Toward a Dual-Constraint Perspective in Real Estate Feasibility Assessment at the Early Design Stage

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ABSTRACT

The building and construction sector is a major contributor to global greenhouse gas emissions through both embodied and operational carbon generated throughout the building lifecycle. As climate-related regulations, sustainability commitments, and investor expectations continue to evolve, real estate development is increasingly required to balance environmental responsibility with financial viability. However, early-stage development decisions remain predominantly driven by conventional financial feasibility assessments, while carbon considerations are frequently evaluated as separate performance metrics rather than integral components of project feasibility. This separation contributes to carbon lock-in, limits opportunities for proactive carbon reduction, and increases exposure to climate-related transition risks. Addressing this challenge, this study proposes a conceptual Dual-Constraint Feasibility Framework (DCFF) that positions carbon and financial considerations as interconnected dimensions of project feasibility during the early design stage. The framework introduces Carbon Baseline and Carbon Ceiling alongside Financial Baseline and Financial Ceiling as project-level boundaries that collectively define the feasible solution space for development alternatives. The Carbon Ceiling is operationalized as the maximum allowable whole-life carbon of a project, covering both embodied and operational carbon, expressed in tCO_2e over a 50-year reference study period, and derived, once an ambition level has been determined at the policy or national level, either from a downscaled carbon budget or from a required reduction below the Carbon Baseline. Building Information Modeling (BIM), Life Cycle Assessment (LCA), and Life Cycle Costing (LCC) are conceptualized as complementary enabling tools that support the generation, assessment, and comparison of alternative development scenarios. The proposed Dual Budget concept enables design alternatives to be evaluated according to their ability to operate within both carbon and financial boundaries simultaneously, so that feasibility is reframed as the capacity of development alternatives to satisfy interconnected environmental and economic requirements rather than optimizing a single objective in isolation. The study contributes to advancing feasibility assessment from a predominantly financial perspective toward a more integrated and systems-oriented approach aligned with low-carbon development, sustainable cities, and climate-resilient infrastructure, and provides a conceptual foundation for future decision-support tools capable of supporting transparent, traceable, and climate-aligned development decisions.

Keyword: BIM-LCA-LCC/ Dual-Constraint Feasibility Framework/ Low-Carbon Development/ Decision Support/ Sustainable Real Estate Development

1. INTRODUCTION

The building and construction sector is a major contributor to global greenhouse gas emissions through both operational and embodied carbon generated throughout the building lifecycle [1, 2]. As climate-related regulations, net-zero commitments, and sustainability expectations continue to evolve, real estate development is increasingly required to balance environmental responsibility with financial viability.

Despite this growing urgency, feasibility assessment in real estate development remains predominantly driven by financial considerations such as project cost, return on investment, and market viability [3, 4]. Environmental impacts are often evaluated separately through sustainability assessments or Life Cycle Assessment (LCA) studies conducted after major design decisions have already been established. As a result, carbon performance frequently functions as a reporting metric rather than a factor that actively influences project feasibility.

This separation creates a significant challenge for low-carbon development. Decisions made during the early design stage, including building form, structural systems, material selection, and building services, have long-term implications for both lifecycle carbon emissions and lifecycle costs [5, 6]. Once embedded within a project, these decisions become increasingly difficult to modify, contributing to carbon lock-in and limiting opportunities for effective carbon reduction [1, 7].

Recent advances in Building Information Modeling (BIM), Life Cycle Assessment (LCA), and Life Cycle Costing (LCC) have improved the ability to quantify environmental and economic performance across the building lifecycle [8, 9]. However, these tools are frequently applied as independent assessment methods, reinforcing a fragmented approach in which environmental and financial performance are evaluated separately rather than within a unified feasibility framework.

To address this gap, this study proposes a conceptual Dual-Constraint Feasibility Framework (DCFF) for early-stage real estate development. The framework introduces Carbon Ceiling and Financial Ceiling as project-level constraints that collectively define the feasible solution space for development alternatives. By positioning environmental and financial requirements as simultaneous conditions of feasibility, the framework seeks to support more integrated, transparent, and climate-aligned decision-making in the built environment.

2. METHODOLOGY

2.1 Framework Development Approach

This study adopts a conceptual framework development approach to explore how environmental and financial considerations can be integrated within a common feasibility assessment structure for early-stage real estate development [10]. The research is motivated by the observation that existing feasibility assessments primarily emphasize financial viability, while environmental performance is frequently evaluated separately through sustainability assessment tools [3]. As a result, project feasibility is often determined without explicitly considering carbon constraints during the decision-making process.

Rather than generating empirical evidence, the purpose of this study is to synthesize existing knowledge from relevant domains and develop a conceptual framework capable of supporting more integrated decision-making. Conceptual framework development is particularly appropriate when knowledge exists across multiple disciplines but remains fragmented and lacks a unified theoretical structure [10]. Accordingly, the proposed Dual-Constraint Feasibility Framework (DCFF) was developed through a process consisting of knowledge domain identification, construct derivation, operationalization of the Carbon Ceiling, conceptual integration, and framework development.

