed to assess the performance of these bamboo fiber-reinforced blocks by comparing their physical and mechanical characteristics against the criteria outlined in the Thai Industrial Standard (TIS 58-2017). Additionally, it sought to determine the optimal mix proportions of key materials—Portland cement, dust stone, and bamboo fibers—that would yield suitable structural properties for practical and efficient construction applications. Emphasizing sustainable development, the study promoted the use of environmentally friendly construction materials by exploring the viability of natural, locally sourced bamboo fibers as a reinforcement material. The materials used in the study included Portland cement as a binder, dust stone as a fine aggregate, and bamboo fibers processed through drying and grinding as a natural fiber reinforcement to enhance ductility, reduce cracking, and improve the mechanical performance of concrete. Prior to mixing, the properties of the materials were preliminarily analyzed through sieve analysis, and the Coefficient of Uniformity (Cu) and Coefficient of Curvature (Cc) were calculated to evaluate particle distribution, which directly affected compaction and concrete density. The dust stone had a Cu of 7.5 and a Cc of 1.30, while the bamboo fibers had a Cu of 4.33 and a Cc of 1.44, both within acceptable ranges for use in concrete mixtures. The concrete mix designs were based on a fixed cement volume ratio of 1, with dust stone varied at ratios of 2, 3, 4, and 5 parts by volume, and bamboo fiber content at 2 and 3 parts by volume. These mixes were tested under water-to-cement (w/c) ratios of 0.75 and 1.00 to study the influence of water content on concrete properties. All samples were tested for bulk density, water absorption, and compressive strength. In the group with a w/c ratio of 0.75, the 1:3:2 mix had a bulk density of 1,432.734 kg/m³; the 1:3:3 mix had 1,360.362 kg/m³; the 1:4:2 mix showed a density of 1,528.413 kg/m³ and water absorption of 276 kg/m³; and the 1:5:2 mix had a density of 1,605.207 kg/m³, water absorption of 213 kg/m³, and an average compressive strength of 4.16 MPa exceeding the minimum requirement of 4.10 MPa per TIS standards. For the mixes with a w/c ratio of 1.00, the 1:3:3 mix had a density of 1,355.257 kg/m³; the 1:4:2 mix had 1,411.837 kg/m³; the 1:4:3 mix had 1,396.224 kg/m³; and the 1:5:2 mix had 1,597.325 kg/m³. All mixtures had densities below 1,680 kg/m³, meeting the standard criteria for lightweight concrete blocks as specified in TIS 58-2560. From all experimental results, it was concluded that the 1:5:2 mix ratio with a w/c of 0.75 provided the most favorable outcomes in terms of low density, low water absorption, and high compressive strength meeting all standard requirements. The findings indicated that using an appropriate amount of bamboo fiber combined with precise control of the water to cement ratio directly enhanced the concrete's performance. This study demonstrated the potential of utilizing local materials such as bamboo fibers in the construction industry to reduce dependence on synthetic materials, lessen environmental impacts, and

support the development of sustainable construction materials within the framework of a circular economy and ecological design.

Keywords: Lightweight concrete block, dust stone cement, bamboo fiber

2. Introduction

Currently, the development of sustainable construction materials has gained widespread attention in both academic circles and the global construction industry. This is because the construction industry is one of the largest consumers of natural resources and a significant contributor to greenhouse gas emissions, which directly impact climate change (Naik & Moriconi, 2005). Therefore, reducing environmental impacts requires the development of materials that are recyclable, utilize local resources, and maintain efficient engineering performance. One of the continuously studied approaches is the development of lightweight hollow concrete blocks, which are ideal for reducing the overall weight of structures, are convenient for transportation and installation, and can be used in various construction applications. However, lightweight hollow concrete blocks often face issues such as brittleness, limited load-bearing capacity, and high-water absorption rates, which affect the product's lifespan, particularly in areas with humid conditions or rapid temperature changes.

To address these problems, several research studies have proposed reinforcing the concrete with natural materials, such as plant fibers, which possess good mechanical properties, are lightweight, and biodegradable. Specifically, bamboo fibers, which are abundant in Thailand, have high tensile strength (500–600 MPa) and appropriate elastic modulus (20–30 GPa) and can distribute well within concrete. Over the past 5-10 years, numerous studies by Thai researchers have supported this approach. For example, Kand Tanon and colleagues (2023) studied the workability and water absorption of recycled aggregate concrete reinforced with natural mineral fibers and found that natural fibers, such as palm oil fibers and coir, helped improve the properties of concrete. Similarly, Vichayapong Thaudao and Sathawat Hariratsapong (2022) studied the mechanical properties and microstructure of concrete mixed with nanosilica and natural mineral fibers, which significantly improved compressive strength and flexural strength. Additionally, Juthamas Laksanakit and colleagues (2023) developed low-cost fiber cement sheets using rubber wood ash mixed with natural fibers such as paper fibers and banana tree fibers, resulting in improved thermal insulation and sound absorption. Meanwhile, Sopha Wisitsak and colleagues (2022) experimented with bamboo fibers in white cement blocks, finding that bamboo fibers effectively increased toughness and reduced brittleness. These studies highlight the growing trend of developing fiber-reinforced natural concrete in Thailand, aiming to enhance engineering quality and reduce environmental impacts, which aligns with the objectives of this research. This study aimed to investigate the engineering properties of lightweight hollow concrete blocks reinforced with bamboo fibers, considering the effects on density, water absorption, and compressive strength, and comparing these results with the Industrial Product Standards (TIS 58-2560) to determine the appropriate mix ratio for practical use.

3. Materials Used in Research

Aggregates, also known as mixing materials, are the main components in the concrete production process. They consist of various materials that serve to fill the gaps between the binder and the reinforcement, helping the concrete achieve strength and durability over time. Aggregates play a crucial role in determining the physical properties of concrete, such as density, strength, and durability against environmental conditions. They serve several functions, such as increasing the density and strength of the concrete, enhancing its resistance to shrinkage and cracking. Fine aggregates are typically used to fill the gaps within the concrete structure, compacting the concrete, while coarse aggregates help improve the concrete's ability to withstand compressive forces. Generally, aggregates are classified into two main types:

1. Coarse Aggregate These are materials with larger particle sizes, such as large stones with a particle size greater than 4 mm.
2. Fine Aggregate These are materials with smaller particle sizes, such as fine sand or dust, with a particle size smaller than 4 mm.

Materials Used in Research Based on the explanation of the aggregates above, this research selected materials with appropriate properties for producing lightweight hollow concrete blocks. The main materials used in this research included Portland cement, dust stone, and bamboo fiber, as described below:

3.1 Portland Cement Type I Portland cement is the primary binder used in concrete production, binding all the mixing materials together into a solid mass. Portland Cement Type I, brand TPI, was used in this research. It conforms to the Industrial Standards TIS 15-1:2555 and ASTM C150. The key chemical components include tricalcium silicate (C_3S), which contributes to the early strength of concrete, and silica (SiO_2), which plays a role in the hydration reaction to form C-S-H, which enhances the concrete's strength.

3.2 Dust stone Dust stone is a fine aggregate produced from the stone crushing process. It has small particle sizes, making it ideal for filling the voids within the concrete structure. It helps improve the density and compressive strength of the concrete. The dust stone used in this research had a Coefficient of Uniformity (Cu) of 7.5 and a Coefficient of Curvature (Cc) of 1.30, both of which are suitable for use in concrete.

3.3 Bamboo Fiber Bamboo fiber is a natural material used to reinforce concrete, known for its high tensile strength of 500–600 MPa and an elastic modulus of 20–30 GPa. These properties help improve the durability and flexibility of the concrete, reduce brittle cracking, and increase toughness. Bamboo fiber is suitable for use in construction projects that aim for sustainability and environmental impact reduction. Its key physical properties include a low density (1.3–1.5 g/cm^3) and good water absorption. Chemically, it consists of cellulose, hemicellulose, and lignin. Cellulose provides strength, while logging adds flexibility. The use of bamboo fiber in concrete can improve its mechanical properties and enhance the sustainability of construction materials.

4. Research Methodology

This research focused on studying the basic engineering properties of lightweight hollow concrete blocks reinforced with bamboo fiber. The process began with the preparation of materials and conducting laboratory tests to assess the impact of mix ratios on the physical and mechanical properties of the concrete. The procedures were divided into the following main steps:

4.1 Material Preparation The materials used for producing the concrete blocks consisted of (1) Portland Cement Type I, brand TPI, which served as the primary binder and met the standards of TIS 15-1:2555 and ASTM C150. (2) Dust stone obtained from the Sila Phichai Stone Crushing Plant in Thong Saen Khan District, Uttaradit Province. The dust stone, screened to a particle size of 0 - 5 mm, was a finely crushed material free from soil or other contaminants, used as the mixing material. (3) Bamboo Fiber, a natural reinforcement material, was processed by cutting, grinding, and sieving through a 1-inch mesh before being sun-dried to reduce moisture content, ensuring good dispersion within the concrete mix.

4.2 Aggregate Characterization The dust stone and bamboo fiber were subjected to particle size analysis using Sieve Analysis, employing a sieve shaker. This process was used to calculate the Coefficient of Uniformity (Cu) and Coefficient of Curvature (Cc), which are engineering indices that help determine the quality of the material's particle distribution. Proper values of Cu and Cc help reduce voids within the concrete mix, leading to denser, stronger concrete with less potential for cracking over time.

4.3 Mix Design The mix design was formulated by using a constant ratio of Portland cement at 1 part by volume. The ratio of dust stone was varied to 3, 4, and 5 parts by volume, while the bamboo fiber was added at 2 and 3 parts by volume. These mixtures were prepared under Water to Cement Ratios (w/c) of 0.75 and 1.00 by volume, resulting in a total of 12 mix designs, as shown in the following table.

mix ratio formula	Cement	Stone Dust	Bamboo Fiber
S1	1	3	2
S2	1	3	3
S3	1	4	2
S4	1	4	3
S5	1	5	2
S6	1	5	3

Table 1: Concrete Mix Ratios (W/C = 0.75)

mix ratio formula	Cement	Stone Dust	Bamboo Fiber
S7	1	3	2
S8	1	3	3
S9	1	4	2
S10	1	4	3
S11	1	5	2
S12	1	5	3

Table 2: Concrete Mix Ratios (W/C = 1.00)

Tables 1 and 2 showed the material proportions of various mix designs, categorized by water-to-cement (w/c) ratios of 0.75 and 1.00, respectively. These tables provided details of the material proportions used in the production of lightweight hollow concrete blocks, with adjustments made to the amounts of dust stone and bamboo fiber in each mix. In each mix, the water-to-cement (w/c) ratio was varied at 0.75 and 1.00 to investigate the effects of changes in mix proportions on the mechanical properties of the concrete. A lower w/c ratio (0.75) was expected to increase the compressive strength of the concrete in the short term, but it would also result in higher density. In contrast, a higher w/c ratio (1.00) would improve the flexibility and distribution of materials, which in turn could affect properties such as water absorption resistance and long-term strength.

For each mix design, concrete samples were tested for various properties, including density, water absorption, and compressive strength, to determine the most suitable mix for producing concrete with optimal mechanical properties for different applications. These properties included compressive strength and durability under environmental conditions.

4.4 Molding and Casting of Test Samples The lightweight hollow concrete blocks were molded using a manual concrete block press, following the industrial product standard. Standard molds of 19 × 39 × 7 cm were used for compressive strength testing, while cylindrical molds with a diameter of 10 cm and a height of 6.3 cm were used for testing density and water absorption. Three samples were produced for each mix design, and each test type was conducted using three samples.

4.5 Curing of Concrete All concrete samples were cured under outdoor atmospheric conditions to simulate a real-world environment. The samples were placed in an open area with a roof to prevent direct exposure to sunlight and rain, while still being subjected to the temperature and humidity of the external environment throughout the curing period. Compressive strength testing was performed after curing for 7 and 28 days to assess the short-term and long-term development of compressive strength under conditions resembling actual use.

4.6 Concrete Property Testing The following tests were conducted to evaluate various properties of concrete:

1. Bulk Density Test Concrete was cast into cylindrical molds, and the saturated surface-dry weight, submerged weight, and oven-dried weight were recorded. The bulk density of the hardened concrete was calculated based on these measurements.

2. Water Absorption Test Cylindrical samples were immersed in water for 24 hours, and the weight before and after immersion was recorded. The water absorption rate was calculated by determining the increase in weight due to water absorption.

3. Compressive Strength Test A compressive strength test was conducted using a compression testing machine. The concrete block samples were tested at ages of 7 and 28 days, with the sample placed vertically. The maximum compressive strength the concrete could withstand was measured.

4.7 Data Analysis The data from all tests were analyzed and compared across the different mix designs. The performance of each mix design was evaluated based on the results for strength, low density, and low water absorption. These results were compared with the standards specified in TIS 58-2560 to ensure that the developed concrete blocks are structurally viable and environmentally sustainable.

5. Research Results

5.1 Particle Size Analysis of Dust stone and Bamboo Fiber

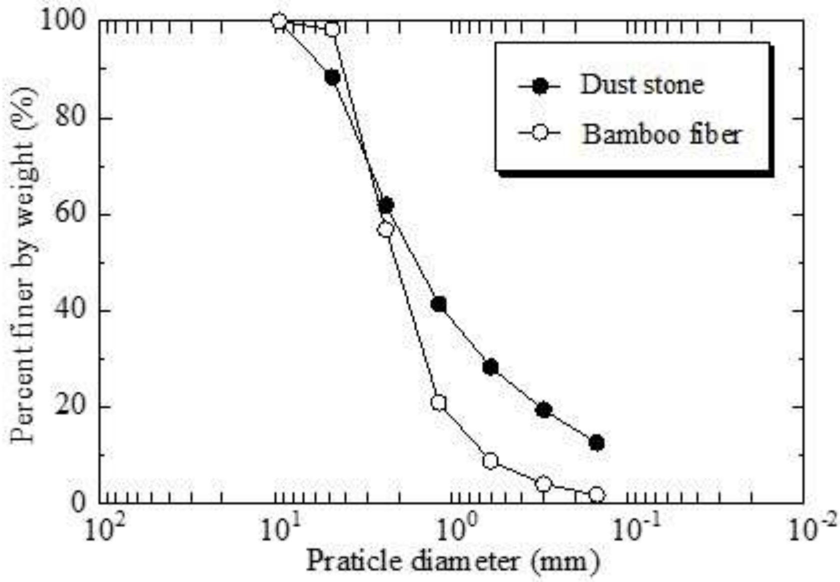
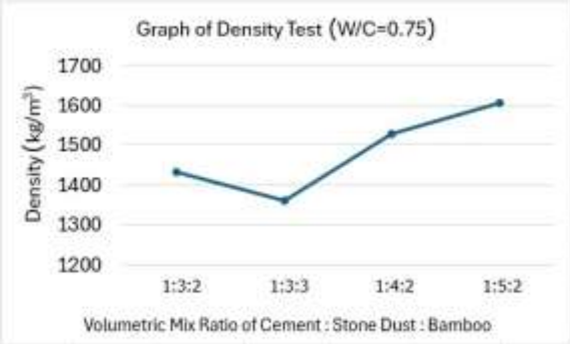


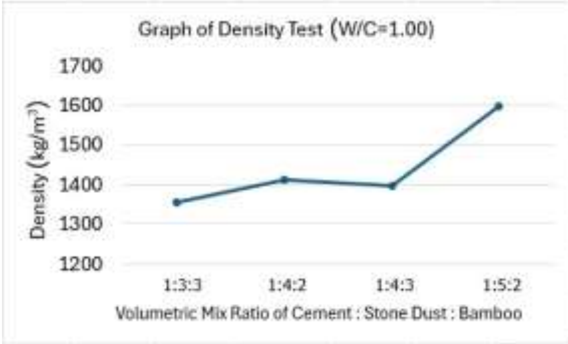
Figure 1: Graph showing the particle size distribution of dust stone and bamboo fibers

Graph Showing Particle Size Distribution of Dust stone and Bamboo Fiber Figure 1: Results of Sieve Analysis for Dust stone (Rock Dust) Cu = 7.50, Cc = 1.30 Interpretation: The uniformity coefficient (Cu) greater than 4 indicates a good particle size distribution, which allows the material to compact effectively. The coefficient of curvature (Cc) in the range of 1–3 indicates a suitable gradation, helping dust stone to fill the gaps between particles in the concrete mix. This improves the density and strength of the resulting concrete. Bamboo Fiber Cu = 4.33, Cc = 1.44 Interpretation: A Cu value greater than 4 indicates an appropriate particle size distribution, while the Cc value within the acceptable range reflects the ability of bamboo fibers to disperse well in the concrete mix. This prevents the fibers from clumping together, which enhances the reinforcement in the concrete, increasing its toughness and reducing cracking effectively. Overall Summary: From the analysis, both dust stone and bamboo fibers were found to have particle size distributions within the engineering standards for uniformity Cu) and curvature (Cc). Therefore, they are suitable as mixing materials in concrete, contributing to increased density, reduced voids within the concrete, and enhanced mechanical properties for lightweight concrete blocks.

5.2 Density Test

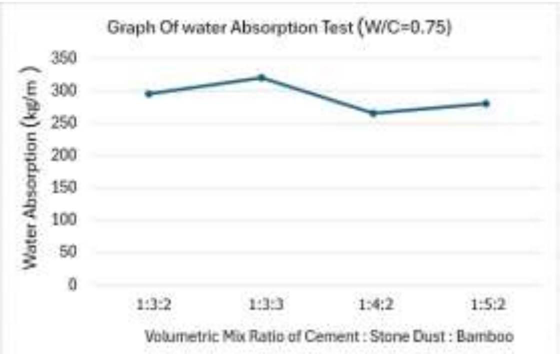
Figures 2–3: Results of Density Testing for Lightweight Hollow Concrete Blocks Reinforced with Bamboo Fiber The test was conducted using concrete mix formulas with water-to-cement ratios (w/c) of 0.75 and 1.00, which were practical and met the density standard set by the Industrial Product Standards (TIS 58-2560) of no more than 1,680 kg/m³. The graph shows that the mixes, which fall within the standard density range, were formable and met the criteria for real-world applications. The experimental results indicated that increasing the proportion of dust stone increased the density of the concrete, as dust stone could fill voids within the concrete mass efficiently. On the other hand, adding bamboo fiber, which is lightweight, reduces the density of the concrete. However, using a w/c ratio of 0.75 improved both the density and strength of the concrete, while a w/c ratio of 1.00 slightly decreased the density but improved the formability and material dispersion of the concrete. This study demonstrated that an optimal mix formula could control the density within the standard range and had potential for effective use in construction requiring lightweight materials.

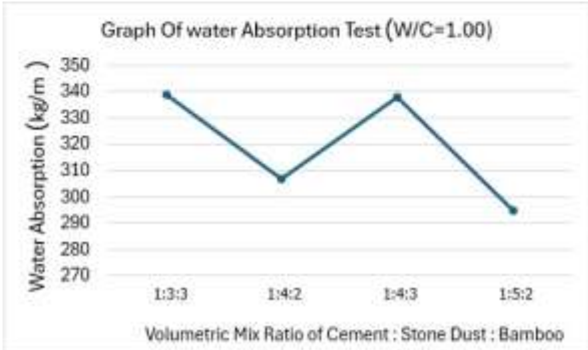




Figures 2-3: Graphs showing the density test results

5.3 Water Absorption Test of Concrete Blocks

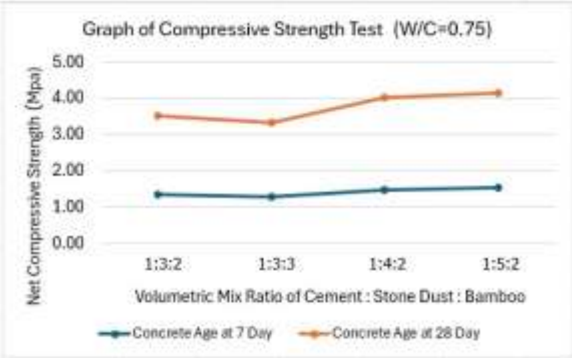


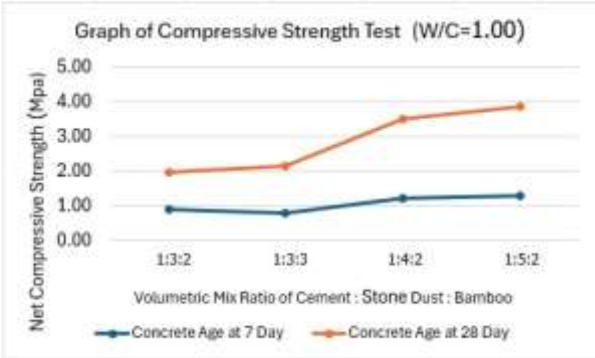


Figures 4-5: Graphs showing the water absorption test results

Figures 4-5: Results of Water Absorption Test for Lightweight Hollow Concrete Blocks Reinforced with Bamboo Fiber. The study found that the mix ratios capable of controlling the water absorption within the standard limits set by the Industrial Product Standards (TIS 58-2560), which specifies that the average water absorption of three blocks should not exceed 288 kg/m³, were only two mix formulas: the mixes with a water-to-cement ratio (w/c) of 0.75 and a mix ratio of dust stone and bamboo fiber of 1:4:2 and 1:5:2. These two formulas resulted in water absorption values of 271 and 280 kg/m³, respectively. These results indicated that a lower water-to-cement ratio (w/c = 0.75) and an appropriate proportion of dust stone in the mix played a crucial role in reducing water absorption in the concrete. The use of dust stone improved density and reduced the voids between aggregates, thereby reducing water penetration into concrete. On the other hand, increasing the amount of bamboo fiber led to increased water absorption, as the fibers are porous and can easily absorb water. If used in large quantities, the fiber could cause the water absorption to exceed the standard limits. From these tests, it can be concluded that selecting a mix formula with controlled water ratios and appropriate proportions of dust stone and bamboo fiber would result in lightweight hollow concrete blocks with a water absorption rate within the standard limits, making them suitable for use in outdoor environments.

5.4 Compressive Strength Test for Hollow Concrete Blocks





Figures 6-7: Graphs showing the compressive strength test results

Figures 6-7: Results of Compressive Strength Test for Lightweight Hollow Concrete Blocks Reinforced with Bamboo Fiber The study found that the mix formula with a water-to-cement ratio (w/c) of 0.75 and a mix ratio of 1:5:2 yielded an average compressive strength of 4.16 megapascals (MPa), which slightly exceeded the minimum required strength of 4.14 MPa as per the Industrial Product Standards (TIS 58-2560). This indicates that the concrete in this mix had sufficient strength and could be used in outdoor environments. However, adding bamboo fiber to the concrete resulted in a reduction in compressive strength as the amount of bamboo fiber increased. Bamboo fibers are lightweight and flexible, which lowers the density of the concrete. This reduction in density increases the voids within the concrete, leading to decreased compressive strength because the concrete's ability to resist pressure is diminished as the volume of gaps between aggregates increases.

6. Discussion and Conclusion

This study aimed to analyze the engineering properties of lightweight hollow concrete blocks reinforced with bamboo fibers, by evaluating the effects of material mix ratios, water-to-cement ratio (w/c), and the inclusion of dust stone on the concrete's properties such as density, water absorption, and compressive strength. The most effective mix formula was found to be 1:5:2 with a w/c ratio of 0.75, which resulted in the lowest density (1,432.73 kg/m³), the lowest water absorption (213 kg/m³), and the highest compressive strength (4.16 MPa), which slightly exceeded the minimum required strength of 4.14 MPa as per TIS 58-2560. In terms of density, increasing the amount of bamboo fiber reduced density because the fibers are lightweight and created more voids within the concrete, while the addition of dust stone helped fill these voids, increasing the density. Regarding water absorption, the mix with a w/c ratio of 0.75 showed the lowest absorption. However, an excessive amount of bamboo fiber increased water absorption due to the fiber's water-absorbing properties, while dust stone helped reduce water penetration by tightening the material structure. For compressive strength, bamboo fibers helped reduce brittleness and increase the toughness of the concrete. However, too much bamboo fiber decreased the compressive strength because the fibers could not withstand compressive forces as well as dust stone. On the other hand, the addition of dust stone significantly increased the compressive strength. The w/c ratio was found to have a direct effect on the concrete's properties: when the w/c ratio was high (1.00), both density and compressive strength decreased, while water absorption increased due to excess water creating pores in the concrete. Therefore, controlling the w/c ratio is a crucial factor that directly affects the concrete's properties. In conclusion, balancing the amount of water, bamboo fiber, and dust stone is essential to develop lightweight hollow concrete blocks that meet the required standards for strength, durability, and sustainability. The mix formula 1:5:2 with a w/c ratio of 0.75 demonstrated outstanding performance in all aspects.

Conclusion The incorporation of bamboo fibers, combined with proper control of mix ratios and the use of dust stone in appropriate quantities, significantly improved the properties of lightweight hollow concrete blocks. The mix formula of 1:5:2 with a w/c ratio of 0.75 provided the best results in terms of low density, high compressive strength, and low water absorption, in line with the requirements set by TIS 58-2560. This shows the potential for using the material as a durable and environmentally friendly building product for the long term.

7. Recommendations

1. The bamboo fiber preparation process should be improved, such as by drying or coating, to enhance compatibility with concrete.
2. Further study should be conducted on additional mixed ratios, particularly in the intermediate range, to find the most optimal formula for strength and weight.
3. Consider using water reduced agents or other additives, such as fly ash, to further improve the properties of the concrete.
4. It is recommended to replace manual block pressing machines with hydraulic block press systems to produce blocks with more consistent density and higher quality.

8. Acknowledgements

This research was successfully completed, and I would like to express my gratitude to my advisor and various institutions, including the Department of Public Works and Town & Country Planning, Uttaradit Province, for providing the laboratory testing facilities. I would also like to thank the Uttaradit Provincial Administrative Organization for their support in material testing, and the University of Pathum Thani for their continuous support and encouragement in the master's degree research.

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Defining Standards for Small-Scale Durian Storage Buildings for Commerce Trade of Durian Products in Thailand

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Abstract

This study presents a novel framework for establishing standardized design and construction cost guidelines for small-scale durian storage facilities in Thailand. The research addresses persistent challenges related to incomplete construction projects and the lack of cost control mechanisms in agricultural infrastructure development. The study aimed to: (1) examine the process of determining appropriate design and cost standards for durian storage buildings; (2) develop standardized building models and corresponding cost benchmarks to assist farmers in making informed construction decisions; and (3) define cost estimates aligned with building designs while accounting for individual farmer profiles. A mixed-methods approach was employed. Quantitative data were collected through structured questionnaires administered to 110 farmers, while qualitative insights were obtained via in-depth interviews with 18 key informants, including experts, academics, contractors, and government officials. The primary research instrument was a five-point Likert scale questionnaire. Descriptive statistics, including frequency distribution, percentages, mean, and standard deviation, were used to analyze the data.

The findings revealed that most farmers preferred buildings with open-sided walls, steel columns, and concrete floors, with a usable floor area of 400–600 square meters. The acceptable construction cost was in the range of THB 4,501–5,000 per square meter. The most critical factor was "building design" (mean = 4.80), followed by "investment cost" (mean = 4.77) and "economic return" (mean = 4.75). These results informed the development of a standardized construction manual comprising three building models, recommended usable space, guidelines for preparing the Bill of Quantities (BOQ), material lists, labor cost estimates, and systematic profit calculations. The study recommends updating regional cost benchmarks every 1–3 years and suggests state-supported mechanisms such as low-interest loan schemes and promoting environmentally friendly materials. This research is a practical prototype for enhancing sustainable agricultural infrastructure in Thailand.

Keywords: Durian dormitory design, Durian dormitory construction price standards, Economic returns, Agricultural crops

Introduction

Thailand is recognized as an agricultural country with a diverse range of produce. Agriculture has long served as a primary occupation for the Thai population and plays a critical role in the national economy, particularly in the export sector. Thai farmers—especially those cultivating fruit such as durian, mangosteen, rambutan, longkong, and longan—have increasingly required dedicated facilities for post-harvest storage and trade of their produce. The use of such facilities shares functional similarities with public infrastructure in the education sector, such as libraries, which emphasize efficient space utilization and resource management (Banla, 2012). However, many farmers have encountered challenges in constructing these buildings, primarily due to underquoted bids by contractors, which often result in incomplete construction. These issues have had adverse effects on both the local economy and the long-term financial stability of the farming community.

