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GREEN BUILDING IMPLEMENTATION AND ENERGY EFFICIENCY: THE MEDIATING ROLE OF SUSTAINABLE DESIGN AND THE MODERATING EFFECT OF REGULATORY COMPLIANCE IN URBAN CONSTRUCTION PROJECTS

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ABSTRACT

Urban construction in emerging economies has adopted green building practices at an accelerating rate, yet certification counts have outpaced measurable reductions in building energy intensity. This study asks why installed green capability so often fails to convert into operational energy performance, and tests two candidate answers: an intra-project translation mechanism (sustainable design integration) and an institutional contingency (regulatory compliance). Drawing on the natural-resource-based view and institutional theory, a moderated mediation model was estimated on survey data from 417 professionals responsible for completed commercial, residential, and institutional construction projects in five Indonesian metropolitan areas, collected between August 2025 and January 2026. Partial least squares structural equation modelling (SmartPLS 4, 5,000 bootstrap subsamples) shows that green building implementation predicts sustainable design integration strongly (beta = 0.634, $p < 0.001$), which in turn predicts energy efficiency performance (beta = 0.472, $p < 0.001$). The indirect path accounts for 55.2 per cent of the total effect, indicating complementary partial mediation. Regulatory compliance significantly moderates the implementation-performance relationship (beta = 0.187, $p < 0.01$): the simple slope is non-significant under weak compliance (0.056) and steep under strong compliance (0.430). Compliance does not, however, moderate the design-performance path (beta = 0.058, $p = 0.217$), suggesting that design quality operates independently of regulatory pressure once it is embedded. The model explains 56.4 per cent of variance in energy efficiency performance. Findings reposition compliance as an enabling condition rather than a driver, and identify design-stage integration as the highest-leverage and lowest-performing lever available to project organisations.

Keywords: **building energy intensity; emerging-economy construction; institutional pressure; moderated mediation; project capability**

1. INTRODUCTION

Buildings and construction together account for roughly 37 per cent of energy- and process-related carbon dioxide emissions worldwide, and operational energy demand in the sector has continued to rise even as the efficiency of individual components has improved (United Nations

Environment Programme, 2024). Indonesia illustrates the resulting tension with unusual clarity. Over the past decade the country has built a recognisable green building institutional apparatus: a voluntary certification scheme administered by the Green Building Council Indonesia, a mandatory national performance guideline issued through Ministerial Regulation 21/PRT/M/2021 on green building implementation, and municipal instruments such as the Jakarta green building code that impose envelope, lighting, and cooling requirements on large new developments. Certified floor area has expanded rapidly and is concentrated in the metropolitan corridors of Jakarta, Surabaya, and Bandung (Green Building Council Indonesia, 2023). Electricity consumption in the commercial and public building segment, however, has continued to grow faster than the national average (Kementerian Energi dan Sumber Daya Mineral, 2024). The problem confronting policymakers and developers is therefore not that green building has failed to diffuse. It is that diffusion and measured energy performance have partially decoupled, and the sources of that decoupling remain poorly specified (Rolando & Ingriana, 2024).

Two largely separate literature streams speak to this decoupling, and neither resolves it alone. The first is technical and building-science oriented. It documents a persistent discrepancy between simulated and metered energy consumption, commonly termed the building performance gap, and attributes it to modelling assumptions, commissioning failures, control-system misconfiguration, and occupant behaviour (de Wilde, 2014; Newsham et al., 2009). Newsham and colleagues, examining certified buildings in North America, found that certification improved average energy performance but that the dispersion around that average was wide enough that a substantial minority of certified buildings consumed more energy than conventional comparators. The second stream is organisational and managerial. It examines what drives firms and project teams to adopt green building technologies in the first place, typically identifying government incentives, client demand, reputational advantage, and cost expectations as the dominant antecedents (Darko, Zhang, & Chan, 2017; Olubunmi et al., 2016), and barriers such as higher first cost, limited technical expertise, and fragmented supply chains as the dominant impediments (Laurensia, 2023;Chan et al., 2018). This literature is rich on the decision to adopt and comparatively thin on what happens afterwards.

The two streams disagree, implicitly, about where the leverage lies. Technical studies locate the problem downstream, in commissioning and operation, and prescribe metering, retro-commissioning, and control tuning. Managerial studies locate it upstream, in adoption incentives, and prescribe subsidies, expedited permitting, and capability building (Rolando & Mulyono, 2026; Judijanto & Rolando,2024.; Rolando, 2025). Both readings are plausible, and each is incomplete in the same way: they treat green building implementation as a relatively undifferentiated bundle whose effect on energy outcomes is either realised or not. Ahmad, Aibinu, and Stephan (2019), reviewing the field, observed that research has concentrated on adoption drivers and life-cycle assessment while the management processes through which green intentions become green outcomes have received far less attention. Zuo and Zhao (2014) reached a similar conclusion a decade ago, and the intervening literature has not substantially closed the gap. What is missing is a specification of the intra-project mechanism that converts installed green features into measured performance, and of the institutional conditions under which that conversion is more or less likely to occur.

This study addresses three concrete gaps. The theoretical gap concerns the natural-resource-based view. Hart (1995) proposed that pollution prevention, product stewardship, and sustainable development constitute path-dependent, causally ambiguous capabilities that generate advantage, and Hart and Dowell (2011) later acknowledged that the framework had said comparatively little about the internal routines through which such capabilities are exercised. Applied to construction, the framework predicts that green building capability yields environmental performance but does not specify the translation routine. The empirical gap concerns model specification. The overwhelming majority of quantitative green building studies estimate direct effects of adoption or of specific technologies on outcome measures; studies that model an intervening design mechanism and an institutional contingency in the same structural model are rare, which means the field has little evidence on whether the mechanism and the contingency operate on the same path or on different ones. The contextual gap concerns setting. Empirical work is dominated by North American, European, Chinese, and Australian samples (Zhang et al., 2019). Emerging-economy urban construction, where a voluntary certification market coexists with a mandatory code that is unevenly enforced across municipalities, presents a configuration in which compliance is genuinely variable rather than assumed, and is therefore an unusually informative site for testing an institutional contingency.

Accordingly, this study pursues four objectives: first, to estimate the effect of green building implementation on energy efficiency performance in completed urban construction projects; second, to test whether sustainable design integration mediates that effect and to quantify the proportion of the total effect that runs through it; third, to test whether regulatory compliance moderates the implementation-performance relationship, the design-performance relationship, or both; and fourth, to establish which specific dimensions of green building capability offer the greatest performance leverage relative to their current level of attainment.

The contribution is threefold. Theoretically, the study specifies and tests a translation routine that the natural-resource-based view has left implicit, and it repositions regulatory compliance from an antecedent of adoption, which is how institutional accounts usually treat it, to a contingency that governs the efficacy of adoption. Empirically, it provides one of the first moderated-mediation estimates in this literature, allowing the mediating mechanism and the moderating condition to be distinguished rather than conflated. Practically, it identifies where limited project resources produce the largest marginal energy gain, using an importance-performance analysis that separates dimensions that are already well executed from those that matter more than current practice reflects.

1.1 Theoretical Framework and Hypothesis Development

The natural-resource-based view holds that firms operating under environmental constraint develop capabilities that are socially complex and difficult to imitate, and that these capabilities are the proximate source of environmental and economic advantage (Hart, 1995; Shrivastava, 1995). In construction, green building implementation is best understood as such a capability bundle rather than as a technology purchase: it comprises material selection and sourcing routines, water conservation systems, site and construction-waste management practices, and the integration of efficient energy systems. Each element requires coordination across designers, contractors, and suppliers, and the bundle is assembled over repeated projects. Sustainable design integration, by contrast, is a design-stage routine: the use of passive strategies suited to the local climate, the optimisation of the building envelope, and the conduct of an integrated design process in which architectural, structural, and mechanical decisions are made jointly rather than sequentially. Teece (2007) would classify the former as an asset-orchestration capability and the latter as a sensing-and-transforming routine; the theoretical claim advanced here is that the first operates on outcomes substantially through the second.

