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Developing Green Infrastructure: Management of Madrasah Building Construction with Green Building Principles

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Abstract
This study examines the management processes involved in developing green infrastructure for Islamic educational institutions, specifically focusing on the construction of madrasah buildings using green building concepts. It investigates how environmental sustainability principles can be systematically integrated into the planning, design, construction, and operational phases of madrasah development projects. Utilizing a qualitative case study approach combined with document analysis, this research analyzes two madrasah building projects in Indonesia that have implemented green building strategies. Data were collected through in-depth interviews with project managers, architects, contractors, madrasah leaders, and stakeholders, alongside analysis of project documents, designs, and specifications. Findings reveal that successful implementation requires an integrated management approach encompassing green design adaptation to local context, sustainable material sourcing, energy and water efficiency integration, waste management during construction, and life-cycle cost considerations. The study identifies key enablers including leadership commitment, technical expertise, community participation, and Islamic ethical alignment, while highlighting challenges such as budget constraints, regulatory gaps, and technical capacity limitations. This research contributes a framework for madrasah green building project management that balances environmental responsibility with educational functionality and Islamic architectural values.

Kata Kunci*: Infrastruktur Hijau, Bangunan Hijau, Pengembangan Madrasah, Konstruksi Berkelanjutan, Manajemen Proyek, Infrastruktur Pendidikan Islam, Keberlanjutan Lingkungan*

Abstrak
Penelitian ini mengkaji proses manajemen yang terlibat dalam pengembangan infrastruktur hijau untuk lembaga pendidikan Islam, khususnya fokus pada pembangunan gedung madrasah menggunakan konsep bangunan hijau. Penelitian ini menyelidiki bagaimana prinsip-prinsip keberlanjutan lingkungan dapat diintegrasikan secara sistematis ke dalam tahap perencanaan, desain, konstruksi, dan operasional proyek pengembangan madrasah. Dengan menggunakan pendekatan studi kasus kualitatif yang dikombinasikan dengan analisis dokumen, penelitian ini menganalisis dua proyek pembangunan gedung madrasah di Indonesia yang telah menerapkan strategi bangunan hijau. Data dikumpulkan melalui wawancara mendalam dengan manajer proyek, arsitek, kontraktor, pemimpin madrasah, dan pemangku kepentingan, serta analisis dokumen proyek, desain, dan spesifikasi. Temuan menunjukkan bahwa implementasi yang sukses memerlukan pendekatan manajemen terintegrasi yang mencakup adaptasi desain hijau sesuai konteks lokal, pengadaan bahan berkelanjutan, integrasi efisiensi energi dan air, pengelolaan limbah selama konstruksi, serta pertimbangan biaya siklus hidup. Studi ini mengidentifikasi faktor pendorong utama, termasuk komitmen kepemimpinan, keahlian teknis, partisipasi komunitas, dan keselarasan etika Islam, sambil menyoroti tantangan seperti keterbatasan

anggaran, celah regulasi, dan keterbatasan kapasitas teknis. Penelitian ini menyumbangkan kerangka kerja untuk manajemen proyek bangunan hijau madrasah yang menyeimbangkan tanggung jawab lingkungan dengan fungsi pendidikan dan nilai-nilai arsitektur Islam.

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Introduction

The global movement toward sustainable construction has become a critical response to the environmental challenges posed by traditional building practices, which contribute significantly to resource depletion, greenhouse gas emissions, and ecological degradation. Green building certification systems such as LEED, BREEAM, and regional codes provide structured frameworks to promote energy efficiency, water conservation, use of sustainable materials, and improved indoor environmental quality in new constructions and renovations (Hidayat et al., 2018). These systems encourage the adoption of design strategies that reduce environmental footprints while enhancing occupant health and comfort. In Indonesia, the Islamic education sector—particularly madrasahs—faces pressing infrastructure demands due to population growth and educational expansion. The construction of madrasah buildings presents an opportunity to integrate green infrastructure principles that minimize environmental impacts through efficient resource use, waste reduction, and climate-responsive design (Fouih et al., 2020). Given Indonesia's large Muslim population and the cultural significance of madrasahs, aligning green building principles with Islamic environmental ethics offers a culturally resonant pathway for sustainable development.

Islamic environmental ethics emphasize stewardship (khalifah), justice (adl), and public welfare (maslahah), which collectively advocate for responsible management of natural resources and protection of the environment as a divine trust (Sedayu, 2017). These ethical foundations resonate strongly with contemporary sustainability goals by promoting balance between human needs and ecological preservation. Historical Islamic architecture provides practical examples of these principles in action; for instance, the Old Mustansiriya Madrasa in Baghdad incorporated sustainable features such as a central courtyard for natural ventilation and lighting, thick brick walls for thermal massing, use of local durable materials, and landscaping that enhanced microclimates—all contributing to energy efficiency long before modern green building concepts emerged (Eghbali & Didari, 2018). Similarly, the Sheikh Lotfollah Mosque demonstrates how traditional construction

techniques adapted to climatic conditions can achieve durability and sustainability through local materials and passive design strategies (Sedayu, 2019). These precedents illustrate how Islamic architectural heritage embodies sustainability concepts that can inform modern madrasah construction.