2.2 Identification of Knowledge Domains

The first stage involved identifying the principal knowledge domains that influence project feasibility within the context of low-carbon real estate development. Four domains were selected based on their relevance to environmental performance, climate mitigation objectives, economic evaluation, and decision-support capabilities.

The first domain, carbon budgeting and climate-target literature, provides mechanisms for translating climate-mitigation objectives into quantifiable emission limits. Carbon budgets are increasingly used to define allowable emission pathways consistent with long-term climate-stabilization goals, and can be downscaled to the sector and building level to set science-based targets [11, 12].

The second domain relates to Whole Life Carbon (WLC) assessment, which evaluates embodied and operational carbon emissions throughout the lifecycle of a building [1]. It provides methods for quantifying environmental performance and identifying the principal sources of emissions associated with development alternatives.

The third domain concerns financial feasibility assessment, which has traditionally guided development decisions through indicators such as development cost, return on investment, profitability, and investment risk [4]. This domain establishes the economic conditions under which projects are considered financially viable [4, 6].

The fourth domain, the integration of Building Information Modeling (BIM), Life Cycle Assessment (LCA), and Life Cycle Costing (LCC), provides analytical capability for generating, evaluating, and comparing development alternatives by linking design information with environmental and financial performance [9, 13].

Although each domain contributes valuable knowledge, existing applications generally treat environmental and financial considerations independently, leaving project feasibility fragmented between economic evaluation and sustainability assessment [3, 8].

2.3 Construct Derivation

Following domain identification, key constructs were extracted and synthesized to represent environmental and financial conditions within a common decision structure [10]. Each dimension is described by three elements: a reference condition, a constraint condition, and the budget, the allowable performance envelope defined by the constraint.

From the carbon budgeting literature, the allowable-emissions concept was translated into the Carbon Budget (CBud), defined as the range of lifecycle emission levels a project may occupy while remaining compliant with its climate target, that is, all levels at or below the ceiling ($0 \leq E \leq CC$), where E is the project's lifecycle emissions and CC is the Carbon Ceiling [11]. The upper bound of this envelope is the Carbon Ceiling (CC), the maximum allowable emissions; it is treated as a science-based target whose stringency reflects the chosen level of climate ambition [11, 12]. Whole Life Carbon assessment contributes the Carbon Baseline (CB), the expected carbon performance of a business-as-usual scenario [1]. Because the baseline typically exceeds the ceiling, the distance between them is defined as the Emissions Gap ($CB - CC$), the reduction a project must achieve to enter its carbon budget, analogous at project level to the widening gap between the sector's actual emissions and its required decarbonization pathway [2]. A business-as-usual design exceeding the ceiling is therefore a stranded, infeasible starting position, in the same sense that assets whose emissions exceed science-based decarbonization pathways face stranding risk [14].

Financial feasibility literature contributes parallel constructs. The Financial Budget (FBud) is the allowable expenditure envelope ($0 \leq C \leq FC$), where C is the project's lifecycle cost, bounded above by the Financial Ceiling (FC), the maximum acceptable spend set by investors, lenders, or affordability [4]. The Financial Baseline (FB) represents conventional development cost. As the baseline lies below the ceiling, the slack between them is defined as the Financial Headroom ($FC - FB$), which is the additional resources available to fund decarbonization while remaining financially feasible.

In both dimensions the budget is the allowable envelope bounded by the ceiling, while the baseline locates the project's starting position relative to that envelope. The carbon baseline lies outside its budget, so a reduction equal to the Emissions Gap is required, whereas the financial baseline lies inside its budget, so the Financial Headroom remains available. Table 1 summarizes the derivation, and Section 2.4 specifies how the Carbon Ceiling is quantified for an individual project.

Table 1. Construct Derivation for the Dual-Constraint Feasibility Framework

Knowledge Domain	Key Concept	Derived Construct	Role in Framework
Carbon Budget and Climate Targets	Allowable emissions envelope	Carbon Budget	Environmental feasible range
Carbon Budget and Climate Targets	Maximum allowable emissions	Carbon Ceiling	Environmental constraint
Whole Life Carbon Assessment	Business-as-usual carbon	Carbon Baseline	Environmental reference
Carbon Budget and Climate Targets	Required reduction	Emissions Gap	Environmental target / gap
Financial Feasibility Assessment	Allowable spend envelope	Financial Budget	Financial feasible range
Financial Feasibility Assessment	Maximum acceptable spend	Financial Ceiling	Financial constraint
Financial Feasibility Assessment	Conventional cost	Financial Baseline	Financial reference
Financial Feasibility Assessment	Available slack	Financial Headroom	Financial resource for reduction
BIM-LCA-LCC Integration	Integrated evaluation	Decision Support Layer	Scenario assessment

2.4 Operationalization of the Carbon Ceiling

To be applied to an individual real estate project, the Carbon Ceiling (CC) is expressed in the same unit, system boundary, and assessment period as the Carbon Baseline (CB) and the lifecycle emissions (E) of each design alternative, so that the three quantities can be compared directly. Table 2 summarizes this operational definition.