According to information obtained from the Chanthaburi Farmers' Association, during the period from 2016 to 2021 (B.E. 2559–2564), several groups of farmers were affected by the failure to complete the construction of agricultural produce collection buildings. These cases were categorized into three groups based on construction cost levels, as illustrated in Table 1.

Table 1. Groups of Farmers Affected by Incomplete Construction Projects during 2016–2021

Affected Farmer Groups (Classified by Average Construction Cost)	Average Construction Cost (Million THB)	Completed Work (%)	Remaining Work Value (THB)
Group 1: 6 Farmers	1.0	25%	750,000
Group 2: 4 Farmers	1.5	50%	750,000
Group 3: 10 Farmers	2.0	25%	1,500,000

Source: Chanthaburi Farmers' Association, 2565 (B.E)

Based on the aforementioned data, the economic loss resulting from incomplete construction projects affecting farmers was estimated at approximately 32 million Thai Baht. This issue underscores the critical need to establish standardized building designs and appropriate construction cost benchmarks to support farmers in making informed and effective investment decisions.

Previous international studies have emphasized the importance of utilizing standardized Bills of Quantities (BOQ) and clear construction cost estimation methodologies to reduce discrepancies and enhance transparency between project owners and contractors (Brook, 2004; Jiamthirasakul, 2013). Furthermore, other international research has proposed agricultural building designs that align with climate-specific conditions, sustainable material use, and safety standards suitable for export-oriented operations (Chittiwusurat & Rattanathavorn, 2013).

Accordingly, this study aimed to investigate farmers' needs regarding building design and construction pricing, using Chanthaburi Province as a case study. The research proposes three building models—200, 400, and 600 square meters in usable area—designed to meet the actual demands of local farmers, while offering a practical foundation for the development of standardized and replicable construction guidelines in the agricultural sector.

Scope of Research

This study focused on data collection from a sample group located in Chanthaburi Province, one of the primary durian-producing regions in Thailand. The research emphasized the analysis of local farmers' needs in terms of building design and construction costs for small-scale facilities used to store and trade durian products. The results serve as a foundation for future efforts to establish standardized building guidelines and pricing frameworks in the agricultural sector.

The study was subject to the following limitations:

1. Data collection was conducted between February and September 2024, during Thailand's post-COVID-19 recovery period. This may have influenced the economic status of farmers as well as the volatility of construction material prices.
2. The study area was limited to Chanthaburi Province. While it is a central durian production zone, it does not represent all agricultural regions in Thailand, which may limit the generalizability of the findings.
3. Contextual differences in climate, technology, and economic systems constrained the application of international building design and cost standards. Thus, such references were used primarily for comparative and adaptive purposes rather than for direct implementation.

Benefits of the Research

1. A set of suitable building models for small-scale durian storage facilities intended for the purchase and sale of durian products.
2. Standardized construction cost estimates for small-scale durian storage buildings to support budgeting and planning.
3. Data that enables project owners to select contractors more effectively and reduce construction-related risks.
4. A practical reference for future academic research and project development in agricultural infrastructure.
5. A comprehensive design manual for small-scale durian storage buildings, including technical specifications and construction guidelines.
6. A framework for comparing international agricultural building standards and adapting them to fit the Thai context.
7. Resources to support transparent negotiations between farmers and contractors based on standardized design and cost information.
8. A prototype case study that can be replicated in other provinces for developing agricultural building standards nationwide.

Research Methodology

This study employed a mixed methods research design, structured according to principles of behavioral science research that emphasize validity, instrument clarity, and data verification through multiple procedures to ensure research credibility and practical applicability (Sincharu, 2010). Both quantitative and qualitative data were utilized to support the development of standardized building models and cost guidelines for small-scale durian storage facilities used in post-harvest trading in Thailand.

For the qualitative analysis, international agricultural building standards were used as a preliminary conceptual framework. These included design principles from agricultural development agencies in Japan and cost estimation methods based on standardized international BOQ (Bill of Quantities) practices. This approach enabled comparative and context-specific assessment of building requirements tailored to the Thai agricultural context.

Population and Sample

The study involved two main population groups:

- Group 1 (Quantitative Research): A total of 152 farmers residing in Chanthaburi Province, distributed across 10 districts.
- Group 2 (Qualitative Research): Experts, academics, and construction contractors responsible for small-scale durian storage facility projects, along with government officials who possessed no less than five years of experience and expertise in relevant fields.

Sample Group

Group 1, representing the quantitative population, consisted of 152 farmers residing in Chanthaburi Province, covering all 10 districts. The participants were selected using proportional stratified random sampling, with the sample size calculated based on Yamane's formula (1967) as follows:

$$n = \frac{N}{1 + N(e)^2}$$

The sample size was calculated from a total population of 152 individuals, with a margin of error accepted at 0.05, ensuring a confidence level of 95%. By applying Yamane's formula, the resulting sample size was determined as follows:

$$n = \frac{152}{1+152(0.05)^2} \qquad n = 110$$

A final sample size of 110 participants was determined and selected from the total population. The sampling process targeted farmers residing in Chanthaburi Province, ensuring representation from all 10 districts. As a result, the study obtained a total of 110 farmers as the sample group, as presented in Table 2.

Table 2: Sample Distribution from Group 1 Population 4

District in Chanthaburi Province	Number of Farmers	Percentage of Population (%)	Number of Samples
1) Mueang Chanthaburi	14	9	10
2) Khlung	11	7	8
3) Tha Mai	23	15	16
4) Pong Nam Ron	15	10	11
5) Makham	8	5	5
6) Laem Sing	6	4	4
7) Soi Dao	10	7	8
8) Kaeng Hang Maeo	24	16	18
9) Na Yai Am	14	9	10
10) Khao Khitchakut	27	18	20
Total	152	100	110

Group 2, used for qualitative data collection, consisted of key informants selected based on their qualifications, expertise, and professional experience, ensuring their capacity to provide information that was directly aligned with the objectives of this research. A total of 18 participants were included in this group, comprising three experts and academics, 14 agricultural facility construction contractors, and one government official.

The data were collected through in-depth interviews using purposive sampling based on the Delphi technique proposed by Macmillan (1971), which recommends that the number of participants should not be less than 17. All informants selected for the interviews possessed a minimum of five years of experience and expertise in their respective fields relevant to the study.

Sources of Data

The data were obtained from farmers across all districts of Chanthaburi Province, as well as from experts, academics, construction contractors involved in agricultural product trading facilities, and government officials within the province. Additional information was gathered from various documents relevant to the study. The data were categorized as follows:

1. **Primary Data**: Collected through structured questionnaires and in-depth interviews.
2. **Secondary Data**: Derived from academic literature, related research studies, and official data from government agencies.

Research Instruments

The instruments used for data collection in this mixed-methods research consisted of two main tools:

1. Quantitative Questionnaire: One structured questionnaire comprising five sections was used. It applied a 5-point Likert scale. The instrument was validated for content accuracy, achieving an Index of Item-Objective Congruence (IOC) of 0.64, and its reliability was confirmed with a Cronbach's Alpha coefficient of 0.81, which indicated an acceptable level of internal consistency.
2. Semi-Structured Interview: This tool was designed to collect qualitative data. The interview guide was reviewed and approved by the academic advisor to ensure its appropriateness and relevance to the research objectives.

Data Collection

Quantitative data were collected between February and September 2024 through the distribution of questionnaires to the sample group. For qualitative data, in-depth interviews with key informants were conducted during November and December 2024.

Data Analysis

Descriptive statistics—including mean, percentage, and standard deviation—were used to analyze the quantitative data, based on a five-point Likert scale. For qualitative data, content analysis was employed by organizing responses into thematic categories that aligned with the research objectives. Key insights were then synthesized to reflect the perspectives of each informant.

To enhance the credibility and trustworthiness of the qualitative findings, several validation techniques were applied:

- Triangulation: Data were compared across multiple expert groups—including academics, contractors, and government officials—to ensure consistency and alignment of perspectives.

Member Checking: In cases involving complex information, data were reviewed and verified with the interviewees to confirm accuracy and intent

- Audio Recording and Transcription: All interviews were audio-recorded and transcribed systematically to enable traceability and verification during the analysis process.

These techniques contributed to the analytical rigor and academic reliability of the qualitative outcomes.

Result

The findings revealed that the process of standardizing the design and construction costs of small-scale durian storage buildings significantly influenced farmers' decision-making, particularly in terms of operational efficiency and return on investment. The building designs were categorized into three types based on usable floor area: 200, 400, and 600 square meters, in order to address the varying needs of the sample group.

Quantitative data analysis indicated that the majority of respondents were male, aged between 41 and 50 years, with educational attainment below the bachelor's level. Most were full-time farmers with an average monthly income exceeding 40,000 THB. Their farmland exceeded 15 rai (approximately 6 acres), and annual durian yields were greater than 15 tons, with the Monthong variety being the most commonly grown. In terms of building preferences, most farmers favored designs with 400–600 square meters of usable space, steel columns, concrete floors, and open-sided walls. The preferred construction cost range was between 4,501 and 5,000 THB per square meter.

According to the five-point Likert scale, farmers rated all factors at the "highest" level of importance. The top-rated factor was building design (mean = 4.80), followed by financial and investment considerations (mean = 4.77), and economic return (mean = 4.75). Usability also received a high rating (mean = 4.52). Furthermore, comparative analysis based on land size showed that farmers with more than 20 rai of farmland placed significantly greater importance on "expandability" and "long-term investment value" compared to those with less than 10 rai (p-value < 0.05).

Qualitative findings from expert interviews indicated that key factors in designing agricultural buildings include functionality of space, future expandability, suitability of materials for the climate, legal compliance, and cost efficiency in both the short and long term. Experts also recommended establishing transparent standard pricing, with cost data being updated every one to three years to reflect market conditions and material prices.

Additional suggestions from experts included developing a comprehensive design manual with building plans, material and labor cost tables, and decision-support tools for farmers. The government was advised to establish consultation units, promote clean construction technologies, encourage the use of local materials, and develop a centralized knowledge-sharing database. Collectively, these measures would support farmers in building sustainable agricultural infrastructure.

Discussion and conclusions

The findings from this study on the development of standardized small-scale durian storage buildings for post-harvest trading in Thailand suggest that most farmers preferred structures that were durable, easy to use, and adaptable for future expansion. Effective building design should consider topography, functional space utilization, and investment value. These preferences aligned with expert recommendations emphasizing that both design and pricing standards must reflect actual construction costs.

In particular, buildings with roof coverage and open-sided walls, combined with proper ventilation systems, were seen as optimal. These features not only improve operational efficiency but also help preserve the quality of durian products, thereby supporting compliance with export standards. The integration of structural flexibility and climate-resilient materials is therefore essential for agricultural buildings intended for both domestic use and international markets.

Overall, the study contributes a practical framework for understanding farmers' infrastructure needs and provides guidance for creating cost-effective and scalable building models that support sustainable development in the agricultural sector.

Building Model Overview:

The illustration presents an overview of the three building models, which differ primarily in terms of usable floor area.

Figure 1. Overview of the three proposed building models for small-scale durian storage, distinguished by usable floor area (200, 400, and 600 square meters).

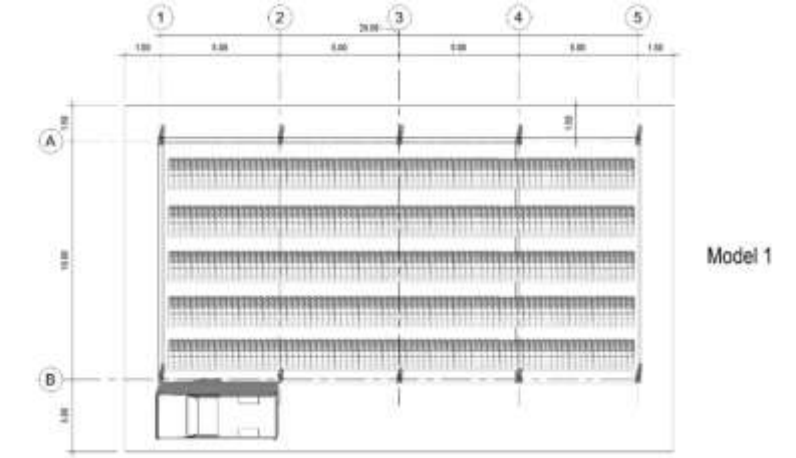
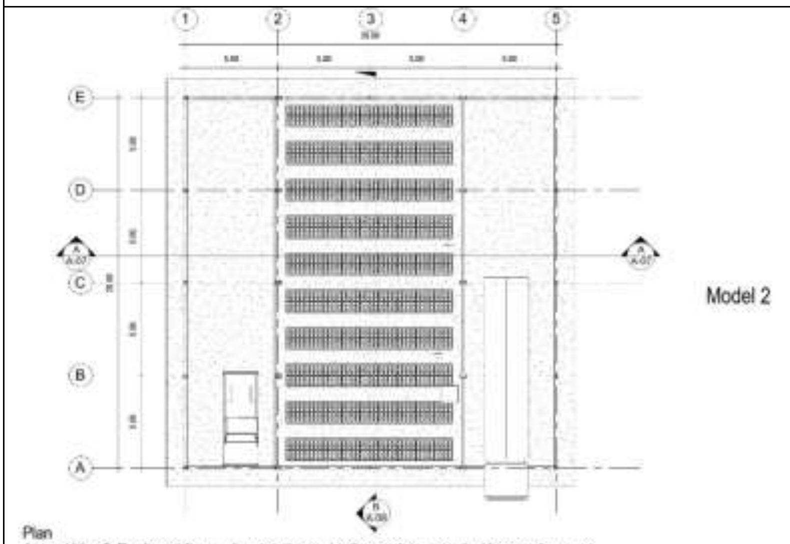
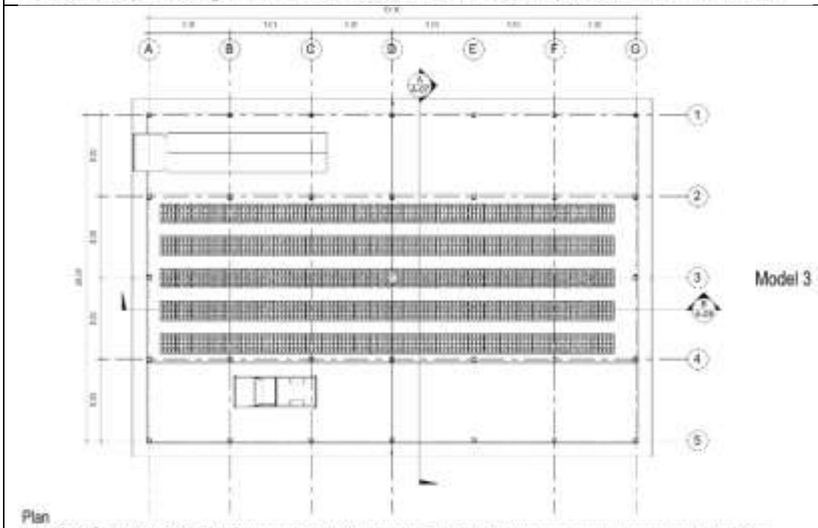
 Plan Area 200 m² Designed for small-scale production with a storage capacity of no more than 5 tons. The cost of the spread footing foundation is THB 1,100,000, while the cost of the piled foundation is THB 1,060,000.	**Model 1 – 200 m²** • Small-scale storage capacity (≤ 5 tons) • Open storage area with service zone • Suitable for limited harvest and land • Spread footing cost: THB 1,100,000 • Piled foundation cost: THB 1,060,000
 Plan Area 400 m² Designed for medium-scale production and equipped with a sorting area. The cost of the spread footing foundation is THB 1,610,000, while the cost of the piled foundation is THB 1,670,000.	**Model 2 – 400 m²** • Medium-scale storage capacity • Includes sorting area • Supports post-harvest handling • Spread footing cost: THB 1,610,000 • Piled foundation cost: THB 1,670,000
 Plan Area 600 m² Designed for high-volume production, featuring dedicated loading zones and export management capabilities. The cost of the spread footing foundation is THB 1,920,000, while the cost of the piled foundation is THB 2,030,000.	**Model 3 – 600 m²** • High-volume storage for commercial use • Dedicated loading and export zones • Designed for exporters and logistics integration • Spread footing cost: THB 1,920,000 • Piled foundation cost: THB 2,030,000

Figure 2. Floor Plans and Comparative Features of the Three Small-Scale Durian Storage Building Models

Suggestion

Based on the findings of this study, the following recommendations are proposed for government agencies:

1. Develop a standardized design manual for small-scale durian storage buildings, including regional model plans and reference cost estimates.
2. Establish a centralized database of updated construction material and labor costs, reviewed annually.
3. Promote the use of local materials and clean energy solutions in agricultural storage facilities.
4. Create advisory units to support farmers in building design and cost management.
5. Facilitate access to low-interest financing schemes to support the development of sustainable agricultural infrastructure.

Suggestions for Future Research

Based on the findings of this study, several areas warrant further investigation to enhance the design and cost standards of small-scale durian storage facilities, ensuring they are more practical, regionally adaptable, and comprehensive in scope. Suggested areas for future research include:

1. Evaluating the long-term cost implications of construction materials, including maintenance, repair, and material lifespan.
2. Assessing the cost-effectiveness of renewable energy systems in relation to installation and long-term operational costs.
3. Investigating region-specific building design strategies suitable for various environmental conditions across Thailand.
4. Examining applicable safety standards for agricultural storage buildings.
5. Exploring the feasibility of centralized agricultural produce collection and distribution centers.
6. Studying the environmental impact of construction materials used in agricultural buildings.
7. Comparing energy-saving performance between open-air and enclosed structures during the rainy season.

Nonetheless, this study has certain limitations. Field data were collected exclusively from Chanthaburi Province, which, although a major durian-producing region, may not represent the entire agricultural landscape of Thailand. Additionally, the economic context during the post-COVID-19 recovery period may have influenced farmers' investment decisions. These limitations should be taken into account when applying the findings to other settings.

Acknowledgements

The researcher would like to express my sincere gratitude to all the farmers in Chanthaburi Province who participated in this research by completing the questionnaires and providing valuable insights. I am also deeply grateful to the experts, academics, entrepreneurs, and government officials who generously shared their time and experience. Their contributions were instrumental in shaping the research direction and ensuring the accuracy of the design framework and data analysis.

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Electricity potential from wind generator by trains opration

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Abstract

This research is to investigate the potential for electricity generation from wind energy produced by the operation of electric trains in the mass transit system. It focuses on analyzing the relationship between the train's speed, headway distance, and the amount of wind energy that can be harnessed to generate electricity. The experiment was divided into four time periods (Time 1–4), which exhibited different patterns of wind energy production. It was found that when the train moves at the optimal speed and frequency, it generates a wind force sufficient to efficiently produce electricity. The experiment's results indicated that the average power generated was 256 watts per unit (1 cycle per period), while the wind turbine's efficiency reached up to 49.87%. Additionally, the average wind speed was 68 kilometers per hour, with a train-to-wind speed ratio of 1:1.

According to the research results, the operation of electric trains shows promise as an alternative source of electricity in station areas, particularly in elevated stations where wind can circulate freely. There are also further recommendations for developing a prototype of a real wind power generation system, including the design of energy storage systems and economic value analysis, to promote the sustainable use of clean energy in the public transportation system.

Keywords: Wind Energy, Skytrain, Power Generation, Renewable Energy, Mass Transportation

Introduction

Currently, the concept of renewable energy has received widespread attention as it is a crucial approach to reducing dependence on fossil fuels and minimizing environmental impact. Wind energy is regarded as one of the clean renewable energy sources and has the potential to generate electricity in a sustainable manner. However, most wind power generation today still relies on natural wind energy, which is unpredictable and difficult to control.

Figure 1 Bangkok Mass Transit map.

This research aims to study the potential for generating electricity from the wind created by the movement of electric trains, particularly in public transportation systems that are continuously in operation and operate at high speeds. This generates a wind flow that can be harnessed for electricity generation. With a proper design of the energy storage and conversion system, (Oñederra , O et al., 2020).

This study focuses on analyzing the amount of wind energy generated by the operation of trains at various speeds, such as 60, 80, and 120 kilometers per hour, while assessing the potential to generate electricity for various systems within the sky train station, including lighting systems. This represents a new approach to efficiently harness latent energy generated during operation.

Therefore, this research aims to identify ways to maximize the use of wind energy generated by electric trains and to develop alternative, environmentally friendly power generation systems for future public transportation.

Research Methodology

In this study, experiments and quantitative data were developed to assess the potential for generating electricity from wind energy produced by electric trains in suburban mass transit systems. (Sindhuja, B. 2013). The research methodology is divided into the following steps:

1. Determination of the Experimental Area The area in the experiment was designated as an elevated station of the suburban rail system, characterized by high-speed train operations and continuous movement. A station with a headway frequency of 8-15 minutes was selected to allow for data collection in various ways continuously.

2. The simulation is divided into two types: Normal Operation and Express Operation, using different speeds of 60, 80, and 120 kilometers per hour to compare results and systematically study the impact on wind energy production in each case.

Figure 2 Express train.

3. Installation and measurement of wind energy The installation of wind power generation equipment, such as small wind turbines or wind force sensors, occurs at the source of the station platform, where the sky train begins to slow down to enter the station..

- Wind Speed
- Electricity Output
- Frequency of wind generated per cycle

4. Data Analysis The data obtained from the experiment will be analyzed comparatively using descriptive statistics to determine the relationship between train speeds, wind speed, and the amount of electricity produced. In addition, a comparison between the two modes of operation will be made to evaluate the most suitable model for practical use.

5. Evaluation of Potential Usage The data from the experiment will be utilized to assess the potential for electricity generation that can be applied in facilities such as lighting systems, announcement systems, or other electronic systems, as well as to evaluate the initial economic value of the wind power generation system.

Figure 3 Rail way structure (station and track).

Result

1 The results of wind power generation from the operation of the electric train during the period (Time 1–4) are shown in Figure 4 as follows:

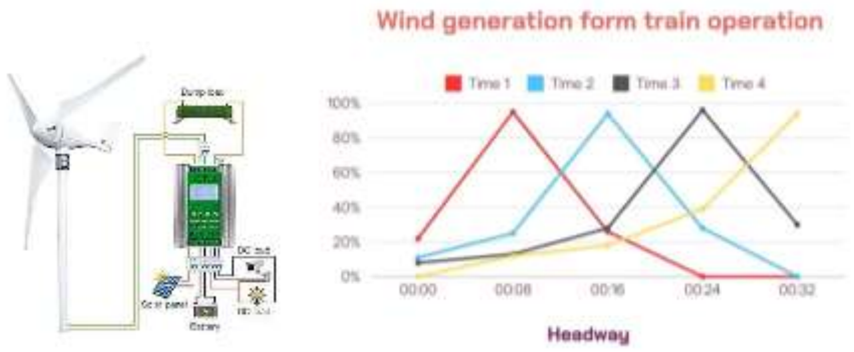

Figure 4 Wind energy production from electric train operation during the period (Time 1–4)

According to the comparative data on wind energy production from Time 1 to Time 4, a clear difference is evident. During Time 1 (red line), wind power production peaked at 00:08 at around 100% and then dropped so rapidly that there was almost no production during the period of 00:24–00:32. In Time 2 (blue line), starting from low production levels, it gradually increased to a peak of approximately 90% at 00:16 before continuing to decline. In Time 3 (black line), production began to increase from the start and peaked at 00:24 at about 100% before significantly decreasing after the peak. This indicates that the value of energy production has risen steadily and remained high until its peak at 00:32, suggesting that wind power production has not yet reached its saturation point by the end of the graph. The characteristics of each period imply that headway has a direct impact on the efficiency of wind energy production from the operation of the sky train. (Asian Development Bank.2016).

Figure 5 Location for wind energy test

2 illustrates the results of electricity generation from the operation of the electric train as outlined below

Figure 6 Activities for test

According to the evaluation of the wind power generation system by the electric train, it has been found that the system can produce an average of 256 watts of power per unit, indicating that its energy generation potential is consistent, stable, and satisfactory. The speed ratio between the train and the wind load is 1:1, meaning that the speed of the train is directly related to the wind speed produced. Consequently, the system can generate energy continuously and efficiently. The measured average wind speed is 68 kilometers per hour (though the image shows it in km/s, likely due to a typo), which is considered appropriate for the operation of small wind turbines. Additionally, the system has a wind turbine efficiency of up to 49.87%, demonstrating its capability to convert wind energy into electricity effectively and cost-efficiently for future use in public transportation or sky train stations.

Discussion and conclusions

According to the study on the potential of wind energy generated by the operation of electric trains, it has been found that the movement of trains can efficiently generate wind force, converting this wind force into electrical energy at a satisfactory level. The average power produced is 256 watts per unit, which is deemed appropriate for use in station systems such as lighting or other electronic applications. (Science Direct. 2019)

Figure 7 Electricity Generation Results

Periodic data analysis (Time 1–4) reveals that each time period exhibits a distinct pattern of energy production. Some periods are marked by rapid increases and decreases (Time 1), while others demonstrate a continuous upward trend (Time 4.This variation influences the amount of wind generated and impacts the power generation capacity.

According to the Performance Dashboard, the speed ratio between the train and the wind is 1:1. This means that the speed of the train can transfer energy directly to the wind turbine, which has an average wind speed of 68 km/h, suitable for small wind turbines, and the efficiency of these turbines is 92%.

Suggestion

The suggestions from this research propose developing and trialing a small wind power generation system at an actual sky train station. To study the system's performance in the real operating environment and compare it with simulation results, the scope of the study should expand by adding the locomotive model and the train's speed range. This will allow for a more comprehensive assessment of energy production potential, especially with trains that experience higher wind loads, such as express trains or newer models. Additionally, energy storage technologies, such as battery systems or grid connections, should be examined to utilize energy when there are no trains passing through, and a cost-reward analysis should be conducted to evaluate the system's economic feasibility for long-term investment. Finally, the potential impacts on utility and passenger safety, such as noise, vibration, or effects on the electrical system within the station, should be assessed to design a cost-effective and safe system. (International Journal of Engineering Research and Technology 2013).

Figure 8 Example equipment to apply the future research

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EXTERNAL ENVIRONMENTAL FACTORS INFLUENCING THE DEVELOPMENT OF ENVIRONMENTALLY SUSTAINABLE HOUSING ESTATE PROJECTS IN BANGKOK AND METROPOLITAN AREAS

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Abstract

This research article aims to 1) Investigate the external environmental factors associated with the development of environmentally sustainable housing estate projects, and 2) Examine the external environmental factors influencing the implementation of such projects in Bangkok and its metropolitan areas. A qualitative research methodology was employed, incorporating SWOT analysis and strategy formulation through the TOWS Matrix. The study is framed within the context of the housing development process, integrating the principles of Sustainable Development Goals (SDGs), Environmental, Social, and Governance (ESG) practices, and PESTEL analysis. Data were collected through in-depth interviews with 26 key informants from the private sector, public agencies, and academia.

The research findings reveal that The external environment influencing sustainable housing development in Bangkok and surrounding areas encompasses several constraints: ambiguous government policies, high initial costs of green technologies, fragmented infrastructure integration, and regulatory limitations. Nevertheless, there are emerging opportunities arising from increasing demand for sustainable housing, technological advancement, and growing consumer environmental awareness. The synthesis from the TOWS Matrix yields four core strategies: 1) SO Strategy – Promote design approaches that integrate clean technologies and comply with LEED/TREES green building standards. 2) ST Strategy – Utilize renewable energy and resource management systems to mitigate environmental risks. 3) WO Strategy – Establish dedicated green innovation funds to support small- and medium-sized developers in accessing eco-friendly technologies. 4) WT Strategy – Foster public–private collaboration mechanisms and strengthen regulatory frameworks to ensure future policy enforcement. These strategies highlight the necessity of integrating environmental engineering and technological knowledge into sustainable urban development strategies, enabling housing estate projects to effectively adapt to and thrive within complex external environments.

Keywords: External Environmental Analysis, Housing Estates in Bangkok and Metropolitan Areas, Environmentally Friendly, Sustainable Development (SDGs), Sustainable Business Practices (ESG).