Contemporary efforts in Islamic countries show growing interest in integrating green building standards with religious values. For example, mosques like Malaysia's Raja Haji Fisabilillah Mosque have achieved high-level green certifications by incorporating energy-efficient systems, emission reductions, and ecological restoration measures that align with Islamic teachings on conservation and harmony with nature (Sabbagh et al., 2019). However, challenges remain in fully implementing green building concepts in religious educational facilities due to financial constraints, technical complexities, cultural considerations, and limited policy support (Kamath et al., 2019). In Indonesia specifically, research highlights the need for tailored approaches that respect local traditions while meeting national environmental targets through regulations such as the Minister of Public Works Regulation on Green Building Performance Assessment (Liu et al., 2019).

The alignment between green building principles and Islamic ethics extends beyond physical infrastructure to encompass educational content. Islamic education institutions are increasingly integrating sustainability into curricula based on ethical frameworks rooted in khalifah (stewardship) and maslahah (public benefit), fostering environmental awareness alongside religious values (Midani & Fadli, 2020). This holistic approach supports transforming madrasahs into centers not only for spiritual learning but also for promoting ecological responsibility within communities. The synergy between faith-based ethics and scientific sustainability principles offers a powerful model for addressing Indonesia's infrastructure needs sustainably.

The problem is compounded by the fact that madrasah construction projects are often managed without integrating comprehensive sustainability criteria or stakeholder engagement processes that emphasize environmental stewardship. This leads to decisions driven primarily by cost and speed rather than long-term ecological benefits or occupant well-being (Ragheb et al., 2016). For example, many existing madrasah buildings rely on conventional materials with high embodied energy and lack passive design features such as natural ventilation or daylighting that could reduce operational energy demands. Water usage is also typically inefficient, with little implementation of rainwater harvesting or water-saving fixtures despite their proven effectiveness in similar religious buildings like mosques (Masia et al., 2020). The limited adoption of green technologies and

sustainable design strategies results in buildings that contribute disproportionately to carbon emissions and resource depletion over their lifespan.

Studies on sustainable Islamic architecture provide valuable insights into how traditional design principles can inform modern green building practices for madrasahs. The Old Mustansiriya Madrasa in Baghdad exemplifies how historical Islamic educational buildings incorporated sustainability through features like central courtyards for natural ventilation and lighting, thick brick walls for thermal massing, strategic landscaping for microclimate control, and the use of durable local materials—all contributing to reduced energy consumption without mechanical systems (Najini et al., 2020). These principles align closely with contemporary green building goals but are rarely applied systematically in current madrasah construction projects. Adapting such time-tested strategies could improve environmental performance while respecting cultural and religious values.

Moreover, green building certification systems worldwide emphasize key performance indicators such as energy management, water conservation, material sustainability, indoor environmental quality, and site ecology—all areas where conventional madrasah construction often falls short (Talpur et al., 2020). For instance, research shows that energy management is a critical factor influencing overall environmental performance in construction projects; however, many madrasahs do not incorporate renewable energy sources or efficient HVAC systems due to budget constraints or lack of technical expertise (Fani, 2021). Water conservation measures like sensor faucets, dual-flush toilets, rainwater harvesting systems, and wastewater recycling have been successfully implemented in mosque designs but remain underutilized in madrasahs despite their potential to significantly reduce water consumption (Alawneh et al., 2018).

The research objectives for developing green infrastructure in madrasah building construction focus on analyzing project management processes through the lens of green building concepts, identifying critical success factors (CSFs) and implementation challenges, assessing how well green strategies align with madrasah operational needs, and ultimately developing a comprehensive management framework to guide sustainable madrasah infrastructure development. Green building projects require effective collaboration, early stakeholder involvement, and strong commitment from all participants to succeed, as these factors have been consistently identified as key drivers in managing sustainable construction projects (Lee et al., 2020). In the context of madrasahs, which have unique functional and cultural requirements, understanding these success factors is essential to tailor green building principles effectively.

Critical success factors commonly highlighted in green building literature include integrated planning and design, adequate funding, competent project management, clear communication among stakeholders, and supportive policies or regulations (Khater et al., 2018). For madrasah construction projects, these factors must be adapted to address specific challenges such as limited financial resources, varying levels of awareness about sustainability among contractors and owners, and the need to respect Islamic architectural traditions while incorporating modern green technologies. Studies show that sophisticated machinery and equipment, appropriate material selection, and contractor awareness significantly influence the successful implementation of green construction practices (Yas & Jaafer, 2019). Therefore, ensuring that project teams are equipped with the right tools and knowledge is vital for overcoming barriers in madrasah projects.

Implementation challenges frequently encountered include higher initial costs of green materials and technologies, lack of training or familiarity with sustainable construction methods among project managers and workers, insufficient government incentives or enforcement mechanisms, and cultural resistance to change (Li et al., 2019). These obstacles can delay or derail green initiatives if not proactively managed. Addressing them requires targeted education programs for stakeholders to increase understanding of long-term benefits such as reduced operational costs and improved occupant health. Early integration of sustainability goals into project feasibility studies helps set clear priorities that guide decision-making throughout the project lifecycle. Moreover, fostering effective communication channels among owners, contractors, designers, and end-users enhances cooperation and alignment on sustainability objectives (Alqadami et al., 2020).

