# Engineering-Based Optimization Model for Empowering Productive *Waqf* to Enhance Educational Infrastructure in Islamic Boarding Schools in Banten Province

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**Abstract:** This research aims to develop an engineering-based optimization model to empower productive *waqf* as a strategic effort to enhance educational infrastructure in Islamic boarding schools (*pesantren*) within Banten Province, Indonesia. Despite the significant potential of *waqf* assets, their contribution to educational development remains underutilized due to poor management systems and lack of engineering-based frameworks. By integrating systems engineering and optimization techniques, this study proposes a model that enables efficient allocation, management, and monitoring of productive *waqf* resources. The methodology involves a combination of qualitative data collection from *pesantren* stakeholders and quantitative simulation using decision-support tools. The results show that the proposed optimization model can significantly improve the planning and utilization of *waqf* assets, leading to measurable enhancements in educational facilities and long-term sustainability. This study contributes to the field of engineering by demonstrating how *waqf*-based asset management can be optimized through a structured, technology-driven approach to solve real-world infrastructure challenges in Islamic education.

*Keywords: Productive Waqf , Educational Infrastructure, Optimization Model, Systems Engineering.*

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## I. INTRODUCTION

Islamic education in Indonesia has deep historical roots, particularly through the role of *pesantren* (Islamic boarding schools) as traditional institutions that nurture not only cognitive knowledge but also spirituality, morality, and character. These *pesantren* are widely dispersed across the archipelago, with Banten Province being one of the regions with a high concentration of such institutions. Despite their crucial role in human development, *pesantren* frequently encounter structural financial constraints, especially concerning the development and maintenance of educational infrastructure and the welfare of teaching staff. [1], [2]

The sustainability of *pesantren*-based education is intrinsically linked to the quality of their infrastructure and teaching resources. However, many *pesantren* operate under financial limitations that restrict their ability to modernize facilities, implement digital learning environments, or support teacher welfare. In this context, *waqf* —as an Islamic philanthropic instrument—presents an underutilized but potentially transformative solution. Productive *waqf* , if managed strategically, offers a self-sustaining financial model that can support the infrastructure and operational needs of Islamic education institutions. [3], [4]

Although numerous *pesantren* in Banten possess valuable *waqf* assets, such as land and buildings, empirical observations reveal that these assets are often not optimized for productive use. Traditional *waqf* management practices tend to be passive and consumptive, failing to unlock the full potential of these assets to support long-term educational goals [5]. Leveraging systems engineering and optimization modeling can introduce structured, data-driven mechanisms to maximize the use of productive *waqf* in enhancing educational facilities and resource planning [6]. Recent studies, such as Bashori et al. (2024), have discussed the role of productive *waqf* in supporting *pesantren* economics through agribusiness and

micro-enterprises [7]. Furthermore, Huda et al. (2024) emphasized the importance of governance quality and institutional collaboration in achieving *waqf* success [8]

However, the existing body of literature largely emphasizes financial returns and economic sustainability, without adequately addressing infrastructure development as a core objective.[9], [10] Moreover, few studies integrate engineering-based frameworks for *waqf* optimization, leaving a critical gap in the practical application of technical methods. This study aims to address that gap by proposing an engineering-based optimization model tailored to the context of *pesantren* in Banten Province. The model integrates principles of systems engineering, decision support systems (DSS), and optimization techniques to enhance the management of productive *waqf* for educational infrastructure improvement.[11], [12]

This study adopts a mixed-method approach with a descriptive-exploratory design to analyze the optimization of productive *waqf* in Islamic boarding schools (*pesantren* ) in Banten. The qualitative approach explores socio-religious, institutional, and managerial aspects,[13] while the quantitative approach develops an engineering-based optimization model for the strategic utilization of *waqf* assets.[14], [15] Data were collected through observations, interviews, document analysis, and surveys conducted in selected *pesantren* using purposive sampling [16], [17]. Participants include *nazhir* (*waqf* managers), *pesantren* leaders, teachers, and local stakeholders. All procedures adhere to ethical research standards and Islamic values, aiming to produce a practical, contextually relevant, and sustainable *waqf* optimization model.[18], [19]

By doing so, this study bridges the conceptual divide between Islamic philanthropy and technical solutions, promoting innovation in *waqf* -based financing models. The novelty of this research lies in its interdisciplinary approach, linking Islamic social finance with modern engineering tools to create a replicable model that improves physical learning environments and supports long-term institutional development.[20], [21] The proposed model also addresses real-world challenges faced by *pesantren* in Banten—such as aging infrastructure, lack of digital facilities, and funding gaps—by leveraging productive *waqf* assets more effectively.[22] In summary, this study responds to the systemic challenge of underdeveloped educational infrastructure in Islamic boarding schools by introducing a structured, technology-driven approach.[23] Through the integration of *waqf* empowerment and engineering-based optimization, it contributes both theoretically and practically to the advancement of Islamic education in Indonesia, with Banten Province as a strategic case.