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Introduction

The rapid urban expansion in Bangkok and its surrounding metropolitan areas has led to the accelerated development of housing estate projects. While these developments have addressed the growing residential demand, they have concurrently intensified environmental challenges, including air pollution, urban flooding, loss of green space, and unsustainable resource consumption (Edelman, 2022). The uncontrolled urban sprawl, coupled with the lack of environmentally-oriented urban planning, has transformed suburban areas into hubs of large-scale construction activities—particularly housing estates—resulting in significant disruptions to urban ecosystems and long-term sustainability. The concept of environmentally sustainable housing estates, or **"Sustainable Residential Development,"** has gained traction as an alternative approach that minimizes environmental impacts while enhancing residents' quality of life. This is achieved through energy-efficient design, integrated waste management systems, allocation of green spaces, and the selection of environmentally friendly construction materials. The real estate sector has become increasingly aware of its responsibility toward environmental and social outcomes and has begun adopting frameworks such as the Sustainable Development Goals (SDGs) and Environmental, Social, and Governance (ESG) principles to guide project development. Notably, SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action) have been explicitly recognized as relevant targets (United Nations, 2015). Concurrently, the ESG framework has encouraged the sector to prioritize low - carbon design, promote occupant health, and establish transparent environmental management systems (Cho, 2023). Despite this growing awareness and the adoption of sustainability principles by some developers, several structural and contextual barriers remain. External environmental factors—including Political (Policy), Economic, Social, Technological, Environmental, and Legal dimensions—exert significant influence on the success or failure of sustainable housing estate development.

To analyze these external influences systematically, this study employs the PESTEL analysis framework, encompassing six dimensions: 1) Political 2) Economic 3) Social 4) Technological 5) Environmental and 6) Legal. This analytical approach is widely accepted in the fields of environmental engineering and urban planning (Yüksel, 2012). It enables the identification of both drivers and barriers that affect the advancement of environmentally sustainable housing estate projects.

Although policy-level efforts and the integration of SDGs and ESG frameworks are increasingly evident in urban development discourse, practical application remains limited—particularly at the level of housing estates, which play a crucial role in urban expansion. There is still a lack of systematic integration of environmental engineering and technological knowledge in these projects (Edelman, 2022). A key research gap is the absence of in-depth studies that utilize engineering-based analytical tools, such as PESTEL analysis, in combination with ESG and SDG frameworks, to evaluate external environmental factors in the context of urban housing estate development in Thailand. This aligns with Yüksel (2012), who noted that PESTEL is underutilized in residential project contexts, especially in Southeast Asia. Furthermore, DIVA Portal (2021) highlights that Thailand's green housing initiatives have yet to thoroughly investigate the socio-technical and legal dimensions that underpin long-term project success.

Therefore, the problem statement of this research is to examine the external environmental factors that influence the development of environmentally sustainable housing estate projects in Bangkok and its metropolitan areas. The research aims to: 1) Investigate the external environmental conditions associated with such development; and 2) Assess how these conditions influence sustainable housing projects within the specified urban context. This study employs a qualitative methodology, including document analysis and in-depth interviews with 26 experts across the private, governmental, and academic sectors. The findings will contribute to the synthesis of strategic pathways grounded in environmental engineering tools and contemporary technologies that concretely align with SDGs and ESG. Ultimately, the study seeks to close existing knowledge gaps and generate a structured evidence base to support policy-making and sustainable urban housing development initiatives.

This research is based on the study titled "EXTERNAL ENVIRONMENTAL FACTORS INFLUENCING THE DEVELOPMENT OF ENVIRONMENTALLY SUSTAINABLE HOUSING ESTATE PROJECTS IN BANGKOK AND METROPOLITAN AREAS" The framework integrates principles from sustainable engineering, environmental planning, and strategic analysis through three core components:

1. Phases of Sustainable Housing Estate Development

1.1 Pre-Construction Phase: 1) Project Initiation and Feasibility Analysis: Land acquisition and assessment of environmental and economic viability. 2) Design and Budgeting: Sustainable design integration (e.g., green building codes, resource efficiency) and financial estimation. 3) Capital Mobilization: Identification of funding sources, including green finance mechanisms and sustainability-linked loans.

1.2 Construction Phase: 1) Regulatory Coordination: Engagement with government agencies for permits and environmental compliance. 2) Construction Management: Implementation of low-impact construction technologies, material lifecycle assessment (LCA), and environmental control measures. 3) Procurement and Supply Chain: Selection of green-certified contractors and sustainable building materials. and 4) Sales and Marketing: Promotion based on energy performance, sustainability features, and health benefits.

1.3 Post-Construction Phase: 1) After-Sales Service and Title Transfer: Legal processes and resident onboarding. 2) Asset and Facility Management: Long-term energy and water efficiency, integration of smart building systems. And 3) Environmental Stewardship and Governance: Waste management, landscape maintenance, and environmental monitoring.

Adapted from the urban development process model proposed by Assoc. Prof. Dr. Kongkoon Tochaiwat.

2. Sustainable Development Dimensions in Housing Estate Projects:

2.1 Environmental Dimension: 1) Climate Change Response: Design for climate resilience (e.g., flood prevention, urban heat island mitigation). 2) Environmental Management Systems: Adoption of green construction innovations (e.g., modular construction, solar PV, green roofs). And 3) Efficient Resource Utilization: Smart metering, water recycling, and material reuse.

2.2 Social Dimension: Community inclusion, enhancement of resident well-being, and accessibility to green public spaces.

2.3 Governance Dimension: Transparent project management, compliance with green certifications (e.g., LEED, TREES), and accountability mechanisms.

Based on ESG (Environmental, Social, Governance) principles from the Thailand Productivity Institute and the United Nations' SDGs framework, particularly SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action),

External Environmental Factors Affecting Sustainable Housing Projects

1. Political Factors
2. Economic Factors
3. Social Factors
4. Technological Factors
5. Environmental Factors
6. Legal Factors

To assess external influences systematically, the study applies PESTEL Analysis (Aguilar, 1967; Macmillan, 1971)

EXTERNAL ENVIRONMENTAL FACTORS INFLUENCING THE DEVELOPMENT OF ENVIRONMENTALLY SUSTAINABLE HOUSING ESTATE PROJECTS IN BANGKOK AND METROPOLITAN AREAS

Key Informants' Perspectives and Recommendations This study employed in-depth interviews with 26 key informants, consisting of:

- Representatives from residential real estate development companies,
- Environmental engineering and urban sustainability experts,
- Academic scholars, and
- Representatives from government agencies and professional associations.

Strategic Context and Policy Alignment. The study aligns with:

Thailand's 20-Year National Industrial Development Strategy (2018–2037) / The 13th National Economic and Social Development Plan (2023–2027) / Strategic objectives under SDGs and ESG frameworks for sustainable urban development.

Figure 1: Conceptual Framework of the Study

Research Methodology

This study, titled **"The external environmental factors that influence the development of environmentally sustainable housing estate projects in Bangkok and its metropolitan areas."** employs a qualitative research design. The research setting includes legally registered and currently operating residential real estate development enterprises across Thailand that have been involved in the development of housing estate projects specifically within the Bangkok Metropolitan Region. As of December 31, 2023, there were **1,100 active entities** registered under this category (Source: Department of Business Development, Ministry of Commerce, 2023).

Key Informants and Data Collection

The target population consists of key information persons selected through purposive sampling based on their specific qualifications, including managerial responsibility in housing construction projects, professional expertise in the real estate sector, and at least five years of direct experience in housing estate development. A total of 26 key informants were interviewed, comprising: 1) 18 representatives from residential property development firms, 2) 4 experts and academic professionals, and 3) 4 representatives from government agencies and professional associations.

This sample size meets the minimum threshold for qualitative inquiry under the Delphi technique as proposed by Macmillan (1971), which recommends a minimum of 17 participants for expert-based qualitative studies. Data were collected through in-depth interviews using a semi-structured interview guide.

Research Instrument Design

This study employed a **semi-structured in-depth interview protocol** as the primary data collection instrument. The design of this tool was grounded in the conceptual framework of real estate project development proposed by **Assoc. Prof. Dr. Kongkunt Tochaiwat**, and was further enriched with the principles of **Environmental, Social, and Governance (ESG)** by the Thailand Productivity Institute and the **Sustainable Development Goals (SDGs)** established by the United Nations. The instrument focused on outcomes across three core dimensions—environmental, social, and governance—while incorporating **External Environmental Factor Analysis** through the **PESTEL Framework** developed by Aguilar (1967), ensuring the tool could systematically capture data in alignment with the research objectives.

Although **qualitative research** does not mandate a rigorous application of the **Index of Item-Objective Congruence (IOC)** as in quantitative studies—due to the inherent emphasis on contextual depth, flexibility, and responsiveness to complex phenomena (Creswell, 2014)—this study implemented **Content Validation Procedures** to ensure relevance and completeness of the interview guide. The **Content Validity** was assessed using the **IOC Technique**, wherein five experts in **Environmental Engineering and Real Estate Development** evaluated the congruence between the interview questions and the research objectives. This approach aligns with established academic practice (Rovinelli & Hambleton, 1977).

The resulting IOC score for the overall instrument was **0.90**, indicating acceptable content validity. The interview protocol was revised based on expert recommendations before being applied in the actual data collection phase. Furthermore, the tool underwent **pilot testing** with two simulated participants who possessed characteristics similar to the key informants. This step ensured the clarity of the interview prompts and their alignment with the research objectives, prior to conducting interviews with the full sample of 26 key informants.

Research Findings

The findings of this study are presented through the lens of PESTEL analysis, which encompasses six critical dimensions: Political, Economic, Social, Technological, Environmental, and Legal. These dimensions are systematically examined in relation to the three core phases of housing estate development: pre-construction, construction, and post-construction. The analysis is further guided by the integration of the Sustainable Development Goals (SDGs) and the Environmental, Social, and Governance (ESG) framework as proposed by the Thailand Productivity Institute.

The research utilized both secondary data analysis and in-depth interviews with 26 key informants, comprising stakeholders from the private sector, academic institutions, and relevant government and regulatory agencies. These informants included representatives from residential real estate development firms, subject-matter experts, and officials from urban planning and environmental authorities. Strategic insights were extracted through a SWOT analysis (See Tables 1 and 2) , and synthesized into actionable recommendations using the TOWS Matrix (See Tables 3). The integrated analysis highlights key external challenges and opportunities that influence the sustainability of housing estate projects in the Bangkok Metropolitan Region.

Overall, the research proposes a set of strategic frameworks aimed at enhancing the adaptive capacity and environmental performance of housing developers. These frameworks enable stakeholders to proactively address the external environmental factors that shape the viability and success of environmentally sustainable housing estate development in urban and peri-urban contexts.

PESTEL Analysis Results

1. Political Factors Although the Thai government has announced several national frameworks—such as the Bio-Circular-Green Economy (BCG) model, environmental and energy master plans, and the Green Bangkok 2030 initiative—aligned with SDG 11 and SDG 13, practical implementation still faces major gaps. In the pre-construction phase, there is a lack of government support mechanisms such as tax incentives or green financing schemes to encourage clean technology adoption. During the construction phase, enforcement of environmental compliance standards remains weak. In the post-construction phase, although tax deductions for solar rooftop installations have shown positive direction, there remains no structured incentive system or performance monitoring mechanisms at the project level.

2. Economic Factors There is growing market demand for environmentally sustainable housing, particularly among middle- and high-income households, as well as investors seeking long-term operational cost savings through energy and resource efficiency. However, high initial costs for sustainable technologies—such as energy-saving materials, wastewater treatment systems, and solar photovoltaics—remain a major barrier, particularly for low- to mid-range housing projects. During the construction phase, inflation and economic volatility often lead to value-engineering decisions that undermine sustainability objectives, thereby conflicting with ESG goals and SDG **13**, which emphasize greenhouse gas emissions reduction.

3. Social Factors Consumers in Bangkok and its surrounding areas are increasingly attentive to wellness-oriented environmental features such as green spaces, security systems, and indoor air quality. However, awareness of green building certification standards such as LEED and TREES remains limited. As a result, in the pre-construction phase, many developers do not prioritize sustainable design integration. During the construction phase, social responsibility issues such as labor conditions and community impacts arise. In the post-construction phase, the behavior of residents significantly affects environmental outcomes, including water conservation, waste separation, and green space maintenance. These behaviors require structured engagement, communication, and promotional activities at the community level.

4. Technological Factors Some projects have begun adopting clean technologies, such as solar PV systems, smart energy management systems, and modular construction techniques in the pre-construction phase. However, barriers persist regarding capital costs, technical expertise, and the absence of smart grid infrastructure or incentives for renewable energy integration. During the construction phase, waste and material management systems remain underdeveloped. In the post-construction phase, building performance monitoring tools (e.g., energy dashboards, sub-metering) are not widely implemented, particularly in mid-sized and small-scale projects, limiting the ability to quantitatively evaluate performance in line with SDG 13.

5. Environmental Factors Bangkok and its surrounding region are increasingly exposed to climate-related risks such as flooding, PM2.5 air pollution, and urban heat stress. These risks influence site selection and project design in the pre-construction phase, especially in areas such as stormwater drainage, heat-reflective building materials, and urban greening to mitigate the Urban Heat Island effect. During the construction phase, certain projects are required to undergo Environmental Impact Assessments (EIA); however, mechanisms for follow-up and enforcement during construction and post-handover remain weak. As a result, progress toward SDGs 11 and 13 is often limited to design-stage documentation, rather than tangible behavioral or operational outcomes.

6. Legal Factors Thailand has legal frameworks that support sustainable development, such as the Energy Conservation Promotion Act (ENCON Act) and the Building Energy Code (BEC). However, these regulations often do not extend to small-to-medium residential housing estates. During both the construction and post-construction phases, while voluntary certification systems like TREES and LEED are available, there is no legal mandate for adoption, nor are there incentives such as zoning bonuses or Floor Area Ratio (FAR) exemptions. Several interviewees indicated that regulatory tightening is expected in the future, including mandatory carbon reporting and energy performance disclosures. Without early preparedness, developers may face higher compliance costs in the coming years.

Table 1: SWOT – Strategic Factor Analysis Summary: (S/W)

Strengths (internal capabilities aiding sustainability)	**Weaknesses (internal limitations in pursuing sustainability)**
S1. Some project developers possess strong capabilities in green construction technologies and maintain dedicated teams specializing in energy and environmental engineering.	**W1.** The initial cost of green technologies remains high, and there is a lack of financial instruments supporting small- to medium-sized sustainable housing projects.

S2. Increasing access to knowledge in energy-efficient building design and smart energy management systems	**W2.** There is a shortage of engineering professionals with expertise in advanced environmental technologies, such as energy modeling, smart grid systems, and modular construction.
S3. Established collaborations with professional organizations such as engineering associations, energy institutions, and innovation centers focused on sustainable construction.	**W3.** Inadequate systems for post-construction monitoring and evaluation of environmental and energy performance.

Table 2: SWOT – Strategic Factor Analysis Summary (O/T)

Opportunities (External conditions that can be leveraged)	Threats (External conditions that pose risks)
O1. Technological advancements in clean energy systems, such as solar photovoltaic panels, energy storage systems, and modular construction techniques, create new possibilities for sustainable housing.	**T1.** Impacts of climate change, including flooding, extreme heat, and PM2.5 pollution, pose serious risks to the long-term sustainability and resilience of housing projects.
O2. Emerging government policy support, such as tax incentives and additional floor area ratio (FAR) allowances for green buildings, encourages environmentally friendly development.	**T2.** Legal and regulatory limitations—such as the non-mandatory application of green standards in general residential projects—may discourage developers from adopting comprehensive sustainability practices.
O3. Increasing demand for housing that emphasizes public health, environmental quality, and livability, especially among urban and health-conscious buyers.	**T3.** Volatility in energy prices and material costs can undermine investment confidence in green technologies, particularly for small to mid-scale developers.

Table 3: TOWS Matrix – Strategic Directions for Environmentally Sustainable Housing Development Using Environmental Engineering and Technology.

	Opportunities (O)	Threats (T)
Strengths (S)	**SO Strategies** (Using Strengths to Maximize Opportunities) **SO1.** Utilize the technical competencies of environmental engineering teams (S1, S2) to develop energy management systems that control energy usage and storage (e.g., solar energy systems) in alignment with national policy (O1, O2). **SO2.** Expand collaboration with research institutions (S3) to co-develop	**ST Strategies** (Using Strengths to Counter Threats) **ST1.** Develop building envelopes that withstand environmental stressors (T1) through BIM-based simulation or CFD modeling, led by environmental engineering teams. (S1, S2) **ST2.** Cooperate with engineering councils and standardization bodies (S3) to prepare for upcoming

	Opportunities (O)	Threats (T)
	low-carbon and high-performance construction technologies, leading to TREES/LEED certification and green zoning incentives. (O2)	regulations and climate adaptation standards (T2).
Weaknesses (W)	**WO Strategies** (Overcoming Weaknesses by Leveraging Opportunities) **WO1.** Access Green Finance and ESG investment mechanisms (O2) to alleviate the high capital cost of sustainable materials and systems (W1), especially for medium- and small-scale projects. **WO2.** Address the skill gap (W2) by developing training programs through partnerships with academic and technical institutions in advanced simulation and green building design (e.g., Building Simulation, LCA, EMS Design).	**WT Strategies** (Minimizing Weaknesses and Avoiding Threats) **WT1.** Establish post-construction Monitoring & Evaluation systems via IoT platforms or cloud-based energy reporting tools to mitigate compliance risks and meet future legal requirements (W3, T2). **WT2.** Implement phased adoption strategies of green technologies to reduce financial burden and align with long-term environmental objectives, especially in anticipation of stricter laws and material cost volatility (W1 , T3).

Table 4: Mapping of PESTEL Factors to SWOT Elements and Strategic Responses via TOWS Matrix

PESTEL Factor	SWOT Mapping	TOWS Strategies
1. Political	**Threat (T2):** Lack of fiscal incentives and weak enforcement of green building regulations	**ST2:** Promote policy engagement through academic and industry collaboration **WT2:** Adopt voluntary green standards in anticipation of future mandates
2. Economic	**Weakness (W1) and Threat (T3):** High initial costs of green technology; macroeconomic volatility	**WO1:** Leverage green finance tools (e.g., green bonds, green loans) **WT2:** Reduce costs through circular construction practices
3. Social	**Weakness (W2) and Opportunity (O3):** Limited awareness of sustainability; rising public interest in well-being and green amenities	**WO2:** Promote sustainability awareness through community engagement **SO1:** Showcase green model homes and demonstrate benefits of eco-living
4. Technological	**Strength (S1, S2) and Opportunity (O1):** Existing	**SO1:** Form partnerships with green technology providers

PESTEL Factor	SWOT Mapping	TOWS Strategies
	technical expertise and emerging clean technologies	**ST1:** Invest in BIM and prefabrication technologies **WO2:** Transfer tech knowledge to small-scale projects
5. Environmental	**Opportunity (O3) and Threat (T1):** Increasing climate risks and public demand for mitigation	**SO2:** Integrate climate-resilient design (e.g., cool roofs, SUDS) **ST1:** Establish post-occupancy environmental monitoring systems
6. Legal	**Weakness (W3) and Threat (T2):** Gaps in mandatory codes and weak legal enforcement	**WT1:** Align with international standards to prepare for future regulations **ST2:** Co-develop minimum environmental engineering standards with regulators

Strategic Summary of Research Findings The strategic synthesis derived from this study aims to enhance the capacity of residential real estate developers to systematically respond to external environmental factors through engineering and technological interventions grounded in environmental and energy research. The strategies emphasize the design and implementation of smart energy systems, low-carbon construction practices, and digital resource management solutions. These approaches serve as key drivers in advancing the Environmental (E) dimension of Environmental, Social, and Governance (ESG) frameworks. Furthermore, they contribute directly to achieving the United Nations Sustainable Development Goals (SDGs), particularly SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action), by promoting environmentally responsible urban development and enhancing resilience to climate change impacts.

Discussion and Conclusion

Discussion of Research Findings

1. Political Factors The findings reveal that although the Thai government has outlined national-level strategies for environmental and energy planning—such as the Bio-Circular-Green (BCG) Economy Model and the Green Bangkok 2030 initiative—concrete policy instruments remain insufficient. Notably, there are still no substantial tax incentives or state-funded subsidies for green-certified housing projects during the pre-construction phase. This aligns with DFDL Legal & Tax (2014), which noted the lack of penalties for non-compliance with green building codes and the absence of regulatory incentives linked to sustainability. Similarly, Baker McKenzie (2025) confirmed that there are no current government programs specifically targeting energy efficiency in buildings. Nevertheless, Thailand's commitment to reducing carbon emissions under the Paris Agreement (UNEP, 2018) may provide a policy impetus for stronger regulatory support in the future.

2. Economic Factors The high upfront capital costs of green technologies—including renewable energy systems, recycled construction materials, and certification processes such as LEED or TREES—are major financial barriers, especially for small-to-medium-scale developers. These findings are consistent with ResearchGate (2021), which identified "high initial costs" and "lack of developer incentives" as top obstacles to green building adoption in

Thailand. Although consumer demand for environmentally friendly housing is increasing, pricing constraints and profit margin concerns continue to limit widespread implementation. Encouragingly, Nation Thailand (2023) highlighted the emerging use of circular construction practices—such as reusing demolition waste and recycled steel—which can effectively reduce material costs and landfill burden.

3. Social Factors Urban residents in Bangkok and surrounding areas are increasingly valuing environmental well-being, health amenities, and green open spaces. However, the general public lacks adequate knowledge of green building standards and long-term sustainability benefits. This corresponds with DIVA Portal (2021), which emphasized that "lack of awareness and technical expertise" are major barriers to sustainable construction. UN Women (2018) further advocates for inclusive planning and urban greening as key elements of SDG 11. Accordingly, effective strategies include public awareness campaigns, demonstration projects, and participatory planning to enhance community engagement and support behavioral change.

4. Technological Factors The research found that some projects have begun incorporating technologies such as solar photovoltaic systems, smart energy management platforms, and modular construction techniques. However, integration challenges persist—particularly due to the lack of supporting infrastructure such as smart grids and technical skill

gaps among project developers. As noted by The Thaiger (2024), the integration of digital technology is a game changer in green housing. Systems like BIM (Building Information Modeling) and energy modeling tools can greatly enhance sustainability performance by optimizing energy use and facilitating informed design decisions.

5. Environmental Factors Several housing projects have implemented measures such as GHG emissions reduction, water conservation, and the use of recyclable materials. Nevertheless, there is still an absence of long-term environmental monitoring mechanisms. UNEP (2018) also identified the post-construction gap in performance assessment as a critical issue in Thailand's green building sector. Nation Thailand (2023) emphasized that effective waste management and circular construction are essential to minimizing environmental impacts. Continuous monitoring of energy and water performance could support the fulfillment of SDG 13 through evidence-based adaptation and mitigation efforts.

6. Legal Factors Although internationally recognized certifications such as LEED and TREES are available in Thailand, there is currently no legal mandate enforcing their application in residential developments. Both DFDL Legal & Tax (2014) and Baker McKenzie (2025) confirm the absence of mandatory legal enforcement or public funding for compliance. Instead, most developers voluntarily adhere to these standards for market differentiation and corporate responsibility. UNEP (2018) suggests that national commitments to carbon neutrality may lead to the enforcement of stricter environmental regulations in the near future. Proactive adoption of international standards is therefore considered a strategic governance approach, enabling developers to stay ahead of regulatory trends.

Research Conclusion

The analysis and synthesis of findings from the research titled **"the external environmental factors that influence the development of environmentally sustainable housing estate projects in Bangkok and its metropolitan areas."** have resulted in a strategic framework for promoting environmentally sustainable housing projects. This framework is grounded in engineering and environmental technology, guided by the PESTEL analysis model, and informed by comparative discussion with related studies. The results indicate that sustainable housing development in Bangkok and its vicinity requires an integrated strategy that systemically aligns ESG (Environmental, Social, Governance) principles with technical knowledge in environmental engineering and sustainable technologies. The key strategic responses are as follows:

1. Environmental Engineering Strategies: 1) Implement technologies for efficient resource management, such as rainwater harvesting and recycling systems, solar photovoltaic integrated with smart grid infrastructure, and cool roof technology. And 2) Design buildings in compliance with LEED/TREES standards and incorporate climate-resilient design principles to adapt to environmental changes.

2. Engineering Innovation & Integration: 1) Promote the adoption of Building Information Modeling (BIM), energy simulation tools, and modular construction to enhance precision, energy efficiency, and waste reduction. And 2) Foster partnerships with private sector stakeholders and specialized engineers to transfer and scale up advanced green technologies.

3. Social Engagement through Engineering Communication: 1) Establish technology demonstration centers or model homes to showcase the benefits of sustainable living environments. And 2) Enhance energy literacy among residents by introducing tools such as home energy dashboards, thereby promoting behavioral change and participatory engagement.

4. Green Finance & Resource-Efficient Engineering: 1) Reduce costs through circular economy practices, including the use of recycled materials and systematic construction waste management. And 2) Access green financing instruments—such as green bonds and green loans—to support investment in clean technologies.

5. Governance Strategy & Policy Engineering: 1) Collaborate with government agencies and professional associations to advocate for mandatory green building policies and propose a "minimum environmental engineering standard" for residential development. And 2) Voluntarily adopt internal sustainability standards as a means of pre-emptive compliance and industry leadership.

6. Policy Advocacy by the Technical Community: 1) Encourage coalitions of developers, engineers, researchers, and academic institutions to engage in evidence-based advocacy through technical bodies such as environmental engineering associations, aiming to influence public policy and create state-level incentive mechanisms.

Key Insight The development of environmentally friendly housing estates in Bangkok and its surrounding areas must be driven by environmental engineering and technological expertise, integrated with ESG and SDG frameworks. This research emphasizes that long-term urban sustainability requires adaptive strategies that respond to external environmental constraints through interdisciplinary knowledge, innovative policy, and engineering-based solutions. This integrated approach not only benefits individual projects but also contributes to broader metropolitan resilience and sustainable urban development.

Recommendations

Achieving sustainable development in environmentally friendly housing estate projects requires an integration of policy-level frameworks that support investment and regulatory oversight with practical implementation grounded in environmental engineering and technology. A systemic and multi-sectoral collaboration across government, private sector, and civil society is essential to realize long-term sustainability.

1. Policy-Level Recommendations These recommendations focus on improving regulatory frameworks, incentives, and national to organizational strategic directions.

1.1 Promote Green Building Incentives: 1) The government should establish a Green Technology Support Fund for projects certified under standards such as LEED, TREES, or national energy conservation frameworks. And 2) Implement tax deductions or construction permit fee reductions for housing developments that integrate environmental technologies and meet green performance benchmarks.

1.2 Strengthen Environmental Regulatory Enforcement: 1) Enact or revise binding regulations mandating energy efficiency, green building, and water conservation standards specifically for residential housing projects. And 2) Develop a Monitoring and Environmental Reporting System linked to future project approvals, ensuring post-construction sustainability compliance.

1.3 Foster Sustainable Urban Development at the Municipal Level: 1) Support local municipalities in issuing green urban planning regulations that mandate provisions for urban green spaces, Sustainable Urban Drainage Systems (SUDS), and renewable energy infrastructure in new developments.

1.4 Support Public–Private Collaboration Mechanisms: 1) Establish PPP (Public–Private Partnership) platforms to drive research and development (R&D) in green building technologies. And 2) Promote joint investment in Smart Grid, Building Information Modeling (BIM), and Green Infrastructure through Thailand's Board of Investment (BOI) incentive schemes.

2. Operational / Practice-Level Recommendations These recommendations are designed for practical adoption by developers, engineers, and local agencies.

2.1 Enhance Capacity in Environmental Engineering: 1) Provide training and technology transfer programs for engineers, architects, and construction supervisors on green building innovations. And 2) Encourage the use of building performance simulation tools such as Building Energy Simulation and BIM in design processes.

2.2 Integrate Green Technologies into Construction Processes: 1) Promote the application of technologies such as solar photovoltaic systems, rainwater harvesting, recycled materials, and modular construction to reduce waste and improve resource efficiency. And 2) Adapt building designs to incorporate climate-resilient features such as permeable pavements and green roofs.