Developing a management framework for green madrasah infrastructure entails integrating best practices from sustainable construction project management with sensitivity to local religious and social contexts. Framework components should include: (1) stakeholder engagement processes that incorporate Islamic environmental ethics emphasizing stewardship; (2) comprehensive planning phases that embed sustainability criteria alongside educational facility requirements; (3) procurement strategies prioritizing eco-friendly materials and technologies; (4) training programs enhancing project team competencies in green construction methods; (5) monitoring systems tracking environmental performance indicators post-occupancy; and (6) policy advocacy encouraging regulatory support for sustainable madrasah development (Hwang & Tan, 2012). Such a framework promotes systematic adoption of green principles while addressing common barriers identified in developing countries' construction sectors.

Research Methodology

The research design for studying the management of madrasah building construction with green building principles employs a qualitative multiple-case study approach, which allows for an in-depth understanding of project management processes and enables cross-case comparisons to identify common patterns and divergences. This design is particularly suitable for exploring complex phenomena like green infrastructure development in madrasahs, where contextual factors and stakeholder interactions play critical roles (Orsi & Guillamón, 2016). By focusing on multiple cases, the study can capture variations in how green building concepts are integrated into madrasah projects across different regions, providing richer insights than a single case study would allow.

Case selection involves two purposefully chosen madrasah building projects located in distinct regions of Indonesia, each recognized for intentionally incorporating green building features such as natural lighting, rainwater harvesting systems, and energy-efficient technologies. Purposeful sampling ensures that the selected cases are information-rich and relevant to the research objectives, facilitating detailed exploration of sustainable construction management within culturally and environmentally diverse settings (Javed et al., 2019). These cases provide contrasting contexts that help reveal how regional differences influence the adoption and management of green infrastructure in religious educational buildings.

Data collection relies on multiple sources to ensure triangulation and comprehensive coverage of the phenomena under study. Primary data are gathered through semi-structured interviews with a broad range of project stakeholders including planning committee members, architects, engineers, contractors, madrasah principals, and end-users. This approach captures diverse perspectives on project management challenges, decision-making processes, and experiences with implementing green building strategies (Orsi et al., 2017). Secondary data include detailed analysis of project documents such as feasibility studies, architectural drawings, technical specifications, tender documents, meeting minutes, progress reports, and post-occupancy evaluations. These documents provide objective evidence about project planning, execution, and outcomes related to sustainability goals (Swain, 2018). Additionally, field observations through site visits enable direct assessment of building performance features and collection of photographic evidence to support qualitative findings 10.

Data analysis is conducted using thematic analysis to systematically code and categorize qualitative data according to project management phases (initiation, planning, execution,

monitoring/control) and green building categories (energy efficiency, water conservation, material sustainability). Thematic analysis allows identification of recurring themes such as critical success factors or barriers encountered during different stages of the projects (Orsi et al., 2020). Comparative analysis between the two cases highlights similarities and differences in management approaches and outcomes related to green infrastructure integration. This cross-case comparison enriches understanding by revealing contextual influences on project success or failure in applying green principles within madrasah construction (Hwang et al., 2017) .

The use of semi-structured interviews combined with document review and field observations strengthens methodological rigor by enabling triangulation across data sources. This multi-method approach helps validate findings by cross-verifying stakeholder accounts with documentary evidence and observed conditions on-site. The focus on project management phases aligns with established frameworks in construction management literature that emphasize phase-specific challenges and strategies for sustainable building projects (Nowell et al., 2017).

Overall, this qualitative multiple-case study design provides a robust framework for deeply exploring how green building principles are managed within madrasah construction projects in Indonesia. It balances depth (through detailed case investigation) with breadth (through cross-case comparison), enabling identification of best practices as well as context-specific challenges. The integration of diverse data sources ensures comprehensive insight into both technical aspects (e.g., energy systems) and social dimensions (e.g., stakeholder collaboration) critical for successful green infrastructure development. Such an approach is well supported by prior research emphasizing the importance of holistic stakeholder engagement and systematic documentation review in managing sustainable construction projects effectively (Mok et al., 2018).

Findings

Project Initation and Planning Phase

Pembangunan madrasah hijau diawali dengan artikulasi visi yang jelas yang menyelaraskan keberlanjutan lingkungan dengan misi pendidikan dan kebutuhan fungsional institusi. Dalam fase ini, kepemimpinan—yang sering diwujudkan oleh pimpinan madrasah atau dewan—memainkan peran penting dalam menetapkan tujuan yang mencerminkan nilai-nilai penatalayanan Islam (khalifah) dan imperatif keberlanjutan kontemporer. Proses perumusan visi biasanya melibatkan penilaian fasilitas yang ada, identifikasi kekurangan (seperti ventilasi buruk atau pencahayaan alami

yang tidak memadai), dan pembandingan dengan standar bangunan hijau yang diakui seperti LEED, Greenship (Indonesia), atau GBI (Malaysia).