Projects that have invested in green building implementation accumulate the technical vocabulary, supplier relationships, and internal legitimacy that make integrated design work feasible. A contractor accustomed to specifying certified materials and managing construction waste has already established the cross-disciplinary coordination that an integrated design process requires; a project team with no such history typically defaults to sequential handoffs in which mechanical engineers size systems around an envelope they did not influence. Darko et al. (2017) found that firms with prior green technology experience were markedly more likely to adopt design-stage practices than firms without it, and Li et al. (2014) reported the same sequencing in Chinese developments. Hence:

H1: Green building implementation has a positive effect on sustainable design integration.

Design-stage decisions determine the great majority of a building's operational energy demand, because envelope thermal performance, orientation, glazing ratio, daylight access, and system sizing are fixed early and are expensive to revise afterwards. Integrated design processes allow trade-offs to be resolved jointly: a better envelope permits smaller cooling plant, which frees capital for higher-efficiency equipment. Studies in the building-science stream consistently find that the projects with the smallest performance gaps are those in which energy modelling informed design iterations rather than merely documented a design already fixed (de Wilde, 2014). This yields:

H2: Sustainable design integration has a positive effect on energy efficiency performance.

Green building implementation should also affect energy performance through channels that bypass design. Efficient chillers, variable-speed drives, LED lighting, and building management systems reduce consumption regardless of whether the envelope was optimised, and disciplined construction practice reduces the thermal-bridging and air-leakage defects that erode designed performance. These are direct, additive contributions. Because both a direct and an indirect channel are theorised, the mediation is expected to be partial and complementary in the sense of Hair et al. (2022), with the two effects sharing the same sign:

H3: Green building implementation has a positive direct effect on energy efficiency performance.

H4: Sustainable design integration mediates the relationship between green building implementation and energy efficiency performance.

Institutional theory supplies the contingency. DiMaggio and Powell (1983) distinguished coercive, mimetic, and normative isomorphic pressures, and Scott (2014) later organised institutional influence into regulative, normative, and cultural-cognitive pillars. Green building research has used this apparatus almost exclusively to explain adoption: regulation drives firms to adopt because non-adoption is sanctioned or delegitimised. The argument advanced here is different. Regulatory compliance, understood as the substantive fulfilment of code requirements together with the verification, documentation, and commissioning obligations that accompany them, changes what installed green capability actually produces. Codes mandate performance verification, minimum envelope values, and commissioning evidence; where those obligations are met, deviations between specified and installed equipment are caught, control systems are properly configured, and the capability is expressed in operation. Where compliance is nominal, the same installed capability sits in a building whose systems are never balanced. Compliance, on this reading, is an enabling condition rather than a driver, and it should amplify the direct implementation-performance path:

H5: Regulatory compliance positively moderates the relationship between green building implementation and energy efficiency performance, such that the relationship is stronger at higher levels of compliance.

Whether compliance also amplifies the design path is less clear, and the competing predictions are worth stating. If regulation works primarily by forcing verification, it should amplify any path whose realisation depends on verification, including the design path. If, however, integrated design produces performance through physical properties that are embedded in the building fabric and require no ongoing institutional enforcement, then design should deliver its effect irrespective of compliance intensity. The second reading implies substitution rather than amplification. Given the theoretical ambiguity, the hypothesis is stated in the amplifying direction so that a null result is informative:

H6: Regulatory compliance positively moderates the relationship between sustainable design integration and energy efficiency performance.

2. RESEARCH METHOD

2.1 Research Design

The study employs an explanatory, cross-sectional survey design with a covariance-free structural equation model. The design is appropriate because the theoretical claim is about a mechanism and a contingency operating on the same set of latent constructs, and because the outcome of interest, energy efficiency performance, is a multidimensional perception-and-record composite rather than a single metered value that could be extracted from an administrative register (Rolando, 2026). The unit of analysis is the completed construction project; each respondent reported on one project in which they had held a substantive role through both design and delivery. Figure 1 sets out the full sequence of research activities, from problem identification through supplementary analysis (Rolando, Mulyono Herry, et al., 2026).

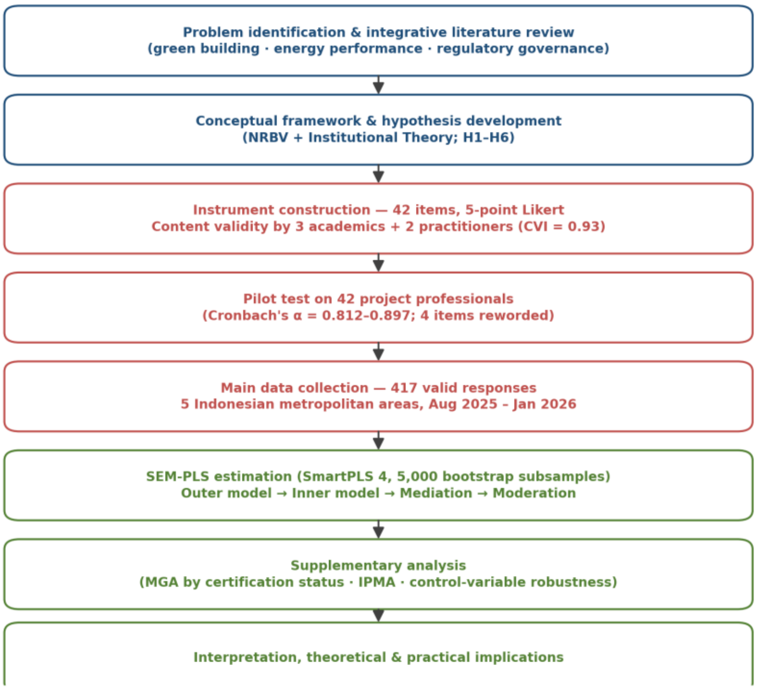

Figure 1. Research procedure

Source: Authors' construction (2026).

2.2 Population and Sample

The target population comprised professionals holding design, delivery, or sustainability responsibility on commercial, residential, and institutional construction projects completed between 2019 and 2025 in five Indonesian metropolitan areas: Jakarta, Surabaya, Bandung, Semarang, and Medan. These five were selected because they contain the great majority of Indonesian projects subject to municipal green building requirements while differing appreciably in enforcement intensity, which is precisely the variation the moderation hypothesis requires. The sampling frame was assembled from three sources: the membership registers of the Indonesian Association of Contractors and the Indonesian Institute of Architects, the public project directory maintained by the Green Building Council Indonesia, and professional referrals from an initial set of respondents. Purposive sampling was applied with three inclusion criteria: the respondent must have held a role of project manager, site engineer, design lead, sustainability or MEP consultant, or owner's representative; must have been engaged on the project for at least twelve months spanning design and construction; and the project must have been operational for at least twelve months so that energy performance could be observed rather than predicted.

Sample size was determined ex ante using the inverse square root method of Kock and Hadaya (2018). Anticipating a minimum path coefficient of approximately 0.19 for the interaction term, the required sample at a significance level of 0.05 and power of 0.80 is n = (2.486 / 0.19)^2, or 172. A parallel calculation in G*Power 3.1 for a regression with five predictors, a medium effect size of f-squared = 0.15, alpha = 0.05, and power = 0.80 returned 138. Both thresholds were exceeded comfortably. Of 640 invitations distributed, 438 responses were returned, a response rate of 68.4 per cent attributable to the referral-assisted distribution strategy. Twenty-one responses were removed: eleven for failing an embedded attention check, six for straight-lining across more than 90 per cent of items, and four for reporting a project that did not meet the twelve-month operational criterion. The final analytical sample is 417.

2.3 Data Collection Procedure

Data were collected between August 2025 and January 2026 through a self-administered online instrument distributed by email and professional messaging groups, supplemented by 63 assisted responses collected in person at two industry events to reduce coverage bias against respondents less active online. The instrument was presented in Bahasa Indonesia, having been translated from English and back-translated by two bilingual construction academics, with discrepancies in four items resolved by discussion. Participation was voluntary and anonymous, no identifying information about the respondent or the project owner was collected, and respondents were informed that responses would be reported only in aggregate. Median completion time was 17 minutes.