## II. LITERATURE REVIEW

### A. The Concept of Productive Waqf and Its Application in Islamic Education

*Waqf* , as an Islamic endowment mechanism, has historically served as a pivotal instrument in sustaining religious, social, and educational activities across the Muslim world.[15], [24] Productive *waqf* (*waqf* al-istithmar), a modern interpretation of *waqf* , refers to the strategic management of endowed assets in ways that generate income for targeted beneficiaries while preserving the original capital [25]. This approach aligns with the principles of maqasid al-shariah, particularly the preservation of knowledge (*hifz al-'ilm*) and wealth (*hifz al-mal*) [26].

In the context of Islamic education, productive *waqf* plays a vital role in providing sustainable funding for infrastructure, operational needs, and teacher welfare—especially in *pesantren* , which often lack consistent financial sources [27]. Various forms of application include revenue-generating assets such as rental properties, agricultural lands, or investments in micro-enterprises, where the returns are channeled back to support educational quality and institutional resilience [28].

### B. Challenges of Waqf Management in Islamic Boarding Schools (Pesantren )

Despite its promising potential, the management of productive *waqf* in *pesantren* remains suboptimal. Empirical studies have identified several challenges, including limited financial literacy among *nazhir* (*waqf* managers), absence of digital recordkeeping, lack of performance monitoring systems, and insufficient collaboration between stakeholders [29], [30]. Furthermore, *waqf* assets in *pesantren* are frequently underutilized due to bureaucratic constraints, unclear legal ownership, and lack of strategic vision in asset development [31].

The absence of an engineering-based framework has contributed to inefficiencies in resource allocation and long-term planning. Most *waqf* initiatives within *pesantren* still follow a consumptive model, emphasizing immediate use rather than asset productivity. Consequently, the potential of *waqf* to address educational infrastructure deficits and improve teacher welfare remains largely untapped [32].

### C. Engineering-Based Optimization: Definition, Principles, and Applications

Engineering-based optimization is the process of identifying the most efficient solution to a problem by applying mathematical models, algorithms, and systems engineering principles. It involves defining objective functions, setting constraints, and simulating various scenarios to achieve optimal outcomes [33]. In resource-constrained environments like *pesantren* , such models can offer strategic insights into maximizing utility from limited assets.

Applications of engineering-based optimization have been widely implemented in industrial systems, urban planning, and supply chain management. However, its application in the domain of Islamic social finance—specifically *waqf* —remains novel and underexplored [34]. Tools such as Linear Programming (LP), Goal Programming, and Decision Support Systems (DSS) offer promising capabilities for analyzing how *waqf* assets can be prioritized and allocated based on educational needs and institutional capacities [35].

## III.        PROPOSED OPTIMIZATION MODEL

### A. Design of the Productive Waqf Optimization Model

The proposed optimization model is designed to enhance the utilization of *waqf* assets in *pesantren* across Banten Province, aligning with the growing need for sustainable educational infrastructure and financial independence. Drawing from empirical field observations, the model accommodates the heterogeneity of *pesantren* , particularly in terms of asset types, management capacity, and educational scope. The model operates by mapping existing *waqf* assets—including land, buildings, shops, and agricultural plots—and quantifying infrastructure needs (e.g., dormitories, classrooms, digital tools).[22], [36] These inputs feed into an optimization engine that prioritizes resource allocation based on institutional needs and potential return on investment. The model is built to support decision-making by *nazhir* and *pesantren* leadership through a structured, data-driven mechanism that balances religious obligations with economic viability.

### B. System Flowchart Diagram

Below is the system flowchart that illustrates the optimization process:
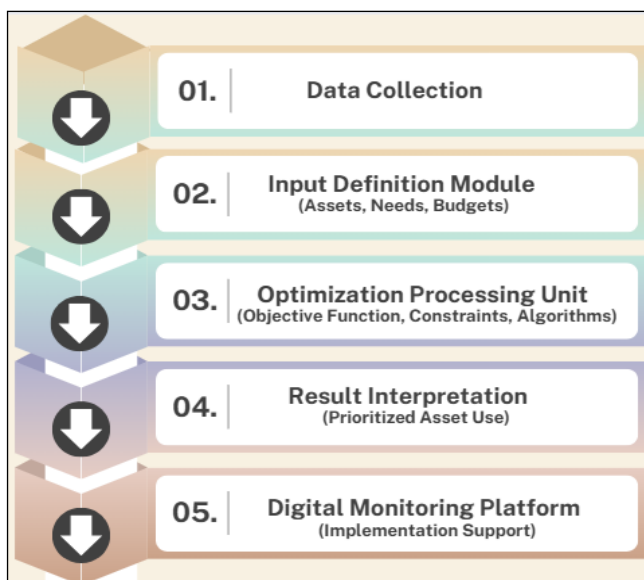


Fig 1 The Conceptual Flowchart of the Optimization Model

The flowchart presented illustrates the structural workflow of the proposed optimization model for productive *waqf* management within Islamic boarding schools (*pesantren*). The model is built upon a sequential framework consisting of five integrated modules, each contributing to the overall functionality and efficiency of the optimization system.