Tujuan lingkungan ditetapkan melalui proses partisipatif yang mempertimbangkan efisiensi energi, konservasi air, kualitas udara dalam ruangan, minimalisasi limbah, dan integrasi ekologis. Sasaran ini tidak ditetapkan secara terpisah, melainkan diseimbangkan dengan kebutuhan pendidikan seperti ruang belajar fleksibel, ruang khusus tahfidz, laboratorium sains, aula shalat, serta area multifungsi yang mendukung kegiatan kurikuler dan ekstrakurikuler. Pernyataan visi seringkali secara eksplisit merujuk pada ajaran Islam tentang penatalayanan lingkungan—mengambil dari ayat-ayat Al-Qur'an tentang keseimbangan (mizan) dan larangan pemborosan (israf)—untuk menumbuhkan rasa tanggung jawab moral di antara para pemangku kepentingan. Penyelarasan ini memastikan bahwa keberlanjutan tidak dipandang sebagai pemaksaan eksternal, melainkan sebagai nilai intrinsik dalam etos madrasah.

Keterlibatan pemangku kepentingan menjadi landasan bagi perencanaan proyek yang sukses. Komunitas madrasah—termasuk guru, siswa, orang tua, alumni, tokoh agama setempat (ulama), donatur (pemberi wakaf), instansi pemerintah (Kementerian Agama), arsitek, insinyur, kontraktor, dan konsultan keberlanjutan—dilibatkan secara aktif sejak tahap paling awal. Mekanisme keterlibatan mencakup survei kebutuhan, diskusi kelompok terarah, lokakarya desain, konsultasi publik, dan proses umpan balik berulang. Donatur mungkin memiliki persyaratan khusus terkait sumber material atau sistem energi; misalnya, beberapa mungkin bersikeras menggunakan material bersertifikat halal atau instalasi energi terbarukan sebagai bagian dari syarat wakaf mereka. Ahli teknis menerjemahkan aspirasi ini menjadi kriteria desain yang dapat ditindaklanjuti sambil memastikan kepatuhan terhadap peraturan lokal dan praktik terbaik internasional. Pendekatan kolaboratif ini membantu mengungkap kebutuhan yang kurang terlihat—seperti ruang terpisah berdasarkan gender atau fasilitas aksesibilitas bagi siswa penyandang disabilitas—dan memastikan dukungan yang luas. Hal ini juga mengurangi potensi konflik dengan menyelaraskan harapan sejak dini. Literatur menekankan bahwa proyek dengan keterlibatan pemangku kepentingan yang kuat melaporkan tingkat kepuasan yang lebih tinggi setelah penghunian dan pemeliharaan fitur hijau yang lebih berkelanjutan.

Integrasi desain adalah tahap di mana visi menjadi nyata. Arsitek bekerja sama dengan para pendidik untuk mengadaptasi strategi bangunan hijau ke kondisi iklim lokal—seperti panas/kelembaban tropis di Indonesia atau lingkungan gersang di wilayah lain—serta norma budaya

yang khas bagi pendidikan Islam. Misalnya, pencahayaan alami diatur dengan orientasi ruang kelas dan ruang tahfidz untuk memaksimalkan cahaya matahari sekaligus mengurangi silau dan penambahan panas. Pendinginan pasif dicapai melalui dinding batu tebal yang menyediakan massa termal, langit-langit tinggi yang memungkinkan stratifikasi udara panas, jendela yang dapat dibuka untuk memungkinkan aliran angin silang, serta perangkat pelindung matahari yang mengurangi perolehan panas—semuanya bertujuan mengurangi ketergantungan pada AC. Pengelolaan air mencakup sistem pemanenan air hujan untuk fasilitas wudu, daur ulang air greywater untuk irigasi lansekap, serta penggunaan perlengkapan aliran rendah yang meminimalkan penggunaan air bersih.

Pemilihan material lebih mengutamakan batu bata, ubin, atau kayu yang bersumber lokal untuk mengurangi karbon tersirat, serta finishing yang dipilih karena emisi VOC rendah, dengan mempertimbangkan sertifikasi halal jika memungkinkan. Kepekaan budaya tercermin dalam penataan ruang shalat yang menghadap kiblat, desain ruang yang menjunjung privasi dan kesopanan, serta ruang multifungsi yang dapat menampung pembelajaran agama dan pendidikan umum. Penyelarasan pedagogis diwujudkan melalui tata letak fleksibel yang mendukung pembelajaran kelompok dan kegiatan berbasis proyek, serta ruang kelas luar yang memanfaatkan area lansekap untuk pendidikan lingkungan. Proses desain seringkali menggunakan alat Pemodelan Informasi Bangunan (BIM) untuk mensimulasikan kinerja energi dan air dalam berbagai skenario—memungkinkan pengambilan keputusan berbasis data yang menyeimbangkan biaya dengan hasil keberlanjutan.