2.4 Measurement of Constructs

All four constructs were measured reflectively on five-point Likert scales anchored at 1 (strongly disagree) and 5 (strongly agree). Green building implementation was operationalised as a second-order construct with four dimensions and fourteen items; sustainable design integration with three dimensions and eleven items; energy efficiency performance with three dimensions and nine items; and regulatory compliance as a single-dimension construct with eight items. Items were adapted rather than adopted verbatim, with wording revised for the Indonesian regulatory vocabulary and for project-level rather than firm-level reference. Table 1 reports the measurement structure, a representative item per dimension, and the source study from which each dimension was adapted.

Table 1. Construct operationalisation and sources of measurement adaptation

Construct	Dimension	Items	Representative item (abbreviated)	Adapted from
Green Building Implementation (GBI)	Material selection & sourcing	4	Certified, low-emission, or locally sourced materials were specified and verified on delivery	Darko et al. (2017)
	Water conservation systems	3	Rainwater harvesting or greywater recovery was installed and commissioned	Zhang et al. (2019)
	Site & waste management	3	Construction waste was segregated and diverted from landfill according to a documented plan	Chan et al. (2018)
	Energy systems integration	4	High-efficiency HVAC and lighting systems were integrated with a building management system	Ahmad et al. (2019)
Sustainable Design Integration (SDI)	Passive design strategy	4	Orientation, shading, and natural ventilation were used to reduce cooling load before equipment was sized	Li et al. (2014)
	Envelope optimisation	4	Glazing ratio and wall assembly were optimised against a modelled thermal target	de Wilde (2014)
	Integrated design process	3	Architects, structural, and MEP engineers resolved energy trade-offs in joint working sessions	Zuo & Zhao (2014)
Energy Efficiency Performance (EEP)	Energy intensity reduction	3	Measured energy intensity is materially lower than a comparable conventional building	Newsham et al. (2009)
	Operational energy management	3	Consumption is metered by system and reviewed against targets on a fixed cycle	de Wilde (2014)
	Renewable energy utilisation	3	On-site renewable generation contributes a measurable share of building demand	Zhang et al. (2019)
Regulatory Compliance (RC)	Single dimension	8	Mandatory commissioning and performance verification evidence was completed and submitted	Olubunmi et al. (2016); Scott (2014)

Source: Authors' compilation (2026).

Content validity was established by an expert panel of three construction management academics and two practising sustainability consultants, who rated each item for relevance and clarity (Rolando, Mulyono, et al., 2026). The resulting scale-level content validity index was 0.93, above the 0.90 threshold. A pilot study with 42 professionals not included in the main sample produced Cronbach's alpha values between 0.812 and 0.897 across the eleven dimensions; four items with ambiguous phrasing around commissioning terminology were reworded before the main survey.

2.5 Analytical Technique

Partial least squares structural equation modelling was selected over covariance-based alternatives for three reasons. First, the model is prediction-oriented and moderately complex, involving a second-order construct, a mediated path, and two interaction terms, a configuration for which PLS-SEM has recognised advantages (Hair et al., 2019). Second, several indicators departed from univariate normality, with absolute skewness up to 1.41 and kurtosis up to 2.08, which violates the distributional assumptions of maximum-likelihood estimation. Third, the analysis is explicitly concerned with maximising explained variance in the endogenous construct rather than with confirming a theoretically fixed covariance structure. Estimation was conducted in SmartPLS 4 using the path weighting scheme, with 5,000 bootstrap subsamples, no sign changes, and bias-corrected accelerated confidence intervals. The second-order constructs were modelled using the two-stage approach, with latent variable scores from stage one serving as indicators of the higher-order construct in stage two. Interaction terms were computed using the two-stage approach recommended for moderation with reflective constructs, and mediation was assessed following the procedure of Preacher and Hayes (2008) as adapted for PLS by Sarstedt et al. (2020), reporting the variance accounted for.

2.6 Validity, Reliability, and Common Method Bias

Convergent validity was assessed through outer loadings, composite reliability, and average variance extracted; discriminant validity through the heterotrait-monotrait ratio of correlations (Henseler et al., 2015) and the Fornell and Larcker (1981) criterion. Because all measures were obtained from a single respondent at a single point in time, common method bias was addressed both procedurally and statistically. Procedurally, respondent anonymity was guaranteed to reduce evaluation apprehension; predictor and criterion items were separated by intervening blocks and page breaks; item wording alternated in specificity and included two reverse-coded items per construct; and no construct labels were shown to respondents (Podsakoff et al., 2003). Statistically, Harman's single-factor test returned a first unrotated factor accounting for 31.7 per cent of total variance, well below the 50 per cent threshold, and a full collinearity assessment produced a maximum variance inflation factor of 2.417, below the conservative 3.3 criterion. Measurement invariance across the certified and non-certified subsamples used in the multi-group analysis was established using the MICOM procedure (Henseler et al., 2016), with partial invariance confirmed at both the configural and compositional stages.

3. RESULTS AND DISCUSSION

3.1 Respondent and Project Profile

Table 2 summarises the composition of the 417-project sample. Project managers and site engineers together account for 58.5 per cent of respondents, which is appropriate given that the constructs concern delivery as well as design; sustainability and MEP consultants contribute a further 21.3 per cent and supply the technical judgement required for the energy performance items. Experience is concentrated in the middle of the distribution, with 68.6 per cent of respondents reporting between five and fifteen years in the industry. Jakarta contributes the largest share of projects at 35.7 per cent, consistent with its dominance of the certified building stock, but the remaining 64.3 per cent are distributed across four other metropolitan areas, which preserves the enforcement variation the design requires. Notably, 43.2 per cent of projects hold no green certification at all, and a further 17.7 per cent are mid-process. This is a deliberate feature rather than a sampling deficiency: restricting the sample to certified projects would have truncated variance in the independent construct and rendered the moderation test uninformative.

Table 2. Respondent and project profile (n = 417)

Characteristic	Category	n	%
Role on project	Project manager	138	33.1
	Site / construction engineer	106	25.4
	Sustainability or MEP consultant	89	21.3
	Architect / design lead	52	12.5
	Owner's representative	32	7.7
Professional experience	Under 5 years	71	17.0
	5-10 years	168	40.3
	11-15 years	118	28.3
	Over 15 years	60	14.4
Highest education	Diploma (D3/D4)	58	13.9
	Bachelor's degree	241	57.8
	Master's degree or higher	118	28.3
Metropolitan area	Jakarta	149	35.7
	Surabaya	88	21.1
	Bandung	71	17.0
	Semarang	56	13.4
	Medan	53	12.7
Project type	Office tower	97	23.3
	Mixed-use development	84	20.1
	Apartment / residential	106	25.4
	Retail / commercial	71	17.0
	Institutional (health, education)	59	14.1
Green certification status	Greenship certified	163	39.1
	Certification in process	74	17.7
	Not certified	180	43.2
Project contract value	Under IDR 100 billion	124	29.7
	IDR 100-500 billion	187	44.8
	Above IDR 500 billion	106	25.4

Source: Primary data (2026).

3.2 Measurement Model Assessment

All 42 indicators loaded on their intended constructs above the 0.70 criterion, with values ranging from 0.741 to 0.868 and no cross-loading exceeding an item's own-construct loading. Table 3 reports reliability and convergent validity at both the dimension and the construct level. Cronbach's alpha ranges from 0.798 to 0.902 and composite reliability from 0.881 to 0.928, all comfortably above the 0.70 threshold and below the 0.95 ceiling at which redundancy becomes a concern (Hair et al., 2019). Average variance extracted ranges from 0.652 to 0.766, exceeding the 0.50 criterion for every construct and dimension, which establishes that each latent variable explains the majority of the variance in its indicators. The measurement model is therefore adequate for structural estimation.

