Article

Space Efficiency as a Method-Dependent Construct: Evidence from High-Rise Timber Buildings

Hüseyin Emre Ilgın

School of Architecture, Faculty of Built Environment, Tampere University, FI-33014 Tampere, Finland; emre.ilgin@tuni.fi; Tel.: +358-50-573-8397.

ABSTRACT

Space efficiency is widely employed as a key performance indicator in high-rise (≥8-story) building research, typically expressed through net-to-gross floor area (NFA/GFA) ratios and core-related metrics. In high-rise timber construction, such indicators are frequently used to compare architectural forms, core configurations, structural systems, and material strategies, often under the implicit assumption that they reflect intrinsic design performance. Although previous studies have documented a relatively narrow range of reported NFA/GFA values, the methodological implications of this convergence have not been systematically examined. This study reconceptualizes space efficiency as a method-dependent analytical construct rather than an objective performance outcome. Using a qualitative meta-interpretive approach, an internally consistent dataset of 79 high-rise timber buildings is re-examined to assess distributional overlap, dispersion patterns, and range compression across architectural, structural, and material categories, without recalculating the original metrics. The analysis demonstrates that the observed convergence of efficiency values is more plausibly attributable to metric construction, definitional alignment, and typical floor standardization than to substantive design equivalence. Limited between-category separation and substantial interquartile overlap indicate that conventional space efficiency ratios possess restricted discriminatory capacity within a uniform measurement framework. These findings reposition space efficiency metrics as conditional analytical tools whose interpretive validity depends on methodological transparency. Greater caution is therefore warranted in the comparative and evaluative use of efficiency ratios in high-rise timber building research and practice.

KEYWORDS: space efficiency metrics; high-rise timber buildings; sustainable building design; measurement methodology; comparative building analysis

Open Access

Received: 12 Feb 2026

Accepted: 07 May 2026

Published: 20 May 2026

INTRODUCTION

Space efficiency has long been employed as a key performance indicator in the evaluation of high-rise buildings, serving as a proxy for functional effectiveness, economic feasibility, and design optimization [1,2]. Typically expressed as net-to-gross floor area (NFA/GFA) ratios, or through complementary indicators such as core-to-GFA ratios, space efficiency metrics are widely used to compare architectural typologies, structural systems, and material strategies across diverse building contexts [3,4]. Within contemporary high-rise building research, these metrics are frequently treated as objective and self-evident measures of design performance that are implicitly assumed to reflect inherent architectural or structural superiority [5–7].

In parallel with this methodological mainstream, high-rise timber buildings have emerged as a rapidly expanding field of research and practice, reflecting a global shift toward renewable construction systems and carbon-conscious design strategies [8]. Driven by environmental imperatives, advances in engineered wood products, and evolving regulatory frameworks, these towers are increasingly positioned as viable alternatives to conventional concrete and steel skyscrapers [9,10]. Recent studies have therefore begun to assess the space efficiency of timber towers relative to non-timber counterparts, finding that well-designed timber towers often achieve comparable or even superior efficiency outcomes [11]. These findings reinforce a growing narrative linking timber construction not only to sustainability and embodied-carbon reduction but also to enhanced spatial performance and functional viability [12]. Because spatial efficiency is frequently mobilized as an implicit proxy for resource optimization and environmental performance, its interpretation carries direct implications for sustainability claims in high-rise timber discourse. Despite the apparent maturity of spatial efficiency research and the growing volume of empirical studies on high-rise timber buildings, a critical methodological issue remains largely unaddressed—the extent to which reported space efficiency values reflect intrinsic design characteristics as opposed to measurement logic, definitional boundaries, and analytical conventions. Spatial efficiency is commonly reported, compared, and generalized without sufficient reflection on how it is constructed, operationalized, and constrained by methodological assumptions [13–16].

This lack of methodological reflexivity becomes particularly consequential in the context of high-rise timber buildings. Unlike conventional high-rise typologies, timber towers frequently employ hybrid structural systems, compact or integrated service cores, and non-standard floorplate configurations shaped by fire safety, acoustic performance, and prefabrication constraints [17]. These characteristics complicate direct comparison with non-timber skyscrapers, yet existing studies often rely on identical efficiency metrics without questioning whether those metrics capture comparable spatial realities. Consequently, observed similarities, or differences, in spatial efficiency outcomes may reflect methodological alignment rather than genuine design convergence or divergence.

Recent large sample studies on high-rise timber towers further expose this tension. Analyses of dozens of realized projects across multiple continents reveal a consistent pattern: When buildings are competently planned, variations in architectural form, core configuration, structural system, or material composition tend to result in only marginal differences in reported spatial efficiency [11]. Average efficiency values cluster within a relatively narrow range, regardless of whether towers employ central or peripheral cores, prismatic or non-prismatic forms, or timber-dominant versus composite structural solutions. While such findings are often interpreted as evidence of design flexibility or material robustness, they simultaneously raise a more fundamental question: What, exactly, do spatial efficiency metrics measure?

If markedly different design strategies yield comparable efficiency ratios, two interpretations are possible. Either diverse architectural and structural solutions genuinely converge toward similar spatial performance, or the metrics themselves lack sufficient sensitivity to discriminate between them. In this study, metric sensitivity refers to the extent to which an indicator meaningfully differentiates between structurally and spatially distinct design configurations. The latter interpretation suggests that space efficiency, as currently operationalized, functions less as an objective performance indicator and more as a method-dependent construct whose meaning is inseparable from the assumptions embedded in its calculation. This distinction is not merely semantic; it fundamentally affects the validity of comparative claims and the evidentiary basis upon which sustainability and performance narratives are constructed.

Figure 1 schematically illustrates the definitional logic underlying spatial efficiency calculations, highlighting how alternative boundary treatments applied to identical spatial configurations can yield different reported efficiency values.

Against this backdrop, this paper advances a critical re-examination of spatial efficiency in high-rise timber buildings. Rather than introducing new empirical data or proposing alternative efficiency formulas, this study deliberately adopts a qualitative meta-interpretive stance. Whereas the author's earlier studies examined spatial efficiency as an empirical outcome to be reported and compared across case-based datasets [11,12], this research does not seek to extend descriptive findings or introduce additional case-based results. Building upon a previously published, internally consistent dataset of 79 cases worldwide [12], the research investigates how spatial efficiency metrics are produced, stabilized, and rendered comparable within the existing literature. The dataset is therefore reused deliberately as a fixed analytical reference, not for empirical replication, but for methodological interrogation. In this sense, the analytical focus shifts from efficiency values as reported outcomes to the metric framework itself as the object of inquiry. By shifting the analytical focus from numerical outcomes to methodological construction, this research seeks to clarify the limits of spatial efficiency as a design performance indicator and to recalibrate its role within high-rise building research.

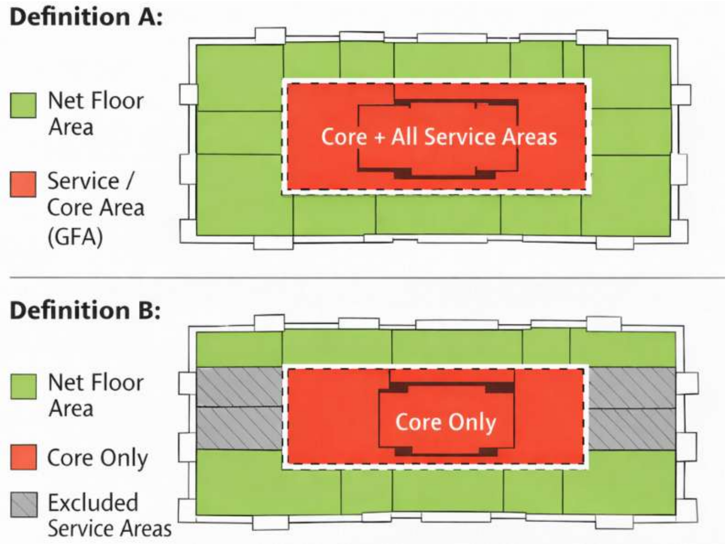

Figure 1. Schematic illustration of the influence of measurement definitions on space efficiency outcomes.

Scientific Significance of the Study

The scientific significance of the study lies in its explicit separation of epistemological and methodological questions surrounding space efficiency metrics. At an epistemological level, this paper challenges the implicit assumption that spatial efficiency constitutes an objective and intrinsic attribute of design performance. Instead, it conceptualizes spatial efficiency as a constructed analytical outcome whose meaning depends on definitional boundaries, measurement conventions, and interpretive context. By repositioning the metric itself as the object of inquiry rather than as a neutral performance indicator, this paper contributes to ongoing debates on the role of quantitative indicators in sustainable building assessment.