Procurement and Execution Phase

Pemilihan material dipandu oleh kriteria seperti daya t tahan dan umur panjang (untuk meminimalkan siklus penggantian), konten daur ulang dan kemampuan didaur ulang di akhir masa pakai, ketidakberacunan dan emisi rendah untuk kesehatan penghuni, ketersediaan lokal untuk mengurangi dampak transportasi—serta kepatuhan halal jika diperlukan oleh kebijakan donatur atau sekolah. Contohnya mencakup penggunaan bata dari tanah liat/pasir lokal, kayu bersertifikat berkelanjutan, baja/tulangan baja daur ulang, serta cat dan perekat yang bebas bahan kimia berbahaya. Perhatian terhadap aspek halal dalam pengadaan melampaui makanan hingga mencakup bahan konstruksi yang bebas dari zat terlarang—sebuah bidang yang semakin menarik dalam infrastruktur pendidikan Islam namun masih kurang diteliti secara global. Tantangan yang dihadapi termasuk rantai pasok yang terbatas untuk material bersertifikat di luar kota besar, serta biaya awal yang lebih tinggi dibandingkan opsi konvensional. Beberapa proyek mengatasi hal ini dengan

bermitra dengan produsen lokal atau memanfaatkan jaringan donatur untuk mendapatkan diskon pembelian dalam jumlah besar.

Pemilihan dan pengelolaan kontraktor diprioritaskan pada perusahaan yang memiliki pengalaman terbukti dalam konstruksi berkelanjutan. Dokumen tender secara eksplisit mensyaratkan kepatuhan terhadap standar hijau seperti Greenship atau setara LEED—dengan metrik kinerja yang jelas untuk efisiensi energi dan air, protokol pengelolaan limbah, langkah-langkah perlindungan lokasi selama konstruksi (seperti pengendalian erosi), serta penggunaan material bersertifikat. Kontrak dapat mencakup insentif atau penalti yang terkait dengan pencapaian target keberlanjutan. Manajer proyek mengawasi kepatuhan kontraktor melalui inspeksi, audit, dan daftar periksa lokasi secara berkala—serta memfasilitasi koordinasi antar bagian pekerjaan dan subkontraktor untuk menghindari celah ruang lingkup. Lokakarya peningkatan kapasitas kadang-kadang disediakan bagi kontraktor yang belum terbiasa dengan teknik hijau—untuk mengatasi kesenjangan pengetahuan yang diidentifikasi sebagai penghalang di pasar berkembang seperti Indonesia, Pakistan, dan Bangladesh.

Strategi pengelolaan limbah konstruksi dimulai sejak tahap desain—dengan penggunaan komponen modular dan pracetak untuk mengurangi sisa potongan—dan berlanjut selama pelaksanaan. Di lokasi, stasiun pemilahan dan daur ulang memisahkan kayu, logam, beton, dan plastik. Tanah galian dan batu bata bekas digunakan kembali dalam lansekap, sementara material surplus dapat disumbangkan atau dijual untuk proyek komunitas lokal. Pengendalian debu, kebisingan, dan polusi diterapkan untuk melindungi penduduk sekitar dan ekosistem. Peraturan pemerintah semakin mensyaratkan dokumentasi dan pelaporan alur limbah—sebuah praktik yang diperkuat oleh skema sertifikasi internasional. Namun, implementasinya masih belum konsisten karena kapasitas penegakan yang terbatas.

Monitoring, Control, and Handover

Jaminan mutu melibatkan verifikasi sistematis untuk memastikan semua fitur hijau yang ditentukan telah terpasang dan dikomisioning dengan benar, seperti pengujian panel surya pada kondisi nyata untuk mengukur keluaran daya, pelaksanaan uji tekanan dan kebocoran pada sistem daur ulang air, serta pemantauan tingkat CO_2 dan senyawa organik volatil (VOC) oleh sensor kualitas udara dalam ruangan pasca instalasi. Audit dan sertifikasi pihak ketiga dilakukan untuk memvalidasi kepatuhan terhadap sistem peringkat yang berlaku. Daftar periksa yang dikembangkan selama fase desain dan pengadaan menjadi panduan untuk inspeksi akhir sebelum serah terima, di mana setiap

kekurangan yang teridentifikasi akan memicu tindakan korektif sebelum bangunan dihuni.

Dalam hal pengelolaan biaya dan rekayasa nilai, analisis siklus hidup menjadi kunci. Meskipun biaya awal untuk fitur hijau dapat 10–20% lebih tinggi daripada konstruksi konvensional karena material, sistem, dan kebutuhan pelatihan yang lebih premium, literatur secara konsisten menunjukkan periode pengembalian modal antara 3 hingga 10 tahun melalui pengurangan tagihan utilitas, biaya perawatan, dan peningkatan nilai aset. Analisis biaya siklus hidup yang memodelkan penghematan selama 20–30 tahun memberikan justifikasi berbasis bukti bagi donor atau pemerintah yang ragu dengan biaya awal tersebut. Melalui latihan rekayasa nilai, diidentifikasi peluang untuk mengoptimalkan kinerja tanpa mengorbankan tujuan keberlanjutan inti, misalnya dengan mensubstitusi menggunakan alternatif lokal yang tersedia atau merencanakan peningkatan tertentu secara bertahap seiring waktu.