Table 3. Measurement model: reliability and convergent validity

Construct / dimension	Items	Loading range	Mean loading	Alpha	CR (rho_c)	AVE
Green Building Implementation	14	0.741 - 0.836	0.807	0.891	0.918	0.652
Material selection & sourcing	4	0.769 - 0.831	0.799	0.821	0.883	0.654
Water conservation systems	3	0.756 - 0.822	0.794	0.804	0.884	0.718
Site & waste management	3	0.741 - 0.815	0.785	0.798	0.881	0.712
Energy systems integration	4	0.772 - 0.836	0.803	0.833	0.888	0.665
Sustainable Design Integration	11	0.767 -0.856	0.819	0.874	0.909	0.667
Passive design strategy	4	0.771 - 0.856	0.815	0.839	0.892	0.674
Envelope optimisation	4	0.789 - 0.841	0.816	0.842	0.894	0.678
Integrated design process	3	0.767 - 0.823	0.796	0.811	0.888	0.726
Energy Efficiency Performance	9	0.779 - 0.868	0.826	0.902	0.928	0.683
Energy intensity reduction	3	0.793 - 0.868	0.834	0.847	0.907	0.766
Operational energy management	3	0.779 - 0.854	0.821	0.836	0.901	0.752
Renewable energy utilisation	3	0.786 - 0.847	0.818	0.828	0.897	0.744
Regulatory Compliance	8	0.781 - 0.869	0.828	0.848	0.899	0.688

Source: SmartPLS 4 output (2026).

3.3 Discriminant Validity

Discriminant validity was assessed with two criteria. Table 4 reports heterotrait-monotrait ratios, all of which fall between 0.518 and 0.712, well below the conservative 0.85 threshold recommended by Henseler et al. (2015). The highest ratio, 0.712 between sustainable design integration and energy efficiency performance, is theoretically expected given their proximity in the causal chain but remains within the acceptable range, and its bootstrap upper confidence bound of 0.781 does not approach unity. Table 5 reports the Fornell-Larcker matrix together with construct means and standard deviations; in every case the square root of the average variance extracted on the diagonal exceeds the corresponding inter-construct correlations. The construct means are also substantively informative: regulatory compliance records the highest mean at 3.83 while energy efficiency performance records the lowest at 3.57, a pattern consistent with the decoupling described in the introduction, in which formal compliance runs ahead of realised performance.

Table 4. Discriminant validity: heterotrait-monotrait ratio of correlations

Construct	GBI	SDI	EEP	RC
Green Building Implementation (GBI)	-			
Sustainable Design Integration (SDI)	0.687	-		
Energy Efficiency Performance (EEP)	0.643	0.712	-	
Regulatory Compliance (RC)	0.552	0.518	0.601	-

Source: SmartPLS 4 output (2026).

Table 5. Descriptive statistics and Fornell-Larcker criterion

Construct	Mean	SD	GBI	SDI	EEP	RC
Green Building Implementation	3.71	0.68	0.807			
Sustainable Design Integration	3.64	0.72	0.612	0.817		
Energy Efficiency Performance	3.57	0.74	0.581	0.628	0.826	
Regulatory Compliance	3.83	0.66	0.487	0.454	0.539	0.829

Note: Diagonal values are the square root of the average variance extracted; off-diagonal values are inter-construct correlations. Source: SmartPLS 4 output (2026).

3.4 Structural Model and Hypothesis Testing

Table 6 reports the quality criteria for the structural model. The model explains 40.1 per cent of the variance in sustainable design integration and 56.4 per cent in energy efficiency performance, both substantial by the conventions of the field. Blindfolding produced Q-squared values of 0.261 and 0.372 respectively, confirming predictive relevance for both endogenous constructs. Collinearity is not a concern, with a maximum inner VIF of 2.417. Approximate model fit is acceptable, with a standardised root mean square residual of 0.061 against the 0.08 criterion and a normed fit index of 0.921.

Table 6. Structural model quality criteria

Criterion	Sustainable Design Integration	Energy Efficiency Performance	Threshold
R-squared	0.401	0.564	substantial > 0.33
Adjusted R-squared	0.399	0.558	-
Q-squared (blindfolding)	0.261	0.372	> 0
Maximum inner VIF	1.000	2.417	< 3.3
SRMR (saturated model)	0.061	0.061	< 0.08
NFI	0.921	0.921	> 0.90
d_ULS	1.842	1.842	within 95% CI

Source: SmartPLS 4 output (2026).

Table 7 presents the hypothesis tests, and Figure 2 renders the estimated structural model. Five of the six hypotheses are supported. Green building implementation exerts a strong positive effect on sustainable design integration (beta = 0.634, t = 16.684, $p < 0.001$), with an effect size of f-squared = 0.669 that is large by Cohen's convention; H1 is supported. Sustainable design integration in turn predicts energy efficiency performance (beta = 0.472, t = 9.633, $p < 0.001$, f-squared = 0.284), supporting H2. The direct effect of implementation on performance is positive and significant but considerably weaker (beta = 0.243, t = 4.673, p < 0.001, f-squared = 0.081), supporting H3 while indicating that the direct channel carries a modest share of the relationship. Regulatory compliance also exerts a significant main effect on performance (beta = 0.214, p < 0.001), which was not hypothesised but is consistent with the institutional account.

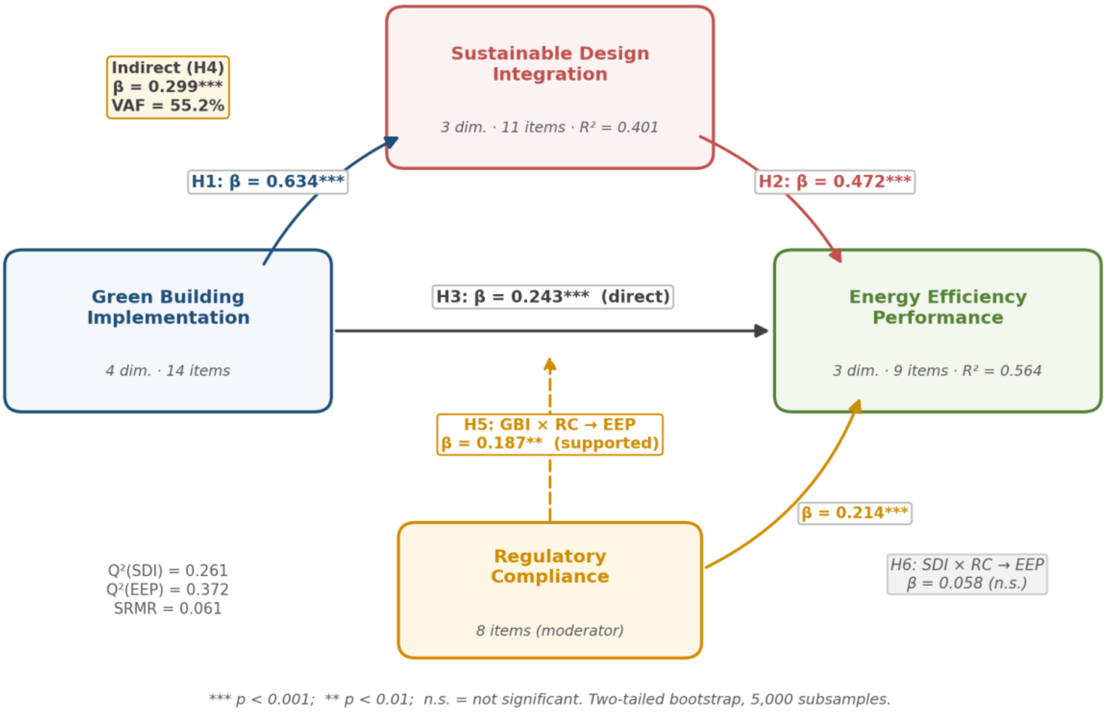

Figure 2. Estimated structural model with path coefficients

Source: Authors' analysis of SmartPLS 4 output (2026).