At the methodological level, the study responds to a growing need for transparency and comparability in high-rise building research. As these buildings continue to proliferate globally [18–20], cross-study synthesis increasingly relies on efficiency metrics that are often assumed to be directly comparable. By demonstrating how methodological alignment can produce apparent performance convergence across diverse designs, this research clarifies the conditions under which space efficiency metrics are meaningful and the limits beyond which comparative interpretation becomes unreliable. In doing so, it strengthens the evidentiary basis for performance-based sustainability claims by distinguishing between genuine design convergence and metric-induced similarity.

Research Questions and Hypotheses

Guided by the above considerations, the study addresses the following research questions:

RQ1: To what extent do report space efficiency values in high-rise timber buildings reflect intrinsic design characteristics as opposed to methodological and definitional choices?

RQ2: Which specific measurement decisions and definitional treatments contribute to the observed convergence of spatial efficiency values across diverse high-rise timber building designs?

RQ3: What are the interpretive limitations of using NFA/GFA and core-to-GFA ratios as comparative performance indicators across different high-rise building typologies?

Based on these questions, this paper advances two central hypotheses:

H1: *Reported spatial efficiency values in high-rise timber buildings are expected to be substantially influenced by methodological alignment, such as the consistent treatment of service cores, circulation areas, and floorplate boundaries, rather than by architectural or structural differentiation alone.*

H2: *The observed convergence of space efficiency outcomes across diverse high-rise timber designs may indicate a limited discriminatory capacity of conventional efficiency metrics rather than a definitive equivalence in spatial performance.*

Research Objectives

In line with these hypotheses, the objectives of the study are threefold:

- To critically reassess the interpretive validity of spatial efficiency metrics commonly used in high-rise timber building research;
- To demonstrate how methodological assumptions influence reported efficiency outcomes, using a large, internally consistent dataset as an analytical lens;
- To reposition spatial efficiency from a deterministic performance indicator to a methodologically conditioned and context-dependent analytical construct, thereby informing the more cautious and transparent use of the metric in future studies and sustainability-oriented performance evaluation frameworks.

Importantly, this research does not seek to invalidate spatial efficiency as a concept. Rather, it aims to refine its use by clarifying what such metrics can—and cannot—reliably indicate about design performance, particularly when mobilized to support comparative or sustainability-related claims.

Novelty & Contributions

The novelty of this study lies not in the introduction of new data, building typologies, or computational methods, but in its explicit methodological reframing of spatial efficiency. While existing literature predominantly treats spatial efficiency as an outcome variable [21–23], this research treats it as an object of inquiry. Rather than assuming the neutrality of the metric, the study systematically examines the conditions under which spatial efficiency values acquire meaning within comparative high-rise building research. More specifically, whereas the author's earlier publications [11,12] focused on describing and comparing spatial efficiency outcomes across datasets, the present study reinterprets the same measurement environment to examine how convergence itself may be methodologically produced and analytically overstated. The contribution of this paper is therefore not empirical expansion, but methodological and interpretive reframing. More specifically, the novelty of this study does not lie in generating additional descriptive summaries from the dataset, but in reinterpreting previously reported convergence as a methodological phenomenon shaped by the metric framework itself.

The study makes four key contributions to the field:

- A conceptual contribution: It introduces a critical distinction between space efficiency as a numerical ratio and space efficiency as a methodological product shaped by definitional and analytical choices, thereby clarifying the epistemic status of efficiency metrics within sustainability-oriented building evaluation.
- A methodological contribution: It demonstrates how large-sample empirical datasets can be repurposed for qualitative meta-interpretive analysis, extending their scientific value beyond initial descriptive findings and highlighting the importance of measurement transparency in cross-study comparison.
- A theoretical contribution: It challenges prevailing causal narratives that directly link specific design strategies (e.g., core type or building form) to efficiency outcomes, advocating for a more nuanced interpretation that distinguishes between genuine design effects and metric-induced convergence.
- A practical contribution: It provides researchers and practitioners with a clearer framework for interpreting efficiency metrics, reducing the risk of overgeneralization and misapplication in design decision-making, particularly when such metrics are mobilized to support performance or sustainability claims.

MATERIALS AND METHODS

Research Design and Methodological Positioning

This study adopts a qualitative meta-interpretive research design that explicitly differs from statistical or quantitative meta-analysis. In this context, meta-interpretation refers to the structured reinterpretation of an internally consistent empirical dataset to identify patterns of convergence, boundary effects, and metric sensitivity, rather than to aggregate effect sizes across heterogeneous studies. This method goes beyond merely summarizing data; it aims to generate higher-order interpretive insights by critically examining how reported findings are constructed and stabilized within existing research traditions [24–26]. Rather than aggregating effect sizes or testing causal relationships across heterogeneous datasets, the study critically interrogates how spatial efficiency metrics are constructed, stabilized, and interpreted within high-rise timber building research. The primary objective is therefore not to generate new empirical measurements, but to examine the epistemic and methodological conditions under which reported efficiency values acquire meaning. In this respect, this study functions as a reinterpretive analysis of an existing dataset under a different analytical lens rather than as an empirical extension of the author's prior case-based publications. The overall analytical logic of the study is summarized in Figure 2, which outlines the sequential stages of dataset selection, metric examination, definitional comparison, sensitivity analysis, and interpretive synthesis adopted in this research.

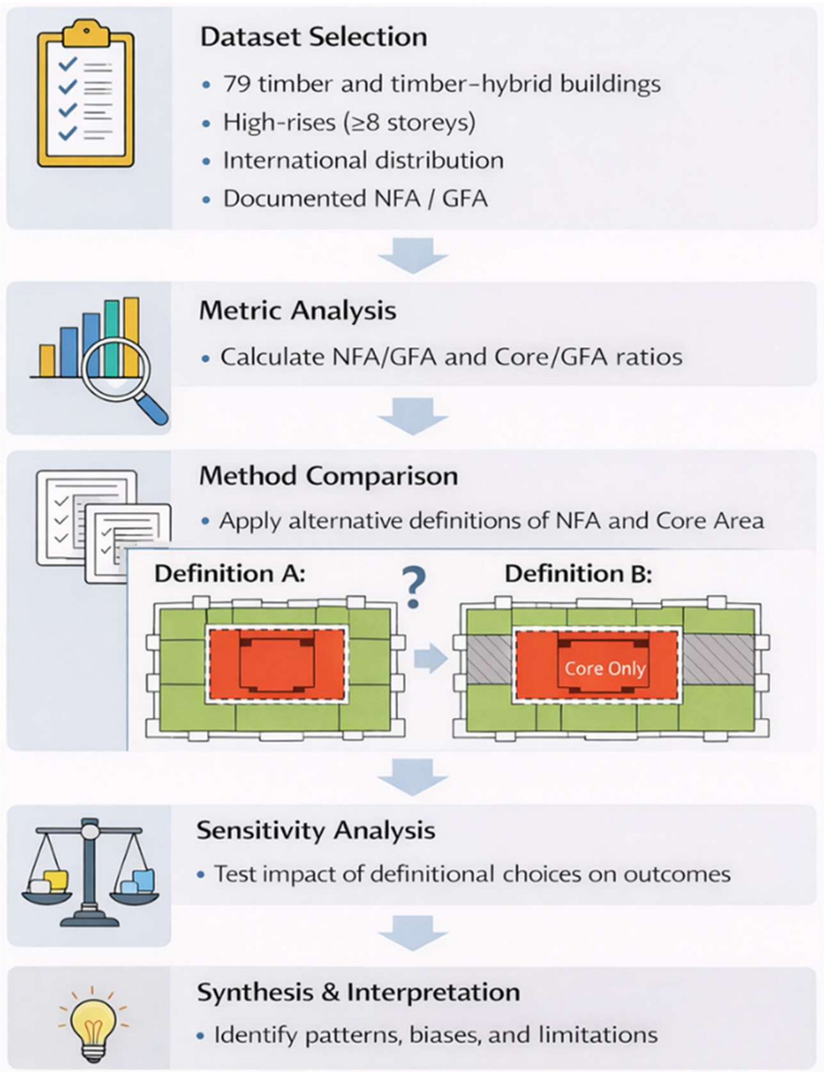

Figure 2. Research design and analytical workflow adopted in the study.

Consistent with qualitative metasynthesis traditions described by [24,26], this study does not merely summarize descriptive findings or replicate distributional statistics. Instead, it undertakes an interpretive transformation of already constructed findings. In contrast to a conventional literature review, which synthesizes thematic content across studies, or a descriptive statistical synthesis, which reports numerical tendencies, this paper operates at a higher-order analytical level. Reported spatial efficiency ratios are treated as second-order constructions, empirical summaries that have already undergone interpretive stabilization within architectural research. The present analysis constitutes a third-order interpretive synthesis, in which these stabilized outcomes are re-examined to evaluate their epistemic robustness, boundary conditions, and discriminatory capacity. Accordingly, the analytical contribution lies not in generating additional case evidence, but in reconsidering the meaning and interpretive status of already reported outcomes.