2.3 Apply Circular Economy Principles in Housing Projects: 1) Encourage recycling of construction materials, reusing debris for sub-base materials, and establishing on-site waste separation systems to reduce landfill burden.

2.4 Increase Consumer and Community Participation: 1) Establish model homes equipped with sustainable water and energy systems to demonstrate benefits to potential buyers. And 2) Form community environmental committees within housing estates to monitor and manage energy and water consumption, promote sustainability practices, and enhance long-term resident engagement.

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Comparative Assessment of Raw Water Transmission Pipe Materials in Thailand: Engineering Properties and Field Suitability

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Abstract

This study comparatively assessed five raw water transmission pipeline materials used in Thailand: Polyvinyl Chloride (PVC), High-Density Polyethylene (HDPE), steel, asbestos cement (AC), and Glass Reinforced Plastic (GRP). A mixed-methods approach was employed, combining technical specification analysis and professional feedback through questionnaires (n = 50) and expert interviews (n = 15). GRP demonstrated superior performance across strength (4.42 ± 0.39), corrosion resistance (4.53 ± 0.38), service life (4.41 ± 0.42), and environmental suitability (4.37 ± 0.40), while HDPE exhibited excellent pressure resistance (4.33 ± 0.43). The findings address a research gap by providing localized recommendations tailored to Thailand's environmental diversity. Cost, procurement limitations, and regional material availability were identified as practical barriers. This study proposes integrating engineering criteria and lifecycle cost analyses into procurement frameworks for improved infrastructure resilience.

Keywords Raw water pipeline, engineering properties, material selection, lifecycle analysis, infrastructure planning

Introduction

The water supply system plays a vital role in safeguarding public health, supporting economic growth, and ensuring quality of life, particularly amid climate change and fluctuating water resources (EPA, 2023; WHO, 2022). Pipeline material selection influences water quality, durability, maintenance costs, and system reliability (Liu et al., 2024; Sun et al., 2022). Thailand's Provincial and Metropolitan Waterworks Authorities face challenges due to diverse environments including saline coastal soils and flood-prone regions (Karadirek et al., 2022; Zhao et al., 2021). Despite widespread use of PVC, HDPE, steel, AC, and GRP, localized comparative evaluations remain scarce. Prior studies often generalize findings without practical integration of local engineering experience (Carrière et al., 2023; Alsabri & Al Ghamdi, 2020). This study addresses this gap by evaluating technical properties and contextual field suitability through a mixed-methods approach.

1. Literature Review

1.1 Summary of Related Studies on Pipe Material Evaluation

Researcher(s) and Year	Research Focus, Methodology, and Key Findings
Thavamony & Rajagopal (2024)	AHP was used to rank pipe materials DI (0.381), HDPE (0.321), GI (0.172), and PVC (0.126). EPANET simulation showed pressure (24–35 m) and velocity (0.6–1.4 m/s) were within acceptable ranges, confirming DI and HDPE as optimal.
Omar (2023)	MCDA analysis showed HDPE scored highest (0.87) for durability, cost, and lifespan, with 50 years of service life and leakage below 0.5% per year, making it the most efficient material.
Vlase et al. (2020)	HDPE tested with UTS = 26.3 MPa, elongation ≈ 700%, and Young's modulus = 950 MPa. FEM confirmed strong resistance to bending and vibration.
Karadirek et al. (2022)	From 1,500+ cases, PVC pipes had 3.2× higher failure risk than DI. Pipes over 25 years showed a 60% higher crack probability, highlighting material and age effects.
Yang & Hu (2021)	PVC burst strength dropped from 2.5 MPa to 1.2 MPa after 15 years, suggesting limited long term use in high pressure systems.

This study adopts a mixed method approach, integrating quantitative and qualitative methodologies to comprehensively evaluate pipeline materials used in raw water transmission systems.

2. Research Methodology

This research adopted a mixed-methods approach, integrating quantitative analysis and qualitative insights to evaluate raw water transmission pipeline materials used across Thailand.

2.1 Technical Data Collection

Technical specifications for each pipe material (PVC, HDPE, Steel, AC, and GRP) were collected through a combination of literature reviews, including technical manuals, ISO/TIS standards, and official manufacturers' data sheets. No experimental testing was performed. All material properties such as density, maximum working pressure, service life, corrosion resistance, and environmental suitability were sourced from verified engineering documents to ensure accuracy.

2.2 Quantitative Methods

Quantitative data were gathered through structured questionnaires administered to a purposive sample of 50 participants from both the public (PWA, MWA) and private sectors involved in water transmission projects. The questionnaire was divided into six evaluation domains: Mechanical strength, Pressure resistance, Corrosion resistance, Service life, Environmental adaptability and Ease of procurement

Each item was assessed on a 5-point Likert scale (1 = Very poor, 5 = Excellent). Validity of the questionnaire was confirmed through expert review by three specialists in water infrastructure and construction management. Reliability was assessed using Cronbach's alpha, which achieved a coefficient of 0.82, indicating a high level of internal consistency.
Statistical analysis was performed using SPSS software, applying:

- Descriptive statistics (mean, standard deviation) to summarize perceptions

- Inferential statistics (One-Way ANOVA) to determine significant differences between pipeline materials across performance domains, at a 95% confidence level ($p < 0.05$).

2.3 Qualitative Methods

Qualitative data were collected through semi-structured interviews with 15 experienced professionals. The interviews explored deeper insights regarding material selection criteria, operational challenges, and regional environmental constraints. Data were analyzed thematically to identify key recurring patterns and cross-validated with quantitative results.

2.4 Ethical Considerations

All participants provided informed consent prior to data collection. Participant anonymity and data confidentiality were strictly maintained throughout the research process.

2.5 Conceptual Framework

This study is grounded in a conceptual framework designed to evaluate the engineering performance and contextual suitability of raw water pipeline materials within Thailand's diverse environmental settings. The framework identifies the relationships among independent variables (types of pipe materials), dependent variables (engineering performance and suitability), and control variables (environmental and geographical conditions).

Independent Variables	Dependent Variable	Control Variables	Theories Used in the Study
1) Type of pipeline material • PVC, • HDPE • Steel • Asbestos Cement (AC) • Glass Reinforced Plastic (GRP)	1) Engineering performance characteristics 2) Mechanical strength 3) Pressure resistance 4) Corrosion resistance 5) Flexibility 6) Service life 7) Environmental adaptability	1) Local environmental and geographical conditions Soil salinity and pH Groundwater chemistry Temperature fluctuations Flood risk and exposure	1) Engineering Material Properties Theory 2) Material Suitability and Selection Theory 3) Framework Application

2.6 Data Analysis Procedures

Quantitative and qualitative data were integrated through methodological triangulation to enhance result validity. Ethical standards, including informed consent and participant confidentiality, were strictly maintained. Data analysis employed descriptive statistics (mean and standard deviation) to summarize material evaluations based on a 5-point Likert scale (1 = Very Poor to 5 = Excellent), providing practical recommendations aligned with Thailand's environmental and operational contexts.

2.7 Statistical Methods Used for Data Analysis

This study employed descriptive statistics to analyze the data collected from questionnaires. The primary statistical measures used were

Mean to identify the overall perception of engineering performance and suitability of each pipe material.

$$\bar{x} = \frac{\sum x}{N} \qquad (1)$$

Where: $\bar{x}$ = arithmetic mean of the sample
$\sum x$ = sum of all data values
N = total number of data points in the sample

Standard deviation to measure the variation in responses among participants.

$$S = \sqrt{\frac{\sum x^2}{N} \quad \bar{x}^2} \qquad (2)$$

Where S = standard deviation of the sample
$\bar{x}$ = mean score of the sample
$\sum x^2$ = sum of the squared scores
N = number of observations

Result

1. Comparative Analysis of Raw Water Pipe Properties

PVC Pipe

PVC pipes offer a service life of up to 50 years with good elasticity, suitable for plumbing and electrical insulation. However, prolonged UV exposure can cause brittleness.
Blue PVC: Used for plumbing (½"–16"); pressure-rated by class (e.g., Class 5 = 5 bar).
Yellow PVC: Used for electrical conduit (3/8"–4"); required by Thai Industrial Standards (TIS).
White PVC: Informally used in agriculture; lacks TIS certification but absorbs less UV.
Gray PVC: Used for drainage; thinner, less pressure-resistant, but more economical.

Table 1 PVC pipe specifications

No.	Specifications	Units
1) Density	1,430	kg/m^3
2) Pipe velocity	200-400	m/s
3) Max working pressure	13.5	kg/cm^2
4) Max Temperature	0-60	°C
5) Max Life	30	Year
6) Used for	Drinking water	TIS.17 2523
7) Acid and Base Resist	X	
8) Internal surface no rust and lime scale	-	
9) It has high corrosion resistance.	-	
10) It can withstand electricity.	-	
11) It is easy to buy, products on the general market	-	

Figure 1 PVC Pipe specifications
Source www.hipchet.com

HDPE Pipe

HDPE (High-Density Polyethylene) pipes are flexible, UV-resistant, chemical-free, and highly durable compared to PVC. Pipe sizes and thicknesses vary by application, indicated by strap color:

Light Blue Strap: Used for plumbing.
Orange Strap: Used for electrical conduit.
Pure Black: Used for general plumbing and agriculture.

Table 2 HDPE pipe specifications

No.		Specifications	Units
1)	Density	955	kg/m^3
2)	Pipe velocity	200-400	m/s
3)	Max working pressure	25	kg/cm^2
4)	Max Temperature	40-80	°C
5)	Max Life	50	Year
6)	Used for	Drinking water	TIS. 982 2548
7)	Acid and Base Resist	X	
8)	Internal surface no rust and lime scale	-	
9)	It has high corrosion resistance.	-	
10)	It can withstand electricity.	-	
11)	It is easy to buy, products on the general market	-	

Figure 2 HDPE Pipe specifications
Source www.marineshine.com

Steel Pipe

Steel or spiral pipes are produced using Submerged Arc Welding (SAW), creating strong welds inside and outside in a spring-like seam. This method allows for large diameters and long lengths. Spiral pipes are widely used in industrial sewage and oil transport systems, such as in sugar factories. They are typically produced with thicknesses ranging from 4.5–19.1 mm. and outer diameters from 200–3,000 mm.

Table 3 Steel pipe specifications

No.		Specifications	Units
1)	Density	7,000-7,800	kg/m^3
2)	Pipe velocity	1,000-1,200	m/s
3)	Max working pressure	25	kg/cm^2
4)	Max Temperature	100-300	°C
5)	Max Life	10-30	Year
6)	Used for	Drinking water	TIS.427 2562
7)	Acid and Base Resist	X	
8)	Internal surface no rust and lime scale	-	
9)	It has high corrosion resistance.	-	
10)	It can withstand electricity.	X	
11)	It is easy to buy, products on the general market	-	

Figure 3 Steel Pipe
Source www.tesco engineers.com

Pressure Resistant Asbestos Cement Pipes

Asbestos cement pipes are valued for their affordability, durability, and long service life, with over 25 years of use in Thailand. Two types are specified:

Type A (Ordinary): Made from Portland Cement Type 1, asbestos, and water, suitable for general use.

Type B (High Sulfate Resistant): Made from Portland Cement Type 5, ideal for environments with alkaline salts or coastal areas.

Table 4 Asbestos cement pipe specifications

No.		Specifications	Units
1)	Density	2,450	kg/m^3
2)	Pipe velocity	600-800	m/s
3)	Max working pressure	25	kg/cm^2
4)	Max Temperature	30-45	°C
5)	Max Life	10-20	Year
6)	Used for	Drinking water	TIS.81 2548
7)	Acid and Base Resist	X	
8)	Internal surface no rust and lime scale	X	
9)	It has high corrosion resistance.	X	
10)	It can withstand electricity.	-	
11)	It is easy to buy, products on the general market	-	

Figure 4 Pressure Resistant Asbestos Cement Pipe
Source www.metalcomplekt.co.th

Glass Reinforced Polyester (GRP) Pipe

GRP pipes are made from thermosetting resin reinforced with glass fiber, providing excellent resistance to acids, alkalis, salts, wastewater, and chemicals. They are lightweight, rust-free, and highly durable, with a lifespan over 50 years. The structure includes:

1. Inner layer: Resin (10–20 mL) reinforced with glass fiber
2. Bulkhead: Two layers of 450 g/m^2 glass fiber
3. Support layer: Varies by strength; uses 450–600 g/m^2 glass fiber
4. Outer layer: Resin with glass fiber and UV protection

Table 5 GRP pipe specifications

	No.	Specifications	Units
1)	Density	1,500-2,000	kg/m^3
2)	Pipe velocity	600-1,600	m/s
3)	Max working pressure	25	kg/cm^2
4)	Max Temperature	40-70	°C
5)	Max Life	30	Year
6)	Used for	No Drinking water	
7)	Acid and Base Resist	-	
8)	Internal surface no rust and lime scale	-	
9)	It has high corrosion resistance.	X	
10)	It can withstand electricity.	X	
11)	It is easy to buy, products on the general market	X	

Figure 5 Fiber glass pipe
Source: www.sst.co.th

From Table 6 shown specification of HDPE, Steel, Asbestos, and GRP pipe for density, pipe velocity, Maximum working pressure, Maximum working temperature, Maximum life, used for drinking water, rust and lime scale deposited, corrosion resist, width stand for electricity and easy to buy.

Table 6 Standard pipe specifications

Specifications	HDPE	Steel	Asbestos	GRP	PVC	Units
Density	955	7,000-7,800	2,450	1,500-2,000	1,430	kg/m^3
Pipe velocity	200-400	1,000-1,200	600-800	600-1,600	200-400	m/s
Max working pressure	25	25	25	25	13.5	kg/cm^2
Max Temperature	40-80	100-300	30-45	40-70	0-60	°C
Max Life	50	10-30	10-20	30	30	Year
Drinking water	SFS 3115:E	AWWAC 600	AWWAC 603	TIS.17 2523	TIS.17 2523	
Acid and Base Resist	X	X	X	-	X	
No rust and lime scale	-	-	X	-	-	
High corrosion resist	-	-	X	X	-	
Electrical withstand	-	X	-	X	-	
It is easy to buy	-	-	-	X	-	

2. Analysis of data from questionnaires

Table 7 Analysis Table of Raw Water Pipeline Material Properties

Pipe Material	Strength (Mean ± S.D.)	Pressure Resistance (Mean ± S.D.)	Corrosion Resistance (Mean ± S.D.)	Service Life (Mean ± S.D.)	Environmental Suitability (Mean ± S.D.)
PVC	3.79 ± 0.49	3.86 ± 0.52	3.75 ± 0.53	3.78 ± 0.54	3.91 ± 0.51
HDPE	4.21 ± 0.46	4.33 ± 0.43	4.29 ± 0.44	4.27 ± 0.45	4.08 ± 0.48
Steel	3.82 ± 0.61	3.96 ± 0.58	3.65 ± 0.64	4.10 ± 0.59	4.03 ± 0.57
Asbestos	3.34 ± 0.72	3.46 ± 0.74	3.49 ± 0.7	3.14 ± 0.73	3.30 ± 0.68
GRP	4.42 ± 0.39	4.38 ± 0.41	4.53 ± 0.38	4.41 ± 0.42	4.37 ± 0.4

2.1 Analysis and Discussion

This study compared five raw water pipeline materials—PVC, HDPE, Steel, Asbestos Cement (AC), and GRP—used in potable water systems in Thailand, focusing on strength, pressure resistance, corrosion resistance, service life, and environmental suitability (Table 7). The findings are summarized as follows:

GRP (Glass Reinforced Plastic) exhibited the highest overall performance, achieving the top mean scores in strength (4.42 ± 0.39), corrosion resistance (4.53 ± 0.38), service life (4.41 ± 0.42), and environmental suitability (4.37 ± 0.40). Its superior durability and chemical resistance make it ideal for saline and alkaline environments common in many Thai regions. These results align with Thavamony and Rajagopal (2024) and Omar (2023), who emphasized GRP's optimal performance in water networks.

HDPE ranked second overall, excelling in pressure resistance (4.33 ± 0.43) and showing consistent strength across all criteria. This corroborates Vlase et al. (2020), who reported HDPE's high tensile strength and mechanical resilience. HDPE is also economically favorable, with moderate initial costs and a long lifespan of 50 years, enhancing its suitability for rural infrastructure where maintenance access may be limited.

Steel pipes demonstrated strong mechanical strength (3.82 ± 0.61) and long service life (4.10 ± 0.59) but underperformed in corrosion resistance (3.65 ± 0.64), especially in aggressive environments. This finding is consistent with Carrière et al. (2023) and Karadirek et al. (2022), who reported that corrosion significantly increases long-term maintenance costs for steel pipelines, impacting operational feasibility.

PVC pipes offered moderate performance, particularly in environmental adaptability (3.91 ± 0.51). While PVC is cost-effective and widely available, its lower long-term durability under high pressure matches the degradation patterns reported by Yang and Hu (2021) and failure rate data from Karadirek et al. (2022). PVC's affordability makes it attractive for rural installations, but its shorter lifespan compared to GRP and HDPE must be considered during procurement planning.

Asbestos Cement (AC) pipes recorded the lowest scores, notably in service life (3.14 ± 0.73) and environmental suitability (3.30 ± 0.68). Their brittleness under fluctuating conditions, as discussed by Zhao et al. (2021) and WHO (2022), raises concerns regarding safety and reliability. Although AC pipes offer low initial costs, their shorter lifespan and increased failure risks limit their long-term economic viability.

Overall, GRP and HDPE emerge as the most suitable options for durable, low-maintenance pipelines, despite higher upfront costs, due to their extended service life and better performance in harsh environments. (See Figure 6 for visual comparison.)

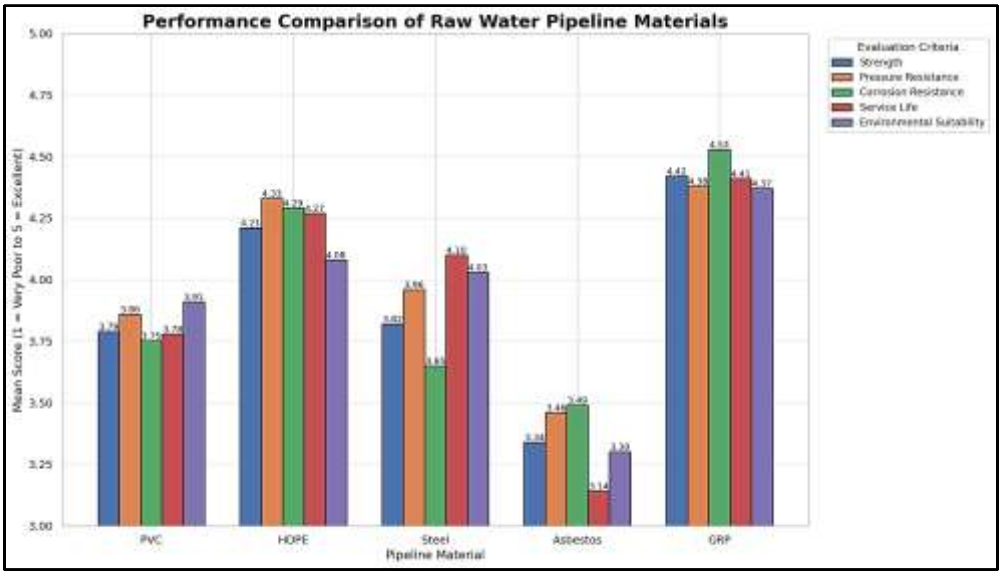

Figure 6 Mean scores of pipeline materials based on five engineering criteria

2.2 Summary of Open-Ended Questionnaire Responses

Table 8 Preferred Raw Water Pipeline Materials and Stated Reasons

Pipeline Material	Number of Respondents	Key Reasons
GRP	20	High corrosion resistance, long service life, non-rusting
HDPE	15	Flexible, pressure resistant, easy to install
PVC	10	Low cost, easy to procure

Table 9 Challenges in Selecting Pipeline Materials

Identified Problem	Number of Respondents	Example Comments
Budget constraints	22	High quality materials are too expensive under current government budget limits.
Procurement policy limitations	14	Recommended materials are not on the approved procurement list.
Lack of technical comparison data	9	Uncertainty about which material is most suitable for local soil conditions.

Based on respondent feedback (Table 8), Glass Reinforced Plastic (GRP) was the most preferred raw water pipeline material, cited for its superior corrosion resistance, long service life, and ability to withstand harsh conditions such as acidic and saline soils. High-Density Polyethylene (HDPE) ranked second, valued for its flexibility, pressure resistance, ease of installation, and lightweight properties. Polyvinyl Chloride (PVC) was recognized for its affordability and accessibility but noted to have lower durability compared to GRP and HDPE.

Key challenges identified (Table 9) included budget constraints, limiting access to high-performance materials, and government procurement regulations that restricted material selection. Respondents also cited a lack of comparative technical information, complicating efforts to select materials suited to local environmental conditions.

In summary, these findings highlight the need for clearer technical guidelines and more flexible procurement policies to facilitate better material selection, thereby improving the durability, reliability, and sustainability of Thailand's potable water systems.

Conclusion

1) The comparative analysis demonstrated that GRP achieved the highest engineering performance among the five materials, particularly in strength, corrosion resistance, service life, and environmental adaptability. HDPE ranked second, showing excellent pressure resistance and consistent overall performance. PVC offered moderate performance with cost advantages, while steel and asbestos cement revealed significant weaknesses, particularly in corrosion resistance and durability. These findings suggest that future material selection standards, design guidelines, and procurement policies should prioritize performance-based criteria to enhance the long-term sustainability of potable water systems.

2) Feedback from 50 public and private sector practitioners supported the technical results, with GRP most frequently recommended for its resilience to harsh environments and HDPE favored for its flexibility and installation efficiency. However, budget constraints, restrictive procurement regulations, and limited comparative technical data were identified as barriers to optimal material adoption. Recognizing these limitations, future studies should incorporate broader regional sampling and life-cycle cost analysis to further refine infrastructure planning and material selection strategies.

Suggestions

Material Selection Framework: Water authorities such as PWA and MWA should adopt a performance-based material selection framework, prioritizing corrosion resistance, service life, and environmental suitability to ensure long-term infrastructure sustainability.

Acknowledgements

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Green hydrogen production from metal in Thailand

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Abstract

Conventional green hydrogen produces from water electrolysis, using solar power, and wind power, it is high production cost and time limited for solar hours only have sun light 4.5 hours, and no continuous wind for 24 hours. Using Aluminum as an energy carrier, water and catalyst has low production cost and large quantity but this process has to buy Aluminum all the times, which is higher cost to make green hydrogen. If we can recycle Aluminum hydroxyl as waste to solid aluminum could make it sustainable and infinite raw materials use to split water to green hydrogen. In old days to convert Aluminum hydroxyl to solid aluminum use very high pollution Coal as reduction substance by using Paulownia convert solar energy to fuel and charge back to solid aluminum had higher power density and no pollution. **Method:** Literature review, Aluminum as an energy carrier, Green hydrogen from aluminum in Thailand, Aluminum dioxide to Aluminum oxide, Aluminum oxide to Aluminum, The Hall–He´roult process, Paulownia as green fuel, Paulownia power plant, Green hydrogen generator without electrolysis. Engineering design, calculation and equipment selection to have the system to convert water to hydrogen without electrolysis **Results:** By using Paulownia convert solar power to energy, as green energy, heat value average 20 MJ/kg, to generate heat for converting Aluminum hydroxyl convert to Aluminum oxide then generate electric to use with arc furnance to recycle Aluminum oxide convert to Solid Aluminum. Paulownia release no pollution not loke coal and petrol. It is the only plant that does not release Sulfur Oxide, Nitrous Oxide, Carbon Mono oxide, Methane and other harmful substances while other fuel release higher value. **Conclusion:** Green hydrogen generator without electrolysis from solid aluminum and paulownia has higher safety, no need for a high-pressure tank, and transportation. It can be produced 24 hours a day, 365 days a year, regardless of the fluctuations of the sun or wind, eliminating the need to use expensive and short-lived batteries in storing electrical energy. This process is sufficient to reduce the cost of producing green hydrogen to a level commercially 65.35 THB/kg and can be produced very fast in large quantities. The cost of electric produce from green hydrogen 2.89 THB/kWh.

Keywords: Aluminum Energy Carrier, Green Electric, Green Hydrogen, Metal to Hydrogen

Introduction

Hydrogen is a very good energy carrier and can be used as a fuel with internal combustion engine, fuel cell, gas turbine, and as a feedstock in industries. In one year the world consumes hydrogen about 100 million tons, mainly from ammonia plants and crude oil refineries. Over 99 percent of the current hydrogen production is made from fossil fuels, either natural gas or coal, equivalent to 900 million tons of CO_2 emitted annually.

We can we produce cheap green hydrogen with fast reaction rate, high quantity, without using electric from grid and fossil fuel as raw materials, using Aluminum as an energy carrier but this process will have Aluminum hydroxyl as waste but it can be recycled to solid aluminum. In tradition way used coal as oxygen reduction but coal give very high pollution it is not green production. Using Paulownia as green energy to generate heat and electric to recycle Aluminum oxide to Solid Aluminum in the solution and very new technology in the world no one do this process yet. Paulownia is the only plant that does not release Sulfur Oxide, Nitrous Oxide, Carbon Mono oxide, methane and other harmful substances while other fuel release higher value. It releases emission less than Coal and Petrol. The average heat value 20 MJ/kg nearly to sub-bituminous. Using Paulownia which absorb solar energy and convert to fuel use to charge aluminum had higher power density than using solar cell or wind energy to run on electrolyser and produce electric from fuel cell to charge solid metal.

Green hydrogen is a potential emission free alternative fuel to replace traditional hydrogen production methods and fossil fuels used in the industry and transport. It is produced hydrogen by using renewable, solar and wind electric feed to electrolyze, split water molecules to hydrogen gas and oxygen gas, without release any greenhouse gases but it high cost and cannot operate continuously as solar hours only 4.5 hours per day and wind energy is not stable.

Liquid hydrogen and ammonia are easy to transport but it needs lot of energy to convert from hydrogen gas to liquid hydrogen and ammonia. The power density is low to use in high heat processes; industries need to mature the fuel switch solutions to hydrogen.

Green hydrogen is a key in the global transition to a sustainable and net-zero emissions.

Research Methodology

1. Literature review:
    a. Aluminum as an energy carrier
    b. Green hydrogen from aluminum in Thailand
    c. Aluminum dioxide converts to Aluminum oxide
    d. Aluminum oxide converts to Aluminum
    e. The Hall–He´roult process
    f. Paulownia as green fuel
    g. Paulownia power plant
2. Engineering design, calculation and equipment selection
3. Green hydrogen generator without electrolysis

Aluminum as an energy carrier

Aluminum is a sustainable energy carrier because it can store energy safely and use a small space, it can reduce carbon dioxide emissions in communities and industries. It is a good energy exchanger, and can store very high energy. The conversion of aluminum into energy is achieved by oxidizing aluminum with water at high temperatures. Hydrogen can be applied to internal and external combustion engines or with fuel cell. In this production process, aluminum hydroxide is emitted as a waste product and ammonium hydroxide can be sold as another product or convert back to solid aluminum by collecting aluminum hydroxide.

Converting aluminum hydroxide back to aluminum has been reviewed in the existing literature on the development of technologies that allow the conversion of aluminum hydroxide back to aluminum without emitting carbon dioxide. Hall–He'roult process use for converting aluminum oxide into aluminum is a technology used today. Therefore, it can be used very well. This process can compete in the cost of producing conventional hydrogen. The cost of replacing aluminum dioxide back to aluminum includes transportation costs, storage, and power generation for converting aluminum hydroxide back to aluminum. Converting aluminum to hydrogen gas is a process that does not emit carbon dioxide. The use of aluminum is slightly more expensive than the use of ammonium, while avoiding toxicity and NOx emissions

Aluminum can be cost-competitive on a chemical energy basis with most common hydrogen carriers. To contextualize the findings, a remote mine case study integrates transportation, storage and power generation costs for aluminum, compared to liquefied hydrogen and ammonia. Aluminum is comparable to other carbon free solutions. Aluminum emerges as marginally more expensive than the direct use of ammonia, while avoiding concerns related to toxicity and NO_x emissions. Aluminum is promising energy carrier that merits further consideration in various applications, as shown in Figure1 (Pascal, 2024).