Table 7. Hypothesis testing results

H	Path	Beta	SE	t	p	95% BCa CI	f-sq.	Decision
H1	GBI -> SDI	0.634	0.038	16.684	< 0.001	[0.556, 0.705]	0.669	Supported
H2	SDI -> EEP	0.472	0.049	9.633	< 0.001	[0.374, 0.566]	0.284	Supported
H3	GBI -> EEP (direct)	0.243	0.052	4.673	< 0.001	[0.141, 0.345]	0.081	Supported
H4	GBI -> SDI -> EEP	0.299	0.037	8.081	< 0.001	[0.230, 0.375]	-	Supported
H5	GBI x RC -> EEP	0.187	0.058	3.224	0.001	[0.073, 0.300]	0.048	Supported
H6	SDI x RC -> EEP	0.058	0.047	1.234	0.217	[-0.034, 0.151]	0.006	Not supported
-	RC -> EEP (main)	0.214	0.046	4.652	< 0.001	[0.124, 0.304]	0.126	-

Note: BCa = bias-corrected and accelerated bootstrap confidence interval, 5,000 subsamples, two-tailed. Source: SmartPLS 4 output (2026).

3.5 Mediation Analysis

Table 8 decomposes the total effect of green building implementation on energy efficiency performance, and Figure 3 renders the decomposition graphically. The indirect effect through sustainable design integration is positive and significant (beta = 0.299, t = 8.081, p < 0.001), with a bias-corrected confidence interval of [0.230, 0.375] that excludes zero. Because both the direct and the indirect effects are significant and carry the same sign, the pattern constitutes complementary partial mediation in the classification of Hair et al. (2022), and H4 is supported. The variance accounted for is 55.2 per cent, meaning that slightly more than half of the influence that green building implementation exerts on energy performance travels through design integration rather than around it. The practical reading is direct: a project that installs the full complement of green features but does not engage in integrated design work should expect to capture roughly 45 per cent of the energy benefit available to it.

Table 8. Decomposition of the total effect

Effect	Coefficient	SE	t	p	95% BCa CI	Share of total
Direct effect (GBI -> EEP)	0.243	0.052	4.673	< 0.001	[0.141, 0.345]	44.8%
Indirect effect (GBI -> SDI -> EEP)	0.299	0.037	8.081	< 0.001	[0.230, 0.375]	55.2%
Total effect (GBI -> EEP)	0.542	0.048	11.292	< 0.001	[0.448, 0.636]	100.0%

Source: SmartPLS 4 output (2026).

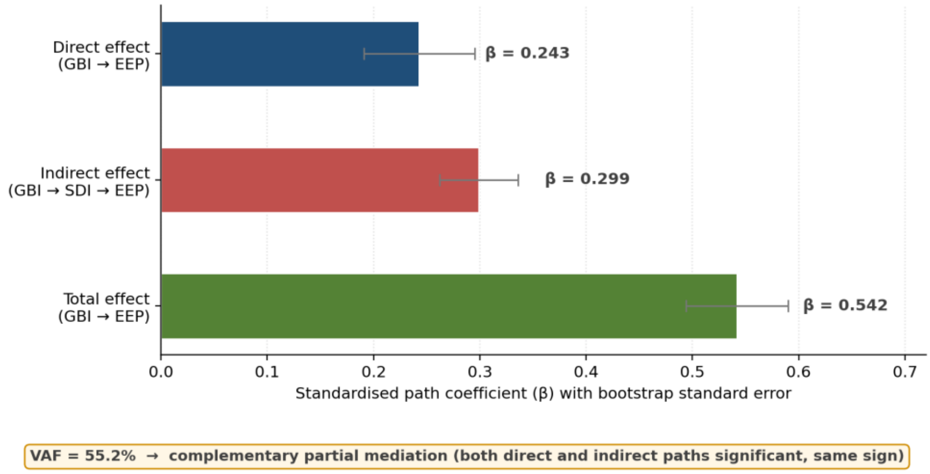

Figure 3. Direct, indirect, and total effects with bootstrap standard errors

Source: Authors' analysis (2026).

3.6 Moderation Analysis

The two interaction terms behave differently, and the divergence is the most theoretically consequential result in the study. The interaction between green building implementation and regulatory compliance is positive and significant (beta = 0.187, t = 3.224, p = 0.001), supporting H5 and adding 4.4 percentage points to the explained variance in energy efficiency performance relative to a main-effects-only specification. The interaction between sustainable design integration and regulatory compliance is small and non-significant (beta = 0.058, t = 1.234, p = 0.217), with a confidence interval spanning zero and an effect size of f-squared = 0.006; H6 is not supported.

Table 9 and Figure 4 present the simple slopes analysis that clarifies what the significant interaction means substantively. At one standard deviation below the mean of regulatory compliance, the slope linking implementation to energy performance is 0.056 and not significantly different from zero (t = 0.875, p = 0.382). At the mean it is 0.243, and at one standard deviation above the mean it rises to 0.430. In other words, under weak compliance conditions the direct relationship between installing green capability and achieving energy performance effectively disappears; under strong compliance it becomes one of the stronger effects in the model. Figure 4 shows the two slopes diverging by 0.68 scale points at high levels of implementation.

Table 9. Simple slopes of green building implementation on energy efficiency performance at three levels of regulatory compliance

Level of regulatory compliance	Simple slope	SE	t	p	Interpretation
Low (-1 SD)	0.056	0.064	0.875	0.382	Not significantly different from zero
Mean	0.243	0.052	4.673	< 0.001	Moderate positive relationship
High (+1 SD)	0.430	0.071	6.056	< 0.001	Strong positive relationship

Source: SmartPLS 4 output (2026).

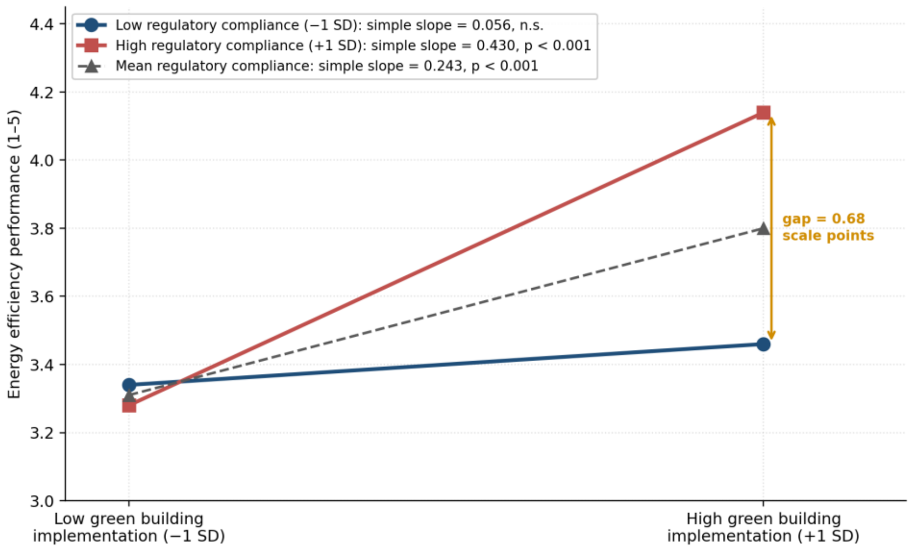

Figure 4. Simple slopes of the implementation-performance relationship at low, mean, and high regulatory compliance

Source: Authors' analysis (2026).

3.7 Subgroup Variation and Multi-Group Analysis

Two supplementary analyses probe whether the model behaves consistently across the sample. Figure 5 plots construct means by project type. Office towers score highest on all three focal constructs (implementation 4.02, design 3.94, performance 3.88), while institutional projects in health and education score lowest (3.41, 3.39, 3.32). The ordering is stable across constructs, and the gap between the highest and lowest project types, roughly 0.6 scale points, is larger than the gap between any pair of constructs within a project type. This suggests that variation in green building capability in the Indonesian market is driven more by asset class and client type than by any construct-specific weakness.