This positioning aligns with the metasynthetic principle that a synthesis should generate meaning that is "more than the sum of parts," producing a novel interpretive insight rather than a cumulative summary [26]. The analytical unit is therefore not the building case itself, nor the numerical outcome per se, but the interpretive logic embedded within the metric framework. By shifting the unit of analysis from outcome to measurement construct, the study extends the qualitative metasynthesis methodology into a quantitatively expressed research domain.

Unlike conventional empirical studies that treat spatial efficiency metrics as dependent variables, this research treats the metric itself as the unit of analysis. This shift in analytical focus necessitates a reflective and interpretive approach that prioritizes internal consistency, definitional transparency, and comparative logic over statistical inference. Statistical significance testing is not pursued, as the epistemic aim of the study is not explanatory causation but the evaluation of the interpretive robustness and discriminatory capacity of the metrics themselves.

In alignment with the qualitative metasynthesis methodology, rigor is grounded in the transparency of the analytical procedure, explicit inclusion logic, and reflexive interrogation of the interpretive assumptions rather than in inferential generalization. The sequential analytical structure mirrors established metasynthesis stages, problem formulation, dataset delimitation, appraisal of definitional coherence, interpretive comparison, and higher-order synthesis, while adapting these procedures to a quantitatively documented architectural dataset.

The study is positioned at the intersection of empirical synthesis and methodological critique, drawing on established practices in qualitative meta-analysis and methodological research where existing datasets are re-examined to expose implicit assumptions, boundary conditions, and analytical limitations.

By explicitly framing the study as a qualitative meta-interpretive analysis, the research avoids conflation with statistical meta-analysis and clarifies that its contribution lies in methodological insight rather than quantitative generalization. Novelty is thus derived not from new data acquisition, but from a systematic reinterpretation of existing evidence under a different analytical lens, with particular attention paid to how measurement conventions shape sustainability-relevant performance narratives in high-rise timber discourse.

Dataset Description and Scope

The empirical foundation of this study is a previously compiled dataset comprising 79 high-rise timber buildings worldwide [12]. The dataset includes projects completed or under construction across Europe, North America, and Australia, reflecting the current geographic distribution of high-rise timber development. The dataset reflects projects realized and sufficiently documented as of March 2026. All cases meet the Council on Vertical Urbanism [formerly the Council on Tall Buildings and Urban Habitat (CTBUH)] criterion for high-rise timber buildings, defined as structures with eight or more stories [27]. The buildings vary in height, function, structural system, and material composition, providing a heterogeneous yet internally consistent basis for comparative analysis. This dataset has been used previously for empirical reporting purposes [12]; in this study, however, it is not employed to extend descriptive case findings, but to support a methodological re-examination of how reported efficiency values are produced and interpreted.

The dataset was constructed through the cross-referenced identification of realized high-rise timber buildings documented in academic publications, industry databases, Council on Vertical Urbanism listings, and publicly accessible architectural documentation. The inclusion criteria were limited to completed or structurally topped-out projects meeting the Council on Vertical Urbanism threshold for high-rise classification and employing timber as a primary structural component within timber-dominant or timber-hybrid systems. Projects lacking sufficiently documented floor area data were excluded to preserve internal measurement consistency.

It is acknowledged that the dataset does not constitute a statistically random sample of all high-rise buildings globally. Instead, it represents the currently realized and sufficiently documented subset of high-rise timber projects available at the time of analysis. Potential sources of selection bias include geographic concentration in regions with advanced timber regulations, differential documentation availability, and the exclusion of unbuilt or concept-stage proposals. These constraints delimit the scope of inference and external generalization; however, they do not affect the internal measurement consistency of the dataset, as the objective of the study is methodological interrogation within a defined empirical population rather than probabilistic generalization to the entire global building stock.

For each building, the dataset documents architectural and structural attributes, including primary function (residential, office, hotel, or mixed-use), building form, service core configuration, structural system, structural material composition (timber-dominant/only or timber-composite/hybrid), and space efficiency metrics. These metrics, specifically the NFA-to-GFA ratio and the core-to-GFA ratio, were originally calculated using consistently redrawn typical floor plans, ensuring internal comparability across cases. Because all spatial measurements were derived using the same definitional framework and drawing conventions, the dataset minimizes measurement-induced variability across cases.

Importantly, this research does not modify, expand, or recalibrate these values. The dataset is treated as analytically fixed, allowing methodological interpretation to proceed without confounding changes in the measurement procedure. The decision to reuse an internally consistent dataset is deliberate and epistemically motivated: Methodological critique is only meaningful when differences in outcomes cannot be attributed to inconsistent data acquisition or calculation logic. In this respect, the dataset functions not as new empirical evidence, but as a controlled analytical environment within which the interpretive behavior of spatial efficiency metrics can be examined. This study therefore does not constitute an empirical extension of previous datasets; it is a reinterpretive analysis of an existing dataset under a different analytical objective. By holding the empirical base constant, the study isolates interpretive variability as the primary object of inquiry rather than empirical noise. Because the full case-level dataset has already been published and remains openly accessible in Reference [12], it is not reproduced in the present manuscript. This study instead reports only the aggregated summaries necessary for methodological reinterpretation.

Analytical Strategy: From Outcome Comparison to Metric Interrogation

The analytical strategy departs from traditional outcome-driven comparison and instead focuses on identifying patterns of convergence and insensitivity within reported spatial efficiency values. In this context, convergence refers to the substantial distributional overlap of efficiency ratios across structurally and spatially distinct design categories, while insensitivity denotes the limited capacity of the metrics to register meaningful differentiation between these categories. For this reason, the purpose of the analysis is not to generate additional descriptive findings from the dataset, but to evaluate the interpretive consequences of treating convergence as a metric-dependent phenomenon. The analysis proceeds in three interrelated steps.

First, space efficiency outcomes are examined across major architectural and structural categories, such as building form, service core configuration, structural system, and material composition, to assess the degree of variance associated with these parameters. Rather than applying statistical significance testing, the analysis emphasizes distributional overlap, clustering, range compression, and relative dispersion across categories. Descriptive statistics (range, mean, and relative spread) are used as diagnostic tools to evaluate discriminatory capacity rather than as inferential instruments for hypothesis testing. This descriptive focus is intentional: The epistemic aim of the study is to evaluate whether commonly cited design variables meaningfully differentiate reported spatial performance outcomes, not to test causal hypotheses.

Second, observed convergence in efficiency values is interpreted in relation to the measurement logic underpinning the calculations. Attention is given to how NFA and core areas are defined, which spaces are included or excluded, and how typical floors are selected. These definitional choices, often treated as neutral technical decisions, are examined as methodological filters that actively shape reported outcomes. Emphasis is placed on boundary-setting decisions and residual-area treatments, as these directly affect calculated ratios without necessarily reflecting substantive spatial differences.

Third, the study compares interpretive claims frequently advanced in literature, such as the presumed efficiency advantages of specific core types or building forms, with the actual discriminatory capacity of the metrics used to support those claims. Where efficiency values remain similar across divergent design strategies, the analysis questions whether causal inferences are warranted or whether they exceed what the metrics can reliably support. This step explicitly distinguishes between empirical similarity and interpretive overreach.

Statistical significance testing is deliberately avoided, as such tests would imply an explanatory ambition inconsistent with the study’s interpretive objective. Because the dataset is internally consistent and not designed for probabilistic generalization beyond its defined population, inferential statistics would not meaningfully enhance the epistemic clarity of the findings. The analysis therefore prioritizes epistemic clarity over quantitative inference, shifting the focus from “what the numbers say” to “what the numbers can legitimately be said to mean.”

Treatment of Spatial Efficiency Metrics

Two spatial efficiency indicators are central to this study: the NFA-to-GFA ratio and the core-to-GFA ratio. Both metrics are widely used in high-rise building research [2–4] and are often assumed to provide complementary insights into spatial performance. The definitional logic underlying the construction of spatial efficiency metrics is schematically illustrated in Figure 3.