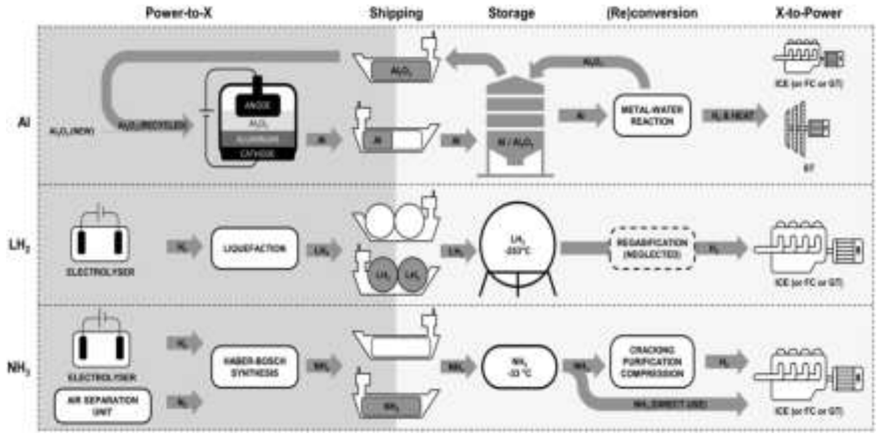

Figure 1: Properties of the energy carriers.
Source: Energy Advance, 2024.

From Table 1, shown energy density of LH_2 2.3 kWh/l, NH_3 3.5 kWh/l, Diesel 10 kWh/l, Aluminum 23.2 kWh/l, Al 4.5 kWh/l, Aluminum had the highest energy density. Once Aluminum released it energy stored will turn to Aluminum Hydroxyl, $Al(OH)_3$. We can convert $Al(OH)_3$ to Aluminum Oxide, Al_2O_3 by heat from Paulownia and Aluminum Oxide, Al_2O_3, to Aluminum, Al, by Hall–He´roult process using electric from Paulownia power plant, which is Green Energy (Paulownia, 2024).

Table1: Properties of the energy carriers

Energy carrier	Specific energy	Density	Energy density
	kWh/kg	kg/m^3	kWh/l
LH_2 (-253 °C)	33.30	70	2.30
NH_3 (-33 °C)	5.20	682	3.50
Diesel	11.80	850	10.00
Aluminum	8.60	2,700	23.20
Aluminum SGA bulk density	4.50	1,000	4.50

Source: Energy Advance, 2024.

Green hydrogen from aluminum in Thailand

Green hydrogen from aluminum in Thailand process without electrolysis has high energy density 23.5 kWh/l, shown in Figure 2.

$$2Al + 2NaOH + 6H_2O \rightarrow 2NaAl(OH)_4 + 3H_2 \qquad (1)$$

$$2NaAl(OH)_4 \rightarrow 2Al(OH)_3 + 2NaOH \qquad (2)$$

From Eq. 1 and Eq. 2 this process uses Solid Aluminum, Water and Sodium hydroxyl as catalyst to get hydrogen gas at 4.4 kWh/kg_{Al}, release heat 4.4 kWh/kg_{Al}, Aluminum hydroxyl and Sodium hydroxyl with heat from biomass and electrical from biomass to Aluminum efficiency approximately 58.7%, as shown in Table 2. This process is recyclable for catalyst and Aluminum hydroxyl.

Table 2: Power to Aluminum Energy used

Process	kWh/kg_{Al}
The calcination	1.6
The smelter	13.2
The chemical energy that can be converted to	
Hydrogen	45.4
Heat	4.4
The efficiency for power to aluminum is approx. %	58.7

Source: Author

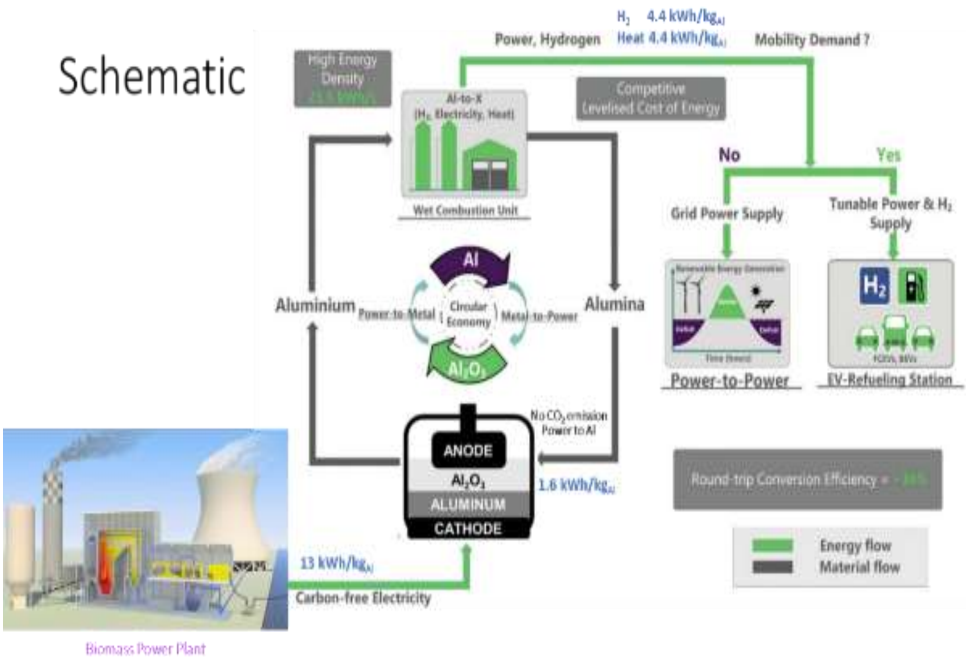

Figure 2: Green hydrogen by metal process without electrolysis
Source: Author

Figure 3, show the process to recycle Aluminum hydroxyl $Al(OH)_3$ to solid aluminum (Al) by using Paulownia to generate heat, 1.6 kWh/kg_{Al}, convert Aluminum hydroxyl $Al(OH)_3$ to Aluminum oxide (Al_2O_3), Calcination, then generate electric, 13.2 kWh/kg_{Al} using with arc furnance, to recycle Aluminum oxide (Al_2O_3) to solid Aluminum (Al), as shown in Table 2.

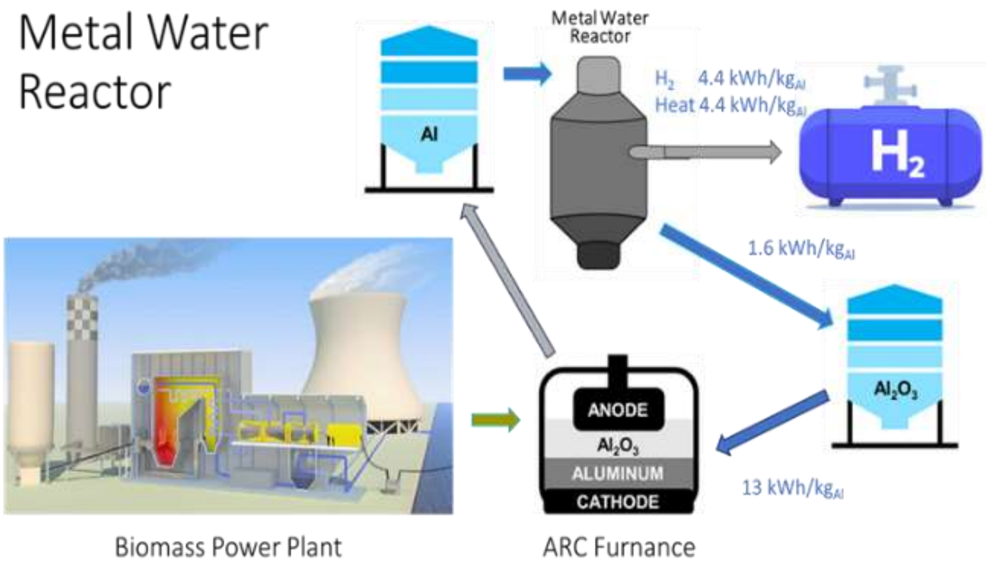

Figure 3, Green hydrogen by metal water reactor with Paulownia Power Plant.
Source: Author

Aluminum dioxide converts to Aluminum oxide

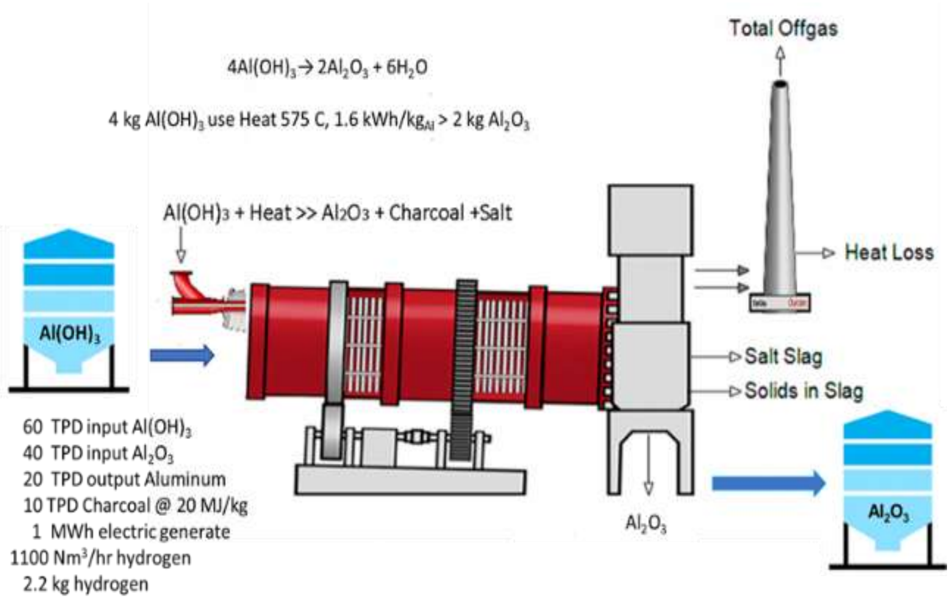

Figure 4: Aluminum hydroxyl converts to aluminum oxide
Source: Author

After the reaction of Aluminum, Sodium hydroxyl, and Water will get Aluminum Hydroxyl 4 kg required heat energy 1.6 kWh/kg_{Al} at 575 C from Paulownia charcoal to convert to Aluminum oxide 2 kg in rotary kiln as shown in Figure 4.

Aluminum oxide converts to Aluminum

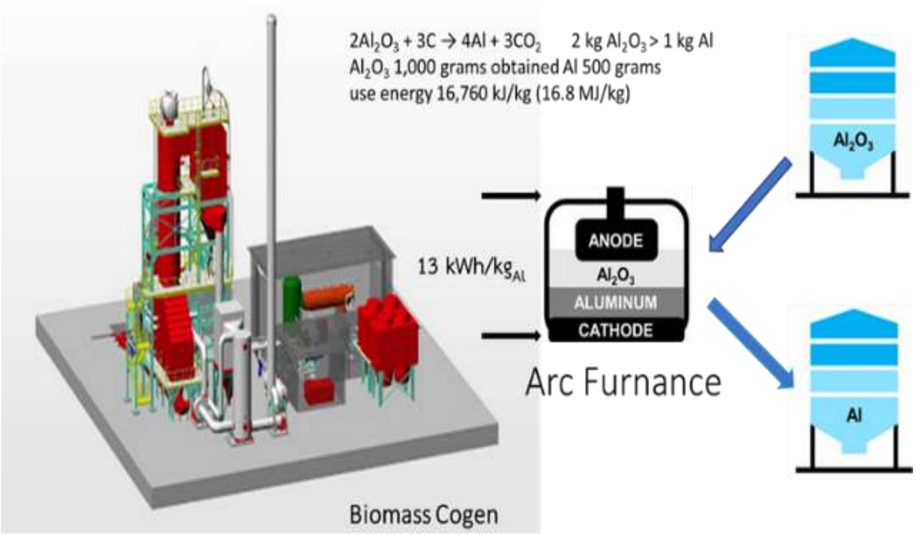

Figure 5: Aluminum oxide converts to Aluminum
Source: Author

Aluminum oxide 2 kg will convert to solid Aluminum 1 kg by Arc furnance, Smelter, Hall–He´roult process. This process as shown in Figure 5 require 16,760 kJ/kg (16.8 MJ/kg). The green electric, 13 kWh/kg_{Al}, supply from Paulownia, biomass, power plant. This process full recyclable as the energy from the sun and CO_2 collected by Paulownia, store energy in biomass, then used biomass as heat source and electrical generator to supply green electric to the conversion process. The Aluminum was charged with solar energy as infinity energy source.

The Hall–He´roult process

The Hall-Héroult process is the industrial method for smelting aluminum, and it uses electrolysis to extract aluminum from bauxite. The process involves dissolving aluminum oxide in a molten electrolyte, then using electricity to separate the aluminum from the electrolyte. Bauxite, a combination of aluminum oxide and other minerals, is mined. Alumina is formed from the bauxite. Alumina is dissolved in a molten electrolyte of cryolite and aluminum fluoride. Electricity passes through the electrolyte, separating the aluminum from the electrolyte. The aluminum collects at the cathode, while oxygen from the alumina combines with carbon to create carbon dioxide as shown in Figure 6.

The Hall-Héroult process requires a lot of energy, so smelters are often located near large power stations. (H. Kvande, 2014)

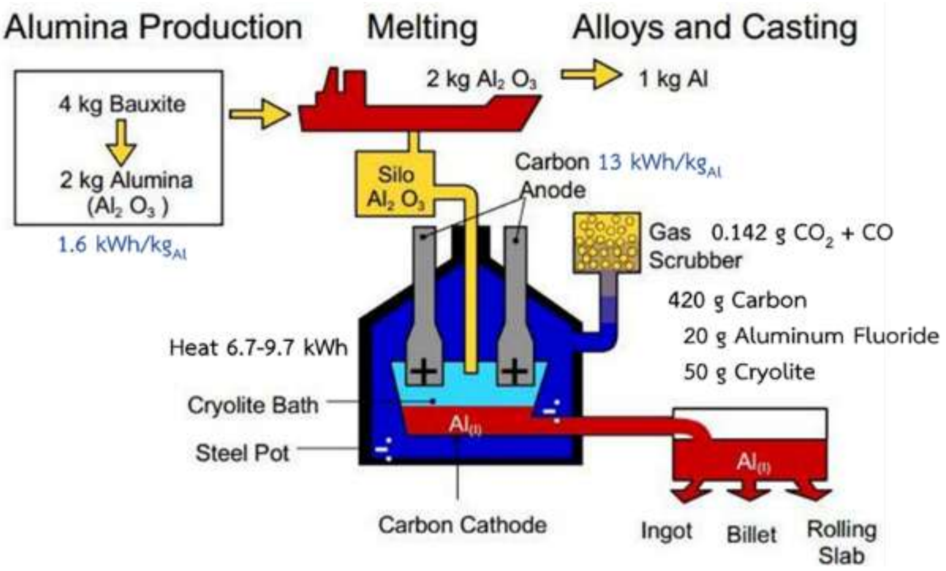

Figure 6: Arc furnance, Smelter, Aluminum oxide (Al_2O_3) convert to Aluminum (Al)
Source: Alternative Technologies, 2014.

Paulownia as green fuel

The paulownia as shown in Figure 7, Paulowniaceae family includes over 20 species, the best known are tomentosa, elongata, fortunei, kawakamii, catalpifolia, Taiwanese and fargesii. It is the fastest growing tree in the world, with huge leaves up to 80 cm. in diameter, large melliferous flowers that can come in different colors, a large crown, and which can well exceed 1 meter in diameter and reach 30 meters in height.

Figure 7: Paulownia tree
Source: Stephen McNair, 2 October. Paulownia Professional Company, 2024

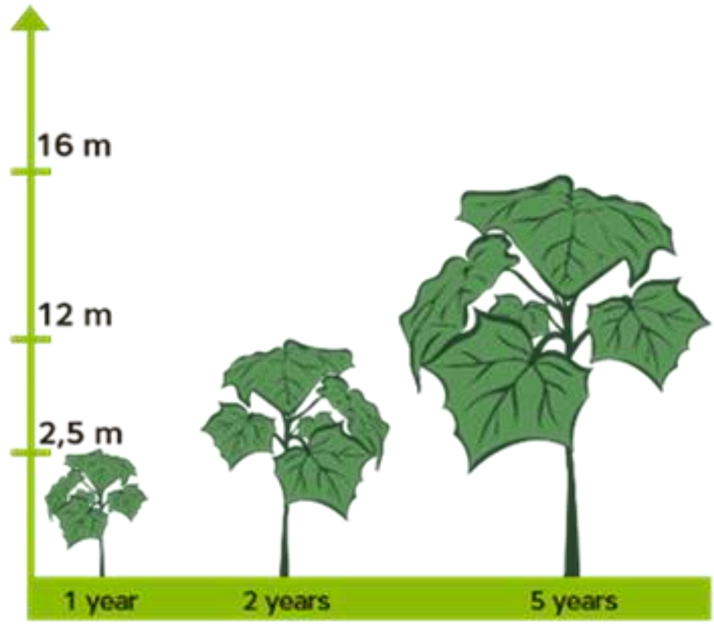

Figure 8: Growth rate
Source: Paulownia

Paulownia is CO_2 absorption plant for its growth. The plant regenerates itself after each cut, can be cut 4-8 times and survive even up to 100 years, after each cut it will regrow more vigorously and faster by taking advantage of the root system developed before the previous cuts as shown in Figure 8 and 9.

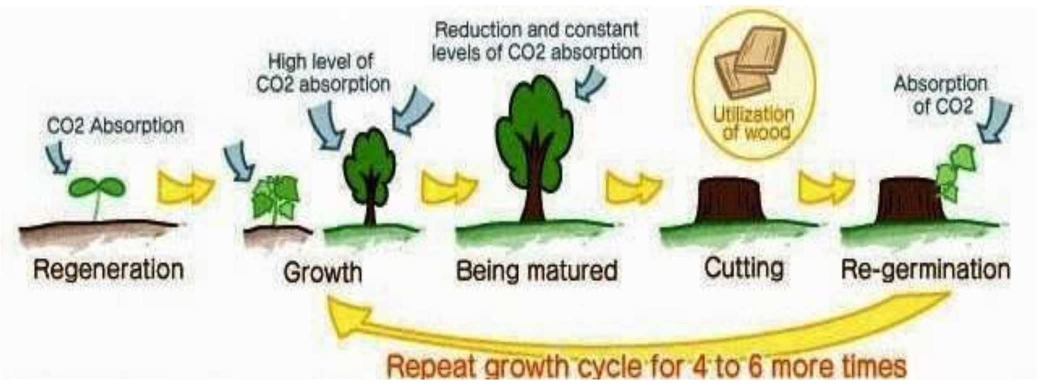

Figure 9: Paulownia plantation
Source: Paulownia Professional Company, 2024

Paulownia wood properties

- Life 100 years.
- In 1 year on an area of 1 hectare will receiving biomass 35-40 tons.
- One paulownia tree can absorb 22 kg of CO_2 and gives 6 kg of oxygen.
- It grows 1 cubic meter in 7-8 years.
- At year 5 the height is 16 m.

Paulownia is a natural renewable resource. It contains stored energy from the sun. By combusting in access air furnance that stored energy can be released under controlled conditions to produce electric and heat. It is a truly sustainable fuel source.

Paulownia based power plant could be a high potential alternative electric generator as well as an incentive for utilizing. It also helps to reduce PM 2.5 air pollution. It releases greenhouse gas emissions less than coal-based power plant, CO_2 emissions vary from 43-61 $kgCO_2/T$.

Table 3: Emission for different type of fuels

Harmful substances	Petrol	Coal	Paulownia
So_x	277	1750	0
No_x	5250	1550	0
CO	0	7	0
CH_4	0	7	0
CO_2	775	550	187
Other harmful substances	2800	140	0

Source: NREL of USDOE

Paulownia release emission less than Coal and Petrol as shown in Table 3. Each Paulownia could absorb 22 kg of CO_2 and release 6 kg of oxygen. It released Sulfur Oxide, Nitrous Oxide, Carbon Mono oxide, methane and other harmful substances 0 while other fuel release higher value. It releases Carbon Dioxide 3 times lower than Coal and 4 times lower than Petrol. The heat value average 18-20 MJ/kg close to Sub-bituminous coal, as shown in Table 4.

Table 4: Paulownia Heat Value

Year		Density	HHV	LHV
		$g.cm^{-3}$	$MJ.kg^{-1}$	$MJ.kg^{-1}$
1	Average	0.26	19.677	18.415
	Standard Deviation	0.01	87.04	87.04
3	Average	0.42	19.761	18.487
	Standard Deviation	0.04	104.09	104.09
5	Average	0.46	19.947	18.680
	Standard Deviation	0.03	31.72	31.72

Source: NREL of USDOE

Paulownia can be used as green energy to produce biofuel. It absorbs Carbon Dioxide from the environment transform to Paulownia tree as biomass. It transforms to Biogas, Bio-Ethanol, Wood chip, Wood Pellets and Charcoal. This fuel use to produce electricity, heat, cold, and Bio-Fuels. Then it releases Carbon Dioxide. The Carbone Dioxide will absorb back by the Paulownia again when it is photosynthesis, as shown in Figure 10.

The physical features from Paulownia cause special burning technology. The low temperature ash melting point is one of these compared to other types of biomasses. It burns temperature

1,000°C not like biomass burn under 700-750°C. The conventional furnaces at temperatures over 1,100°C would lead to slagging within the boiler. Paulownia not release chlorine like another biomass. Paulownia not requires special construction and process to avoid corrosions during the low and high temperature ranges. The advantages of Paulownia as fuel are the less disturbance variables. Paulownia fuel availability very comparable to conventional power plants.

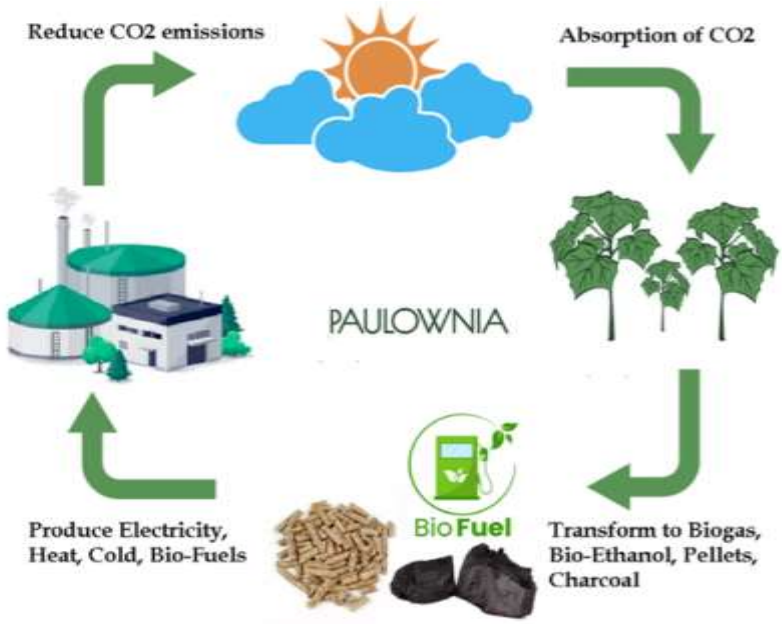

Figure 10: Paulownia Biofuel
Source: Paulownia Professional Company, 2024

Conventional green hydrogen production use water electrolysis from solar power, and wind power is more expensive it cannot be used commercially.

On demand green hydrogen generator without electrolysis has produced the world's first successful huge quantity green hydrogen from water with aluminum in Thailand, Hydrogen by metal. This process was created to replaced coal or natural gas as fuel without electrolysis by using green aluminum process able to produce carbon-free aluminum. Green aluminum use with catalyst to produce green hydrogen from water.

Production of green hydrogen from industrial aluminum scraps, soft drink cans, scrap wires, etc., using alkaline solution as a catalyst. This process is sufficient to reduce the cost of producing green hydrogen to a level that makes the total production cost of green hydrogen per kilogram commercially reasonable and can be produced in large quantities.

Paulownia power plant

The Paulownia is kept in storehouse (1) and transfer by the bale hoop opener (2) to the boiler house, where it is burned on a vibration grate (4) cooled by water prevents slagging of the burning fuel. Afterwards the ash is moved out by the wet ash remover (5) out of the boiler. The flue gas is cleaned to reach Thailand emission standard. That implies that the injection of additives absorbs for example chlorine compounds which can be separated efficiently in addition with dust and other unburnt materials by the fabric filter (11). The heat which is generated in the furnace is used to vaporize the water by the boiler walls (3). The separation of feed water and steam happens in the steam drum above the boiler. The saturated steam is superheated at temperature of 522 °C within the downstream super heater (6) as shown in Figure 11.

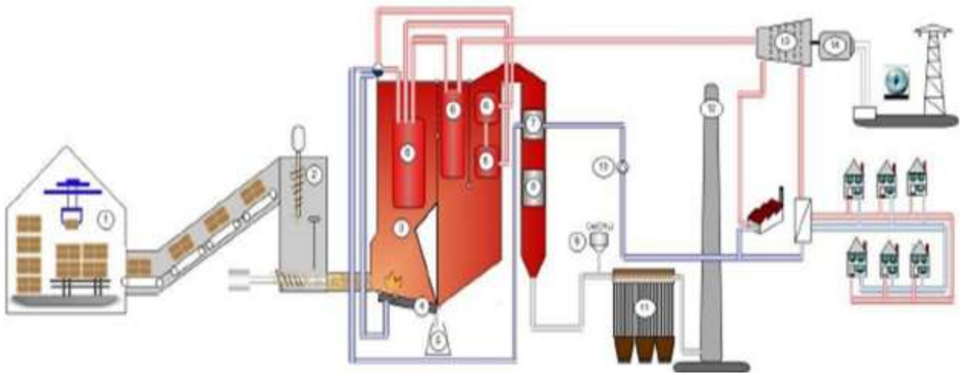

Figure 11: Paulownia power plant

Source: Hermes Engineering Procurement Construction, 2024

1. Paulownia store house 2. Bale-hoop-opener 3. Steam boiler 4. Vibration grate 5. Wet ash remover 6. Super heater 7. Economizer 8. Air pre-heater 9. Dry absorption 10. Feed water pump 11. Fabric Filter 12. Chimney 13. Steam turbine 14. Generator

Green hydrogen generator without electrolysis

Green hydrogen generator without electrolysis process has higher safety, no need for a high-pressure tank and transportation. Does not release Carbon dioxide. This process proof to be green Purity 99.999 %. Operate continuously 24 hours a day, 365 days a year, regardless of the fluctuations of the sun or wind, eliminating the need to use expensive and short-lived batteries. in storing electrical energy. It uses renewable energy and this process recyclable 100%.

This green hydrogen can be used with internal combustion engine and fuel cell to produce electric. Cost of electricity from green hydrogen using this process is less than the cost of producing electricity from the Electricity Distribution Company.

Figure 12: Green Hydrogen Generator
Source: Author

1. Hydrogen Generator 2. Cooler Condenser 3. Low Pressure Drier 4. Hydrogen Purifier 5. Scrubber 6. Hydrogen Compressor 7. H.P. Driers and Filters 8. Hydrogen Storage

Metal Water Hydrogen Generator as shown in Figure 12 has metal water hydrogen generator with large vessel to get reaction between water, metal, and catalyst to generate hydrogen gas, this reaction will generate heat it will have cooler condenser to cool down. Once it cools down the hydrogen gas which has low pressure will be clean at hydrogen purifier and remove moisture out at low pressure drier the hydrogen gas will pass thru scrubber then increase pressure with hydrogen compressor once pressure increased the gas will remove moisture again at high pressure driers and filters. Once it clean and increase pressure to 2,000 PSI it will store in the cylinder.

Green hydrogen generator without electrolysis benefits

1. Uses water, aluminum, and catalyst to produce green hydrogen purity 99.999%.
2. Lowest production costs with very fast production rate.
3. It is green hydrogen and does not release carbon dioxide from the system.
4. Can be used in conjunction with fuel cells and combustion engine very well.
5. By-products from the production process can recycle to aluminum.
6. Highly secure, easy to use.
7. No need to compress or turn hydrogen into liquid for transportation.