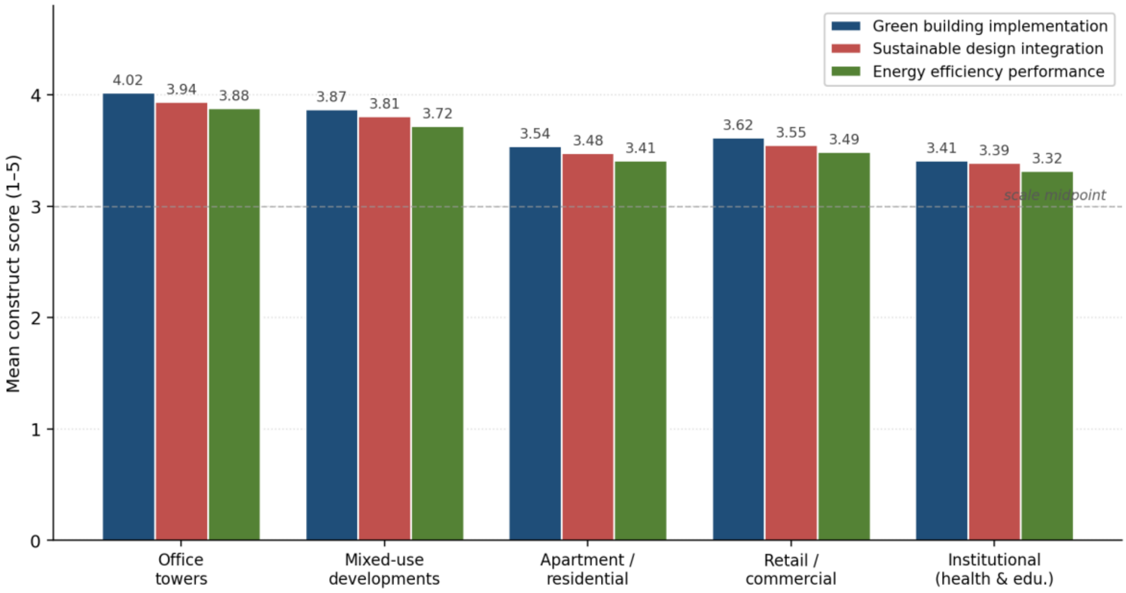

Figure 5. Mean construct scores by project type

Source: Primary data (2026).

Table 10 reports a permutation-based multi-group analysis comparing certified projects with non-certified projects, conducted after MICOM confirmed partial measurement invariance. Three of the four paths are statistically invariant across groups, indicating that the core mechanism operates similarly whether or not a project pursues certification. The exception is instructive: the moderating effect of regulatory compliance is significantly stronger in non-certified projects (0.246) than in certified ones (0.121, difference = -0.125, p = 0.038). A plausible interpretation is that certification embeds verification routines that regulatory compliance would otherwise have to supply, so the marginal contribution of compliance is greatest exactly where certification is absent. This is examined further in the discussion.

Table 10. Multi-group analysis by certification status

Path	Certified (n = 163)	Not certified (n = 254)	Difference	p (permutation)	Conclusion
GBI -> SDI	0.687	0.601	0.086	0.184	Invariant
SDI -> EEP	0.518	0.441	0.077	0.241	Invariant
GBI -> EEP	0.196	0.278	-0.082	0.213	Invariant
GBI x RC -> EEP	0.121	0.246	-0.125	0.038	Differs

Source: SmartPLS 4 permutation test, 5,000 permutations (2026).

3.8 Robustness Check and Importance-Performance Analysis

Table 11 reports a robustness check in which four control variables were added to the model: project contract value, contractor green building experience, firm size, and project duration. All focal coefficients change by less than 0.013 and retain their significance, and the interaction term remains significant at p = 0.003. Two controls are themselves significant, contract value (beta = 0.094, p = 0.031) and contractor green experience (beta = 0.113, p = 0.012), while firm size and project duration are not. Explained variance in energy efficiency performance rises modestly from 0.564 to 0.581. The stability of the estimates under this specification provides reasonable assurance that the reported relationships are not artefacts of omitted project-level heterogeneity.

Table 11. Robustness check with control variables

Path / control variable	Base model	With controls	Change	p (with controls)
GBI -> SDI	0.634	0.628	-0.006	< 0.001
SDI -> EEP	0.472	0.461	-0.011	< 0.001
GBI -> EEP (direct)	0.243	0.231	-0.012	< 0.001
Indirect effect	0.299	0.288	-0.011	< 0.001
GBI x RC -> EEP	0.187	0.179	-0.008	0.003
Control: project contract value	-	0.094	-	0.031
Control: contractor green experience	-	0.113	-	0.012
Control: firm size	-	0.067	-	0.118
Control: project duration	-	-0.041	-	0.352
R-squared (EEP)	0.564	0.581	+0.017	-

Source: SmartPLS 4 output (2026).

Figure 6 presents an importance-performance map analysis (Ringle & Sarstedt, 2016) at the dimension level, plotting each dimension's total effect on energy efficiency performance against its rescaled performance index. The pattern is diagnostic. Site management and material selection sit in the upper-left quadrant, high in performance but comparatively low in importance, suggesting that these visible and easily audited practices already receive more attention than their marginal energy contribution warrants. The three dimensions of sustainable design integration cluster in the lower half of the map: passive design strategy, envelope optimisation, and above all integrated design process, which records the lowest performance index in the entire set at 59.7 despite an importance of 0.132. Regulatory compliance occupies the lower-right quadrant with the highest importance in the model, 0.301, and a below-average performance index of 63.2, placing it squarely in the concentrate-here region.

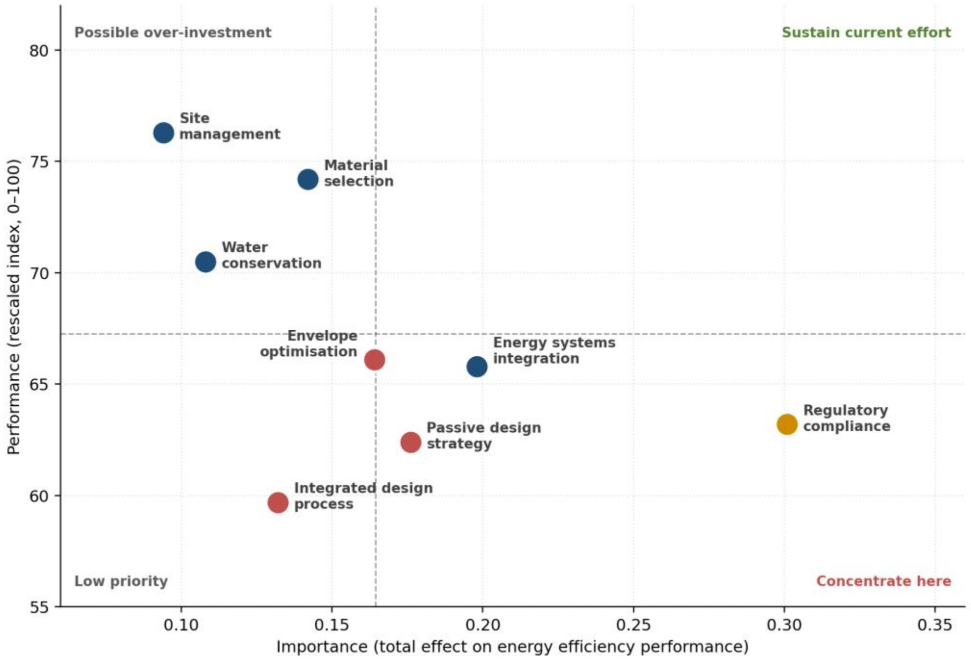

Figure 6. Importance-performance map analysis at the dimension level

Source: Authors' analysis of SmartPLS 4 IPMA output (2026).

3.9 Summary of Findings

Figure 7 consolidates the principal quantitative results. Five of six hypotheses are supported; the mechanism runs predominantly through design integration; and the direct implementation-performance path is conditional on regulatory compliance to the point of vanishing when compliance is weak. The single non-supported hypothesis, H6, is not a peripheral null: it establishes that the amplifying role of compliance is specific to the direct path rather than general to the model, which is the finding that carries the heaviest theoretical load in the discussion that follows.