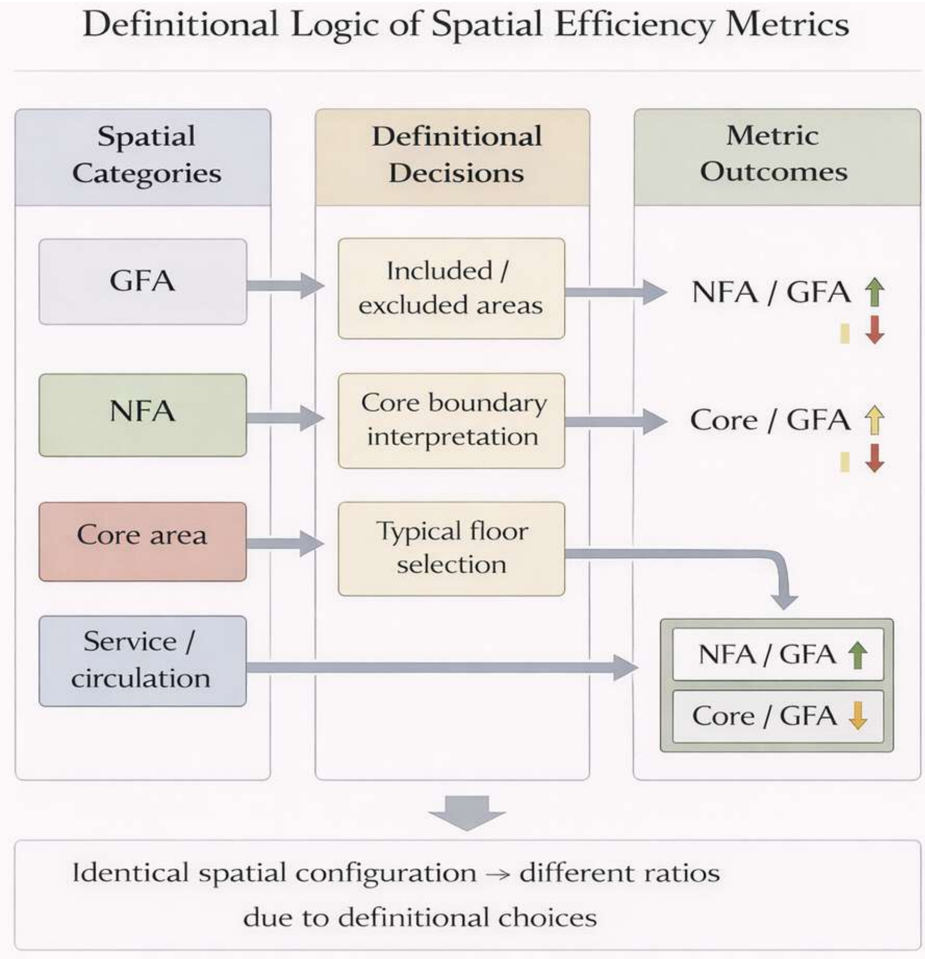

Figure 3. Definitional logic underpinning spatial efficiency metrics used in the study.

In this study, these metrics are treated as method-dependent constructs rather than neutral performance indicators. Their interpretive value depends on how consistently and transparently they are defined and applied. Three issues are particularly salient: (1) NFA is not a universally defined quantity, but a residual category shaped by what is excluded from GFA; (2) service core boundaries are subject to interpretive judgment, particularly in hybrid systems where structure, services, and circulation may spatially overlap; and (3) the selection of a "typical floor" can substantially influence the reported efficiency in buildings with vertical programmatic variation.

To illustrate the impact of definitional choices, consider a hypothetical floorplate of an identical gross area (e.g., 1000 m^2). If 150 m^2 of service and circulation space is fully classified as the core area in one case, the resulting NFA/GFA ratio would be 85%. If 50 m^2 of that area is instead reclassified as usable support space, the reported NFA increases to 900 m^2, yielding an efficiency ratio of 90%. Despite an identical spatial configuration, the metric shifts by five percentage points solely due to definitional treatment. Such variation reflects the methodological framing rather than substantive design differences. By foregrounding these issues, the study refrains from proposing alternative efficiency formulas and instead clarifies the conditions under which existing metrics can be meaningfully compared, particularly when used to support comparative or sustainability-oriented performance claims.

Addressing Validity and Reliability

Given its interpretive orientation, this study addresses validity and reliability through methodological transparency and definitional consistency rather than inferential statistical validation. Because the study evaluates the interpretive behavior of established metrics within a defined empirical population, robustness is grounded in analytical coherence rather than probabilistic generalization.

Internal validity is supported by using a single, consistently compiled dataset, eliminating variability arising from heterogeneous data sources or measurement procedures. Because all cases were analyzed using the same spatial definitions and calculation logic, observed similarities or differences in efficiency values can be attributed to either design characteristics or metric limitations rather than procedural inconsistency. This controlled analytical environment strengthens causal caution by isolating metric-related effects from data-related noise.

Analytical reliability is reinforced through categorical consistency. Architectural and structural classifications, such as core configurations and structural systems, follow typologies widely used in high-rise building research, ensuring that the critique engages directly with concepts familiar to the field rather than introducing idiosyncratic categories. This alignment enhances the replicability of the interpretive logic, even if numerical replication is not the primary objective.

External validity is therefore framed in terms of conditional transferability within the population of realized and documented high-rise timber buildings, rather than as universal statistical generalization. The study does not claim that its findings apply across all building typologies or measurement frameworks. Instead, it argues that spatial efficiency metrics are transferable only under conditions of explicit methodological alignment. In this sense, external validity is treated not as an inherent property of the metric, but as an outcome contingent upon transparency in definition, measurement, and interpretation. Accordingly, the study reframes generalizability as a function of methodological comparability rather than as an automatic property of numerical similarity.

Limitations and Methodological Boundaries

The methodological boundaries of the study are explicitly acknowledged. The analysis is confined to high-rise timber buildings selected in this research and does not extend to speculative or purely conceptual projects. This restriction ensures empirical grounding but limits extrapolation to emerging or unbuilt typologies. Alternative efficiency definitions derived from real estate appraisal standards such as

[28–30] or post-occupancy evaluation are intentionally excluded, as the focus is on architectural and structural research conventions rather than market-based interpretations. Accordingly, the conclusions pertain to research-oriented efficiency metrics rather than to commercial valuation frameworks or user-experience assessments.

While the dataset is global in scope, it reflects the current concentration of high-rise timber development in specific regions and should be understood as representative of contemporary practice rather than exhaustive of all possible configurations. As high-rise timber construction expands into new regulatory and cultural contexts, additional comparative work may reveal alternative measurement behaviors.

Finally, this paper does not seek to resolve the methodological issues it identifies through prescriptive standardization. Instead, it positions itself as a diagnostic intervention intended to prompt greater methodological reflexivity in future spatial efficiency research. The study therefore advances critique rather than prescription, emphasizing interpretive clarity over normative reform.

RESULTS

Overview of Observed Spatial Efficiency Outcomes

Across the dataset of 79 case study buildings, reported spatial efficiency values, expressed as the ratio of NFA to GFA, exhibit a relatively narrow distribution. The interquartile concentration of cases between approximately 75% and 90% indicates range compression relative to the architectural and structural heterogeneity of the sample. The majority of cases cluster within this band, with only a limited number of outliers approaching the upper and lower bounds of the observed spectrum. A similar pattern is evident in core-to-GFA ratios, which predominantly fall between 6% and 14%, despite a broader absolute range. The proportional similarity of these bands across categories suggests limited metric dispersion in relation to design diversity. The statistical summaries reported in this section are not presented as stand-alone new empirical findings, but as analytical evidence supporting the present methodological reinterpretation of spatial efficiency convergence.

To provide a concise overview of these patterns, Table 1 summarizes spatial efficiency ranges and central tendencies across key architectural, structural, and material categories. The table illustrates the substantial overlap in efficiency values across design variables that are commonly assumed to exert a strong influence on spatial performance. No category exhibits a mean displacement that results in descriptive distributional separation when dispersion (SD and IQR) is taken into account. Accordingly, Table 1 is not used here to extend the descriptive record of the dataset. Instead, it aids in establishing the empirical pattern whose methodological implications are examined in this study.

Table 1. Summary of spatial efficiency outcomes across design categories.

Category	Subcategory	NFA/GFA Range (%)	Typical Core-to-GFA Range (%)	Observed Pattern
Building Form	Prismatic	~75–90	~6–14	Full overlap with non-prismatic forms
	Non-prismatic/ tapered	~76–88	~7–15	No systematic deviation
Core Configuration	Central	~77–90	~6–13	Overlapping with peripheral cores
	Peripheral/external	~75–89	~7–14	Comparable efficiency outcomes
Structural System	Shear wall/frame	~76–89	~6–14	Marginal differences only
	Other systems	~75–88	~7–15	No consistent penalty or premium
Material Strategy	Timber-dominant	~76–90	~6–13	No systematic efficiency advantage
	Hybrid	~75–88	~7–15	Comparable efficiency clustering

Note: Ranges are reported for descriptive orientation only; full distributional statistics (mean, SD, IQR, CV) are provided in Table 2.

