

Optimizing Blockchain Digital Signature Security in Driving Innovation and Sustainable Infrastructure

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ABSTRACT

Indonesia challenge with a significant increase in cyberattacks, averaging 158 attacks per second. These attacks target critical digital systems, particularly in government and business sectors, causing financial losses and eroding public trust. This underscores the inadequacy of data protection measures, as traditional authentication systems relying on centralized servers are vulnerable to data breaches and document forgery. The **gap** identified is the lack of a secure and efficient system to protect sensitive digital information while addressing vulnerabilities in centralized systems. Existing solutions fail to provide the robustness, scalability, and reliability required for largescale implementations. To fill this **gap**, the **method** employed in this research is agile scrum, the development of a blockchain based digital signature system, AlphaSign, using the Agile Scrum framework. This iterative development approach ensures that the system is continuously refined based on user feedback and evolving requirements. Key features include decentralized data recording, qr code automation for real-time verification, and strong encryption to enhance security and prevent document forgery. The **novelty** of AlphaSign lies in its integration of Blockchain technology with a sustainable digital infrastructure approach. By aligning with SDG goals, particularly Goal 9 (Innovation Infrastructure) and Goal 16 (Strong Institutions), it offers a unique solution that combines security, transparency, and sustainability in digital signature authentication. The **findings** highlight AlphaSign ability to reduce hacking risks, enhance data resilience, and enable efficient document verification. This **makes** it a viable solution for securing digital systems across public and private sectors, fostering trust and efficiency in an increasingly digitalized world.

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1. INTRODUCTION

The rapid increase in cyberattacks highlights vulnerabilities in digital systems across various sectors, particularly in government and business, which are often targeted due to their reliance on centralized systems [1]. These numerous attacks not only result in significant financial losses but also erode public trust. This

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indicates that data protection within existing digital infrastructures remains suboptimal [2]. Traditional authentication systems that rely on centralized servers or third parties introduce additional risks, including data breaches, manipulation, and document forgery [3].

The need for a more secure and efficient system to support sustainable digital infrastructure has become increasingly urgent. Despite the ongoing progress of digitalization, incidents of fraud involving critical documents remain prevalent [4]. As a solution, this research proposes a novel approach in the form of a decentralized Blockchain-based digital signature named AlphaSign to enhance data security and strengthen document verification processes [5]. This technology is designed to support digital security and integrity in alignment with the Merdeka Belajar Kampus Merdeka (MBKM) program. By adopting the Agile Scrum methodology, the development of this technology aims to align with user needs and incorporate feedback from partners at every stage of the development process [6].

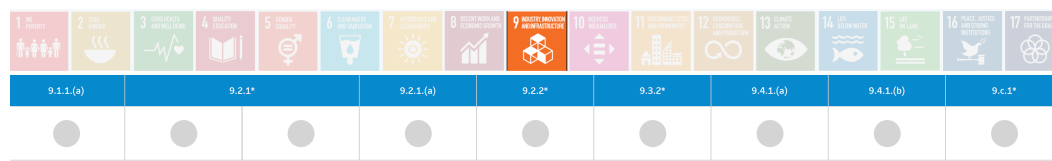


Figure 1. Sustainable Development Goals Indicator

Source: (<https://sdgs.bappenas.go.id/dashboard/>)

As shown in figure 1 alphaSign aims to develop a blockchain-based digital signature system that ensures security, prevents document forgery, and guarantees document authenticity [7]. Additionally, the system is expected to accelerate the verification process for large volumes of documents through QR code-based automation while supporting the development of sustainable and accessible digital infrastructure in line with the Sustainable Development Goals (SDGs) [8]. The advantages of AlphaSign align with the achievement of Higher Education Key Performance Indicators (KPIs) by utilizing blockchain technology, which ensures decentralized recording of every signature and reduces the risk of hacking and forgery [9]. The QR Blockchain technology developed enables users to verify document authenticity in real-time simply by scanning a QR code. Furthermore, the system is designed to support robust digital infrastructure, making it relevant for both industrial and public sectors while contributing to the achievement of the SDGs, particularly Goal 9 (Industry, Innovation, and Infrastructure) and Goal 16 (Peace, Justice, and Strong Institutions) [10].