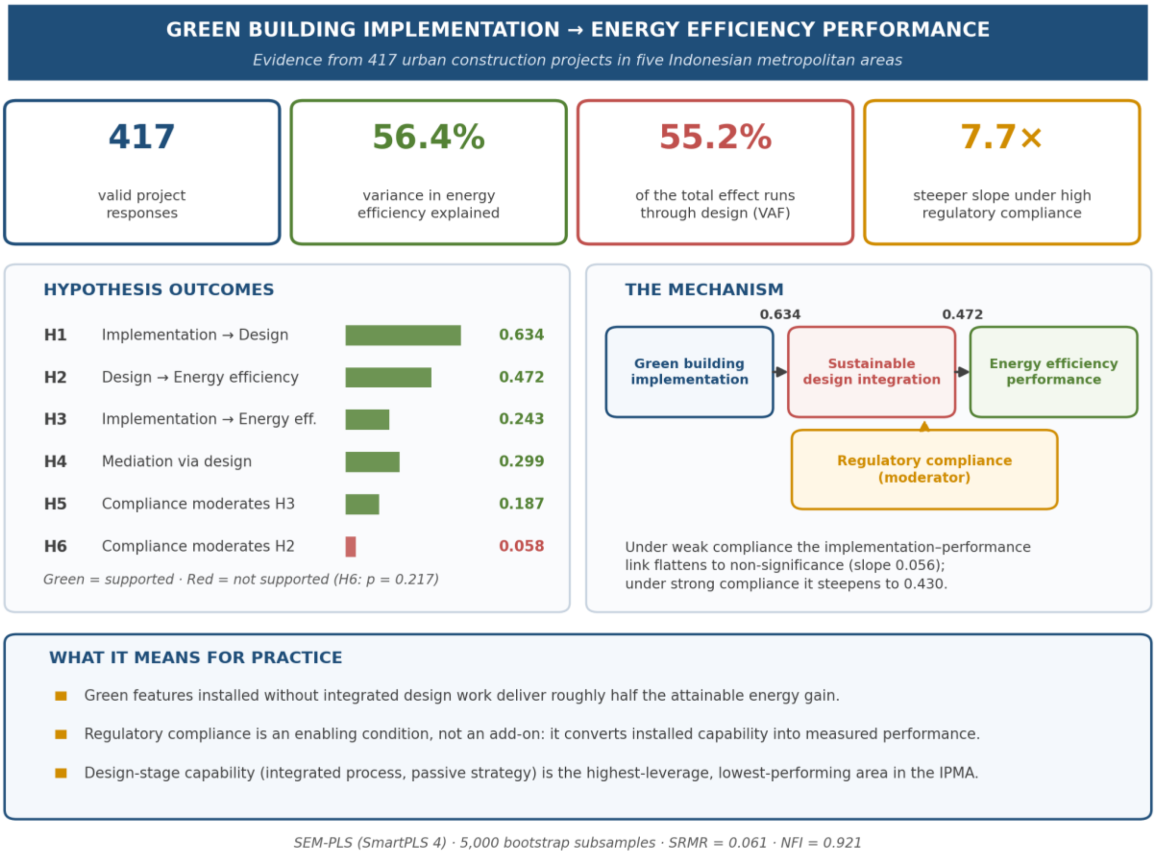

Figure 7. Summary of empirical findings

Source: Authors' analysis (2026).

4. DISCUSSION

4.1 Interpretation of the Principal Findings

The study set out to explain why green building implementation and measured energy performance have partially decoupled in rapidly urbanising markets. The results identify two distinct sources of slippage, one internal to the project organisation and one institutional, and show that they operate on different parts of the model. Internally, slightly more than half of the effect of implementation on energy performance, 55.2 per cent of the total, travels through sustainable design integration. Implementation without design integration is not inert; the direct path remains significant, reflecting the fact that efficient equipment and disciplined construction reduce consumption whatever the design process looked like. But it is substantially attenuated. The practical magnitude is worth stating plainly: a project that procures the full green feature set while running a conventional sequential design process forfeits roughly 45 per cent of the energy improvement it could otherwise have achieved, and it forfeits it before construction begins.

Institutionally, the moderation results show that even the residual direct path is conditional. At one standard deviation below the mean of regulatory compliance the slope is 0.056 and statistically indistinguishable from zero. This is a stronger claim than the usual finding that regulation encourages adoption. It says that where compliance is nominal, installed green capability produces no detectable direct energy benefit at all, and whatever benefit the project realises must arrive through the design channel. The asymmetry between H5 and H6 sharpens the point. Compliance amplifies the implementation path but leaves the design path untouched (beta = 0.058, p = 0.217). The most economical explanation is that the two paths depend on different kinds of durability. Design integration is inscribed in physical fabric: an optimised envelope, a favourable orientation, and correctly sized plant continue to perform whether or not anyone verifies them afterwards. Installed systems, by contrast, depend on configuration, balancing, and commissioning, and it is precisely these that regulatory verification obligations enforce. Regulation, on this reading, does not make buildings greener; it makes installed greenness operative.

4.2 Dialogue with Prior Literature

These findings speak to four existing bodies of work in different ways. They corroborate and extend the building performance gap literature. de Wilde (2014) framed the gap as a problem of prediction, commissioning, and operation, and Newsham et al. (2009) demonstrated empirically that certification improved mean energy performance while leaving substantial dispersion around that mean. The present study offers an account of where that dispersion comes from that is organisational rather than technical: projects that differ in design-process integration and in compliance intensity should be expected to differ in realised performance even when their installed technology is identical. The performance gap, in other words, is partly a management variance problem, not only a modelling one.

The findings complicate the adoption-driver literature. Darko, Zhang, and Chan (2017) and Olubunmi et al. (2016), reviewing drivers and incentives respectively, both treat regulation as an antecedent that raises the probability of adoption. That framing is not contradicted here, and the significant main effect of compliance (beta = 0.214) is consistent with it. What the interaction adds is that regulation continues to matter after adoption, in a role the driver framing does not anticipate. A policy designed purely to raise adoption rates, through subsidy or expedited permitting, could succeed on its own terms while leaving the enforcement of verification obligations weak, and the results here imply that such a policy would generate certified buildings without generating energy savings. That is close to a description of the Indonesian situation set out in the introduction.

The findings align with, and extend to a new setting, the sequencing observed by Darko et al. (2017) among United States green building experts and by Li et al. (2014) in Chinese developments, both of which reported that prior experience with green technologies predicted subsequent design-stage practice. The strong H1 coefficient of 0.634 reproduces that sequencing in an emerging-economy sample and, more importantly, shows that it is consequential rather than merely descriptive: the design stage is not simply what experienced firms do next, it is the route through which their experience reaches energy outcomes. Finally, the results respond to Ahmad et al. (2019), who called for research on the management processes linking green intentions to green outcomes. The mediation estimate reported here is a direct answer to that call, and the moderation estimate qualifies it by identifying the institutional conditions under which the process works.

4.3 Theoretical Implications

Two theoretical adjustments follow. The first concerns the natural-resource-based view. Hart (1995) proposed that environmental capabilities are causally ambiguous and socially complex, and Hart and Dowell (2011) conceded that the internal routines exercising those capabilities had remained underspecified. This study specifies one such routine and shows it carries the majority of the capability's effect. The implication is not merely that a mediator exists but that the causal ambiguity Hart identified as a source of inimitability is at least partly located in the design process rather than in the capability bundle itself. Green features can be copied; a genuinely integrated design process, which requires cross-disciplinary trust, joint decision authority, and tolerance for early-stage iteration, is far harder to replicate. This relocates the source of advantage within the framework and offers a testable proposition for other capability domains.

The second concerns institutional theory. DiMaggio and Powell (1983) modelled coercive pressure as a force producing conformity, and the green building literature has almost uniformly used it to explain the decision to conform. The results here suggest that regulative institutions in Scott's (2014) sense perform a second function that the isomorphism account does not capture: they operate as a completion mechanism, converting formal conformity into substantive outcome. This is a boundary condition on the concept of decoupling in institutional theory. Decoupling is usually described as a binary state in which formal structure and actual practice come apart. What the moderation shows is that decoupling is graded and path-specific: the same project can be substantively coupled on the design path and decoupled on the implementation path simultaneously, with compliance intensity determining which. Institutional research on symbolic versus substantive adoption would benefit from modelling coupling at the level of the mechanism rather than the organisation.