To further substantiate the observed range compression, additional descriptive statistical indicators were calculated for NFA/GFA ratios across the dataset and major design categories (Table 2). Categories with fewer than three observations are retained for reporting completeness; however, interpretive emphasis is placed on groups with sufficient representation. The overall distribution (n = 79) yields a mean value of 0.841 with a standard deviation of 0.056 and an interquartile range (IQR) of 0.084. The coefficient of variation (CV = 6.65%) indicates relatively low relative dispersion across the full sample. These statistics are reported not as independent empirical contributions, but as the distributional basis for assessing whether convergence reflects design performance or the limited discriminatory capacity of the metric framework.

Category-level analysis reveals that although modest differences in mean values exist across architectural form, core configuration, structural system, and function, intra-category dispersion remains limited. In most categories, coefficients of variation fall within a narrow band (approximately 4–7%), and IQRs demonstrate substantial overlap. Across major categories ($n \geq 10$), no pair of interquartile intervals is fully non-overlapping, indicating that the central 50% of distributions intersect consistently across design variables. These dispersion patterns reinforce the interpretation that spatial efficiency values cluster within a constrained analytical bandwidth despite design heterogeneity.

Table 2. Distribution of NFA/GFA ratios by design category (n = 79).

Category Type	Subcategory	n	Mean	SD	IQR	CV (%)
Building Form	Free	14	0.860	0.039	0.062	4.48
	Prismatic	64	0.836	0.059	0.083	7.00
	Tapered	1	0.884	—	—	—
Core Configuration	Central	46	0.838	0.057	0.085	6.78
	Peripheral	31	0.840	0.053	0.078	6.35
	External	2	0.921	0.016	0.011	1.70
Structural System	Shear wall	22	0.804	0.048	0.040	5.94
	Shear walled frame	48	0.852	0.049	0.070	5.76
	Shear trussed frame	5	0.856	0.093	0.153	10.82
	Framed-tube	1	0.913	—	—	—
	Trussed-tube	3	0.887	0.013	0.013	1.49
Function	Residential (R)	51	0.827	0.052	0.070	6.33
	Office (O)	23	0.871	0.057	0.088	6.51
	Hotel (H)	2	0.801	0.018	0.013	2.27
	Mixed (R+O)	1	0.884	—	—	—
	Mixed (R+O+H)	2	0.855	0.028	0.020	3.23

Note: Categories with fewer than three observations are retained for reporting completeness; however, interpretive emphasis is placed on groups with sufficient representation.

Importantly, the limited magnitude of between-category means separation (generally below 0.05) combined with overlapping IQRs across major design variables provides quantitative confirmation that the observed convergence is not merely range-based but distributionally embedded. Between-category mean differences across major groups generally remain below 0.05 (5 percentage points), a magnitude that remains small relative to intra-category dispersion levels. In this respect, the results section moves beyond simple descriptive tabulation by using the reported summaries to evaluate the methodological meaning of convergence rather than to present the tables as stand-alone empirical endpoints.

Figure 4 visually reinforces the statistical patterns reported in Table 2, illustrating the substantial overlap in central tendency and dispersion across categories. Figure 4 visualizes overlapping medians and interquartile intervals rather than merely full observed ranges, reinforcing the statistical basis of the convergence claim. The graphical representation reinforces the absence of systematic displacement between categories, further supporting the interpretation that efficiency ratios demonstrate convergence rather than categorical divergence.

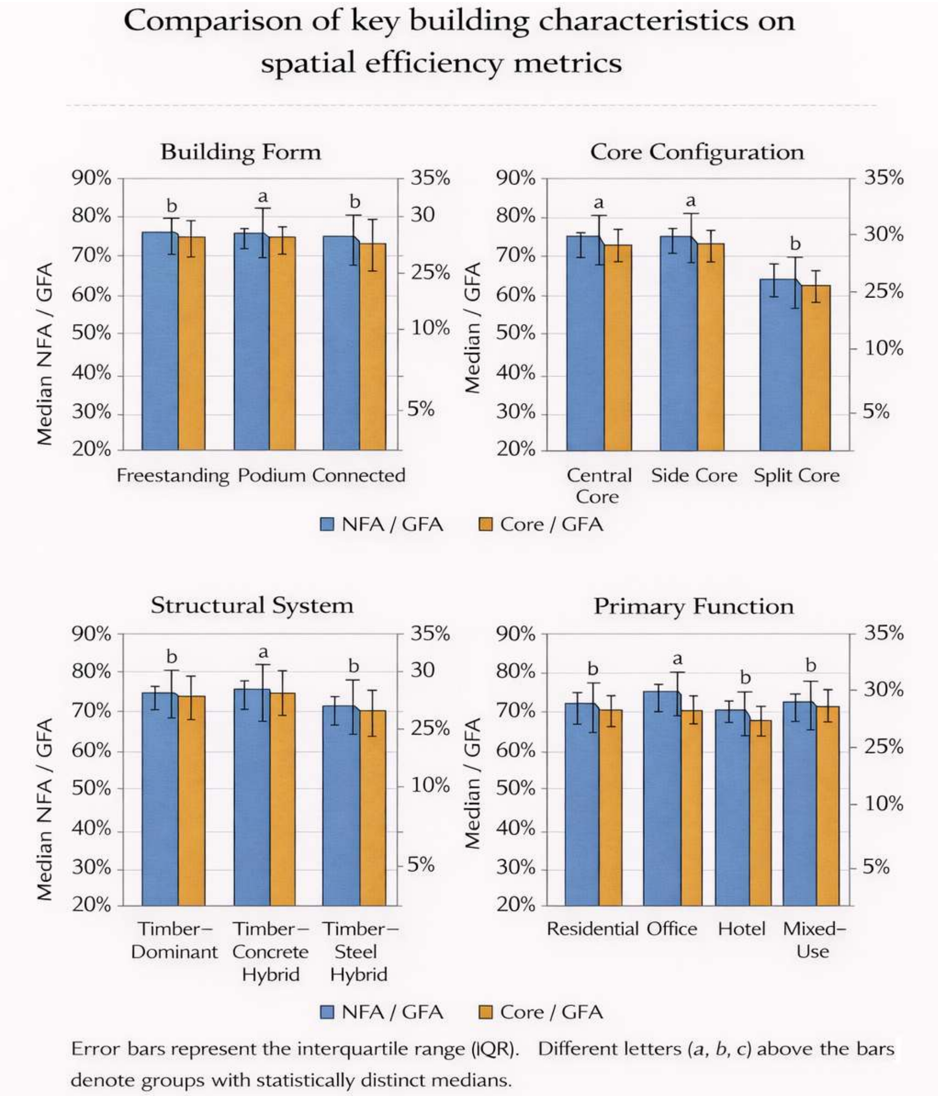

Figure 4. Spatial efficiency outcomes across key design categories in high-rise timber buildings.

Spatial Efficiency Across Architectural Forms

When spatial efficiency values are examined in relation to building form, a clear pattern of convergence emerges. Prismatic towers, which constitute most cases in the dataset, display efficiency values spanning nearly the entire observed range. Free-form and tapered towers, despite their geometric complexity and non-orthogonal configurations, exhibit spatial efficiency values that largely overlap with those of prismatic buildings. The absence of range separation indicates that volumetric differentiation alone does not translate into measurable efficiency divergence within the applied metric framework.

No systematic efficiency advantage is observed for any specific form category. Non-prismatic forms do not demonstrate consistently lower efficiency outcomes, contrary to common assumptions that geometric complexity necessarily reduces usable floor area. Conversely, prismatic towers do not exhibit a distinct upper-bound advantage in spatial efficiency. Mean values across form categories remain within a narrow band, and dispersion patterns do not suggest categorical stratification.

The key result is therefore not the absence of variation, but the degree of overlap between fundamentally different volumetric strategies. Spatial efficiency metrics do not meaningfully discriminate between architectural forms when buildings are competently planned, suggesting that form-related variation is largely absorbed by the measurement framework rather than explicitly reflected in reported efficiency values. This finding implies that geometric complexity, while architecturally significant, is weakly registered by aggregate NFA/GFA ratios, thereby limiting the metric's sensitivity to form-driven spatial differentiation.

Core Configuration and Efficiency Insensitivity

A similarly convergent pattern is observed when spatial efficiency outcomes are disaggregated by service core configuration. Central, peripheral, and external core arrangements all yield efficiency values within comparable ranges, with overlapping distributions and no clear separation between categories. Neither the mean values nor the dispersion patterns indicate categorical differentiation attributable solely to core location.