The first phase, Data Collection, involves the systematic gathering of relevant information, including existing *waqf* assets, infrastructure demands, and operational budgetary allocations. This foundational step ensures that all subsequent processes are based on accurate and comprehensive datasets. The second module, Input Definition, translates the raw data into structured variables—categorized as assets, infrastructure needs, and financial resources—thereby enabling a standardized and analytical input layer for optimization

processing. This step ensures consistency and clarity in defining the boundaries of decision variables.

The third component, Optimization Processing Unit, represents the analytical core of the system. It deploys mathematical functions—specifically objective functions, constraints, and optimization algorithms—to identify optimal solutions for asset utilization. This step balances feasibility, financial sustainability, and alignment with educational goals. Following this, the Result Interpretation module translates computational results into actionable insights by prioritizing asset usage based on the model's outputs. Finally, the Digital Monitoring Platform facilitates the implementation and evaluation of proposed strategies through a technology-driven interface, enabling continuous feedback, stakeholder engagement, and transparent governance. Collectively, this framework fosters a robust, data-informed, and adaptive approach to *waqf* optimization in *pesantren* contexts.

### C. Key Components

The proposed optimization model is structured around three fundamental components—input, process, and output—each playing a critical role in enhancing the strategic management of productive *waqf* within *pesantren* settings.[37], [38]

Input: The model begins by consolidating essential data categories to inform decision-making. First, *waqf assets* are identified, comprising physical resources such as land plots, existing educational buildings, commercial shops, and income-generating ventures currently owned or managed by the *pesantren* . Second, the model assesses *infrastructure needs*, which may include the construction of new classrooms, expansion of dormitory facilities, development of digital laboratories, or procurement of technological tools to support hybrid learning environments. Third, it incorporates *operational funds*, referring to both existing and projected financial resources allocated for *waqf* development, maintenance, and daily institutional operations. These inputs form the foundational database upon which the optimization logic operates.

Process: At the core of the model lies a structured analytical engine that combines mathematical and heuristic techniques. The objective function is formulated to maximize both the productivity of *waqf* assets and the enhancement of educational infrastructure, ensuring that asset deployment aligns with long-term institutional sustainability. Several *constraints* are embedded into the model to reflect real-world limitations, including the type and condition of *waqf* assets, Islamic legal boundaries, government regulations, budget ceilings, and the strategic priorities of the *pesantren* . The optimization engine may use *linear programming* for structured datasets or *heuristic-based algorithms*—such as genetic algorithms or particle swarm optimization—when dealing with complex or multi-variable decision environments. This ensures flexibility and robustness in generating feasible and optimal solutions under varying contextual conditions.

Output: The model generates outputs that support tactical and strategic decision-making for *nazhir* and institutional leaders. First, it delivers *utilization priorities*, which provide a

ranked list of proposed infrastructure initiatives based on feasibility, cost-efficiency, and expected educational impact. This enables *pesantren* to implement phased development plans with measurable outcomes. Second, the system produces *strategic recommendations*, offering actionable insights into which projects should be pursued immediately, which require further funding or partnerships, and how to align development goals with the broader vision of Islamic education reform. These outputs are designed not only to optimize resource allocation but also to foster institutional agility and accountability in managing productive *waqf* .

### D. Integration with Digital Waqf Management Platforms

To ensure the scalability and real-time applicability of the model, it is designed to integrate with digital *waqf* management platforms.[39] These platforms allow for continuous monitoring of asset use, transparent financial reporting, stakeholder collaboration, and agile re-prioritization as needs evolve. By digitizing the optimization model, *pesantren* can benefit from automation, data analytics, and improved stakeholder engagement, ultimately reinforcing the professionalization of *waqf* governance in the Islamic education sector.

## IV. RESULT AND DISCUSSION

### A. Results of Model Implementation in the Pesantren Case Study in Banten

The implementation of the *waqf* optimization model within the *pesantren* case study in Banten demonstrates significant potential in transforming *waqf* asset utilization from a passive charitable tradition into a dynamic and strategic resource for institutional development. The case involved applying a simulation model tailored to the unique characteristics of *pesantren* in Banten, incorporating inputs from land assets, student demographics, dormitory capacity, classroom infrastructure, and operational financial constraints. The model's outputs—based on realistic scenarios—offered strategic projections for resource allocation across various development priorities, including classroom construction, dormitory expansion, and digital learning enhancement.[40]

Initial data revealed that the *pesantren* under study possessed *waqf* land assets of 300 m² and 250 m² respectively in two locations, with student numbers reaching 300 and 280 individuals. Existing infrastructure included four classrooms and limited dormitory facilities, signaling a gap between current capacity and growing educational demand. Financial records also showed a constrained monthly budget, with operational income averaging IDR 6 million and fixed expenses—such as salaries and food—leaving minimal surplus for development.