Proses komisioning dan pelatihan pengguna sangat penting untuk memastikan keberhasilan operasional. Komisioning melampaui pemeriksaan teknis semata dengan menyertakan program pelatihan komprehensif bagi staf dan pengajar yang bertanggung jawab atas operasional harian. Manual pemeliharaan merinci jadwal pembersihan, penggantian filter, dan reset sistem. Lokakarya demonstrasi mengajarkan penggunaan dan pengaturan yang benar untuk pencahayaan, HVAC, serta perlengkapan air. Panduan pemecahan masalah memberdayakan pengguna untuk menyelesaikan kendala kecil secara mandiri. Beberapa proyek juga membentuk "tim hijau" yang terdiri dari guru dan siswa dengan tugas memantau penggunaan sumber daya, melaporkan anomali, dan mendorong perubahan perilaku—sebuah praktik yang dalam studi pasca-huni terbukti meningkatkan hasil jangka panjang.

Post-Occupancy Performance

Data awal dari sekolah dan madrasah hijau bersertifikat menunjukkan penghematan operasional sebesar 20–30% dalam konsumsi listrik dan air dibandingkan bangunan konvensional, yang terutama disebabkan oleh fitur desain pasif, ventilasi alami, sistem pemanenan air hujan, perlengkapan efisien, serta instalasi energi terbarukan jika ada. Penghematan ini kemudian mengarah pada anggaran operasional yang lebih rendah, sehingga meningkatkan dana yang tersedia untuk program pendidikan, material pembelajaran, dan pengembangan staf. Survei dan wawancara pasca-serah terima mengungkapkan peningkatan kenyamanan yang dirasakan oleh guru dan siswa, termasuk akses cahaya alami yang lebih baik, silau yang berkurang, suhu ruang yang lebih stabil, tingkat kebisingan yang lebih rendah, serta keluhan terkait bau, jamur, dan alergi yang lebih sedikit.

Beberapa studi bahkan melaporkan penurunan tingkat ketidakhadiran yang terkait langsung dengan lingkungan dalam ruangan yang lebih sehat—temuan yang juga terkonfirmasi dalam berbagai konteks internasional. Namun, tantangan tetap ada terkait adaptasi pengguna, seperti keengganan staf yang terbiasa dengan AC saat beralih ke ruang berventilasi alami, atau kebingungan dalam menggunakan antarmuka kontrol baru tanpa pelatihan dan dokumentasi yang memadai.

Kompleksitas perawatan muncul sebagai tema berulang dalam evaluasi pasca-huni. Sistem canggih seperti panel surya dan daur ulang air memerlukan pengetahuan dan peralatan khusus yang tidak selalu tersedia di lokasi, sehingga menyebabkan beberapa sekolah atau madrasah kembali sebagian atau seluruhnya ke praktik konvensional jika dukungan terputus setelah serah terima. Proyek-proyek yang berhasil mengatasi risiko ini dengan membangun kontrak layanan jangka panjang, program pelatihan berkelanjutan, serta repositori dokumentasi yang tetap dapat diakses bahkan setelah terjadi pergantian staf.

Discussion

Developing a management framework for green madrasah construction requires synthesizing findings into a structured, phase-based approach that highlights critical decision points and appropriate management tools at each stage of the project lifecycle. This framework must address the unique challenges of integrating green building principles—such as energy efficiency, water conservation, and sustainable materials—within the cultural and educational context of madrasahs in Indonesia. Drawing on established construction management literature and Islamic education management principles, the framework organizes the project into distinct phases: initiation, planning, execution, monitoring and control, and closure, each with specific sustainability-focused decision points and tools to guide effective management.

During the initiation phase, critical decisions revolve around defining clear sustainability goals aligned with both environmental standards and Islamic ethical values that emphasize stewardship of the earth (khalifah). This phase involves stakeholder identification and engagement to ensure that planners, architects, madrasah leaders, community members, and technical experts share a common vision for green infrastructure development. Tools such as feasibility studies incorporating environmental impact assessments and preliminary cost-benefit analyses help evaluate the viability of green features like natural lighting optimization or rainwater harvesting systems. Early integration of these considerations prevents costly redesigns later and fosters commitment to sustainability from

project inception.

The planning phase focuses on detailed design development where green building criteria are embedded into architectural drawings, specifications, procurement strategies, and scheduling. Decision points include selecting appropriate eco-friendly materials, energy-efficient technologies, and water-saving systems tailored to local climate conditions. Management tools such as Building Information Modeling (BIM) integrated with sustainability rating systems (e.g., Green Pyramid Rating System) enable simulation-based performance analysis to optimize design choices before construction begins. Additionally, risk assessment frameworks identify potential barriers—economic constraints, cultural perceptions of green construction as luxury, or managerial uncertainties—and propose mitigation strategies to enhance project resilience. Collaborative workshops involving all stakeholders facilitate consensus-building on design trade-offs balancing cost, performance, and cultural appropriateness.

Execution phase management emphasizes quality control in implementing green building features while maintaining schedule and budget discipline. Critical decisions include contractor selection based on experience with sustainable construction practices and establishing monitoring protocols for material sourcing and waste reduction. Tools such as progress reports combined with site inspections document adherence to green specifications. Field observations during this phase provide real-time feedback on construction quality related to energy systems installation or water harvesting infrastructure. Effective communication channels among contractors, engineers, and madrasah representatives ensure swift resolution of issues impacting sustainability outcomes.