Central cores, often cited in the literature as inherently more space-efficient due to compact circulation and structural logic, do not consistently outperform peripheral or external configurations. Likewise, peripheral cores, frequently assumed to reduce efficiency due to elongated circulation paths, do not exhibit systematically lower NFA/GFA ratios. The expected efficiency gradient between centralized and distributed service cores is not empirically observable within the reported metric ranges.

These findings indicate that core location alone is not a reliable predictor of reported spatial efficiency. Instead, efficiency outcomes are more strongly conditioned by boundary definition, service allocation strategies, and dimensional proportioning than by geometric placement per se. Well-optimized peripheral cores can achieve efficiency levels comparable to those of central cores, while poorly proportioned central cores may negate their presumed advantage. This suggests that aggregate efficiency ratios register the quantity of service space but remain largely insensitive to its spatial organization or configurational logic.

Structural Systems and Material Strategies

Disaggregation by structural system and material composition reveals a comparable lack of differentiation. Although structural systems display modest mean variation (≈0.048 between shear wall and shear walled frame systems), relative dispersion within categories remains moderate, and IQRs substantially overlap. Similarly, timber-dominant buildings and composite timber–concrete or timber–steel systems exhibit comparable spatial efficiency outcomes. No structural category demonstrates a consistent displacement in efficiency values sufficient to suggest a systematic material-based advantage or penalty.

Although composite systems are often associated with increased structural depth or additional service integration, these factors do not translate into systematically lower efficiency ratios. Conversely, timber-dominant systems do not demonstrate a consistent efficiency premium despite their lighter structural profiles. The anticipated correlation between reduced structural mass and improved spatial efficiency is not empirically supported within the observed metric framework.

The absence of a strong differentiation across structural and material categories suggests that spatial efficiency metrics do not directly capture material-specific spatial advantages. Instead, such advantages may be subsumed within broader planning and integration decisions that are not explicitly represented in aggregate NFA/GFA or core-to-GFA ratios. From a sustainability perspective, this indicates that spatial efficiency metrics alone are insufficient proxies for material performance or resource optimization, as they may mask structurally embedded spatial trade-offs.

Cross-Sectional Synthesis: Convergence Across Design Dimensions

Taken together, the analyses across architectural form, core configuration, structural system, and material strategy reveal a consistent cross-sectional pattern: Spatial efficiency metrics converge across diverse design strategies. The magnitude of distributional overlap exceeds what would be expected if individual design variables exerted an independent and measurable influence on aggregate efficiency ratios. This convergence is not attributable to a lack of architectural or structural variation within the dataset, but rather to the limited discriminatory capacity of the metrics employed.

Across all examined categories, efficiency values display substantial overlap, and no single design variable produces a systematic shift in reported spatial performance. Range compression and categorical interpenetration characterize the dataset, indicating that efficiency ratios operate within a constrained analytical bandwidth. This recurring pattern suggests that conventional spatial efficiency metrics are calibrated in a manner that absorbs design variability, rendering many spatial differences analytically invisible. In this respect, this study differs from earlier empirical reporting by treating convergence not simply as an observed descriptive pattern, but as evidence of the methodological behavior of the metric framework itself.

This synthesis reduces the need for repetitive interpretation across individual subsections and underscores the central empirical finding of the study: Similarity in reported efficiency outcomes should not be interpreted as evidence of design equivalence, but as a reflection of methodological alignment. In other words, convergence in reported ratios reflects metric behavior rather than architectural convergence.

Vertical Averaging and Suppressed Heterogeneity

An additional methodological consideration concerns the use of a representative or "typical" floor in calculating NFA/GFA ratios. While this approach ensures comparability across cases, it may suppress vertical heterogeneity in buildings with programmatic variation. In mixed-use towers within the dataset, residential, office, and hotel segments often occupy distinct vertical zones characterized by differing floorplate geometries and core configurations. Reliance on a single typical floor for efficiency calculation therefore produces a building-level average condition rather than capturing segment-specific spatial performance.

This vertical averaging effect may partially contribute to the convergence patterns identified in the dataset by attenuating internal variability within individual buildings. In this sense, the observed distributional overlap across categories should be interpreted not solely as metric insensitivity across design variables, but also as a consequence of methodological standardization in floor selection.

Core-To-GFA Ratios and the Limits of Interpretability

While NFA/GFA ratios display limited variability across design categories, core-to-GFA ratios exhibit a wider numerical range. However, this increased spread does not translate into clear interpretive differentiation. Although dispersion in core allocation is more pronounced, the absence of a consistent correlation with overall efficiency outcomes limits its explanatory value. Buildings with relatively large core-to-GFA ratios may still achieve high overall spatial efficiency, while buildings with compact cores do not necessarily outperform others in terms of usable area.

This apparent paradox reveals a structural limitation in ratio-based evaluation rather than a contradiction in building performance. Core-to-GFA ratios quantify the proportion of space allocated to vertical circulation and services, but they do not capture qualitative differences in core geometry, spatial integration, redundancy, or long-term adaptability over the building lifecycle. As a result, numerical variation in core allocation can mask substantial differences in spatial organization and operational performance. In analytical terms, the metric captures allocation magnitude but not configurational intelligence.

The results therefore reinforce the need for caution in drawing causal conclusions from spatial efficiency metrics alone, particularly when such metrics are used as proxies for design quality or functional superiority. Variation in numerical ratios should not be equated with variation in experiential or operational performance without supplementary spatial analysis.

DISCUSSION

Reinterpreting Convergent Spatial Efficiency Outcomes

The results reveal a consistent convergence of spatial efficiency metrics across architectural forms, core configurations, structural systems, and material strategies in high-rise timber buildings. As shown in Table 2, overall dispersion remains limited (CV = 6.65%), with category-level coefficients of variation predominantly between approximately 4.5% and 7.0%, and mean differences across major categories generally below 0.05.

At a superficial level, such convergence could be interpreted as evidence of design maturity, suggesting that contemporary high-rise timber buildings have reached comparable levels of spatial optimization. However, this interpretation becomes less convincing under closer examination. Table 2 demonstrates that convergence is characterized not only by limited overall dispersion, but also by persistent interquartile overlap across major design categories ($n \geq 10$), with no category exhibiting systematic displacement in the central tendency. If convergence were primarily driven by progressive design optimization, limited dispersion would likely be accompanied by observable between-category stratification aligned with established design variables, such as core location, structural system, or volumetric strategy. No such directional clustering is observed: Central and peripheral cores, shear wall and shear-walled frame systems, and prismatic and non-prismatic forms display overlapping IQRs and minimal mean separation (generally < 0.05). Instead, the empirical pattern is characterized by simultaneous low dispersion and substantial categorical overlap, without consistent directional differentiation.

This absence of stratification weakens the maturity argument and foregrounds the behavior of the metric itself as a primary explanatory factor. Conventional spatial efficiency indicators, particularly NFA/GFA and core-to-GFA ratios, appear to lack sufficient resolution to register meaningful spatial differentiation within a uniform measurement framework. In this sense, convergence may reflect, at least in part, metric-induced compression rather than purely architectural equivalence. The combination of low relative dispersion and cross-category interpenetration of central distributions provides empirical support for this interpretation. Importantly, this reading differs from earlier empirical studies, including the author's own prior work, in which convergence was primarily reported as an observed outcome across case groups. Here, the same convergence pattern is reinterpreted as evidence of the methodological behavior of the metric itself, rather than as a direct indication of design equivalence or performance maturity.

Why Design Differences Appear to "Disappear"

A striking implication of the results is the apparent disappearance of expected performance differences between commonly discussed design strategies. For example, central and peripheral core configurations exhibit nearly identical mean values (0.838 vs. 0.840) with comparable dispersion (CV ≈ 6–7%), indicating an absence of categorical separation. Their IQRs substantially overlap, and no consistent directional displacement is observable across the distribution. This does not suggest that such design decisions are inconsequential, but rather that their spatial consequences are not adequately registered by aggregate efficiency ratios. The issue lies not in the absence of difference, but in the limited discriminatory capacity of the metric.

Several mechanisms contribute to this effect. First, spatial efficiency ratios operate at a high level of abstraction, reducing complex spatial configurations to a single scalar value and thereby obscuring distinctions related to circulation logic, spatial hierarchy, adaptability, and long-term flexibility. The consistently low coefficients of variation across categories (predominantly 4.5–7.0%) indicate that this scalar reduction compresses variability even where configurational differences are present. Second, efficiency calculations based on typical floors may suppress vertical heterogeneity in buildings with podium differentiation, transfer levels, or mixed-use stacking. Third, definitional conventions governing NFA classification and core boundaries normalize diverse spatial organizations into standardized numerical outputs.