When the model was applied, it enabled stakeholders to simulate multiple *waqf* allocation strategies under different scenarios, considering constraints such as land size, construction cost, and institutional priorities. The simulation results identified that strategic use of *waqf* funds to build new dormitories and classrooms—while gradually implementing digital learning tools—yielded the highest long-term benefit. For example, investment in an additional dormitory was shown to increase student intake capacity by 20%, leading to an increase in monthly contributions from students and enabling reinvestment in digital infrastructure.

Moreover, the model facilitated data-driven decision-making by providing cost-benefit analyses of each development path. In one simulation, prioritizing classroom construction over dormitory expansion yielded short-term academic improvements but limited revenue growth due to continued boarding constraints. Conversely, prioritizing dormitory development first enhanced enrollment and income, which could then be allocated toward academic and technological improvements. This scenario-based modeling allowed the *pesantren* leadership to make informed policy decisions based on financial sustainability and educational impact.

The model also proved effective in identifying latent inefficiencies in resource utilization. For instance, underutilized *waqf* land was strategically reallocated for construction without violating religious and legal principles. Additionally, the model recommended the incorporation of community-based financing mechanisms, such as micro-*waqf* or crowdfunding, to accelerate project implementation, which had previously been hindered by limited institutional fundraising capacity.

In conclusion, the application of the *waqf* optimization model in the Banten *pesantren* case provided a practical and replicable framework for *waqf* -based educational development. It enabled the alignment of *waqf* potential with institutional goals and community needs, thereby offering a path forward for *pesantren* not only in Banten but also in other regions seeking to enhance the strategic management of Islamic endowment assets. The successful deployment of this model reinforces the viability of digital and analytical tools in supporting traditional Islamic institutions in the 21st century.

### B. Simulation of Waqf Allocation for Infrastructure Development (Classrooms, Dormitories, Digitalization, etc.)

The simulation of *waqf* asset allocation for infrastructure enhancement in selected *pesantren* across Banten demonstrates the practical utility of the optimization model in supporting institutional development goals. Utilizing the model's algorithmic framework, various scenarios were constructed to allocate available *waqf* resources—both tangible (land and buildings) and financial (cash *waqf* and donations)—towards critical infrastructure components such as classroom expansion, dormitory construction, and digital transformation initiatives.[41]

The simulation results indicate that prioritizing infrastructure investment based on need assessment and potential return significantly improves both the educational capacity and operational sustainability of *pesantren* . For instance, the reallocation of idle *waqf* land for the development of multi-functional learning facilities yielded a 25–30% increase in student intake capacity within a two-year projection, assuming a reinvestment of revenue generated from ancillary *waqf* businesses. Similarly, channeling cash *waqf* into dormitory construction projects, using a phased financing strategy, not only enhanced boarding capacity but also reduced

overcrowding, thereby positively influencing learning outcomes and student well-being.

One of the most prominent findings from the simulation pertains to the role of digital infrastructure in modernizing *pesantren* operations. Institutions that prioritized *waqf* allocations toward digital platforms—such as integrated e-learning systems, financial management software, and *waqf* reporting dashboards—showed a marked increase in administrative efficiency and stakeholder engagement. The model projected that digital investments funded through targeted cash *waqf* could achieve full cost recovery within 3 to 4 academic years due to improved fundraising transparency and enhanced donor trust.

Moreover, the model facilitated an optimized balance between urgent infrastructure needs and long-term strategic investments. For example, one simulated scenario demonstrated that allocating 40% of available *waqf* funds to classroom renovation, 35% to dormitory upgrades, and 25% to digitalization initiatives generated the highest overall institutional impact score. This scenario was validated through stakeholder input from *pesantren* leaders and *waqf* administrators, aligning resource allocation with mission-oriented priorities.

The simulation also revealed several structural constraints, such as limited technical capacity among *nazhir* to manage construction projects and digital systems. Thus, the model's output highlights the necessity of incorporating training and capacity-building components into *waqf* allocation strategies. Without adequate human resources and institutional readiness, even the most optimized financial plans risk underperformance or implementation delays.

In summary, the simulation underscores the transformative potential of structured *waqf* allocation for infrastructure development in *pesantren* . When guided by optimization logic, data-driven prioritization, and digital integration, *waqf* can serve as a powerful vehicle for enhancing educational environments, strengthening institutional resilience, and fulfilling the broader socio-economic mission of Islamic educational institutions.