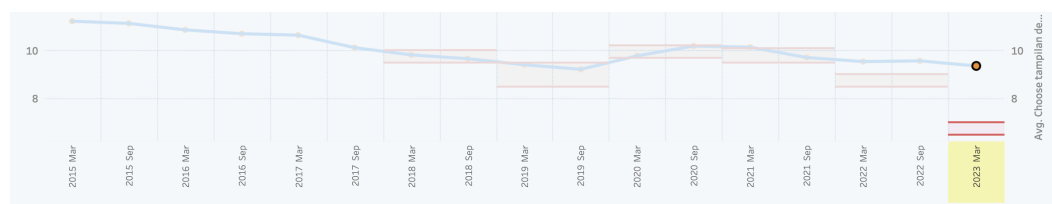


Figure 2. Sustainable Development Goals Indikator 9.4.1

Source: (<https://sdgs.bappenas.go.id/dashboard/>)

Data figure 2 from the Ministry of National Development Planning/Bappenas, the emission intensity in Indonesia's industrial sector, as measured by indicator 9.4.1 of SDG 9, has shown fluctuations from 2015 to 2021. Although there were decreases in emissions during certain years, maintaining consistency in these reductions remains a challenge, particularly in energy-intensive sectors such as manufacturing. With the increasing adoption of digital technologies that support industrial process efficiency, there is potential to reduce emission intensity through technological innovation, including the implementation of Blockchain-based systems [11].

Blockchain technology addresses weaknesses in traditional digital signatures, which are often insufficient in securing data. It ensures security for every signature transaction, while QR code-based automation accelerates the document verification process [12]. This system is well-suited for institutions and large enterprises that require efficient, secure, and sustainable document authentication solutions. AlphaSign is expected to become a key document authentication solution in the evolving digital economy, providing security for all stakeholders involved and fostering a reliable and transparent digital economy [13].

2. LITERATURE REVIEW

2.1. Multi-Factor Authentication and Data Security

Data security and authentication are critical aspects of AlphaSign's development. To safeguard documents and user identities, the system employs multi-factor authentication (MFA) and advanced encryption features, ensuring that access to user data is granted only to authorized parties. Additionally, an audit trail records all system activities in real-time, guaranteeing transparency and providing reliable legal evidence. In the context of governance, AlphaSign ensures compliance with data protection regulations, such as the GDPR in Europe or Indonesia's PDP Law, making its use both secure and legally sound [14].

2.2. Agile Scrum Methodology in AlphaSign Development

AlphaSign's development adopts the Agile Scrum methodology, emphasizing flexibility and continuous product improvement [15]. This approach structures the project into sprints—short iterations that include development, testing, and evaluation phases. At the end of each sprint, evaluations are conducted through feedback from users and stakeholders, enabling immediate adjustments to features based on user needs and field challenges [16]. By involving collaboration among technical teams, government representatives, and industry players, Agile Scrum ensures that AlphaSign evolves to meet the requirements and standards of various sectors effectively [17].

2.3. System Sustainability in Digital Infrastructure

Sustainability is a key focus in the development of AlphaSign. The system is designed to be energy-efficient, aligning with sustainable development goals to optimize robust and eco-friendly digital infrastructure [18]. System adaptability is prioritized to ensure that AlphaSign remains relevant to current needs while being adaptable to future technological advancements. As a result, AlphaSign not only meets high-security standards but also supports the sustainable development of Tangerang City [19].

2.4. Relevance of AlphaSign to Sustainable Development in Tangerang City

This study highlights AlphaSign's relevance to Tangerang City's sustainable development, focusing on enhancing digital infrastructure quality and strengthening data and information security [20]. Through this solution, digital authentication security and efficiency are achieved, contributing directly to improved communication and informatics while supporting regional competitiveness on a national level. AlphaSign aligns with the Sustainable Development Goals (SDGs), particularly Goal 9 (Industry, Innovation, and Infrastructure) and Goal 16 (Peace, Justice, and Strong Institutions). Thus, AlphaSign serves as a technological initiative that supports transparent and efficient governance while fostering the well-being of Tangerang City's community through sustainable digital infrastructure [21].

3. RESEARCH METHOD

This research adopts the Agile Scrum approach, a software development methodology that emphasizes flexibility, collaboration, and iterative feature improvements based on user feedback [22]. In the development of AlphaSign, this method breaks the project into a series of sprints or short iterations lasting two to four weeks, encompassing phases of planning, development, testing, and evaluation. At the end of each sprint, a sprint review meeting is conducted to assess progress and gather input from stakeholders or users [23].