In mixed-use towers represented in the dataset, this effect is particularly pronounced. Where residential and office floors exhibit different spatial proportions, core allocations, or service densities, aggregation through a single representative floorplate necessarily compresses vertically differentiated conditions into a scalar average. As a result, internal variation that might otherwise expand the distribution of efficiency outcomes becomes analytically invisible. This internal compression is consistent with the broader pattern of cross-category overlap documented in Table 2, reinforcing the interpretation that convergence is structurally embedded in the measurement procedure.

Together, these mechanisms produce analytical flattening, whereby multidimensional spatial diversity is compressed into a narrow numerical band. The disappearance of design differences should therefore be understood as a property of the measurement framework rather than as evidence of architectural convergence. In this respect, the present study moves beyond prior descriptive reporting by treating convergence not simply as a recurring empirical pattern, but as a methodological effect requiring reinterpretation. In sustainability-oriented discourse, such flattening risks overstating the comparability of materially and spatially distinct systems.

Methodological Alignment Versus Design Performance

The findings highlight a critical distinction between methodological alignment and actual design performance. When similar definitions, spatial boundaries, and calculation procedures are applied across studies, reported efficiency values are likely to converge, even where buildings differ substantially in spatial logic, material integration, and user experience. In this context, numerical coherence may indicate calculative consistency rather than empirical equivalence. The narrow distribution observed in the present dataset illustrates how methodological uniformity can structurally amplify numerical similarity across heterogeneous cases.

Such alignment may be misinterpreted as the empirical validation of performance convergence. However, it reflects consistency in measurement rather than convergence in spatial quality. Under conditions of internally consistent calculation frameworks, the homogeneity of the results can be produced by the metric itself rather than by the underlying architectural equivalence. This is also the point at which this study separates itself most clearly from earlier outcome-oriented analyses: The aim here is not to extend the descriptive record of spatial efficiency values, but to interrogate the interpretive consequences of using those values as evidence of design performance.

This distinction carries important implications for comparative research. Spatial efficiency ratios are meaningfully comparable only under explicit methodological alignment; otherwise, numerical similarity may be misleading. Even where alignment exists, similarity in ratios should not be equated with similarity in experiential, operational, or lifecycle performance. Uncritical comparison risks reinforcing unsupported design hierarchies, particularly in sustainability-oriented evaluation where metric symmetry may be mistaken for substantive material or typological superiority.

Implications for Timber Versus Non-Timber Comparisons

The methodological dependency of spatial efficiency metrics is particularly consequential in comparisons between timber and non-timber high-rise buildings. Although existing literature frequently suggests that timber towers achieve superior spatial efficiency due to lighter structural systems and reduced load-bearing thickness, the present findings caution against interpreting ratio-based indicators as direct evidence of material superiority. Within the examined metric framework, no systematic efficiency premium attributable solely to material category is observed; category-level mean differences remain limited and dispersion does not indicate categorical separation.

This does not imply that timber construction lacks spatial or environmental advantages. Rather, it indicates that spatial efficiency ratios alone cannot substantiate material-performance claims. Because these metrics depend on boundary definitions, service classification, and aggregation logic, observed differences may reflect methodological framing as much as functional spatial improvement.

Absent a clear distinction between measured allocation efficiency and experiential or operational spatial quality, timber versus non-timber comparisons risk conflating numerical similarity with substantive performance equivalence. This caution is particularly relevant in sustainability discourse, where efficiency ratios are often mobilized to reinforce low-carbon material narratives. Greater methodological nuance is therefore required when efficiency metrics are used to support broader design, investment, or policy claims.

Rethinking the Role of Spatial Efficiency Metrics

The findings suggest that spatial efficiency metrics should be reconsidered not as definitive performance indicators but as context-dependent analytical tools. More precisely, they function as descriptive allocation indices rather than evaluative proxies for design quality. Their primary contribution lies in standardizing spatial allocation comparisons, not in delivering absolute judgments about functional or architectural superiority. Accordingly, the purpose of this study is not to broaden the empirical evaluation through additional performance dimensions, but to isolate and examine the interpretive behavior of the spatial efficiency metric itself within a fixed analytical frame.

This reframing encourages interpretive restraint. Efficiency ratios may indicate proportional distribution of space, yet they cannot, in isolation, diagnose spatial intelligence, experiential quality, or long-term adaptability.

It also underscores the need for complementary analytical approaches capable of addressing dimensions of spatial performance beyond aggregate ratios, including circulation quality, adaptability, service integration, and lifecycle usability. Embedding efficiency metrics within multidimensional assessment frameworks would preserve their descriptive utility while reducing the risk of overinterpretation. In sustainability-oriented evaluation, this requires distinguishing between allocation efficiency and material-resource performance rather than conflating both within a single numerical indicator.

Implications for Future Research on High-Rise Timber Buildings

The findings point to several methodological priorities for future research on high-rise timber buildings. First, definitional and analytical assumptions underlying spatial efficiency calculations should be explicitly documented. Transparency in boundary definitions and residual classifications is essential for meaningful comparison and synthesis; without such clarity, comparative claims remain epistemically fragile.

Second, caution is warranted when attributing causal significance to design variables on the basis of efficiency ratios alone. Where convergence is observed, alternative explanations, including metric insensitivity, should be considered alongside design-based interpretations. Numerical reporting should therefore be accompanied by analytical reflexivity, particularly when efficiency outcomes are invoked to support sustainability or material-performance narratives.

Third, complementary indicators are needed to capture dimensions of spatial performance not addressed by aggregate ratios, including spatial flexibility, service integration, and adaptability to changing programmatic conditions. Such measures should aim to register configurational intelligence while remaining interoperable with established metrics, thereby enabling multidimensional performance assessment rather than metric substitution.

Finally, interpretive and meta-analytical inquiries should be recognized as integral to methodological advancement in high-rise building research. In rapidly evolving domains such as high-rise timber construction, critical examination of measurement logic is foundational to responsible and transparent performance evaluation.

Broader Methodological Implications Beyond Timber Construction

Although this study centers on high-rise timber buildings, its methodological implications extend beyond this domain. Spatial efficiency ratios are widely applied across building typologies and material systems, often under comparable assumptions regarding boundary definitions and interpretive use. The patterns identified here, metric convergence, limited discriminatory capacity, and interpretive overreach, are therefore not timber-specific but structurally inherent to scalar ratio-based evaluation. Whenever multidimensional spatial phenomena are reduced to aggregate numerical indicators, compression effects are likely to occur.

Conceptualizing spatial efficiency as a method-dependent construct invites a broader reconsideration of performance metrics within the built environment disciplines. Rather than serving as self-evident validators of design quality, quantitative indicators should be situated within explicit measurement logics and boundary conditions. This position does not reject quantification; it reframes it as conditional and context-sensitive.

In the context of evidence-based design and sustainability assessment, such methodological reflexivity is essential. Numerical similarity should not be equated with substantive equivalence in spatial, material, or environmental performance. Acknowledging the conditional nature of performance metrics is therefore necessary to prevent analytical compression from being mistaken for architectural convergence.

CONCLUSIONS

This study critically re-examined the role and interpretive validity of spatial efficiency metrics in the context of high-rise timber buildings. Rather than introducing new empirical measurements or expanding existing datasets, the research deliberately shifted focus toward the methodological construction of spatial efficiency itself. By reinterpreting an internally consistent dataset of 79 high-rise timber towers, the study demonstrated that commonly reported efficiency values are less indicative of intrinsic design performance than is often assumed. Unlike earlier empirical studies based on the same research trajectory, this study does not extend the descriptive record of efficiency values but reinterprets those values as outputs of a method-dependent measurement framework. This study is directly related to, but distinct from, the author's earlier empirical work on space efficiency in tall and high-rise timber buildings. Whereas the earlier studies focused on reporting and comparing spatial efficiency outcomes across case-based datasets, the present paper does not replicate or extend those descriptive findings. Instead, it uses prior empirical evidence as a fixed analytical basis for reinterpreting spatial efficiency as a method-dependent construct shaped by metric construction, definitional alignment, and typical floor standardization. The contribution of this study therefore lies in methodological and interpretive reframing rather than in empirical expansion.

The central conclusion is clear: Spatial efficiency, as currently operationalized in high-rise building research, is a method-dependent construct rather than an objective performance indicator. The observed convergence of NFA/GFA and core-to-GFA ratios across diverse architectural forms, core configurations, structural systems, and material strategies does not signify design equivalence. Instead, it reflects the limited discriminatory capacity of aggregate efficiency metrics when applied within a uniform measurement framework. Similar numerical outcomes should therefore not be interpreted as evidence that design choices are inconsequential, nor should they be used to support causal claims regarding the superiority of specific forms, core types, or material systems.