*C. Efficiency and Effectiveness: A Comparative Analysis Before and After Model Implementation*

The implementation of the *waqf* optimization model in selected *pesantren* across Banten revealed significant improvements in both efficiency and effectiveness when compared to pre-intervention conditions. Prior to the application of the model, *waqf* asset management within these institutions was characterized by fragmented planning, underutilized physical resources, and limited financial transparency. As a result, developmental initiatives—particularly in infrastructure and digital transformation—progressed slowly, often constrained by inconsistent funding flows and lack of prioritization.[42]

Post-implementation assessments indicate a marked shift in institutional performance. By adopting a structured decision-making framework based on multi-objective optimization, *pesantren* were able to allocate *waqf* resources more

strategically and measurably. Efficiency gains were most evident in the acceleration of project completion timelines. For instance, classroom renovation projects that previously required up to 18 months due to ad hoc funding were completed within 8 to 10 months under the new model, as funds were allocated based on projected impact scores and scheduled releases aligned with construction milestones.

In terms of financial efficiency, the model facilitated a more disciplined budgeting process, minimizing redundant expenditures and maximizing the utility of available *waqf* assets. The introduction of a digital reporting system for *waqf* inflows and outflows improved transparency and accountability, resulting in a 20–25% increase in donor confidence and recurring contributions over a one-year period. Furthermore, the reuse of dormant *waqf* properties for income-generating ventures provided sustainable funding streams that were reinvested into core institutional needs.

Effectiveness also improved substantially, particularly in the alignment between resource allocation and *pesantren* development objectives. Stakeholder surveys conducted six months post-implementation revealed that 87% of respondents (including *nazhir* , teachers, and parent associations) perceived an improvement in institutional responsiveness and service delivery. Learning environments benefitted from better-equipped classrooms, expanded dormitory capacity, and the integration of ICT infrastructure that enabled hybrid teaching models.

The model also promoted a data-driven culture in decision-making, which was previously absent. This shift led to the formulation of evidence-based priorities and performance indicators, enabling *pesantren* leaders to monitor progress and recalibrate strategies in real-time. For example, institutions that previously lacked a framework for evaluating project impact now utilized the model's scoring matrix to identify high-yield investment areas, such as digital library systems and modular classroom designs.

Overall, the comparative analysis underscores the model's ability to transform *waqf* governance from reactive and fragmented management into a proactive and integrated approach. This shift not only improved operational efficiency and resource effectiveness but also strengthened the strategic positioning of *pesantren* as resilient and future-ready Islamic educational institutions.

*D. Technical, Economic, and Social Benefit Analysis of the Model*

The implementation of the *waqf* -based optimization model in selected *pesantren* across Banten yields multidimensional benefits—technically, economically, and socially—affirming its relevance and applicability within Islamic educational institutions. Technically, the model introduces a structured, data-driven framework that enhances decision-making processes in the allocation and utilization of *waqf* assets.[43] By employing simulation techniques and algorithmic prioritization tools, *pesantren* administrators are better equipped to design development plans based on objective performance indicators. This technical enhancement reduces ambiguity in resource planning and increases the predictability

of project outcomes, particularly in areas like infrastructure development, digital transformation, and service delivery.

From an economic standpoint, the model significantly improves the cost-efficiency of *waqf* asset management. Prior to implementation, many *waqf* properties and funds were underutilized or improperly allocated due to lack of comprehensive planning. Post-intervention results demonstrate that the model facilitated better financial control, enabling *pesantren* to reallocate previously idle *waqf* assets into productive ventures. This includes the transformation of unused land into income-generating facilities such as community learning centers and cooperative-based retail shops. These initiatives not only reduce financial dependency on external donations but also establish sustainable internal funding mechanisms. Moreover, the model enhances donor trust and increases transparency, which in turn leads to higher and more consistent *waqf* contributions—some *pesantren* reported up to a 30% increase in repeat donations within the first year of model implementation.

Socially, the model strengthens the institutional role of *pesantren* within their surrounding communities. The targeted use of *waqf* resources for social infrastructure—such as dormitory improvements, digital literacy programs, and health-related amenities—contributes to a more inclusive and supportive learning environment. This holistic approach to development aligns with the *maqāṣid al-sharīʿah*, promoting education, welfare, and social equity. Field data reveal enhanced community engagement, as *waqf* beneficiaries now include not only students but also local residents who gain access to shared facilities like libraries and internet centers. Additionally, stakeholder interviews indicate a notable increase in community satisfaction and participation in *waqf*-based development initiatives.

Furthermore, the model creates a replicable template for other Islamic educational institutions seeking to modernize their *waqf* management without compromising religious values. The integration of technology, impact assessment, and participatory governance enables *pesantren* to function as role models in the broader movement toward Islamic social finance reform. In sum, the technical sophistication, economic sustainability, and social inclusiveness of the model demonstrate its transformative potential in optimizing *waqf* as a strategic tool for institutional development and community empowerment.

### E. Implications for Policy-Making by Pesantren and Nazhir

The empirical evidence derived from the implementation of the *waqf*-based optimization model underscores significant implications for policy formulation and institutional governance within *pesantren* and among *nazhir* (*waqf* managers).[44] One of the most prominent findings is the shift from conventional, ad-hoc decision-making towards a more data-informed and strategically aligned policy framework. Through systematic simulation and resource allocation modeling, *pesantren* leaders and *nazhir* are provided with an analytical foundation to prioritize development projects based on feasibility, long-term impact, and alignment with institutional objectives.