This feedback is then utilized to adjust feature priorities for the next sprint, enabling AlphaSign to dynamically adapt to user needs and changes in the government sector, ensuring that the final product is more relevant, responsive, and effective [24]. By employing the Agile Scrum approach, the development of AlphaSign involved collaboration among technical teams, government representatives, and industry stakeholders, allowing feedback from the Business and Industry sectors (DUDI) to be promptly implemented [25].

This approach supports the creation of a reliable digital signature system that complies with government security standards and regulations while remaining adaptable for future developments.

One of the key advantages of applying Agile Scrum in AlphaSign's development is its ability to streamline communication among cross-functional teams. Through daily stand-up meetings, developers, project managers, and government stakeholders stay aligned on project goals and address any roadblocks in a timely manner. This close collaboration fosters transparency and accountability, ensuring that all stakeholders remain

engaged throughout the software development process. Additionally, continuous feedback loops help refine security protocols and compliance measures, reinforcing AlphaSign's ability to meet the stringent requirements of government regulations and industry best practices.

The Agile Scrum approach also enhances scalability by allowing the development team to prioritize and implement features incrementally. This flexibility enables AlphaSign to support a wide range of digital signature use cases, from e-governance applications to secure document verification in business transactions. As user needs evolve, new functionalities can be seamlessly incorporated without disrupting the existing infrastructure. This modular development strategy ensures that AlphaSign remains a future-proof solution, capable of adapting to technological shifts and policy changes within the digital governance landscape.

Leveraging Agile Scrum, AlphaSign benefits from a robust testing framework that ensures system reliability and security at every development stage. Each sprint includes comprehensive testing phases, ranging from unit tests to security audits, to identify potential vulnerabilities and enhance system robustness. This proactive approach minimizes the likelihood of critical failures while ensuring compliance with cybersecurity standards. As a result, AlphaSign delivers a highly secure and efficient digital signature solution, empowering government institutions and businesses with a reliable tool for secure and legally recognized electronic transactions.

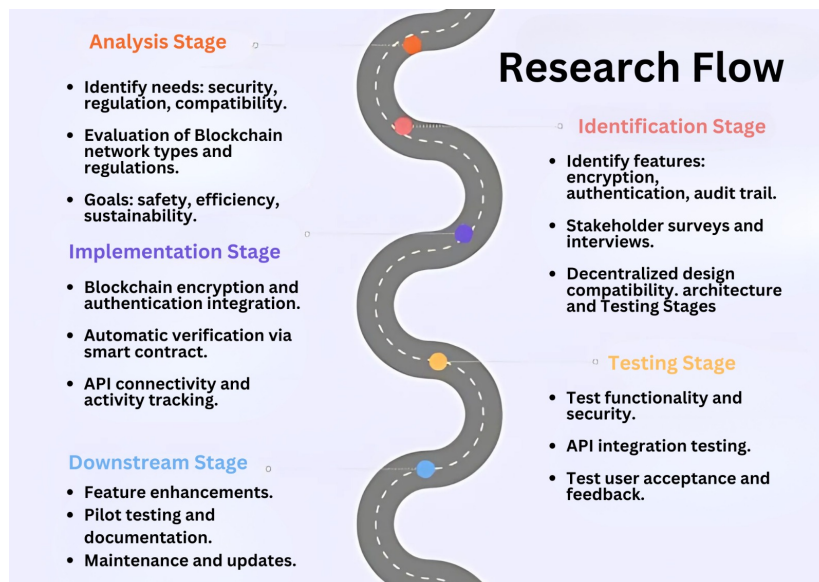


Figure 3. Flow of Research Stages

As shown in figure 3 illustrates the research workflow from analysis to downstream implementation. Each stage is designed to ensure a systematic process, focused on achieving the research objectives. These stages aim to provide in-depth insights into the application of Blockchain technology for digital document authentication, particularly through the Alpha Sign platform, with an emphasis on security, efficiency, and sustainability within the industrial sector [26].

The initial phase of the workflow involves an extensive analysis of current challenges and opportunities in digital document authentication. This includes identifying vulnerabilities in traditional systems, exploring potential risks, and evaluating the compatibility of Blockchain solutions. By addressing these factors, the research establishes a strong foundation for implementing a robust and reliable authentication system [27].

Subsequently, the development phase focuses on designing and integrating the Alpha Sign platform. This stage encompasses creating a decentralized framework, configuring smart contracts, and implementing encryption protocols to enhance security and efficiency. Rigorous testing is conducted to ensure the platform meets industry standards and performs optimally under various scenarios [28].