Results

60 Tons per day Aluminum hydroxyl $Al(OH)_3$ can convert to Aluminum oxide (Al_2O_3), 40 Tons per day using Paulownia charcoal, 10 Tons per day. Aluminum oxide (Al_2O_3) 1,000 grams can convert to Aluminum 500 grams use energy 16.8 MJ/kg or 13 kWh/kg_{Al}.

From Table 5 shown asset cost of Aluminum in 10 years 0.1 THB/kg. The catalyst NaOH recycle in process average cost 0.02 THB/kg. Cost to covert $Al(OH)_3$ to Al_2O_3 by rotary kiln with Paulownia Biomass 1.20 THB/kg. Cost to convert Al_2O_3 to Aluminum by Hall–He´roult process 2.51 THB/kg This makes green hydrogen cost at 65.35 THB/kg.

Table 5: Production cost of green hydrogen from water without electrolysis in Thailand

Descriptions	kg	THB/kg	THB
Aluminum asset cost for 10 years	8.92	0.10	0.85
NaOH recycle	13.23	0.02	0.26
H_2O	17.88	0.05	0.89
Cost to convert $Al(OH)_3$ to Al_2O_3	25.80	1.20	0.96
Cost to convert Al_2O_3 to Al	12.90	2.51	2.38
Green Hydrogen Cost	1.00		65.35

Source: Author

From Table 5 show new aluminum in Thailand cost 350.00 THB/kg, Aluminum can and waste aluminum from industrial process cost 50.00 THB/kg The aluminum recycles from this process cost 30.00 THB/kg. Electric produce from Paulownia 2.16 THB/kWh, green hydrogen 2.89 THB/kWh. Thai's electric from EGAT 1.80 THB/kWh. Thai's electric from MEA and PEA 7.50 THB/kWh.

Table 6: Cost of Electric and Aluminum

Green Electric from Paulownia	2.16	THB/kWh
Electric from Green hydrogen	2.89	
Thai's electric from EGAT	1.85	
Thai's electric from MEA and PEA	7.50	
Green hydrogen	55.64	THB/kg
Aluminum recycle cost	54.52	
New Aluminum	350.00	
Can Aluminum	50.00	

Source: Author

Discussions and Conclusions

Conventional green hydrogen produces from water electrolysis, using solar power, and wind power, it is higher production cost with time limited, solar hours, and no wind 24 hrs.

Using Aluminum as an energy carrier, the production of green hydrogen from Metal, Water and catalyst has low production cost and can produce in large quantity and very fast reaction.

This process will have Aluminum hydroxyl as waste but it can be recycled to solid aluminum. In tradition way used coal as oxygen reduction but coal give very high pollution it is not green production. Using Paulownia as green energy to generate heat and electric to recycle Aluminum oxide to Solid Aluminum in the solution and very new technology in the world no one do this process yet. Paulownia is the only plant that does not release Sulfur Oxide, Nitrous Oxide, Carbon Mono oxide, methane and other harmful substances while other fuel release higher value. It releases emission less than Coal and Petrol. The average heat value 20 MJ/kg nearly to sub-bituminous. Using Paulownia which absorb solar energy and convert to fuel use to charge aluminum had higher power density than using solar cell or wind energy to run on electrolyser and produce electric from fuel cell to charge solid metal.

Green hydrogen generator from metal without electrolysis has higher safety, no need for a high-pressure tank, and transportation, operate continuously 24 hours a day, 365 days a year, regardless of the fluctuations of the sun or wind, eliminating the need to use expensive and short-lived batteries in storing electrical energy. This process is sufficient to reduce the cost of producing green hydrogen to a level commercially 65.35 THB/kg and can be produced very fast in large quantities. The cost of electric produce from green hydrogen 2.89 THB/kWh.

Suggestions

Green hydrogen generator from metal without electrolysis has higher safety, no need for a high-pressure tank, and transportation. operate continuously 24 hours a day, 365 days a year. We can use solid aluminum to produce green hydrogen at site to use internal combustion engine or fuel cell to generate electric charge EV at charging station to reduce cost of electric from PEA and MEA. With micro grid connected to reduce transmission line and sub -station system as high demand for EV charge will increase too high in Thailand.

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Diesel-Hydrogen engine conversion for truck, Euro 2 to Euro 5

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Abstract

Most of the trucks used in Thailand run on diesel fuel, it emits air pollution, causing global climate change and affecting human health. In year 2025 The Department of Land Transport, Traffic Police Division the Pollution Control Department has announced the establishment of black smoke standards used for the inspection of both old and new vehicles, with an opacity value of not more than 45 percent will not get permit to operate on road any more. The fleet operator must change the fleet to other fuel or use electric vehicles as no emissions release. Therefore, we must find a way to use diesel as fuel to emit the least amount of pollution than 30% index. While being able to save fuel and achieve close to active torque. In this research literature reviews for fuels characteristics, diesel fuel, hydrogen, combustion of diesel with hydrogen in diesel engines, EURO 2 and EURO 3 engine after installed additional equipment are equivalent to EURO 5 with a hydrogen mix up to 34% at full load. Run bi-fuel reduces emissions better than used diesel alone. With bi-fuel the highest efficiency occurs with hydrogen 12%. When using hydrogen with diesel in internal combustion engine CO, CO_2, and soot reduced, while NOx and HC increased. Diesel-Hydrogen engine conversion for truck can delay the replacement for entire fleet of EURO 2, EURO 3, and EURO 4 standard to electric trucks, as electric truck does not yet have the right technology suitable for Thailand and costly. The performance and emissions of diesel engines using bi-fuel, hydrogen and diesel fuel improve to EURO 5 standard also the fuel consumption reduce.

Keywords: Dual Fuel, Diesel-Hydrogen, Euro 2 to Euro 5, Fuel saver, PM 2.5.

Introduction

Most of the trucks used in Thailand run on diesel fuel. It emits air pollution, causing global climate change and affecting human health. Therefore, we must find a way to use diesel as fuel to emit less pollution while able to save fuel with the same torque. If you replace a truck that runs on diesel fuel with EURO 2, EURO 3, and EURO 4 standard to electric trucks, does not yet have the right technology suitable for Thailand, immediately the problem still existing. The Department of Land Transport, Traffic Police Division the Pollution Control Department has announced the establishment of black smoke standards used for the inspection of both old and new vehicles, with an opacity value of not more than 45 percent.

Use of fossil fuels widely contributes to the significant deterioration of the world's environment, causing harm to human health and the earth's atmosphere. It affects changes in air temperature and seasonality. Today's diesel engines are subject to strict emission control regulations, especially smoke, incomplete combustion, Carbon monoxide, CO, Sulfur dioxide, SOx, Nitrous oxide, NOx, and PM 2.5. Exhaust gas control and the reduction of diesel fuel consumption have become very important requirements in the field of engine development. This demand has led to the search for alternative fuels from petroleum.

Hydrogen gas is considered an option for use in diesel engines, can use hydrogen and diesel fuel, together to achieve energy and environmental benefits. Using hydrogen and diesel fuel

has a low fuel cost, significantly reduce emissions, increase engine efficiency. Hydrogen gas has one
problem; its self-ignition temperature is high that it is not accessible in the combustion engine chamber. Therefore, hydrogen is used to ignite diesel fuel instead of use as fuel, requiring the installation of additional equipment.

Research Methodology

1. Methodology
2. Fuels Characteristics
   2.1. Diesel Fuel
   2.2. Hydrogen as Fuel
3. Combustion of Diesel with Hydrogen in diesel engines

1. Methodology

Combustion hydrogen with diesel fuel. Measure fuel and air consumption, exhaust gas emissions CO, CO_2, NOx, and soot, were monitored with Diesel fuel emission standard as shown in Table 1. The hydrogen supplied to the engine was set at 4%, 7%, 12%, 23%, and 34%. Analyze the obtained results.

Table 1: Diesel fuel emission standard

EURO	Sulfur	CO	NOx	HC+NOx	PM
	PPM	vPPM	vPPM	vPPM	g/m^3
0	5,000				0.450
I	2,000	2.72	-	0.97	0.140
II	500	1.00	-	0.70	0.080
III	350	0.64	0.50	0.56	0.050
IV	50	0.5	0.25	0.30	0.025
V	10	0.5	0.18	0.23	0.005
VI	1	0.5	0.08	0.17	0.005

Source: Emission Standards for Diesel Engines at the Pollution Control Department, EU, USA
There will be no control of SOx gas, but the control of PM will be used instead

2. Fuels Characteristics

2.1 Diesel Fuel

Diesel fuel is a product of crude oil distill at atmospheric pressure. It consists of hydrocarbons, naphthenic, paraffinic, and aromatic. Diesel has calorific value 42.7 MJ/kg. Diesel fuel must meet the EN590 standard and have a cetane number of at least 51.

Why Diesel fuel was EPA Regulates

Diesel fuel has very high sulfur. Sulfur creates air pollution that has serious human health and environmental effects. Pollution from diesel exhaust includes.

- Particulate matter (PM 2.5)
- Nitrous Oxide
- Hydrocarbons
- Carbon Monoxide
- Other air pollutants

This air pollution can cause heart and lung disease and a range of other health effects. It can also damage plants, animals, crops, and water resources.

2.2 Hydrogen as fuel

Hydrogen can be used as fuel. When it burnt it not release air pollution. It is released only heat and water. It can be used with internal or external combustion engine, fuel cell, and burner for vehicle, home, and industrial.

Normally hydrogen production from hydrocarbon such as natural gas by steam reform, coal gasification, and electrolysis of water. Hydrogen has highest calorific value, approx. 120 MJ/kg. It's very low density when considering volume-related values. Hydrogen is flammability and easy to explode when it mixes with air compared to other fuels.

Hydrogen is excellent energy carrier, with water vapor as the by-product of its combustion. Nevertheless, the production of pure hydrogen is complex and energy-intensive, while its transportation and storage require extraordinary precautions. Due to its high-octane number 130, hydrogen is a desirable fuel for spark-ignition engines. However, its low cetane number 5–10 prevents it from being used as a standalone fuel for compression ignition engines.

Combustion of Diesel with Hydrogen in diesel engines

Hydrogen alone is not suitable for combustion in ignition compression piston engine due to it can ignition them self at high temperature with low cetane number. Hydrogen combustion increases temperature and pressure, leading to knocking in combustion chamber of the engine and increase NOx[1]. The combustion of diesel with hydrogen in diesel engines typical hydrogen is inject to the air intake and mixture with air to ignite the fuel injected direct at piston head inside combustion chamber[2]. To ignite hydrogen requires a spark plug with small power the mixture in the combustion chamber is quickly consumed[3]. By shorten the combustion time and reduce the carbon hydrogen ratio can reduce exhaust emissions[4]. In a bi-fuel engine where hydrogen is the minor fuel introduced into the intake manifold, the volumetric efficiency of the engine decreases as a portion of the air volume was replaced by hydrogen engine reduce loads[5].

Hydrogen Diesel Schematic

A hydrogen injector is a system that mix hydrogen, diesel and oxygen from the air into combustion chamber of diesel engine system as shown in Figure 1. Hydrogen is used to ignite diesel fuel, requiring the installation of additional equipment, it reduces emissions, and fuel saver as test report below:-

- Reduces emissions up to 80%
- Cleaner burn reduces PM 2.5 up to 90%
- More power, increase torque up to 20%
- Reduce fuel consumption 8 to 20%

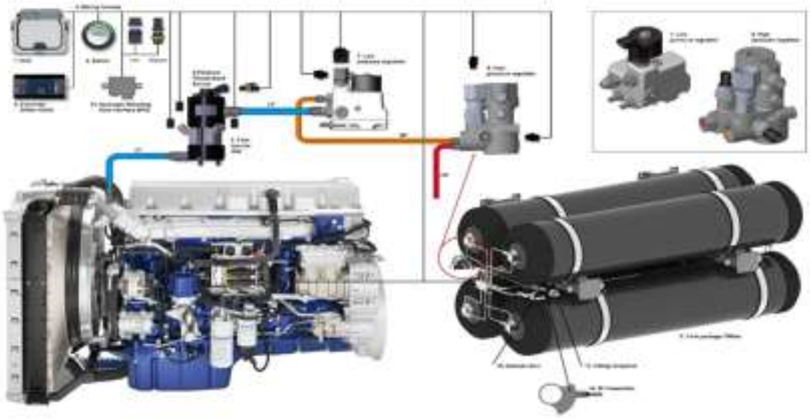

Figure 1: Hydrogen to Diesel schematic
Source: Prins

Economic

- As hydrogen gives a clean burn, carbon deposits and soot production is reduced keeping engine components cleaner.
- This can reduce costs and downtime by extending engine service intervals. Analysis of engines oil samples from trucks using the Hydrogen/Diesel System showed 65% less soot (carbon).
- All in all, the Hydrogen/Diesel System provides a fast return on investment (ROI).

Environmental

- Hydrogen has the environmental advantage of being a completely clean burning fuel with no harmful emissions.
- The system has been proven to reduce engine emissions 80%, less diesel particulate matter, 22 % less Nitrous Oxides, 25% less carbon monoxide and 8% less carbon dioxide.
- An ECS with proprietary control methods and algorithms to allow the control and setting of operating parameters of a fuel conserving and emissions reduction system.
- As the engine life is extended, the need for replacement parts and fluids is decreased which carries an additional environmental saving.

Efficient

- Run diesel with hydrogen is simple.
- Low maintenance, reliable and reduce emissions.
- Extend engine life.
- Hydrogen heat value 120 MJ/kg compared with diesel 44 MJ/kg.

Results

Hydrogen is excellent fuel for reciprocating engines due to its high combustion efficiency and very low emission. One way to utilize hydrogen in a reciprocating engine is to use dual fuel ignition compression. Engine powered by diesel with hydrogen contributing up to 34% of the energy share. The CO, CO_2, HC, NOx, and soot was reduced.

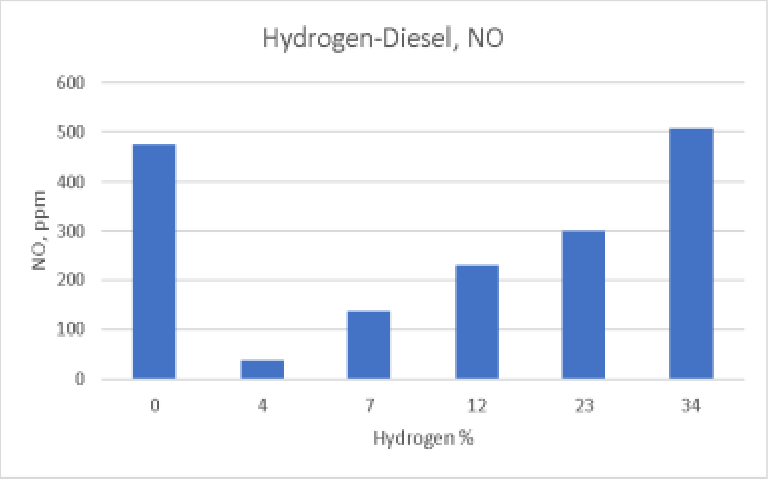

Figure 2: Nitrous oxide (NOx) emission for hydrogen with diesel
Source: Author

Figure 2, shown the variations in NOx concentration in the engine's exhaust when combusting hydrogen with diesel fuel 476 ppm. The addition of hydrogen to diesel fuels increases in NOx emissions from 4% to 34%. The total emissions were higher when hydrogen was burned with diesel. The increased overall emissions associated with the presence of diesel fuel were primarily due to the heightened combustion intensity and higher heat release rate

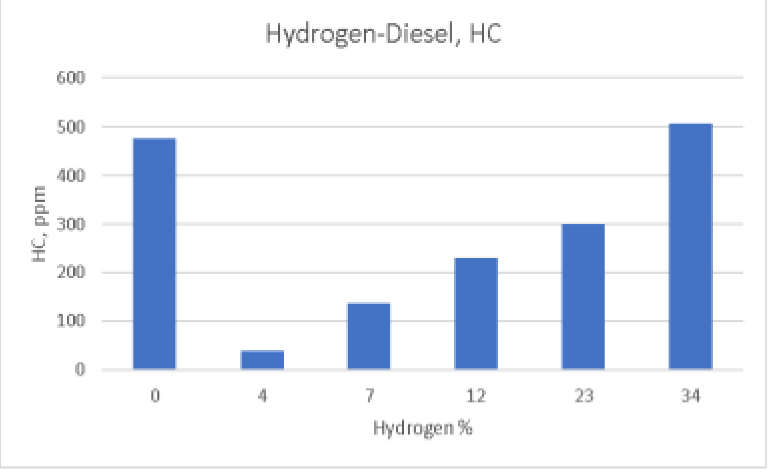

Figure 3: Hydrocarbons (HC) emission for hydrogen with diesel
Source: Author

Figure 3, shown variations in HC concentration in the exhaust gas from hydrogen and diesel fuel compared to the diesel fuel emission 81 ppm. The addition of hydrogen to diesel fuels increases in HC emissions from 4% to 34%. The highest concentrations of hydrocarbons in the exhaust gas were recorded with a 34% hydrogen content.

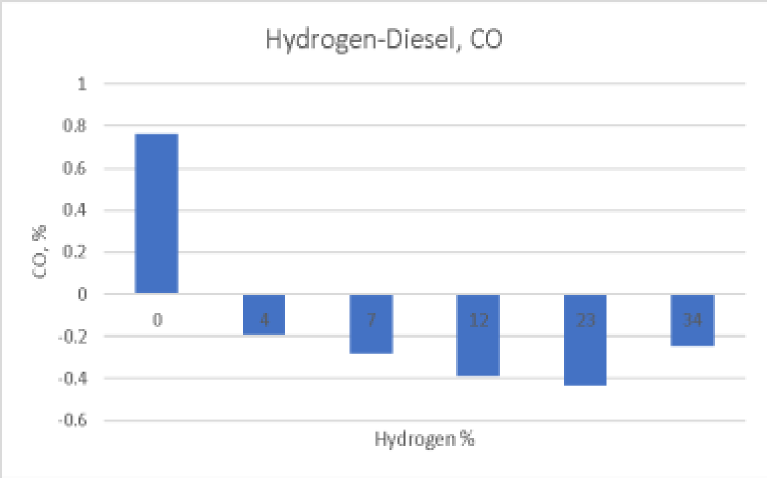

Figure 4: Carbon monoxide (CO) emission for hydrogen with diesel
Source: Author

Figure 4, shown the CO emissions from combustion of hydrogen with diesel fuel, compared to emissions measured when using diesel fuel alone 0.76%. The addition of hydrogen to the diesel fuels increased the combustion rate, reduced the amount of carbon in the fuel mixture, and had a positive impact on CO emissions. In hydrogen diesel dual combustion, reductions in carbon monoxide concentration in the exhaust gas.

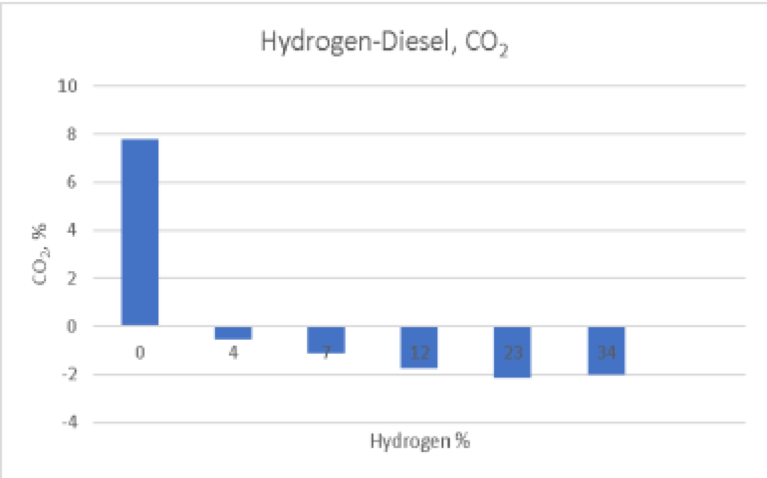

Figure 5: Carbon dioxide, CO_2, emission for hydrogen with diesel
Source: Author

Figure 5, shown the combustion of diesel fuel alone resulted in a comparable emission of carbon dioxide 7.80%. The addition and increase of hydrogen content combusted with diesel fuel had a positive effect on CO_2 emissions, which was associated with a decrease in the amount of elemental carbon supplied by the fuel.

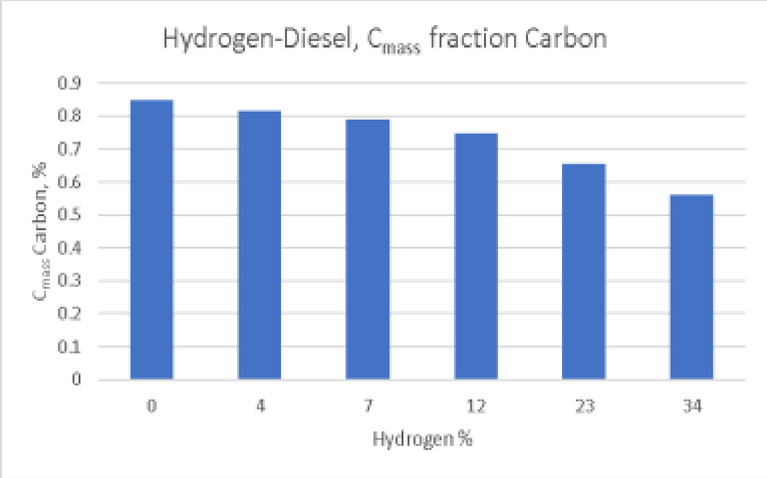

Figure 6: Mass fraction of carbon emission for hydrogen with diesel
Source: Author

Increase the amount of hydrogen supplied to the engine as shown in Figure 7, the carbon content decreased as shown in Figure 6.

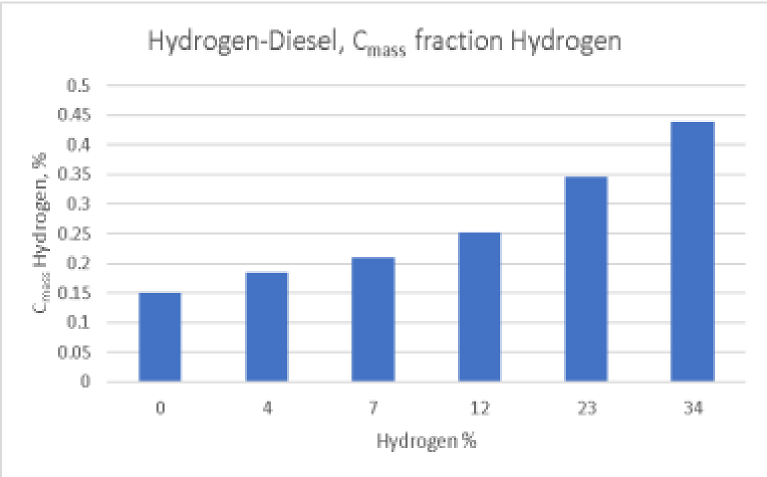

Figure 7: Mass fraction of hydrogen emission for hydrogen with diesel
Source: Author

The formation of soot occurs due to the incomplete combustion of carbon-containing fuel, primarily during the diffusion phase, which is influenced by the fuel-air mixture's mixing. The exhaust system captures heavy hydrocarbons, nitrogen compounds, and sulfur, releasing them into the atmosphere as solid particles, PM, as shown in Figure 8.

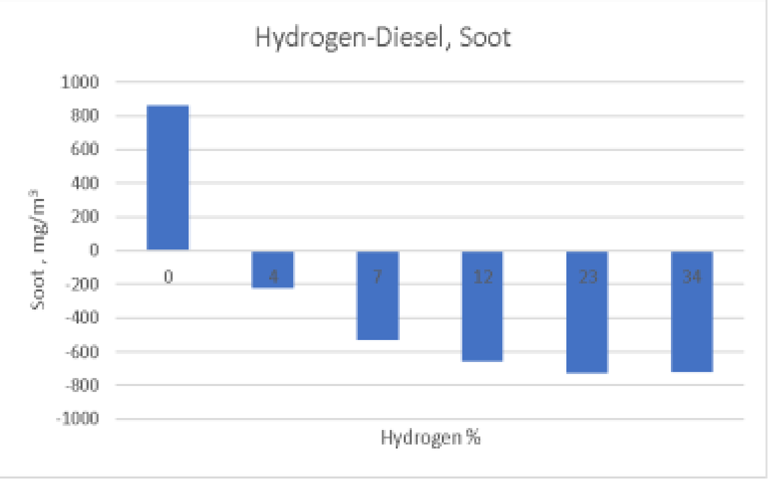

Figure 8: Soot emission for hydrogen with diesel
Source: Author

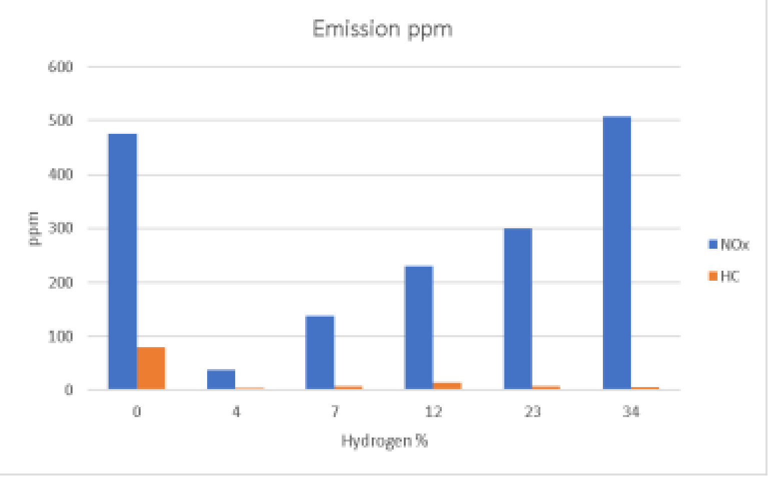

Figure 9: NOx and HC comparison for diesel only and hydrogen with diesel
Source: Author

Nitrous oxide, NOx, 476 ppm without hydrogen. When the amount of hydrogen increases the amount of Nitrous Oxide, NOx, increased. The best amount of hydrogen 2-4 %, 20-38 ppm NOx. Hydrocarbon, HC, 81 ppm without hydrogen. When the amount of hydrogen increased the amount of HC, HC, increased maximum at hydrogen 12%, HC 15 ppm then HC decreased from 2-4 %, HC 2-5 %. As shown in Figure 9.

Without hydrogen the CO, CO_2, is high 0.76, 7.8 % respectively. With hydrogen CO_2 reduce when hydrogen increased maximum at 23 % CO_2 –2.14 %. When the amount of hydrogen increased the amount of CO increased maximum at hydrogen 23%, CO -0.432 % then CO decreased from 2-4 %, CO – 0.075 to -0.195 %. As shown in Figure 10.

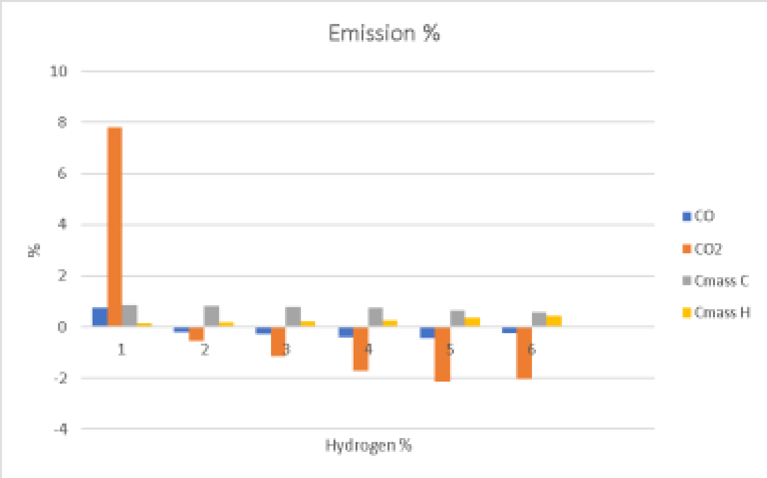

Figure 10: CO, CO_2, C_{mass} C, and C_{mass} H comparison for diesel only and hydrogen with diesel engine powered, Source: Author

Discussions and Conclusion

Using both hydrogen gas and diesel fuel in diesel engines, EURO 2 and EURO 3 standards, after installing additional equipment, EURO 2 and EURO 3 are equivalent to EURO 5 engines, operating at maximum load, with a hydrogen content 4%, NOx 38 ppm, HC 5 ppm, CO -0.195 ppm Sulfur 10 ppm PM -223 g/m^3. It is not only controlling diesel engine emission it also reduces emissions better than normal standard. In terms of energy efficiency, a 12% hydrogen content resulted in the highest efficiency for the dual-fuel engine. Regarding emissions, hydrogen as a fuel in compression ignition engines demonstrated favorable outcomes for CO, CO_2, and soot emissions, while NO and HC emissions increased.