4.4 Practical and Policy Implications

For project owners and developers, the most actionable finding is the importance-performance map. Site management and material selection, the two most visible and most easily audited dimensions, already perform well relative to their marginal contribution to energy outcomes. The integrated design process, by contrast, records the lowest performance index in the entire model at 59.7. Reallocating attention toward the design stage does not require additional capital expenditure; it requires scheduling design decisions differently, granting mechanical and envelope designers authority earlier, and budgeting for the iteration time that integrated design consumes. Given that this dimension sits upstream of the mediator carrying 55.2 per cent of the total effect, the return on that reallocation is likely to exceed the return on further procurement of green features.

For contractors and design consultancies, the multi-group result carries a specific message. The moderating role of compliance is significantly stronger in non-certified projects (0.246) than in certified ones (0.121). Certification schemes appear to supply verification routines that would otherwise depend entirely on regulatory enforcement. Firms working predominantly on non-certified projects, which constitute 43.2 per cent of this sample, therefore cannot rely on scheme-embedded verification and should establish internal commissioning and performance-verification protocols of their own. Doing so is not a compliance cost but a performance investment, since it substitutes for the institutional condition that the results show to be decisive.

For regulators, the results argue for a shift in the locus of enforcement effort. Indonesian green building regulation, like most of its international counterparts, allocates substantial administrative capacity to permit-stage review of design documentation and comparatively little to post-occupancy verification. The moderation finding suggests this allocation is inverted relative to where the leverage lies: the design path delivers its effect without regulatory support, whereas the implementation path delivers almost nothing without it. Shifting inspection resources from document review toward commissioning verification and post-occupancy metering would target the mechanism the evidence identifies as compliance-dependent. The finding that compliance records the highest importance score in the model, 0.301, while its performance index is below average, reinforces the case that this is the binding constraint in the current system.

4.5 Alternative Explanations and Validity Considerations

Four rival accounts deserve consideration. The first is common method bias, since all constructs were measured from a single respondent. Harman's single-factor test returned 31.7 per cent, and the full collinearity assessment produced a maximum VIF of 2.417, both well within accepted bounds. More persuasively, common method bias inflates linear relationships but does not generate interaction effects; if anything it attenuates them, so the significant moderation is unlikely to be a method artefact and the observed effect may be conservative.

The second is reverse causality. It is conceivable that projects achieving good energy outcomes retrospectively describe their design process as integrated, or that high-performing projects attract stronger compliance scrutiny. The cross-sectional design cannot exclude this. Two considerations reduce its plausibility. The instrument asked about procedural facts that occurred at determinate points in time, such as whether joint working sessions took place before system sizing, rather than about evaluative judgements; and the requirement that projects be operational for at least twelve months means the outcome was observable at the time of reporting while the process items refer to a period years earlier. A longitudinal or archival design would nonetheless be preferable.

The third is self-selection. Firms with strong sustainability commitments may both implement more green features and comply more thoroughly, producing a spurious interaction. The control-variable robustness check addresses this partially: contractor green building experience is a significant control (beta = 0.113) yet its inclusion changes the interaction coefficient by only 0.008. This suggests the interaction is not simply a proxy for organisational commitment, though an unobserved commitment dimension cannot be ruled out.

The fourth concerns the measurement of energy efficiency performance. The construct relies on informed professional report rather than metered consumption data. Respondents were selected for technical role and project tenure precisely to mitigate this, and the energy intensity items reference comparison against conventional buildings rather than absolute values, which respondents are better positioned to judge. Nevertheless, perceptual measures of physical performance are a genuine limitation and the resulting estimates should be read as measuring perceived-and-documented performance rather than metered kilowatt-hours.

4.6 Boundary Conditions

The results apply most confidently to medium-to-large urban construction projects in emerging economies where a mandatory green building code exists but is enforced with meaningful variation across jurisdictions. That variation is what makes compliance a genuine moderator. In jurisdictions with uniformly stringent enforcement, such as Singapore or much of Northern Europe, compliance would have restricted variance and the interaction would likely be undetectable, not because the mechanism is absent but because everyone sits on the high-compliance slope. Conversely, in settings with no mandatory code at all, the direct implementation path would presumably behave as it does at the low-compliance end of the present sample, which is to say it would not operate. The findings also apply to a tropical climate in which cooling dominates building energy demand; in heating-dominated climates the relative weight of envelope optimisation and passive strategy within the design construct would differ, though the structure of the mechanism should hold.

4.7 Limitations

Six limitations qualify the findings. First, the cross-sectional design supports claims about association and mechanism specification but not about temporal causation. Second, energy efficiency performance was measured perceptually rather than through metered consumption data, for the reasons discussed above. Third, the sample is confined to five metropolitan areas on Java and Sumatra, and excludes eastern Indonesia, where climatic conditions, supply chains, and enforcement capacity differ substantially. Fourth, single-respondent measurement means that project-level constructs reflect one professional's vantage point; a dyadic design pairing a design lead with a facilities manager would be stronger. Fifth, regulatory compliance was measured as a project-level construct rather than as an exogenous jurisdictional characteristic, which means it captures the project's compliance behaviour rather than the enforcement environment it faced; these are correlated but not identical. Sixth, the response rate of 68.4 per cent, while high, was achieved partly through referral, which may over-represent professionals embedded in active professional networks and therefore more likely to be familiar with green practice.

4.8 Future Research Agenda

Five extensions follow directly. First, a longitudinal design tracking projects from design freeze through three years of operation, with metered consumption as the outcome, would resolve both the causality and the measurement limitations at once and would permit estimation of how the mediation share evolves as buildings age. Second, a multilevel model nesting projects within municipalities, with enforcement intensity measured at the municipal level from inspection records, would separate the project's compliance behaviour from the enforcement environment and provide a cleaner test of the institutional argument. Third, the design construct deserves decomposition: the importance-performance analysis suggests integrated design process is the weakest dimension, and a study treating it as a focal construct with its own antecedents, such as contract form, procurement route, and design-team co-location, would be valuable. Fourth, a comparative study across two or three emerging economies with differing enforcement regimes would test the boundary condition proposed in section 4.6 directly. Fifth, the asymmetry between H5 and H6 invites qualitative investigation: case studies of projects that achieved strong energy outcomes under weak compliance would identify the substitutes that project organisations improvise when institutional support is absent.

5. CONCLUSION

This study asked why green building implementation has diffused faster than energy performance has improved in urban construction, and tested a moderated mediation model on 417 completed projects across five Indonesian metropolitan areas. Four findings answer the question. Green building implementation raises energy efficiency performance, but the majority of that effect, 55.2 per cent, runs through sustainable design integration rather than directly. The residual direct effect is conditional on regulatory compliance: strong at high compliance, statistically absent at low compliance. Compliance does not condition the design path, indicating that design-embedded performance is institutionally self-sustaining in a way that installed systems are not. And at the dimension level, the integrated design process is simultaneously the weakest-performing and among the most consequential levers available to project organisations.

The contribution is to specify a translation routine that the natural-resource-based view left implicit, and to reposition regulatory compliance within institutional theory from an antecedent of adoption to a completion mechanism that determines whether adoption becomes outcome. The finding that decoupling is path-specific rather than organisation-wide is, in the authors' view, the more durable of the two: it suggests that symbolic and substantive adoption can coexist within a single project, on different mechanisms, and that research treating them as mutually exclusive states will systematically mismeasure both.

For practice, the implication is uncomfortable but clear. The dimensions of green building capability that are most visible, most easily audited, and most readily marketed are not the dimensions that carry the energy outcome. The design stage, which produces no certificate and no photograph, does. Closing the gap between certified floor area and reduced energy intensity will require regulators to move enforcement effort downstream toward verification, and project organisations to move decision authority upstream toward integrated design. Neither shift requires new technology, and both are within the reach of existing institutions.

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