The downstream phase emphasizes the practical application and commercialization of the Alpha Sign platform [29]. This includes collaboration with industry stakeholders, addressing regulatory requirements, and conducting training sessions to promote adoption. By focusing on real-world deployment, this stage ensures

that the research findings translate into tangible benefits, driving innovation and sustainability within the industry [30].

3.1. Analysis Phase

During the analysis phase, the primary requirements are identified, focusing on security, regulations, and system compatibility. AlphaSign must ensure data security through encryption and authentication while adhering to data protection laws such as Indonesia's PDP Law. Regulatory analysis is crucial to ensure the system complies with applicable legal standards, ensuring safe and legitimate use. Additionally, compatibility is a key aspect to support widespread system adoption across various devices and digital platforms.

Blockchain analysis determines the most suitable network type, such as public networks (e.g., Ethereum) for openness or private networks (e.g., Hyperledger) for stricter control. Smart contract technology is utilized to enable automated and efficient authentication and verification processes. In this context, the primary goal of AlphaSign development is to create a secure, efficient, and sustainable system that enhances data security through decentralization while ensuring robust and durable digital infrastructure.

3.2. Identification Phase

AlphaSign's key features include data encryption, multi-factor authentication for securing digital data, and an audit trail for real-time user activity tracking, ensuring transparency. To address diverse needs, stakeholder identification is conducted, encompassing individuals, companies, and government institutions. Through surveys and interviews, AlphaSign is tailored to meet the specific requirements of each sector. Its decentralized Blockchain-based architecture ensures immutable data security, supported by smart contracts for automated verification. Designed with APIs and broad document format support, AlphaSign can be integrated into various devices, providing an accessible solution tailored to government needs.

3.3. Implementation Phase

AlphaSign's implementation involves integrating Blockchain to secure every digital signature through high-level encryption and decentralized authentication, which is difficult to manipulate. Smart contracts enable automated verification, optimizing the speed and efficiency of the signing process. The system also provides APIs for external platform integration, allowing access from internal government systems. Equipped with an audit trail, AlphaSign records each transaction in detail, enabling users to track activities for audit and evaluation purposes. Thus, AlphaSign offers a secure, efficient, and easily integrable digital signature solution, supporting data transparency through comprehensive tracking.

3.4. Testing Phase

Testing ensures all functions operate optimally and meet high-security standards. Functionality testing verifies that features such as encryption, authentication, and automated verification work correctly. Comprehensive security testing ensures system resilience against cyber threats and protects data from unauthorized access. API integration testing confirms that AlphaSign seamlessly connects to various platforms, enabling users to access digital signature services directly from other applications. Following technical tests, User Acceptance Testing (UAT) is conducted using real-world scenarios, where user feedback is utilized to enhance system usability and efficiency, making AlphaSign more reliable and user-friendly.

3.5. Deployment Phase

The deployment phase begins with refining features based on user feedback from UAT. This refinement ensures that core functions, such as encryption, authentication, and audit tracking, align with users' operational needs. The system is then tested in real-world scenarios through pilot testing to ensure its reliability for large-scale use. Comprehensive documentation is prepared to guide system installation and usage, requiring minimal technical support. This documentation also aids IT teams in system maintenance. Specialized training sessions are conducted for users, covering key features, API integration, and data security measures. In the final stage, continuous maintenance is performed, including performance monitoring, bug fixes, and security certificate updates. These steps ensure AlphaSign is effectively implemented and supports long-term user needs in the government sector.

By adhering to the Agile Scrum methodology, AlphaSign development ensures that every feature is continuously evaluated and improved based on user needs. The findings of this scientific work demonstrate that AlphaSign is a digital signature solution ready to support the government sector in addressing the challenges of digital security, transparency, and efficiency required in modern digital infrastructure.

3.6. Agile Scrum Process for AlphaSign

The agile scrum process is a widely adopted framework for iterative software development, emphasizing collaboration, flexibility, and continuous improvement. It is particularly effective for projects AlphaSign, where dynamic requirements and a need for robust security demand regular feedback loops and adaptability. This process ensures that teams deliver incremental improvements while aligning with user needs and project goals.

The agile scrum framework promotes transparency and accountability through its structured yet adaptable workflow. By fostering close collaboration among cross-functional teams, including developers, product owners, and stakeholders, it ensures swift decision-making and efficient resolution of challenges. This approach is particularly advantageous for projects AlphaSign, where rapid iterations and real-time adjustments are critical to addressing complex issues such as blockchain integration, security audits, and performance optimization.