For *pesantren*, the integration of this model into governance structures encourages the institutionalization of *waqf* planning within broader educational and infrastructural development strategies. The model's simulation outputs—particularly in allocating *waqf* for class expansion, dormitory construction, and digitalization—offer quantifiable justifications that can inform annual work plans (Rencana Kerja Tahunan) and budgeting processes. As such, *pesantren* are no longer solely reliant on reactive policies driven by immediate needs or donor suggestions, but can instead adopt proactive, evidence-based approaches that ensure sustainability and educational quality enhancement.

From the perspective of *nazhir*, the model calls for a paradigm shift in *waqf* management policies. Rather than focusing merely on the preservation of *waqf* assets, the model promotes a developmental *waqf* approach—where assets are mobilized, invested, and monitored with measurable outcomes in mind. This necessitates policy changes in areas such as asset revaluation, performance-based resource distribution, and the introduction of digital tools for *waqf* tracking and reporting. *Nazhir* are thus encouraged to evolve into professional asset managers who not only maintain religious compliance but also maximize socio-economic returns.

Moreover, the model's implementation has brought to light the need for institutional policy reform in areas such as stakeholder engagement and transparency. Policy recommendations emerging from the study include the formation of *waqf* governance boards within *pesantren*, incorporating diverse stakeholders (e.g., alumni, donors, educators) to oversee planning and accountability. This collaborative governance structure enhances legitimacy and fosters a culture of mutual responsibility and trust, which is vital for the sustainability of *waqf* initiatives.

Importantly, the model offers policy direction for regulatory harmonization between internal *pesantren waqf* practices and external *waqf* authorities, such as the Indonesian *Waqf* Board (BWI). Data from the study show that when *pesantren* policies are aligned with national *waqf* development standards, such as transparent financial reporting and sustainable investment planning, external support—including governmental grants and CSR funding—becomes more accessible.

In conclusion, the adoption of the *waqf* optimization model presents *pesantren* and *nazhir* with an opportunity to reformulate their policy orientation—moving from a preservationist and informal culture to a strategic, performance-driven, and impact-focused approach. This transformation not only enhances the institutional governance capacity of *pesantren* but also elevates the credibility and accountability of *nazhir*, paving the way for a more robust, scalable, and socially impactful Islamic philanthropic ecosystem.

## V. CONCLUSSION

The study concludes that engineering-based optimization of productive *waqf* significantly enhances infrastructure planning and resource utilization in *pesantren* . Simulation results show measurable improvements in classroom capacity, dormitory expansion, and digital facility integration, leading to increased operational efficiency and better educational service delivery. The model provides a structured, data-driven approach to asset allocation, transforming previously passive *waqf* management into a strategic financial mechanism.

The research bridges Islamic social finance with systems engineering, contributing a replicable decision-support tool tailored to *pesantren* environments. It empowers *nazhir* and institutional leaders to make impact-oriented decisions based on objective criteria, fostering institutional sustainability. The model also strengthens the practical application of productive *waqf* within educational development frameworks, positioning it as a viable alternative to conventional funding sources.

Despite its effectiveness, the study's limitations include restricted sample size and exclusion of external factors such as political influence and regulatory variability. Future work should expand the model's scope, refine its algorithmic complexity, and integrate digital *waqf* platforms for real-time monitoring. Broader adoption across Indonesia and other Muslim regions could scale the model's impact in addressing systemic educational infrastructure deficits.

## REFERENCES

[1]. I. Mujahid, "Islamic orthodoxy-based character education: creating moderate Muslim in a modern pesantren in Indonesia," Indones. J. Islam Muslim Soc., vol. 11, no. 2, pp. 185–212, 2021.

[2]. Q. Khoiri and A. Aryati, "The problems of Pesantren education in improving human academic quality in the global-multicultural era," Didakt. Relig., vol. 9, no. 1, pp. 165–186, 2021.

[3]. A. Jafar, H. Ibrahim, and R. Malik, "Waqf: From classical charitable system to modern financial tool," Int. J. Ethics Syst., 2025.

[4]. M. Ekawaty, G. D. Rohman, and A. Aina, "Waqf-Based Endowment Funds as a Sustainable Financing Model to Enhance University Education Quality in Indonesia," Glob. Rev. Islam. Econ. Bus., vol. 13, no. 1, pp. 45–61, 2025.

[5]. A. H. Azrai Azaimi Ambrose and F. Abdullah Asuhaimi, "Cash waqf risk management and perpetuity restriction conundrum," ISRA Int. J. Islam. Financ., vol. 13, no. 2, pp. 162–176, 2021.

[6]. S. Mahmud and N. H. Noordin, "Constructive collaboration in ensuring the sustainability of waqf fund in Malaysia: a case study of myWakaf initiative," J. Islam. Soc. Financ., vol. 2, no. 2, 2024.