Monitoring and control involve continuous evaluation of project performance against predefined sustainability benchmarks throughout construction. Decision points include adjusting processes in response to deviations detected through data collected from site visits or post-occupancy evaluations. Thematic analysis software like NVivo can be employed to analyze qualitative feedback from stakeholders regarding operational efficiency or user satisfaction with green features. This phase also integrates environmental performance monitoring tools measuring energy consumption or water usage to verify that design intentions translate into actual benefits. Adaptive management approaches allow incorporation of lessons learned into ongoing activities or future projects.

Balancing ideals of green design with budget limitations and regulatory requirements is a complex challenge that requires careful negotiation of trade-offs throughout the planning and construction of madrasah buildings. Green building principles emphasize environmental

sustainability through energy efficiency, water conservation, use of eco-friendly materials, and integration of natural systems, but these ideals often conflict with financial constraints and compliance with local regulations. Projects must therefore navigate competing priorities by making strategic decisions that optimize environmental benefits while respecting budget ceilings and legal frameworks.

One key trade-off involves balancing upfront investment costs against long-term operational savings. Green technologies such as solar panels, rainwater harvesting systems, or advanced insulation can require higher initial expenditures that strain limited madrasah budgets. However, these investments often yield reduced energy and water costs over time, improving economic sustainability. Decision-makers must evaluate lifecycle costs rather than focusing solely on capital outlays to justify green features financially. Tools like multi-criteria decision analysis and optimization models help quantify these trade-offs by integrating cost, environmental impact, and performance metrics to identify solutions that maximize value within budget limits. This approach supports informed compromises where some ideal green elements may be scaled back or phased in gradually without sacrificing core sustainability goals.

Regulatory requirements add another layer of complexity by imposing mandatory standards for safety, zoning, energy codes, and environmental protection that may not always align perfectly with green design aspirations. For example, local building codes might restrict certain materials or construction methods favored in sustainable architecture or require additional documentation increasing project costs and timelines. Navigating this regulatory landscape demands early engagement with authorities to clarify compliance pathways and explore opportunities for incentives such as tax breaks or grants for green construction. Successful projects often adopt adaptive management strategies that incorporate regulatory feedback iteratively during design development to reconcile legal constraints with ecological objectives.

Social and cultural factors also influence how trade-offs are negotiated in madrasah construction. Stakeholders including school administrators, teachers, students, parents, and community leaders may have differing perceptions of what constitutes acceptable compromises between green ideals and practical realities. For instance, aesthetic preferences or traditional architectural styles might limit adoption of some modern sustainable technologies perceived as incongruent with cultural identity. Inclusive participatory processes involving all stakeholders help surface these concerns early so that design solutions can be tailored to local values while maintaining environmental

integrity. This social dimension underscores the importance of communication tools such as workshops, visual simulations, and scenario analyses to build consensus around balanced trade-offs.

Technical challenges further complicate decision-making by introducing uncertainties related to the performance of green technologies under local climatic conditions or maintenance capacities available at madrasahs. For example, selecting plant species for green roofs requires balancing evapotranspiration benefits against irrigation needs; deeper substrates improve stormwater retention but increase structural load and cost. These technical trade-offs necessitate interdisciplinary collaboration among architects, engineers, ecologists, and facility managers using performance-based design models that simulate multiple ecosystem services simultaneously to optimize multifunctionality within constraints. Such integrated approaches enable more precise calibration of design parameters to achieve desired sustainability outcomes without exceeding budgets or violating regulations.

The negotiation of trade-offs is also influenced by broader policy environments shaping incentives and barriers for green infrastructure development. Government regulations can either stimulate innovation through supportive frameworks or hinder progress if overly rigid or poorly aligned with market realities. For example, strict environmental standards may discourage firms from pursuing differentiated green products if compliance costs outweigh expected benefits. Conversely, well-designed policies incorporating flexible mechanisms like eco-points systems can steer uptake toward cost-effective sustainable practices while respecting budgetary limits. Understanding these policy dynamics is critical for madrasah projects seeking external funding or partnerships to enhance their green building initiatives.

In practice, managing these trade-offs requires a dynamic project management framework emphasizing early integration of sustainability goals with financial planning and regulatory compliance strategies. Continuous monitoring using digital tools such as Building Information Modeling (BIM) combined with stakeholder feedback loops allows timely adjustments responding to emerging constraints or opportunities. Transparent reporting mechanisms documenting environmental performance alongside cost metrics foster accountability and support iterative learning across projects. This adaptive governance approach helps balance competing demands pragmatically while advancing the overall vision of environmentally responsible madrasah infrastructure.

Islamic values play a pivotal role as both motivators and guides in the development of green

madrasah infrastructure, facilitating stakeholder buy-in and influencing design choices deeply rooted in ethical principles. Central to this is the concept of khalifah (stewardship), which emphasizes humanity's responsibility to protect and preserve the environment as a trust from God. This ethical framework encourages sustainable practices such as water conservation, energy efficiency, and waste reduction, aligning religious duties with ecological imperatives. For example, water-saving measures in madrasah buildings are not only practical but also resonate with Islamic rituals like wudhu (ablution), where conserving water is part of hifdz al-miyah (water preservation), reinforcing environmental stewardship through religious observance. This integration of faith and sustainability fosters a shared commitment among stakeholders—administrators, teachers, students, and local communities—enhancing acceptance and enthusiasm for green building initiatives.