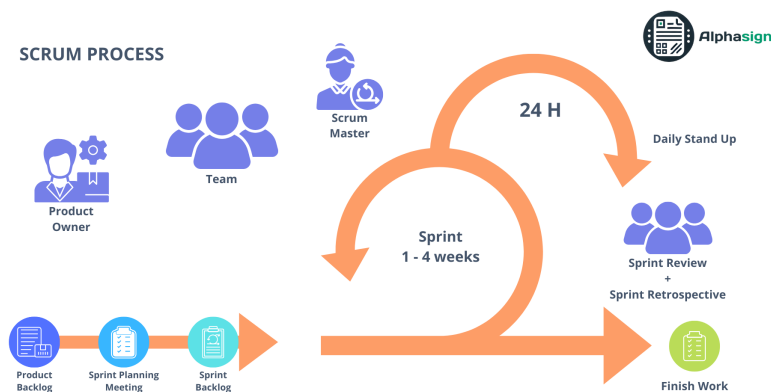


Figure 4. Scrum process

As shown in figure 2 highlights a collaborative and iterative approach to software development, focusing on delivering incremental improvements in short, manageable cycles. This process emphasizes key roles, such as the Product Owner, Scrum Master, and Team, each playing a vital role in ensuring the project's success. Through structured phases, including product backlog refinement, sprint planning, daily standing meetings, and sprint reviews, the team maintains alignment and adaptability. The use of continuous feedback in Sprint Retrospectives helps refine workflows and deliver high-quality finished products, as shown in the final output.

In the context of AlphaSign, the iterative development process ensures that the blockchain-based digital signature platform evolves efficiently to meet stakeholder needs. The image above clearly illustrates this flow, starting with backlog prioritization and leading to a sprint cycle, ensuring all tasks are delivered as Finished Work. Using this process, AlphaSign remains adaptable, secure, and effective in addressing modern digital security challenges.

4. RESULT AND DISCUSSION

The development of AlphaSign began with the creation of a prototype focused on Blockchain security and QR code verification. Following trials with industry partners, the system was optimized based on user feedback and a comprehensive guide was prepared for the initial launch. Subsequent implementation included a public rollout with onboarding for new users in the industrial, governmental, and educational sectors, along with the addition of security features such as multifactor authentication and audit logs. Collaborative expansion into the financial and healthcare sectors broadened AlphaSign's reach. The evaluations revealed that AlphaSign improves the efficiency and security of digital document authentication.

AlphaSign also improves the credibility of academic institutions by providing a tamper-proof verification system for diplomas, certificates, and academic transcripts. Using blockchain technology, it ensures that issued documents are immutable, reducing the risk of forgery and unauthorized alterations. This not only

benefits graduates by simplifying employment verification, but also aids employers in efficiently validating candidates' credentials, fostering trust within the job market.

AlphaSign empowers government agencies and regulatory bodies by offering a secure and transparent mechanism for document authentication. Public institutions can streamline administrative processes, reducing bureaucratic inefficiencies, and eliminating manual verification efforts. This contributes to a more resilient and corruption resistant governance framework, ultimately driving progress toward a more accountable and digitally integrated public sector.

Table 1. Beneficiaries Program

No	Beneficiaries	Quantity
1	PT. Baliola Adi Maha Putra	1 Entity
2	Denpasar City Government	1 Entity
3	Denpasar City Creative Agency (BKRAF)	1 Entity
4	MBKM Students of Universitas Raharja	500 Students
5	Lecturers of Universitas Raharja	100 Lecturers
6	Universitas Wiraraja	500 Students

The data presented in table 1 highlights the wide range of beneficiaries involved in the program. These include diverse entities such as government organizations, creative agencies, and educational institutions. Notably, PT. Baliola Adi Maha Putra, the Denpasar City Government, and the Denpasar City Creative Agency (BKRAF) represent the institutional partners contributing to and benefiting from the program's initiatives. Their participation ensures that the program is aligned with regional development goals and supports the local creative industry ecosystem.

In addition to institutional entities, table 1 showcases the significant impact of the program on the academic community. A total of 500 students from the University of Raharja and the University of Wiraraja, along with 100 lecturers from the University of Raharja, have actively participated in the program. This demonstrates the program's role in promoting educational advancement and fostering collaboration between academia and industry, paving the way for future innovations and partnerships.

5. MANAGERIAL IMPLICATION

The implementation of blockchain based digital signatures presents several key managerial implications that organizations must consider. These implications impact digital security governance, operational efficiency, regulatory compliance, and scalability strategies, ensuring that businesses can harness blockchain technology effectively.