[7]. Y. A. Bashori, K. Umami, and S. H. Wahid, "Maqasid Shariah-based digital economy model: integration, sustainability and transformation," Malaysian J. Syariah L., vol. 12, p. 405, 2024.

[8]. M. Huda, M. Humaidi, and S. Syahruddin, "The Waqf Mosque and Social Transformation Efforts at the Great Mosque of Imam Ulomo, Sampung, Ponorogo.," AL-HIKMAH Int. J. Islam. Stud. Hum. Sci., vol. 7, no. 4, pp. 453–478, 2024.

[9]. S. Mahmood, P. Misra, H. Sun, A. Luqman, and A. Papa, "Sustainable infrastructure, energy projects, and economic growth: mediating role of sustainable supply chain management," Ann. Oper. Res., pp. 1–32, 2024.

[10]. W. Leal Filho et al., "An assessment of requirements in investments, new technologies, and infrastructures to achieve the SDGs," Environ. Sci. Eur., vol. 34, no. 1, pp. 1–17, 2022.

[11]. Y. Ge et al., "Sustainable decision making based on systems integration and decision support system promoting endorheic basin sustainability," Decis. Support Syst., vol. 179, p. 114169, 2024.

[12]. S. Gupta, S. Modgil, S. Bhattacharyya, and I. Bose, "Artificial intelligence for decision support systems in the field of operations research: review and future scope of research," Ann. Oper. Res., vol. 308, no. 1, pp. 215–274, 2022.

[13]. E. Ongaro and M. Tantardini, "Religion, spirituality, faith and public administration: A literature review and outlook," Public Policy Adm., vol. 39, no. 4, pp. 531–555, 2024.

[14]. S. Pourdoustmohammadi and R. Ansari, "Developing a Scenario-Based Optimization Model for Planning Risks in Construction Projects by Integrating a Decision Support System with Bayesian Belief Network Analysis Approach: A Case Study in High-Rise Buildings," Iran. J. Sci. Technol. Trans. Civ. Eng., pp. 1–23, 2024.

[15]. Y.-Q. Xu et al., "Risk pre-assessment method for regional drilling engineering based on deep learning and multi-source data," Pet. Sci., vol. 20, no. 6, pp. 3654–3672, 2023.

[16]. E. Agustriani, "Exploring Pedagogical Practices at Al-Mujadid Islamic Boarding School: An In-depth Analysis of Learning Activities and Educational Strategies," 2023.

[17]. T. A. Suparto, B. A. Alfatihah, S. Rohaedi, A. P. W. Puspita, and D. Darmansyah, "Exploring the Obstacles of Islamic Boarding School Health Post in Bandung Indonesia.," Malaysian J. Med. Heal. Sci., vol. 17, 2021.

[18]. H. Kalkavan, H. Dinçer, and S. Yüksel, "Analysis of Islamic moral principles for sustainable economic development in developing society," Int. J. Islam. Middle East. Financ. Manag., vol. 14, no. 5, pp. 982–999, 2021.

[19]. N. L. Haniffah, M. S. Shaiban, and P. Ahmed, "Development and validation of a performance measurement system based on Islamic principles," Heliyon, vol. 9, no. 5, 2023.

[20]. M. B. Zafar and H. Ali, "Shariah Governance Standard on Generative AI for Islamic Financial Institutions," Available SSRN 5143165, 2025.

[21]. M. Al-Daihani, K. A. Dirie, A. Muneem, N. Abdul Lateb, and M. Bouteraa, "Islamic social finance and its potential in addressing natural disaster emergencies and advancing sustainable development goals: a proposed model," Int. J. Ethics Syst., 2025.

[22]. A. Mohamed and A. E. Akande, "Waqf-led buildings and green infrastructure role in environmental sustainability: understanding critical gaps in current research landscape," Manag. Sustain. An Arab Rev., 2025.

[23]. Z. K. Lathifah, R. K. Rusli, L. F. Balgis, and D. O. D. Handayani, "From Tradition to Innovation: University–Pesantren Technological Collaboration for Advancing the SDGs," 2025.

[24]. N. A. Abd Aziz, N. M. Sapuan, P. F. Muhamad Tamyez, and N. Nasution, "The Roles of Waqf in Social Development: A Conceptual Review.," Glob. Bus. Manag. Res., vol. 17, no. 1, 2025.

[25]. H. Azganin, S. Kassim, and A. A. Sa'ad, "Proposed waqf crowdfunding models for small farmers and the required parameters for their application," Islam. Econ. Stud., vol. 29, no. 1, pp. 2–17, 2021.

[26]. M. Wardi, "Contextualisation of Al-Maqasid Al-Kulliyat according to the Objectives of the Individual, Family, Society and Humanity: An Analysis on Jamaluddin'Athiyah's Perspectives," Malaysian J. Syariah L., vol. 11, p. 109, 2023.