Suggestion

Diesel with hydrogen conversion for truck can delay the replacement of EURO2, EURO3, and EURO4 engine to electric motor. From PTT public company research state that for large Electric truck was not economy to use and operate or replace for internal combustion truck and it did not has the right technology for Thailand and it is costly, the performance and emissions of diesel engines using diesel with hydrogen improve emission standard to EURO5 and the fuel consumption also reduce with same power output.

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Green Hydrogen from Waste Aluminum

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Abstract

Green hydrogen produces from solar cell and wind thru electrolyzer, which is low efficiency and high production cost. Usually, hydrogen from this process will convert to liquid hydrogen or ammonia as it easy to transport and higher power to weight ratio but it needs lot of energy to convert from gas to liquid hydrogen. Reaction of aluminum with water and catalyst has higher power energy to weight ratio, lower cost, and recyclable. It is easy to transport in solid form, easy to convert to hydrogen and it is green process. Producing green hydrogen from waste aluminum with alkaline solution as catalyst. This process will have aluminum hydroxide as waste. The objective of this study is to demonstrate the possible way of producing green hydrogen at low cost from waste aluminum with alkaline solution. The cost to produce hydrogen 1 kg 949.50 THB/H_2 1 kg without sell out $Al(OH)_3$. The aluminum hydroxide can sell at minimum price 124 THB/kg equal to 6,448 THB/H_2 1 kg, this process earn income 5,498.50 THB/H_2 1 kg. By sell out waste product drive costs down to a level that the total production cost of green hydrogen per kilogram and the cost of electric per kilowatt hour, is significantly less than power generation company costs. Currently, green hydrogen production cost per kilogram pushes cost factors to a prohibitive commercial price. The process consumes water and aluminum, which are cheap materials, we are able to overcome the cost constraints for green hydrogen generation.

Keywords: Aluminum, EV Charger, Green Electric, Green Hydrogen, Metal to Hydrogen

Introduction

Thailand power generating stations used natural gas or coal as fuel source, coal and natural gas is a major contribution to release CO_2, CO, SO_x, and NO_x, natural gas 60%, and coal 20% on a national scale.

Solar energy for grid connected could be a viable alternative but limited by solar hours, 4.5 hours per day. Thai Government's plan to increase solar energy to supply nation grid to reduce CO_2 emissions. Wind energy is another option to use but it not steady.

Biofuels is a process used microbiologically converted under anaerobic conditions to biogas. It may be used on a large scale, transformed into Bio-CNG, and used as an automotive fuel.

New era of green power generation, there is no getting around the truth that the source of fuel to produce green electric still has a significant carbon footprint which in the generation mix has a bulk contribution from conventional sources, and thus a large dependency on fossil fuels. Green hydrogen could use as an environmentally friendly fuel to reduce greenhouse gas emission from the burning of fossil fuels. They release lower toxic emissions that contribute to air and water pollution as well as climate change, making them cleaner and more environmentally friendly.

Further, green hydrogen, solar, and wind energy being sustainable, won't run out like fossil fuels. They are not subject to price variations brought on by geopolitical events or market changes, they are less expensive and more reliable for long time period. Finally, renewable energy can be decentralized, reducing infrastructure. Green hydrogen electric generation for grid connect are one source of decentralized renewable energy.

Development of technology to generation hydrogen not base on fossil fuels and low production cost is becoming more important to provide a clean fuel for the 21st century.

Research Methodology

1. Literature review:
    a. Hydrogen production from aluminum
    b. Waste commercial aluminum alloys
2. Key aspects of aluminum hydroxide ($Al(OH)_3$)
3. Experiment setup

Hydrogen production from aluminum

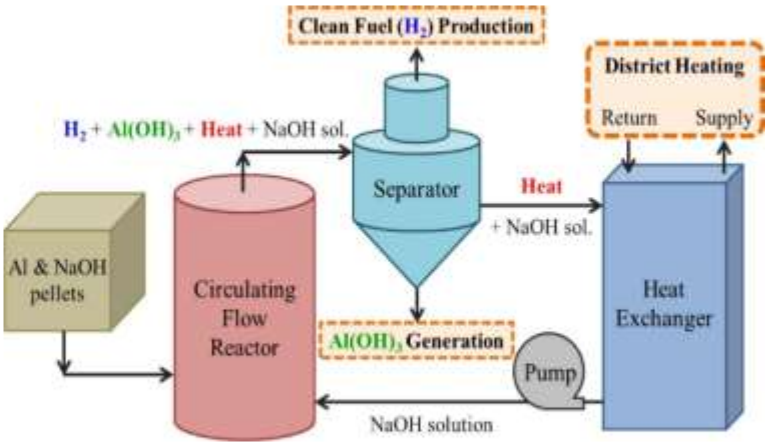

Figure 1. Hydrogen from waste commercial aluminum alloys process
Source: Fuel Volume 374, 15 October 2024, 132510[1].

Green hydrogen electrical generator technology as shown in Figure 1 uses water to generate hydrogen on board for internal combustion engine, a hydrogen-powered mobile power generator, or MPG.

Hydrogen production from aluminum can be achieved under mild conditions of temperature and pressure. The reactions of aluminum with sodium hydroxide in aqueous solution to produce hydrogen have been studied [2].

$$2Al + 2NaOH + 6H_2O \rightarrow 2NaAl(OH)_4 + 3H_2 \qquad (1)$$

ΔG = -437.80 kJ/mol ΔH = -415.50 kJ/mol

Two moles of Aluminum, two moles of Sodium Hydroxide and six moles of Water react to form two moles of Aluminum sodium hydroxide and three moles of Dihydrogen. This reaction give change in enthalpy 415.50 kJ/mol and change in exothermic 437.80 kJ/mol.

$$2\ NaAl(OH)_4 \rightarrow 2\ Al(OH)_3 + 2\ NaOH \qquad (2)$$

ΔG = 10.50 kJ/mol ΔH = -3.20 kJ/mol

Two moles of Aluminum sodium hydroxide react to form two moles of Aluminum hydroxide and two moles of Sodium Hydroxide. This reaction give change in enthalpy -3.20 kJ/mol and change in endothermic 10.50 kJ/mol.

Sodium hydroxide consumed in the hydrogen generating reaction (1) can be regenerated in reaction (2) and the overall process is in Equation (1) and Equation (2). Thus, only aluminum and water are the consumed as raw materials to produce hydrogen and give Aluminum Hydroxide as waste.

Hydrogen evolved at S.T.P. on complete reaction of 27 gram of aluminum with excess of NaOH aqueous would be (3)

$$n = \frac{m}{M} \tag{3}$$

where,

n	=	The number of moles,
m	=	The given mass,
M	=	The molar mass.

From equation (3) No. of mole aluminum equal to 1

$$No. of mole Aluminum = \frac{27}{27} = 1$$

From equation (1) at STP

2 moles of Al, 2 moles of NaOH, 6 moles of H_2O releases 2 moles of Aluminum hydroxide, 3 moles of Hydrogen gas. Then,

1 moles of Al, 1 mole of NaOH, 3 moles of H_2O releases 1 moles of Aluminum hydroxide, 1.5 moles of Hydrogen gas.

1 mole of Aluminum	=	26.98 gm,	
1 mole of NaOH	=	39.9997	gm,
3 moles of H_2O	=	18.0146	gm,
1 mole of $Al(OH)_3$	=	78.004	gm,
1.5 moles of Hydrogen gas	=	1.5 x 1.0078	
	=	1.5117	gm.

At STP

1 moles of Hydrogen gas	=	22.4	L and
1.5 moles of Hydrogen gas	=	33.6	L

1.5 moles of Hydrogen gas, weight 1.5117 g, 33.6 L, and 1 mole of Aluminum hydroxide, 78.004 g, is released on complete reaction of 1 mole of Aluminum, 26.98 g with excess of NaOH aqueous, 1 mole of NaOH 39.9997 g, 3 moles of H_2O 18.0146 g.

Hydrogen gas 1 kilogram, 22,226.63 L and Aluminum hydroxide, 51.658 Kg, is released on complete reaction of Aluminum, 17.868 Kg with excess of NaOH aqueous, NaOH 26.490 Kg, H_2O 35.791 Kg.

Aluminum alloys with other small metals, tin, rhenium, indium, calcium, bismuth, gallium, magnesium or lead, have higher reactivity than aluminum, but it higher cost and not easily available. The use of waste aluminum and sale aluminum hydroxide as by product from process could reduce hydrogen production costs.

To increase hydrogen production rate, increasing solution temperature and NaOH molar concentration, whereas the H_2 evolution rate was not reduced significantly with increases in the amount of waste aluminum pellets feed in to the reactor or the mass flow rate of the NaOH solution. From single operation, the average heat and hydrogen production rate from aluminum beverage can were 2.06 Wh_{th}/g_{Alcan}, and 2.72 Wh_{H2}/g_{Alcan}. [3]

As shown in Figure 2 used of a catalyst to turn aluminum into a water reactive fuel, oxidizes aluminum with water, converting its stored energy inside aluminum to heat and hydrogen. This can work with low quality aluminum waste.

This process can transport aluminum and oxidize very easy and quickly at higher power density in an aqueous environment where hydrogen is needed. This allows us to transport aluminum instead of liquid hydrogen or hydrogen gas, which is safe, simple and the energy density is 10 times higher than liquid hydrogen. Aluminum contains energy 8.6 MWh/Ton, or 23 MWh/m^3, it is one of the most volumetrically energy dense materials.

One aluminum can contain enough energy to charge an iPhone 14 over 10 times. The source of this energy from electricity consumed during the aluminum smelting process, as enormous battery chargers, this processes up to 70% efficient. The energy density is double of diesel fuel and 10 times higher than liquid hydrogen. We can transport very high amounts of energy in much smaller tanks or vessels than the industry is used.

Key aspects of aluminum hydroxide

- Antacid
- Pharmaceuticals
- Water Treatment
- Flame Retardant
- Catalyst
- Gemstone Enhancement

Experimental setup

2.1. Chemical

- Flake Sodium hydroxide 98%.
- Deionized water to prepare alkali solution.
- 1 M NaOH solution, dissolve 40.00 gm of sodium hydroxide in 250 ml deionized water and make up the solution to 1 liter.
- Waste aluminum from soda can.

2.2. Materials and measurements

The waste aluminum size 3x3 mm. has been performed in a beaker containing NaOH solutions 1 M at 35°C. Hydrogen produced by aluminum from the reactor through a Tigon tube 2 mm internal diameter and 30 cm long passed through a water bath at ambient temperature in order to condense the water vapor and hydrogen gas was collected in an inverted burette to measure the quantity of hydrogen produced as shown in Figure 2.

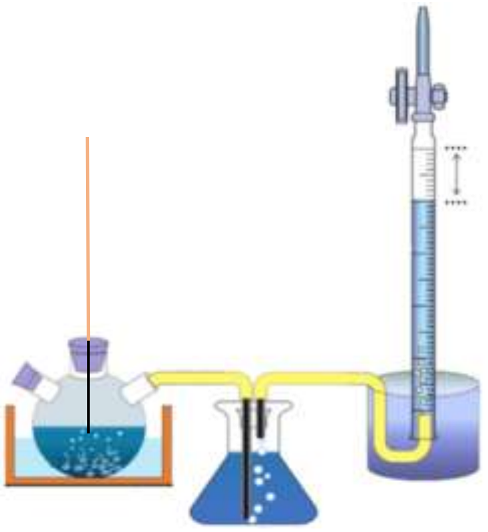

Figure 2. Experimental set up with Pyrex glass reactor, thermometer, Tigon tube, beaker filled with water at room temperature and water filled burette

Source: Author

Results

From Table 1, Hydrogen gas weight 0.01 g 0.22 L equivalent to Hydrogen gas 1 kg 22,000 L, and $Al(OH)_3$ 0.52 g equal to 52 kg, is released on complete reaction of aluminum 0.18 g equal to 18 kg with excess of NaOH aqueous, NaOH 0.27 g equal to 0.27 kg and H_2O 0.36 g equal to 36 kg

Table 1: Materials use and product

Materials	grams	L	kg	L
Waste Aluminum	0.18		18	
NaOH	0.27		27	
H_2O	0.36		36	
H_2O	0.01	0.22	1	22,000
$Al(OH)_3$	0.52		52	

Source: Author

With calculation from test results as shown from Table 2 Hydrogen gas 1 kg, volume 22,000 L has production cost 949.50 THB/H_2 1 kg and Aluminum hydroxide, $Al(OH)_3$ 52 kg has selling cost 124 THB/kg Total 6,448 THB/H_2 1 kg is released on complete reaction of Waste Commercial Aluminum 18 Kg at cost 50 THB/Kg 900 THB/H_2 1 kg with excess of NaOH aqueous, NaOH 27 kg at cost 40 THB/kg and it recycle automatic from the process so the cost will be 0.50 THB/kg and H_2O 36 kg 36 THB/H_2 1kg. This processes the cost of $Al(OH)_3$ to sell out at minimum cost 124 THB/kg equal to 6,448 THB this make this process earn income 5,498.50 THB/H_2 1 kg instead of the cost production 949.50 THB/H_2 1 kg without sell out $Al(OH)_3$.

Table 2: Production cost of 1 Kg Green Hydrogen

Green hydrogen gas 1 kg volume at STP = 22,000 L			
Materials	kg	THB/kg	THB
Waste Aluminum	18.00	50.00	900.00
NaOH 40 THB/kg (recycle)	27.00	0.50	13.50
H_2O	36.00	1.00	36.00
Green hydrogen gas	1.00	2,016.00	949.50
$Al(OH)_3$	52.00	124.00	(6,448.00)
Production cost for green hydrogen gas 1 kg with sale of by product			(5,498.50)

Source: Author

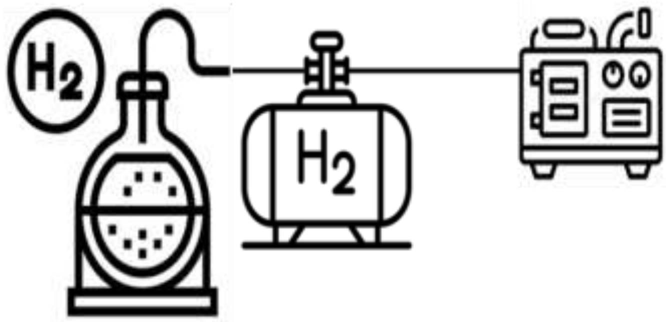

Figure 3. Internal combustion electric generator
Source: Author

From Table 3 The car and use hydrogen gas 1 kg to run 100 km, 20.16 THB/km without sell by product, -44.32 THB/km with sell by product. It can make profit 24.16 THB/km.

For internal combustion engine as shown in Figure 3 use hydrogen from process, 1 kg can generate 12.00 kWh, 168.00 THB/kWh without sell by product, -369.33 THB/kWh with sell by-product. It can make profit 201.33 THB/kWh.

Table 3: Hydrogen cost per kilometer and kilowatt hour

Hydrogen 1 Kilogram			No sale	Sale	Profit		
			By-product				
Car can run	100	Km	20.16	-44.32	24.16		THB/km
Internal combustion	12.00	kWh	168.00	-369.33	201.33		THB/kWh
Fuel cell	33.33		60.49	-132.97	72.48		
Hydrogen from electrolyze by wind[4]	48.00		259.00				
Hydrogen from electrolyze by solar[4]	48.00		322.00				

Source: Author

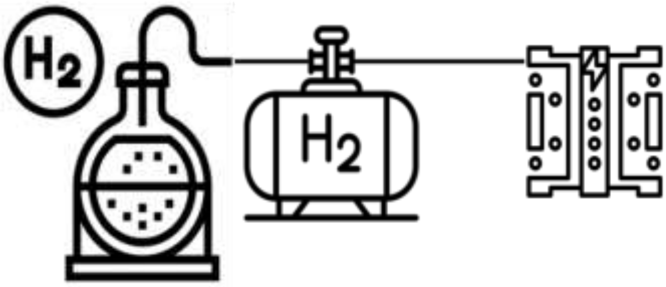

Figure 4. Fuel cell electric generator
Source: Author

For fuel cell use hydrogen from process as shown in Figure 4, 1 kg can generate 33.33 kWh, 60.49 THB/kWh without sell by product, -132.97 THB/kWh with sell by product. It can make profit 72.48 THB/kWh.

1 kg hydrogen, Fuel cell can produce electric 33.33 kWh, internal combustion engine can produce electric 12.00 kWh. Fuel cell has better efficiency than internal combustion engine.

To make 1 kg of hydrogen from electrolyzer need 48 kWh and the production cost for Solar cell 322.00 THB/kgH_2, Wind 259.00 THB/kgH_2 as shown in Figure 9 to produce 1 kg of hydrogen from electrolyze [4].

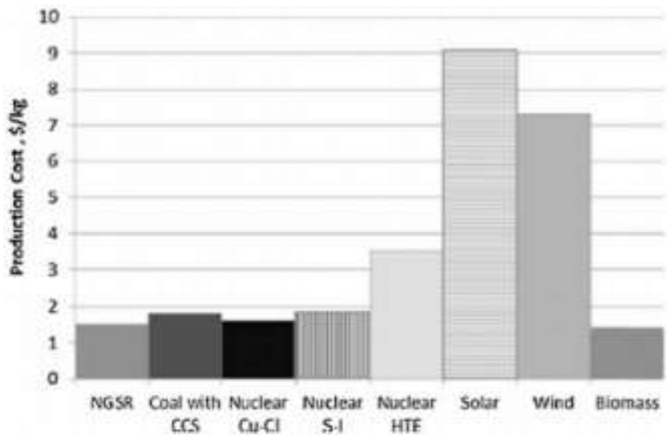

Figure 5. Cost comparison of hydrogen production
Source: Hydrogen as energy Carrier in Malaysian primary energy mix[4].

Discussion and Conclusion

In this study, the technically described process has been demonstrated. Generate green hydrogen from waste aluminum in alkaline solutions is a simple method and could reduce production costs. To reduce green hydrogen production cost, aluminum hydroxide from the process could be sold ensuring economic feasibility.

Suggestions

To reduce green hydrogen production cost, the by product from the process could be sold ensuring economic feasibility. It may have other solution to reduce cost of production by sale waste from process. If we can recycle by product back to solid aluminum or called charge the power back to solid aluminum for easy transportation and higher power density.

Acknowledgements

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Performance Evaluation of a Photovoltaic Solar Chimney

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Abstract

This research aims to study, design, and construct a photovoltaic solar chimney (PSC) in order to compare its performance with that of a conventional non-photovoltaic solar chimney (NPV). Two types of solar chimneys were developed : one incorporating photovoltaic (PV) panels within the structure, and the other as a standard chimney without PV integration. Both chimney types were designed with identical geometric dimensions 4.00 meters in height and 0.40 meters in width, with inlet and outlet openings measuring 0.40 × 0.30 meters to ensure fair performance comparison.

Experimental testing and performance analysis reveal that the PV-integrated chimney demonstrates superior thermal energy accumulation. This enhancement is attributed to the dual function of the photovoltaic panels, which not only convert solar radiation into electricity but also increase internal heat retention, thereby improving the buoyancy-driven airflow within the chimney. Temperature distribution measurements indicate that the PV chimney consistently maintains higher temperatures throughout the day compared to the NPV chimney. The front wall surface (SC), positioned closest to direct solar radiation, exhibited the highest temperatures, while the rear wall (Back) showed the lowest. Peak temperatures occurred between 12:00 and 14:00, with the PV chimney retaining heat for a longer duration. Furthermore, temperature values at 3.40 meters were higher than those at 2.40 meters and 1.20 meters, confirming the presence of thermal stratification and effective convective heat transfer. The findings demonstrate that integrating photovoltaic panels into solar chimneys enhances both thermal performance and airflow dynamics, offering a promising solution for sustainable ventilation and energy utilization in building systems.

Keywords: solar chimney, photovoltaic, natural ventilation, convective heat transfer, thermal performance

Introduction

Thailand is located in the tropical monsoon region of Southeast Asia, characterized by a hot and humid climate throughout the year. The country experiences an average annual temperature of approximately 27°C. During the summer months, particularly in April, temperatures in certain areas can reach as high as 40°C or even higher. These climatic conditions significantly affect daily life, especially within residential settings, where individuals spend the majority of their time.

The concept of thermal comfort has therefore become a critical consideration in architectural design and energy management within buildings. In countries with hot and humid climates like Thailand, creating indoor environments that promote thermal comfort is essential-not only for improving the quality of life of occupants but also for enhancing energy efficiency in cooling and ventilation systems. Addressing thermal comfort in residential design is a key step toward sustainable living and energy conservation in tropical regions.

The Solar Chimney is a device that facilitates effective air circulation through natural means. It operates by directly harnessing thermal energy from solar radiation. The principle underlying the solar chimney is based on the buoyancy of heated air: as air at the bottom of the chimney absorbs solar heat, its temperature increases, causing it to rise and flow upward. This creates a continuous airflow cycle, as cooler air replaces the rising warm air. The air inside the solar chimney, upon receiving solar energy, becomes heated and ascends through the chimney structure. This phenomenon is governed by the natural process of heat transfer, where thermal energy moves from regions of higher temperature to those of lower temperature. Solar radiation penetrates the transparent glass cover and is absorbed by the heat-absorbing surface below. This absorbed heat is then transferred to the air within the chimney, raising its temperature and causing it to move from the air inlet at the base of the chimney to the outlet at the top. This airflow is driven by the natural convection process, resulting from temperature-induced density differences within the air mass. The use of solar chimneys can significantly increase indoor thermal comfort and reduce the dependence on mechanical cooling systems, especially in hot and humid climates such as Thailand.

Objective

1. To study, design and construct solar chimneys.
2. To compare the efficiency of solar chimneys and chimneys non-photovoltaic .

Research Methodology

The research was conducted in the following steps:

1.Conduct research and gather information : Study relevant information and collect knowledge related to the topic.

2.Solar chimney design two types of solar chimney will be constructed to study and compare their performance:

2.1) solar panel-mounted solar chimney, which integrates photovoltaic panels inside the chimney structure, will be developed to study and analyze the impact of solar panel placement on thermal and electrical performance.

2.2) A standard solar chimney is a solar chimney without the installation of solar panels. It serves to cool and increase the circulation of indoor air . Natural Convection

3. Draft and create models using AutoCAD: Design small models for study and performance comparison. (Figure 1) Two types of solar chimneys were developed : one incorporating photovoltaic (PV) panels within the structure, and the other as a standard chimney without PV integration. Both chimney types were designed with identical geometric dimensions 4.00 meters in height and 0.40 meters in width, with inlet and outlet openings measuring 0.40 × 0.30 meters to ensure fair performance comparison.

4. Build a model based on the design created by AutoCAD. (Figure 2)

4.1) Type 1 : Photovoltaic Solar Chimney (PSC). The Photovoltaic Solar Chimney using 10 mm. thick smartboard covered with 0.18 mm. thick flat galvanized sheet, using 4 solar panels, size 400 x 1000 mm., 4 panels, size 12 watts, 17.5 volts. Amorphous silicon solar cell chimney has openings on the top and bottom which are located on the back of the solar cell chimney, size 0.30 x 0.40 meters.

4.2) Type 2 : non-photovoltaic solar chimney (NPV). The solar chimney is 4.00 meters high and 0.40 meters wide. There are two openings at the back of the chimney, one at the bottom and one at the top. The openings are 0.40 x 0.30 meters in size. The top and bottom openings are the same size.

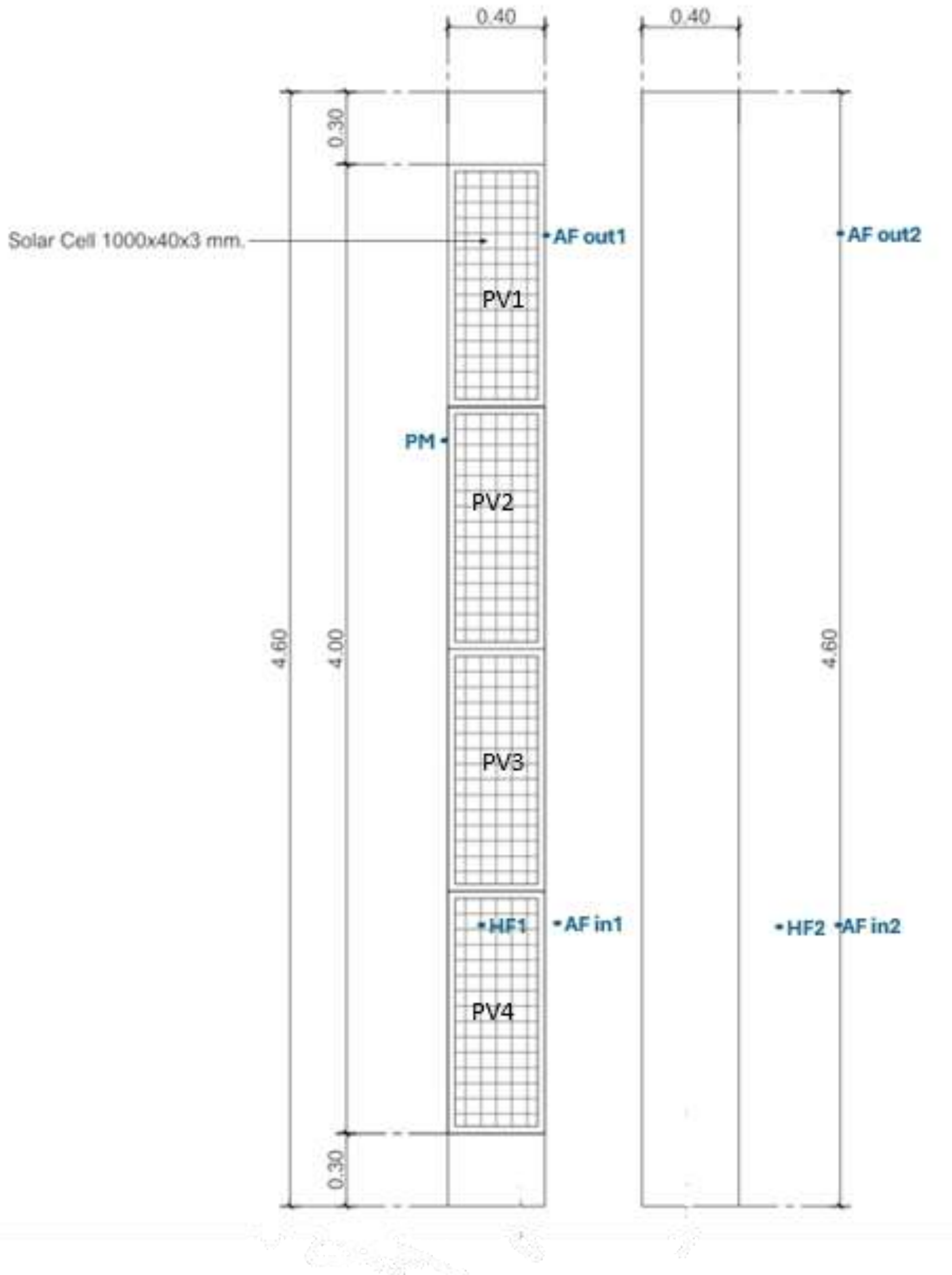

Figure 1 Design of solar chimney Using AutoCAD

Figure 2 Solar chimney modeling and installation

5. Instrumentation and Data Acquisition

Accurate and reliable instrumentation was installed to record key parameters throughout the system. The measurement setup consisted of the following components :

5.1 Data Logger: A Supmea data recorder, model SUP-RN3000, was used for continuous data logging and storage of measured values.