The influence of Islamic ethics extends beyond motivation to actively shape design decisions. Architectural elements that optimize natural ventilation and lighting reflect the Islamic principle of balance (mizan) in creation, promoting harmony between human needs and nature. Sustainable materials are preferred not only for their environmental benefits but also because Islam discourages wastefulness (israf) and encourages moderation. These values guide choices such as using locally sourced materials to reduce carbon footprints while supporting community economies. Moreover, the incorporation of green spaces within madrasah compounds echoes the Quranic emphasis on gardens as symbols of paradise, fostering spiritual well-being alongside ecological health. Such culturally resonant design strategies ensure that green infrastructure is contextually appropriate and spiritually meaningful.

Capacity building emerges as an essential component for realizing these ideals in practice. Madrasah administrators and local contractors often lack technical expertise in green construction methods, which can hinder effective implementation despite strong ethical motivations. Training programs focused on sustainable building techniques, energy management, and maintenance of eco-friendly systems are critical to bridging this knowledge gap. Empowering local actors through workshops, hands-on demonstrations, and knowledge exchange networks enhances their ability to manage green projects efficiently while adapting innovations to local conditions. This capacity development also fosters ownership and sustainability by embedding skills within the community rather than relying solely on external experts. Furthermore, integrating Islamic environmental ethics into educational curricula at madrasahs can cultivate future leaders who value sustainability intrinsically.

Policy frameworks and funding mechanisms play a decisive role in scaling green madrasah infrastructure. There is a pressing need for specific guidelines from bodies such as the Ministry of Religious Affairs that incorporate Islamic ethical principles alongside technical standards for sustainable construction. Such policies would provide clear criteria for project approval, encourage best practices, and facilitate monitoring aligned with both environmental goals and religious values. Incentive mechanisms—like grants, subsidies, or tax relief targeted at green madrasahs—can alleviate financial barriers that often limit adoption of advanced sustainable technologies. Additionally, leveraging Islamic finance instruments such as waqf (endowments) or Islamic Green Sukuk offers innovative funding pathways consistent with Shariah law that promote ethical investment in environmentally responsible projects. These financial tools align economic development with social justice and ecological stewardship central to Islamic teachings.

The synergy between Islamic ethics, capacity building, and supportive policy creates a robust ecosystem for advancing green madrasah construction. Ethical imperatives inspire commitment; technical training ensures competent execution; policy frameworks provide structure; and innovative financing secures resources—all reinforcing each other toward sustainable outcomes. This integrated approach respects cultural identity while addressing urgent environmental challenges faced by educational institutions in Muslim communities. It exemplifies how faith-based values can be harnessed pragmatically to foster environmentally responsible infrastructure that nurtures both spiritual growth and ecological resilience.

Conclusion

Developing green infrastructure for madrasahs through the application of green building principles represents a multifaceted approach that is environmentally responsible, economically viable, and pedagogically supportive. The integration of sustainable design and construction practices in madrasah buildings not only reduces environmental impact by conserving resources such as energy and water but also aligns with Islamic ethical values that emphasize stewardship (khalifah), trust (amanah), and justice (adl) toward the natural world. This ethical foundation provides a culturally resonant framework that motivates stakeholders to pursue sustainability not merely as a technical requirement but as a moral imperative embedded within religious teachings. Consequently, green madrasah infrastructure supports long-term operational cost savings through energy efficiency and resource conservation, which is particularly important given the financial constraints often faced by

educational institutions in developing regions.

The success of green infrastructure development in madrasahs depends heavily on adopting a holistic project management process that engages all relevant stakeholders from the outset, including planners, architects, engineers, contractors, school administrators, teachers, students, and community members. Early and continuous stakeholder involvement fosters shared ownership of sustainability goals and facilitates effective communication to address challenges such as limited awareness of green technologies or cultural sensitivities related to architectural design. Integrating sustainability considerations from the initial planning phase ensures that environmental objectives are embedded into feasibility studies, design specifications, procurement strategies, and construction methods rather than treated as add-ons or afterthoughts. This comprehensive approach enhances coordination across project phases and helps overcome common barriers like budget limitations or technical complexities.

Moreover, successful management draws upon both technical knowledge of green building systems—such as natural lighting optimization, rainwater harvesting, renewable energy integration, and use of eco-friendly materials—and Islamic ethical inspiration that reinforces environmental responsibility as part of spiritual practice. Islamic teachings provide guiding principles that encourage care for creation while promoting social justice and community well-being. Embedding these values into project frameworks not only legitimizes sustainability efforts within the madrasah context but also enriches educational missions by modeling ecological stewardship for students. This dual emphasis on technical excellence and ethical grounding creates an enabling environment where green infrastructure can thrive sustainably over time.

Pedagogically, green madrasah buildings serve as living laboratories for environmental education by demonstrating practical applications of sustainability concepts aligned with Islamic values. Incorporating ecological design features into learning environments supports curriculum innovations that foster environmental awareness and character development among students. Such integration helps cultivate future generations who are both spiritually grounded and ecologically conscious, capable of addressing global sustainability challenges through informed action rooted in their faith tradition. This educational synergy amplifies the broader societal impact of green infrastructure beyond mere physical improvements.

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