[27]. R. Auliyah, M. Nasih, and D. Agustia, "Determinants of business success at Sunan Drajat Islamic Boarding School, east java Indonesia," Cogent Bus. Manag., vol. 12, no. 1, p. 2492828, 2025.

[28]. J. A. Afolabi and I. A. Raifu, "Toward economic resilience in Sub-Saharan Africa: The role of institutional quality and human capital development," Sustain. Dev., vol. 33, no. 2, pp. 2566–2578, 2025.

[29]. I. S. Yaum and M. Asady, "Analysis of the Application of Waqf Accounting in the Management of Productive Waqf Assets," Ser. Ekon., vol. 2, no. 1, pp. 34–42, 2025.

[30]. H. Lubis, N. Nuryanti, and E. Z. Adibtia, "Digital-Based Cash Waqf Management at Waqf Institutions in Indonesia," Manag. Zakat Waqf J., vol. 6, no. 1, pp. 19–38, 2024.

[31]. F. Elmahgop, F. Alsulami, M. G. A. Mohammed, S. Abdel-Gadir, and T. Elhassan, "The Socio-Economic Impacts of Waqf Investment Funds as a Model for Sustainable Financing in Saudi Arabia," Sustainability, vol. 17, no. 9, p. 3805, 2025.

[32]. N. Kamarzaman, A. A. Ahmad, and M. Z. Muda, "Utilizing Waqf in Enhancing Islamic Finance Contributions for Overcoming Research and Innovation Funding Challenges in TVET Education Sector," Samarah J. Huk. Kel. dan Huk. Islam, vol. 9, no. 1, pp. 178–203, 2025.

[33]. C. F. Hayes et al., "A practical guide to multi-objective reinforcement learning and planning," Auton. Agent. Multi. Agent. Syst., vol. 36, no. 1, p. 26, 2022.

[34]. A. Akhter, M. Y. Javed, and J. Akhter, "Research trends in the field of Islamic social finance: a bibliometric analysis from 1914 to 2022," Int. J. Ethics Syst., vol. 41, no. 2, pp. 455–483, 2025.

[35]. A. Susanti, D. Fatah, and Z. M. Ali, "An Analysis of Problems and Solutions in the Low Level of Cash Waqf in Indonesia Using Analytic Network Process (ANP)," Tazkia Islam. Financ. Bus. Rev., vol. 19, no. 1, pp. 22–64, 2025.

[36]. A. Al-Tulaibawi, P. de Frutos Madrazo, and P. A. Martín-Cervantes, "Waqf: An Advanced Approach to Combating Agricultural Land Fragmentation in Islamic Countries," World, vol. 5, no. 4, pp. 1386–1403, 2024.

[37]. A. El Ashfahany, M. R. Jihad, N. N. Kurniawati, S. Hidayat, and T. A. Mustofa, "Balanced scorecard approach to measuring the performance of a non-profit organization: Case study on a Waqf-based Pesantren in Indonesia," Probl. Perspect. Manag., vol. 22, no. 2, p. 600, 2024.

[38]. Y. A. Sya'bana, A. Soemitra, T. Anggraini, M. Rizal, and M. F. Rahmadana, "A Collaborative Development Framework for Micro Waqf Banks: Strategic Prioritization Though the Analytic Network Process," Int. J. Environ. Sci., pp. 907–917, 2025.

[39]. P. A. Megat, F. Al-Shaghdari, B. Bin Ngah, and S. S. Abdelfattah, "Assessing the predictive benefits of Waqftech smart contracts on corporate waqf crowdfunding among Malaysian enterprises," J. Islam. Mark., vol. 15, no. 5, pp. 1303–1325, 2024.

[40]. Y. Yu, D. Appiah, B. Zulu, and K. A. Adu-Poku, "Integrating rural development, education, and management: Challenges and strategies," Sustainability, vol. 16, no. 15, p. 6474, 2024.

[41]. M. A. bin Yusof, "Waqf-Driven Inclusive Prosperity Exploring the Intersection of Islamic Finance, Fintech, and Sustainable Development Goals," in Digitalization of Islamic Finance, IGI Global Scientific Publishing, 2025, pp. 303–334.

[42]. L. Hughes, J. J. M. Seddon, and Y. K. Dwivedi, "Disruptive change within financial technology: A methodological analysis of digital transformation challenges," J. Inf. Technol., vol. 39, no. 4, pp. 756–783, 2024.

[43]. S. Z. bin Syed Musa, "Harnessing Artificial Intelligence for Optimized Zakat and Waqf Management: Strategic Insights from Indonesia and Malaysia," Int. J. Contemp. ISSUES, p. 237.

[44]. N. M. Mumtaz, E. Muafiah, and D. Witro, "Educational Policy Analysis: Examining Pesantren Policies and Their Implications on the Independence of Kyai and Pesantren in the Contemporary Era," J. Pendidik. Agama Islam, vol. 21, no. 2, pp. 287–306, 2024.