A second key conclusion concerns cross-study comparison. Numerical alignment across datasets may arise from shared definitional conventions rather than comparable spatial realities. Without explicit documentation of how net areas, service cores, and typical floors are defined and measured, spatial efficiency values cannot be meaningfully compared across studies. This limitation is particularly consequential in sustainability-oriented discourse, where efficiency ratios are frequently mobilized to substantiate material or typological advantages.

Importantly, this study does not advocate abandoning spatial efficiency as a research concept. Spatial efficiency remains a useful descriptive tool when its methodological boundaries are clearly articulated. What requires reconsideration is not the metric itself, but its interpretive deployment.

Rather than serving as a deterministic indicator of design quality, spatial efficiency should be treated as a context-specific descriptor whose evidentiary strength depends on transparent and consistent measurement logic. For this reason, this study does not seek to expand empirical coverage through additional performance dimensions but instead isolates the metric framework itself as the primary object of analysis.

Looking forward, future research would benefit from three complementary directions. First, greater transparency and partial standardization in the reporting of measurement conventions are necessary to clarify how boundary definitions and residual classifications influence reported efficiency values. Second, spatial efficiency ratios should be embedded within multidimensional performance frameworks capable of registering configurational intelligence, vertical heterogeneity, and lifecycle adaptability, thereby mitigating the interpretive compression associated with single-ratio indicators. Third, comparative studies should systematically test the sensitivity of efficiency outcomes under alternative definitional scenarios to evaluate the degree to which observed convergence reflects measurement logic rather than intrinsic design performance. Advancing such a framework would extend the present methodological reframing and enhance the analytical credibility of sustainability-oriented performance claims in high-rise building research.

Ultimately, the contribution of this paper lies in clarifying the epistemic status of spatial efficiency metrics. Convergence in reported ratios reflects metric behavior rather than architectural equivalence. Recognizing this distinction is essential for responsible comparison, credible sustainability claims, and more robust methodological practice in high-rise building research.

DATA AVAILABILITY

All data generated from the study are available in the manuscript.

CONFLICTS OF INTEREST

The author declares no conflicts of interest.

FUNDING

This research received no external funding.

REFERENCES

1. Tugrul Okbaz F. Evaluation of space efficiency criteria in high-rise buildings based on functions: a case study of Türkiye. Archit Eng Des Manag. 2025;21(1):60-77. doi: 10.1080/17452007.2024.2404115
2. Huang P, Zheng X, Zhang Y, Shen P. Space layout automation and optimization for energy-efficient buildings: A multi-objective evolutionary approach with machine learning analytics. Energy Build. 2026;358:117213. doi: 10.1016/j.enbuild.2026.117213

3. Kalwry H, Atakara C. Exploring energy-efficient design strategies in high-rise building façades for sustainable development and energy consumption. Buildings. 2025;15(7):1062. doi: 10.3390/buildings15071062
4. Wang J, Luo Y, Zhou X, Zhao W, Lei Y, Xie W. Impact of assistance behavior on evacuation efficiency in high-rise hospital inpatient buildings: An agent-based simulation study. J Build Eng. 2025;112:113780. doi: 10.1016/j.jobe.2025.113780
5. Trabucco D, William Douglas M. Measuring the floor area of buildings: problems of consistency and a solution. J Civ Eng Archit. 2019;13(2):107-14. doi: 10.17265/1934-7359/2019.02.005
6. Sev A, Özgen A. Space efficiency in high-rise office buildings. METU J Fac Archit. 2009;26(2):69-89. doi: 10.4305/METU.JFA.2009.2.4
7. Kim H, Elnimeiri M. Space efficiency in multi-use tall building. Proceedings of the Tall Buildings in Historical Cities-Culture and Technology for Sustainable Cities; 2004 Oct 10-13; Seoul, Republic of Korea. pp. 10-3.
8. Ramage MH, Burridge H, Busse-Wicher M, Fereday G, Reynolds T, Shah DU, et al. The wood from the trees: the use of timber in construction. Renew Sustain Energy Rev. 2017;68:333-59. doi: 10.1016/j.rser.2016.09.107
9. Blanchet P, Perez C, Cabral MR. Wood building construction: trends and opportunities in structural and envelope systems. Curr For Rep. 2024;10(1):21-38. doi: 10.1007/s40725-023-00196-z
10. Kathiravel R, Hou D, Feng H. Optimizing structural and environmental performance in mass timber hybrid high-rise buildings through parametric design. J Build Eng. 2025;118:115005. doi: 10.1016/j.jobe.2025.115005
11. Ilgın HE, Aslantamer ÖN. Space efficiency in tall timber buildings: a comprehensive review. Highlights Sustain. 2025;4(2):122-45. doi: 10.54175/hsustain4020008
12. Ilgın HE, Aslantamer ÖN. Spatial effectiveness in high-rise timber towers: a global perspective. Buildings. 2024;14(9):2713. doi: 10.3390/buildings14092713
13. Ibrahimy R, Mohmmand MA, Elham FA. An evaluation of space use efficiency in residential houses, Kabul City. J Res Appl Sci Biotechnol. 2023;2:1-6. doi: 10.55544/jrasb.2.3.1
14. Goessler T, Kaluarachchi Y. Smart adaptive homes and their potential to improve space efficiency and personalisation. Buildings. 2023;13:1132. doi: 10.3390/buildings13051132
15. Arslan Kılınç G. Improving a model for determining space efficiency of tall office buildings [dissertation]. Istanbul (Turkey): Mimar Sinan Fine Art University; 2019.
16. Tuure A, Ilgın HE. Space efficiency in Finnish mid-rise timber apartment buildings. Buildings. 2023;13(8):2094. doi: 10.3390/buildings13082094
17. Ilgın HE. High-rise residential timber buildings: emerging architectural and structural design trends. Buildings. 2023;14(1):25. doi: 10.3390/buildings14010025

18. Yan L, Klingner R, Al-Qudsi A, Chen H, Dand JA. Current market landscape and industry voices in key timber construction markets. Buildings. 2025;15(18):3381. doi: 10.3390/buildings15183381
19. Kuzmanovska I, Gasparri E, Monne DT, Aitchison M. Tall timber buildings: emerging trends and typologies. Proceedings of the 2018 World Conference on Timber Engineering; 2018 Aug 20-23; Seoul, Republic of Korea.
20. Skullestad JL, Bohne RA, Lohne J. High-rise timber buildings as a climate change mitigation measure–a comparative LCA of structural system alternatives. Energy Procedia. 2016;96:112-23. doi: 10.1016/j.egypro.2016.09.112
21. Ilgın HE. Space efficiency in tapered super-tall towers. Buildings. 2023;13(11):2819. doi: 10.3390/buildings13112819
22. Feng L, Zhao Y, Liu S, Zhang Z, Luo G, Chen X, et al. Automated traffic core layout optimization in modular high-rise residential buildings using differential evolution. J Build Eng. 2025;114:114295. doi: 10.1016/j.jobe.2025.114295
23. Okbaz FT, Sev A. A model for determining the space efficiency in non-orthogonal high rise office buildings. J Fac Eng Archit Gazi Univ. 2023;38:113-25. doi: 10.17341/gazimmfd.831937
24. Nye E, Melendez-Torres GJ, Bonell C. Origins, methods and advances in qualitative meta-synthesis. Rev Educ. 2016;4(1):57-79. doi: 10.1002/rev3.3065
25. Ma N, Roberts R, Winefield H, Furber G. Utility of qualitative metasynthesis: advancing knowledge on the wellbeing and needs of siblings of children with mental health problems. Qual Psychol. 2015;2(1):3-28. doi: 10.1037/qup0000018
26. Erwin EJ, Brotherson MJ, Summers JA. Understanding qualitative metasynthesis: issues and opportunities in early childhood intervention research. J Early Interv. 2011;33(3):186-200. doi: 10.1177/1053815111425493
27. Council on Vertical Urbanism, Illinois Institute of Technology. [Internet]. Available from: https://verticalurbanism.org/. Accessed on 2026 Apr 30.
28. Building Owners and Managers Association (BOMA). [Internet]. Available from: https://www.boma.org/. Accessed on 2026 Apr 30.
29. Royal Institution of Chartered Surveyors (RICS). [Internet]. Available from: https://www.rics.org/. Accessed on 2026 Apr 30.
30. International Property Measurement Standards (IPMS). [Internet]. Available from: https://www.rics.org/profession-standards/rics-standards-and-guidance/sector-standards/real-estate-standards/international-property-measurement-standards. Accessed on 2026 Apr 30.

How to cite this article:
Ilgın HE. Space Efficiency as a Method-Dependent Construct: Evidence from High-Rise Timber Buildings. J Sustain Res. 2026;8(2):e260048. https://doi.org/10.20900/jsr20260048.