5.2 Temperature Measurement : Type K thermocouples were employed to measure temperature at various points within the system due to their suitability for high-temperature environments.

5.3 Solar Radiation Intensity : A pyranometer (brand: RIKA, model: RK200-03), with a measurement range of 0 to 2,000 W/m², was used to monitor global solar irradiance.

5.4 Ambient Temperature and Humidity : The surrounding air temperature and relative humidity were measured using an ambient sensor (brand: RIKA, model: RK330-01), with a temperature range of -40°C to 60°C and a humidity range of 0% to 100%.

Result

Solar Chimney Design the solar chimney was designed in two configurations : 1) a photovoltaic solar chimney (PSC), which integrates photovoltaic panels into the structure, and 2) non-photovoltaic solar chimney (NPV), which does not include any photovoltaic components. Both chimney types were constructed with identical dimensions 4.00 meters in height and 0.40 meters in width with two ventilation openings located at the back: one at the bottom and one at the top. Each opening measured 0.40 × 0.30 meters, ensuring a consistent airflow cross-section for both designs.

In the PSC configuration, four amorphous silicon photovoltaic panels were installed on the front surface. Each panel measured 40 × 100 centimeters and had a rated output of 12 watts at 17.5 volts. In contrast, the front surface of the NPV was covered with a plain galvanized steel sheet with a thickness of 0.18 millimeters, serving solely as a solar absorber without electrical generation capability.

In studying the temperature inside the two types of solar chimneys, the considerations were divided into two main parts to allow a systematic comparison and analysis of the impact of the chimney designs, as follows :

1. Analysis of temperature values at the same height but different positions

This is the analysis of temperature values at the same height but measured from different positions within each type of solar chimney. This study allows to assess the temperature differences at different points within the chimney and the design effects on heat transfer and air flow.

2. Analysis of temperature values at the same location but different heights

It is the measurement of temperature values at the same location of the solar chimney. This study helps to understand the trends of temperature change with altitude and its impact on air circulation within the chimney.

Analysis of temperature values at the same height but different locations. In the study of the temperature values inside the solar chimney, temperature measurement points at different heights were determined to enable detailed analysis of the temperature distribution and heat transfer behavior inside the chimney.

- Height of temperature measurement point The temperature measurement inside the solar chimney is divided into 3 height levels :

• 1.20 meters (lowest)
• 2.40 meters (mid-level)
• 3.40 meters (highest)

Temperature measurement locations at each height level. Within each height level, temperature measurement points are installed at 3 main locations to study the behavior of heat distribution and air flow, namely :

1) SC (Surface Contact) position

- It is a position to measure the temperature on the inner wall of the chimney.
- For solar chimneys with solar panels, this position is located at the back of the panel.
- Used to study the effect of materials and heat energy accumulation on the chimney wall.

2) Air Position (Central Air Zone)

- It is the position that measures the temperature in the center of the chimney.
- Used to study the air flow conditions inside the chimney and the heat distribution in the gaps of the chimney.

- It shows the temperature of the air that is heated and rises in the system.

3.) Back Position (Back Wall Contact)

- It is the position to measure the temperature at the inner back wall of the chimney.

- Used to analyze the effect of heat accumulation at the back wall and heat transfer from the front to the back of the chimney.

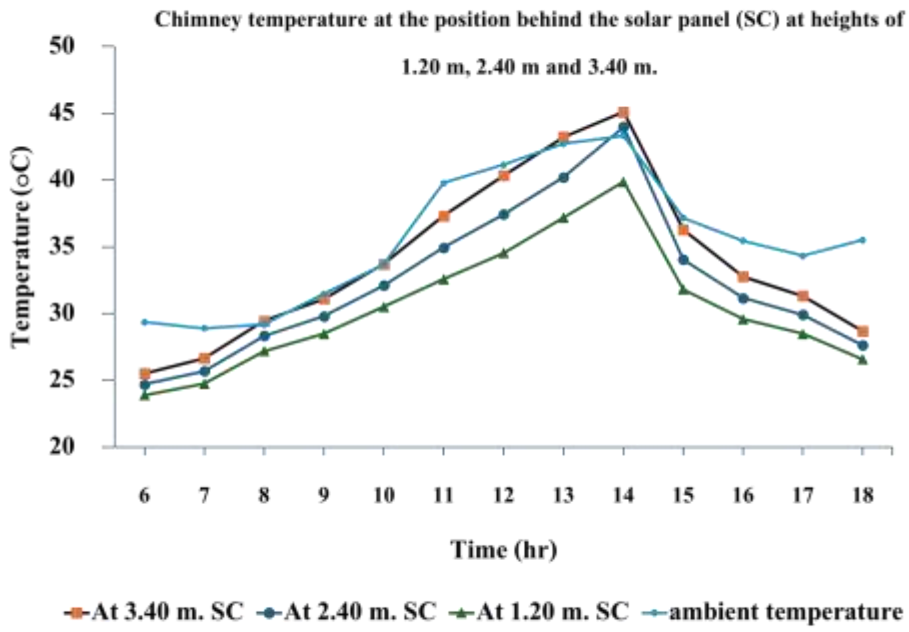

Figure 3 Chimney temperature at the position behind the solar panel (SC) at heights of 1.20 m, 2.40 m and 3.40 m.

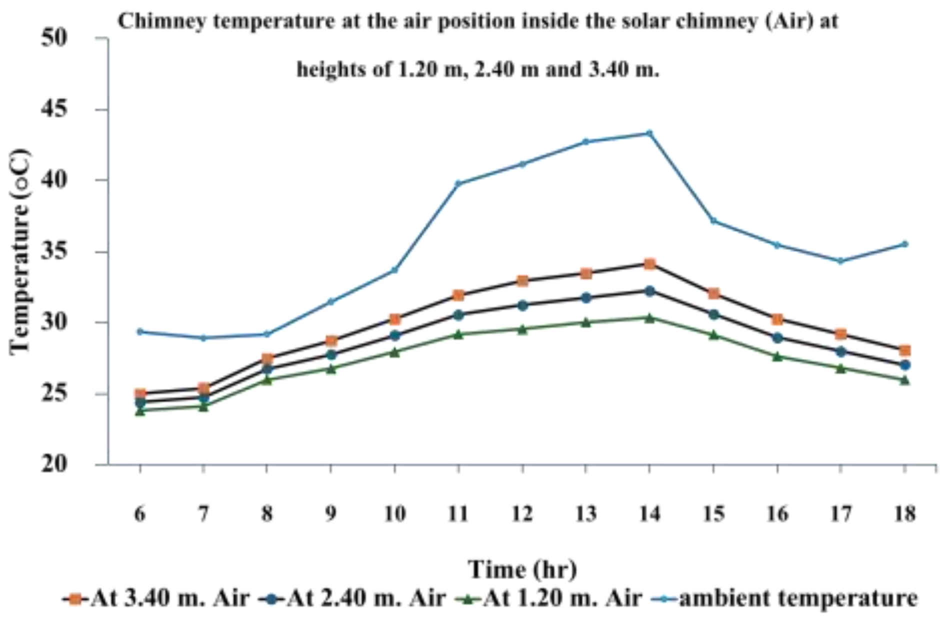

Figure 4 Chimney temperature at the air position inside the solar chimney (Air) at heights of 1.20 m, 2.40 m and 3.40 m.

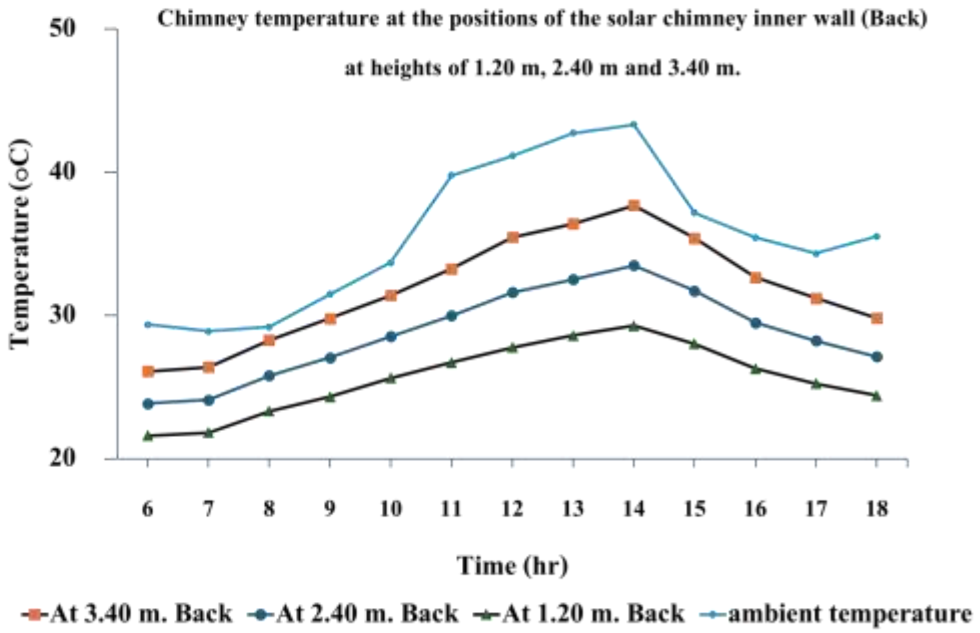

Figure 5 Chimney temperature at the positions of the solar chimney inner wall (Back) at heights of 1.20 m, 2.40 m and 3.40 m.

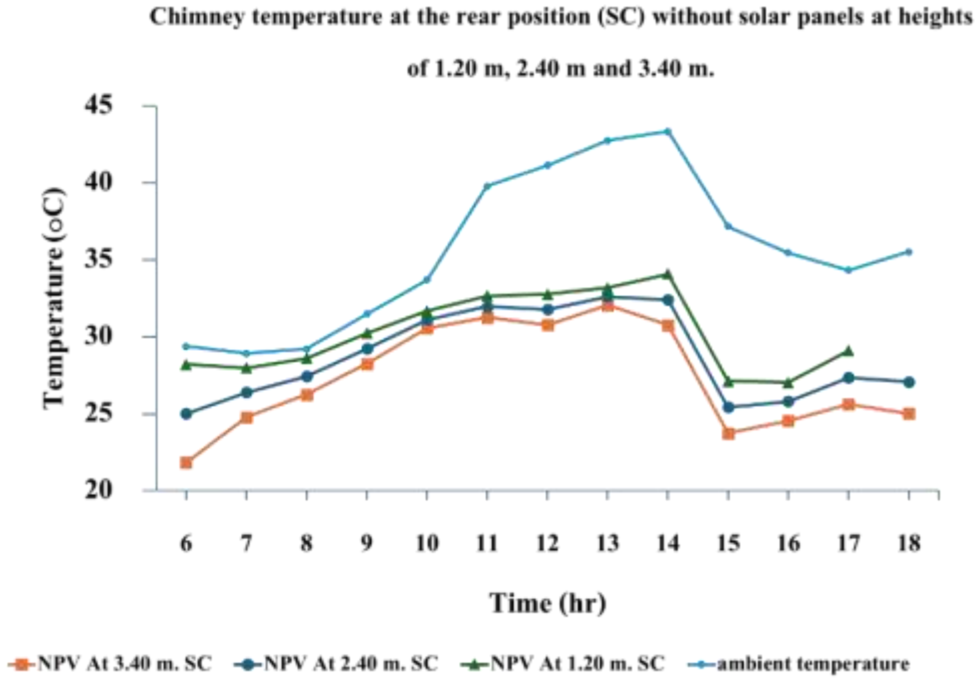

Figure 6 Chimney temperature at the rear position (SC) without solar panels at heights of 1.20 m, 2.40 m and 3.40 m.

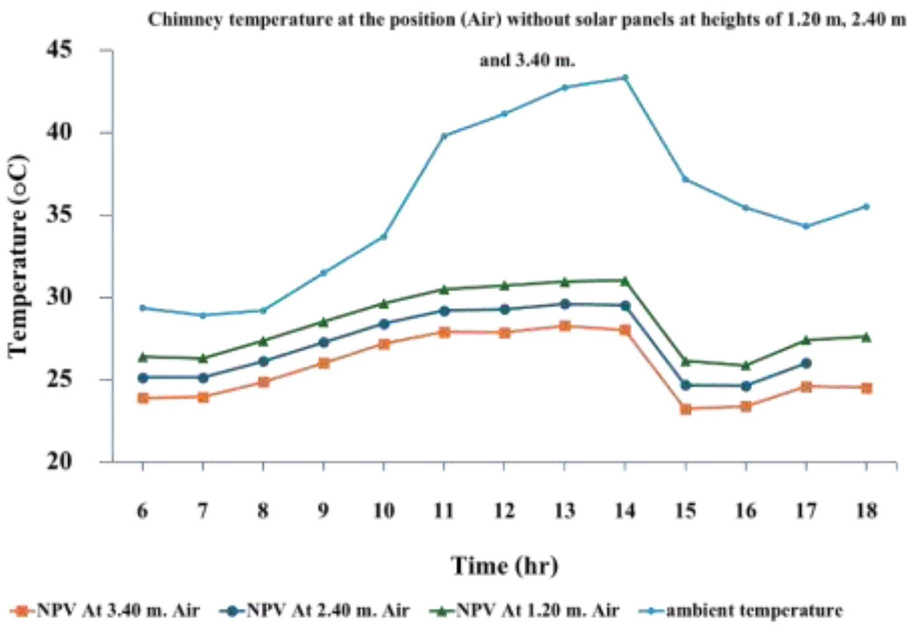

Figure 7 Chimney temperature at the rear position (Air) without solar panels at heights of 1.20 m, 2.40 m and 3.40 m.

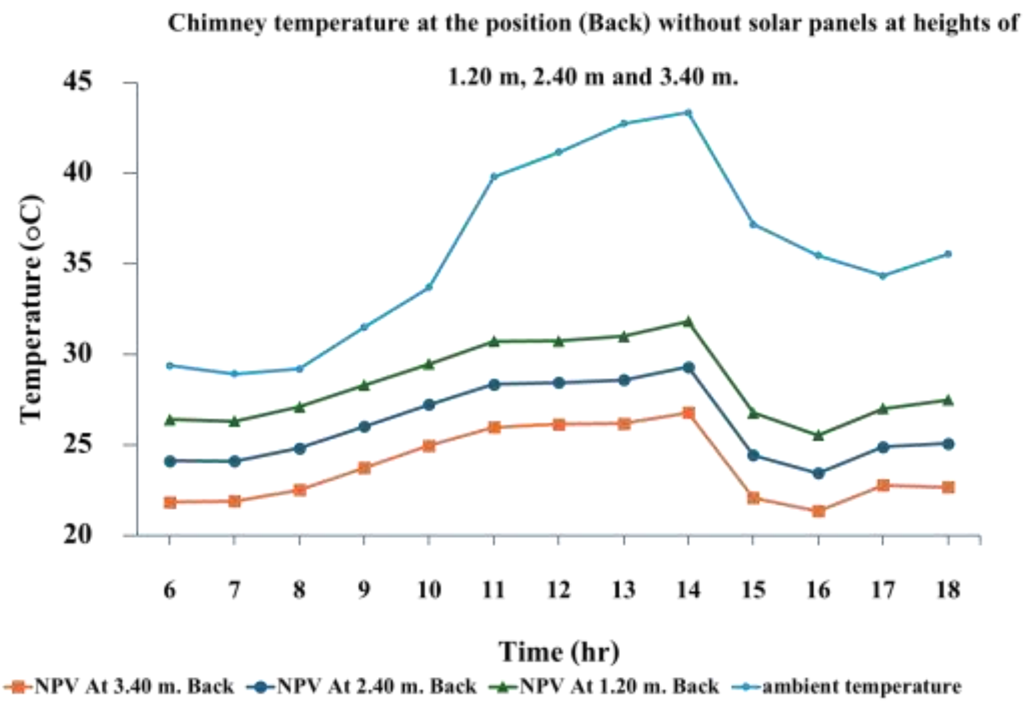

Figure 8 Chimney temperature at the rear position (Back) without solar panels at heights of 1.20 m, 2.40 m and 3.40 m.

Discussion and conclusions

In the design of solar chimneys, there are 2 types of designs: 1) Solar chimneys with solar panels installed and 2) Standard solar chimneys, which are solar chimneys without solar panels installed. Temperature data collected at three vertical levels 1.20 meters, 2.40 meters, and 3.40 meters across three positions (SC: front surface, Air: internal airflow, and Back: rear surface) reveal the following key observations:

1. The photovoltaic solar chimney (PV) consistently exhibited higher temperatures throughout the day compared to the non-photovoltaic chimney (NPV), indicating enhanced thermal energy accumulation due to the integration of solar panels.

2. The SC position (front surface) recorded the highest temperatures, as it is closest to the heat source (solar radiation), while the Back position showed the lowest temperatures due to its distance from direct sunlight.

3. Peak temperatures for both PV and NPV systems were observed between 12:00 and 14:00, corresponding to the period of maximum solar intensity.

4. After 14:00, temperatures gradually decreased in response to the declining ambient temperature. However, the PV chimney retained heat for a longer duration than the NPV chimney, reflecting more effective thermal storage and slower heat dissipation.

5. The PV chimney demonstrated a greater capacity to store and retain heat during late afternoon hours, highlighting its superior performance in terms of heat transfer efficiency and internal convective airflow dynamics.

Suggestion

1. Study the effect of heat insulation materials to increase the efficiency of heat storage

2. There should be additional simulation studies to compare with the actual study results.

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Association of Particulate Matters and the Pneumonia Cases in Pathumthani Province

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Abstract

This correlational research aimed to identify the incidence rate ratios (IRRs) from particulate matter to the monthly pneumonia cases in Pathumthani province. The monthly pneumonia cases and the monthly dailay average particulate matter came gathered from Ministry of Public Health and Pollution Control Department, respectively. The data period were during January 2021 to September 2024, a total of 45 months. Data were analyzed by descriptive statistics, Pearson's correlation, and the generalized linear model using the jamovi statistical software together with the GAMLj module. The results showed that the monthly pneumonia cases and the monthly dailay average particulate matter had very low Pearson's correlations. The negative binomial regression model that best fitted to the data showed showed the monthly average of 987.959 cases; and the incident rate ratio, if the monthly daily average of PM10 increases by 1 µg/m³, the monthly pneumonia cases will increase by 1.047 times or 4.7 percent. If the monthly daily average of PM2.5 increases by 1 µg/m³, the monthly pneumonia cases will decrease to 0.922 times or decrease by 7.8 percent.

Keywords: Pneumonia cases, Particulate matter, Generalized linear model, Incident rate ratio.

Introduction

Particulate matter (PM), especially fine particles like PM2.5 and PM10, has been shown to have a significant association with pneumonia cases: 1) Respiratory irritation. PM can penetrate deep into the lungs, causing inflammation and irritation in the respiratory tract. This makes the lungs more susceptible to infections like pneumonia. 2) Weakened immune response. Prolonged exposure to PM can impair the immune system's ability to fight off pathogens, increasing the likelihood of developing pneumonia. 3) Increased hospital visits. Studies have found that higher levels of PM in the air correlate with an increase in hospital admissions for pneumonia, particularly during colder seasons when air pollution tends to be higher (Chen et al., 2020; Zhang et al., 2021). 4) Vulnerable populations. The effects of PM are more pronounced in vulnerable groups, such as young children, the elderly, and individuals with pre-existing respiratory conditions (Duan et al., 2016).

As per the report from the Health Data Center (HDC Report) of the Ministry of Public Health (MOPH) (2024), the number of pneumonia cases in Pathumthani province from 2020 to the first nine months of 2024 showed that the mean and median of annual cases were 10,113 and 7,876, respectively.

Once the correlation between particulate matter and pneumonia cases is established, the study in Pathumthani province will enhance public health planning and administration for the population in this province. The level of particulate matter represents Pathumthani province available on Air4Thai website provide by Planning and Processing Section, Air and Noise Quality Management Division, Pollution Control Department (2025).

Objectives

- To evaluate the correlation between the pneumonia cases and the amount of particulate matter in Pathumthani province.
- To identify the incidence rate ratios (IRR) corresponding to the level of PM and the pneumonia cases in Pathumthani province,

Research Methodology

This research was the correlational study between the pneumonia cases and the amount of particulate matter in Pathumthani province.

Population

The population in this study were the pneumonia cases in Pathumthani province and the level of particulate matters that covered the area of Pathumthani province.

Samples

The samples were the total monthly pneumonia cases in Pathumthani province and the monthly daily average of 24-hour average of Particulate Matters in μg/m^3 during the data period from January, 2020 to September, 2024.

Instrument

The data recording tool is a table form in Excel.

Data Collection

The number of monthly pneumonia cases in Pathumthani province was collected from the HDC service website provided by the Ministry of Public Health. (2024). Using the Standard Report Group >> Air Pollution Diseases >> Number of patients classified by disease group and disease by month with air pollution-related diseases Health Region 4, Pathum Thani Province, processing date: October 21, 2024. The data period from January, 2020 to September, 2024.

The monthly daily average of 24-hour average of Particulate Matters in μg/m^3 were collected from Air4Thai website provided by Planning and Processing Section, Air and Noise Quality Management Division, Pollution Control Department (2024). The source of air quality data was from the Pathum Thani Air Quality Monitoring Station, Pathumthani-Bangkok University, Rangsit Campus (20T). The data period covered January 2021 to December 2024.

The monthly data used in this analysis were the monthly pneumonia cases and the monthly daily average of PM levels were available at the same monthly period from January 2021 to September 2024, a total of 45 months.

Ethical considerations for human research

The number of pneumonia cases between January, 2020 to September, 2024 were the monthly total number of cases published to the public and accessible to the general public according to the report of by the Ministry of Public Health (2024). No individual patient data were collected, and no personal information was available for the researcher to trace to that patient. Therefore, this research was not human research (Mahidol University, 2022; Center for the Promotion of Ethics in Human Research, 2022).

Data Analysis

In the Generalized Linear Model, for the count number time series, if the equidispersion data then the Poisson regression model is used, for overdispersion, the quasi Poisson regression model is used, and for both overdispersion or underdispersion, then the negative binomial regression model is used (Walker, 2024; Sarakarn and Jumparway, 2020; Gallucci, 2019).

In Poisson regression, the response variable y is an occurrence count recorded for a particular measurement window. Usually, this window is a length of time, but it can also be a distance, area, etc. For example, y could count the number of flaws in a manufactured tabletop of a certain area. If the observations recorded correspond to different measurement windows, a scale adjustment has to be made to put them on equal terms, and we model the rate or count per measurement unit.

For the random component, we assume that the response y has a Poisson distribution. That is, $y_i \sim poisson(\mu_i)$, for $i = 1, 2, ..., N$ where the expected count of y_i is $E[y_i] = \mu_i$. The link function is usually the (natural) log, but sometimes the identity function may be used. The systematic component consists of a linear combination of explanatory variables x; this is identical to that for logistic regression. Thus, in the case of a single explanatory, the model is written

$$\ln(y) = \alpha + \beta x$$

This is equivalent to

$$y = e^{\alpha+\beta x} = e^{\alpha} e^{\beta x}$$

Interpretations of these parameters are similar to those for logistic regression. e^{α} is the effect on the mean of y when $x = 0$, and e^{β} is the multiplicative effect on the mean of y for each 1-unit increase in x.

If $\beta = 0$, then $e^{\beta} = 1$, and the expected count, $\mu = E[y] = e^{\alpha}$, and y and x are not related.

If $\beta > 0$, then $e^{\beta} > 1$, and $\mu = E[y]$ the expected count is e^{β} times larger than when $x = 0$.

If $\beta < 0$, then $e^{\beta} < 1$, and $\mu = E[y]$ the expected count is e^{β} times smaller than when $x = 0$ For multiple variables, the model is

$$\ln y = a + b_1 x_1 + b_2 x_2 + ... b_n x_n \text{ or}$$

$$y = e^{(a+b_1x_1+...+b_nx_n)} = e^{a} e^{b_1x_1} ....e^{b_nx_n}$$

when y is the dependent variable,

$x_1, x_2, ..., x_n$ is the independent variables 1,2,…,n,

e^{a} is the average of y, when $x_1, x_2, ..., x_n$ equal to 0.

$b_1, b_2, ..., b_n$ is the coefficeints of the independent variables 1,2,…,n.

Exponentiated Coefficients: Also known as incidence rate ratios (IRRs), these values are often more interpretable because they explain the multiplicative change in the event rate. For instance, consider if a coefficient $\beta_1 = 0.15$ for the predictor x_1. The IRR would be $e^{0.15} = 1.16$. This indicates that with every one-unit increase in x_1, th expected count increases by approximately 16%, holding all other variables constant (Lee, 2025).

Software for statistical analysis

The jamovi statistical software was used (jamovi stat open now, 2018) together with the GAMLj module (Gallucci, and Jonathon, 2024).

Result

Descriptive statistics

The 45-month data period had descriptive statistics as shown in Table 1.

Table 1 Descriptive statistics of the monthly Pneumoni cases and the Particluate matter

	Pneumonia cases	PM10	PM25
N	45	45	45
Mean	1025	44	23
Median	686	42	21
Standard deviation	969	17.6	11.3
Variance	938433	309	127
Minimum	245	21	10
Maximum	5188	84	47
Shapiro-Wilk W	0.694	0.928	0.907
Shapiro-Wilk p	< .001	0.008	0.002

Sources: The authors calculated from the monthly pneumonia cases from Ministry of Public Health, 2024 and the monthly average daily PM from Pollution Control Department, 2025.

The Pearson's Correlation

The Pearson's Correlation between the monthly pneumonia cases and particulate matter as shown in Table 2.

Table 2 The Pearson's correlation coefficients

		Pneumonia cases	PM10
PM10	Pearson's r	-0.094	—
	df	43	—
	p-value	0.541	—
PM25	Pearson's r	-0.159	0.941
	df	43	43
	p-value	0.297	< .001

Sources: The authors calculated from the monthly pneumonia cases from Ministry of Public Health, 2024 and the monthly average daily PM from Pollution Control Department, 2025.

The best fitted generalized linear models

The monthly pneumonia cases showed overdispaersion as shown in Table 1, after tried both the quasi-Poison regression model and the negative binomial model. The generalized linear models that best fit the data corresponded to the monthly pneumonia cases in Pathumthni province was the negative binomial with significant Loglikelihood ratio tests as the equation shown below,

The pneumonia cases = $e^{6.8956+0.0457PM10-0.0815PM2.5}$

$e^{6.8956} = 987.959$

with 95% Exp(B) Confidence Interval Lower and Upper = 815.091 and 1213.314,

The IRR of PM10, $e^{0.0457} = 1.047$

with 95% Exp(B) Confidence Interval Lower and Upper = 1.005 and 1.085,

The IRR of PM2.5, $e^{-0.0815} = 0.922$

with 95% Exp(B) Confidence Interval Lower and Upper = 0.875 and 0.981.

Discussion and conclusions

The 45-month data period showed the monthly average and median of pneumonia cases of 1,025 and 686 cases, respectively; with overdispersion, the Shapiro-Wilk $p < .001$, their distribution was not normal.

The linear correlation between the monthly pneumonia cases and PM10 was -0.094 (negligible correlation) and with PM2.5 was -0.159 (weak correlation) (Schober, Boer, & Schwarte, 2018). The negative binomial model that best fitted to the 45 monthly data showed the monthly average of 987.959 cases; if the monthly daily average of PM10 increases by 1 $\mu g/m^3$, the monthly pneumonia cases will increase by 1.047 times or 4.7 percent. If the monthly daily average of PM2.5 increases by 1 $\mu g/m^3$, the monthly pneumonia cases will decrease to 0.922 times or decrease by 7.8 percent.

Correlation and regression alone cannot establish causation. To determine causality, a model must incorporate regression or correlation analysis alongside a robust theoretical framework connecting the variables involved. There are two essential criteria for establishing causality. Firstly, there must be a statistically significant correlation between the variables. Secondly, one of two conditions must be satisfied: either a temporal order is evident (e.g., variable A is measured before variable B in time), or there exists a well-supported and logical theory explaining the direction of the causal relationship (DATAtab Team, 2025).

Suggestion

The particulate matter is linked to the pneumonia cases in Pathumthani province. The provincial public health authority will examine the particulate matter levels in each season and strategize to address the number of pneumonia cases. The coverage of meteorological stations should be expanded to better represent the area of Pathumthani province.

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