5.1. Enhancing Digital Security Governance

The implementation of Blockchain-based digital signatures requires a strategic shift in digital security governance. Organizations must establish robust cybersecurity policies that integrate blockchain authentication mechanisms to mitigate risks associated with data breaches and unauthorized access. By adopting AlphaSign, enterprises can enhance document integrity and streamline verification processes through decentralized digital authentication.

Managerial teams should ensure continuous training and awareness programs to educate employees on the importance of blockchain security protocols. A well-informed workforce can effectively leverage digital signature solutions, reducing vulnerabilities linked to traditional authentication systems and fostering a culture of cybersecurity resilience.

5.2. Operational Efficiency and Cost Optimization

Integrating blockchain technology into document authentication significantly enhances operational efficiency. Organizations can automate verification processes using QR-code-based authentication, minimizing manual verification efforts and reducing administrative burdens. This shift not only accelerates workflow processes but also reduces human errors, enhancing overall productivity.

From a financial perspective, blockchain-based document authentication eliminates intermediary costs associated with traditional certification and verification systems. Management should focus on leveraging these

cost-saving opportunities by reallocating resources to innovation-driven projects that enhance service delivery and operational excellence.

5.3. Regulatory Compliance and Legal Considerations

Regulatory compliance is a crucial factor in the adoption of blockchain-based digital signatures. Businesses must ensure that AlphaSign aligns with local and international data protection regulations, such as the Personal Data Protection Law (PDP Law) in Indonesia and GDPR in Europe. Compliance with these legal frameworks fosters trust among stakeholders and minimizes risks associated with legal disputes.

To strengthen regulatory adherence, managerial teams should establish dedicated compliance units that monitor evolving legal requirements and ensure that blockchain implementation aligns with national cybersecurity policies. Collaborating with legal experts can further support seamless integration and regulatory acceptance of digital signature solutions in various sectors.

5.4. Scalability and Future Adaptation Strategies

The scalability of blockchain-based authentication systems is essential for long-term sustainability. Managers should prioritize the development of flexible blockchain architectures that can accommodate increasing document authentication demands across industries. AlphaSign's adaptability to emerging technological advancements ensures that businesses remain competitive in the digital era.

Managerial strategies should emphasize ongoing research and development to explore integration opportunities with artificial intelligence and cloud-based solutions. A forward-thinking approach to digital transformation will enable organizations to maintain relevance in a rapidly evolving technological landscape while ensuring seamless adoption of future innovations in blockchain security.

6. CONCLUSION

AlphaSign offers an advanced solution for enhancing security and efficiency in digital document authentication by utilizing Blockchain technology. Equipped with features like high-level encryption, multi-factor authentication, and QR code-based automated verification, AlphaSign ensures exceptional security and speeds up document validation processes. Its decentralized framework minimizes risks of forgery and data tampering, making it an ideal choice for large institutions and public sector needs.

Aligned with the Sustainable Development Goals (SDGs), AlphaSign contributes to Goal 9 (Industry, Innovation, and Infrastructure) and Goal 16 (Peace, Justice, and Strong Institutions). By strengthening digital infrastructure and promoting transparent governance, AlphaSign supports efficient operations in government and industrial sectors. Developed with Agile Scrum methodology, the system is tailored to meet user needs, making it highly adaptable to the evolving challenges of digital transformation.

Looking ahead, AlphaSign can further enhance its impact by incorporating AI-driven anomaly detection, optimizing energy-efficient Blockchain protocols like Proof of Stake, and expanding interoperability with document management systems and e-government platforms. Broader pilot testing in education, healthcare, and financial sectors would provide valuable insights into its large-scale performance. By integrating real-time monitoring mechanisms and educating users on regulations such as the Personal Data Protection Act (UU PDP), AlphaSign can solidify its position as a reliable, efficient, and sustainable solution in the digital era.

7. DECLARATIONS

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7.2. Author Contributions

Conceptualization: AR, RW, and WS; Methodology: MM; Software: OS; Validation: AR and RW; Formal Analysis: WS and MM; Investigation: AS; Resources: OS; Data Curation: AR; Writing Original Draft Preparation: RW and WS; Writing Review and Editing: MM; Visualization: AR; All authors, AR, RW, WS, MM and OS, have read and agreed to the published version of the manuscript.

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The data presented in this study are available on request from the corresponding author.

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7.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

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