In terms of unit, CC is an absolute quantity of greenhouse gas emissions expressed in tonnes of carbon dioxide equivalent (tCO_2e) per project over the assessment period. For benchmarking across projects of different sizes, it is also reported as an intensity in kilograms of carbon dioxide equivalent per square meter of gross floor area ($kgCO_2e/m^2$), where the absolute value equals the intensity multiplied by the gross floor area.

In terms of scope, CC covers whole-life carbon, meaning both embodied and operational carbon. Following the modular structure of EN 15978 [15], embodied carbon comprises the product and construction stages (modules A1–A5), maintenance, repair, and replacement during use (B1–B5), and end of life (C1–C4), while operational carbon comprises operational energy use (B6) and, where relevant, operational water use (B7). Loads and benefits beyond the system boundary (module D) are reported separately and are not credited against the ceiling. Where early-stage information is limited, a screening boundary of A1–A5 and B6 may be applied, provided that the same boundary is used for CB, CC, and E.

In terms of assessment period, CC is defined over a reference study period (RSP) of 50 years, which is also used as the analysis period for Life Cycle Costing so that the carbon and financial dimensions share the same time horizon. A 60-year period, as specified in the RICS whole life carbon assessment standard [16], may be adopted where national or client requirements call for it, provided that CB, CC, and E are calculated over the same period.

In terms of ambition, a project cannot set its own climate target, so CC is derived in two levels. At the policy level, an ambition level is first determined from national or sectoral commitments, such as Thailand's Long-Term Low Greenhouse Gas Emission Development Strategy [17], or from a chosen climate pathway [11, 12]. At the project level, this ambition level is then translated into a Carbon Ceiling for the individual project. The ambition level must therefore be determined before the ceiling is set, and a higher ambition level produces a lower, more stringent ceiling.

In terms of calculation, CC is derived from the selected ambition level through one of two routes, depending on whether a downscaled carbon budget is available. In the budget-based route, a carbon

budget consistent with the selected ambition level is allocated to the building sector and then to new floor area [11], giving an allowable whole-life carbon intensity that is scaled to the project:

$$CC = CI_{lim} \times GFA \quad (1)$$

where CI_{lim} is the allowable whole-life carbon intensity over the RSP ($kgCO_2e/m^2$) and GFA is the gross floor area of the project (m^2), with the result converted to tCO_2e. In the reduction-based route, applied where no downscaled budget is available for the national context, CC is set as a required reduction below the project's own baseline:

$$CC = CB \times (1 - r) \quad (2)$$

where r is the required reduction rate corresponding to the selected ambition level. Under Equation (2), the Emissions Gap equals CB × r. For example, a design with CB = 100 tCO_2e and r = 40% has CC = 60 tCO_2e and an Emissions Gap of 40 tCO_2e, which are the illustrative values used in Figures 1 to 3. For symmetry, the Financial Ceiling (FC) is expressed in Thai baht (THB) of lifecycle cost over the same RSP, following the life-cycle costing principles of ISO 15686-5 [18].

Table 2. Operational definition of the Carbon Ceiling (CC) for an individual project

Element	Operational specification
Ambition level	Determined first, at the policy or national level, e.g., national long-term strategy or climate pathway; a higher ambition gives a lower CC
Unit	tCO_2e per project over the reference study period; also reported as $kgCO_2e/m^2$ of gross floor area for benchmarking
Scope	Whole-life carbon: embodied (A1–A5, B1–B5, C1–C4) and operational (B6, B7) carbon per EN 15978; module D reported separately; screening boundary A1–A5 and B6 at the early design stage
Assessment period	50-year reference study period, identical to the LCC analysis period; 60 years where the RICS standard applies
Calculation	From the selected ambition level: budget-based route, $CC = CI_{lim} \times GFA$; reduction-based route, $CC = CB \times (1 - r)$
Consistency rule	CB, CC, and E use the same unit, system boundary, and assessment period

2.5 Conceptual Integration and Framework Development

The final stage integrated the constructs into a unified feasibility structure. In contrast to conventional approaches that treat financial performance as the primary determinant of viability [4], the framework conceptualizes feasibility as the simultaneous satisfaction of environmental and financial requirements.

The integration begins by establishing the Carbon Budget within the environmental dimension and the Financial Budget within the financial dimension. Each budget is the allowable envelope bounded by its ceiling, while the Emissions Gap and Financial Headroom describe, respectively, the reduction required and the resources available to achieve it (Figure 1). The intersection of the two budgets forms the Dual Budget (CBud ∩ FBud), the joint decision space within which development alternatives must operate. Alternatives located outside either constraint boundary are infeasible regardless of their performance in the other dimension.

On this basis, the Dual-Constraint Feasibility Framework (DCFF) positions feasibility as an emergent condition arising from the interaction of environmental and financial boundaries rather than the optimization of a single objective. BIM, LCA, and LCC are positioned as enabling mechanisms supporting the generation, evaluation, and comparison of alternatives within the feasible space [9, 13], providing a conceptual foundation for future climate-aligned, financially viable decision-support systems.

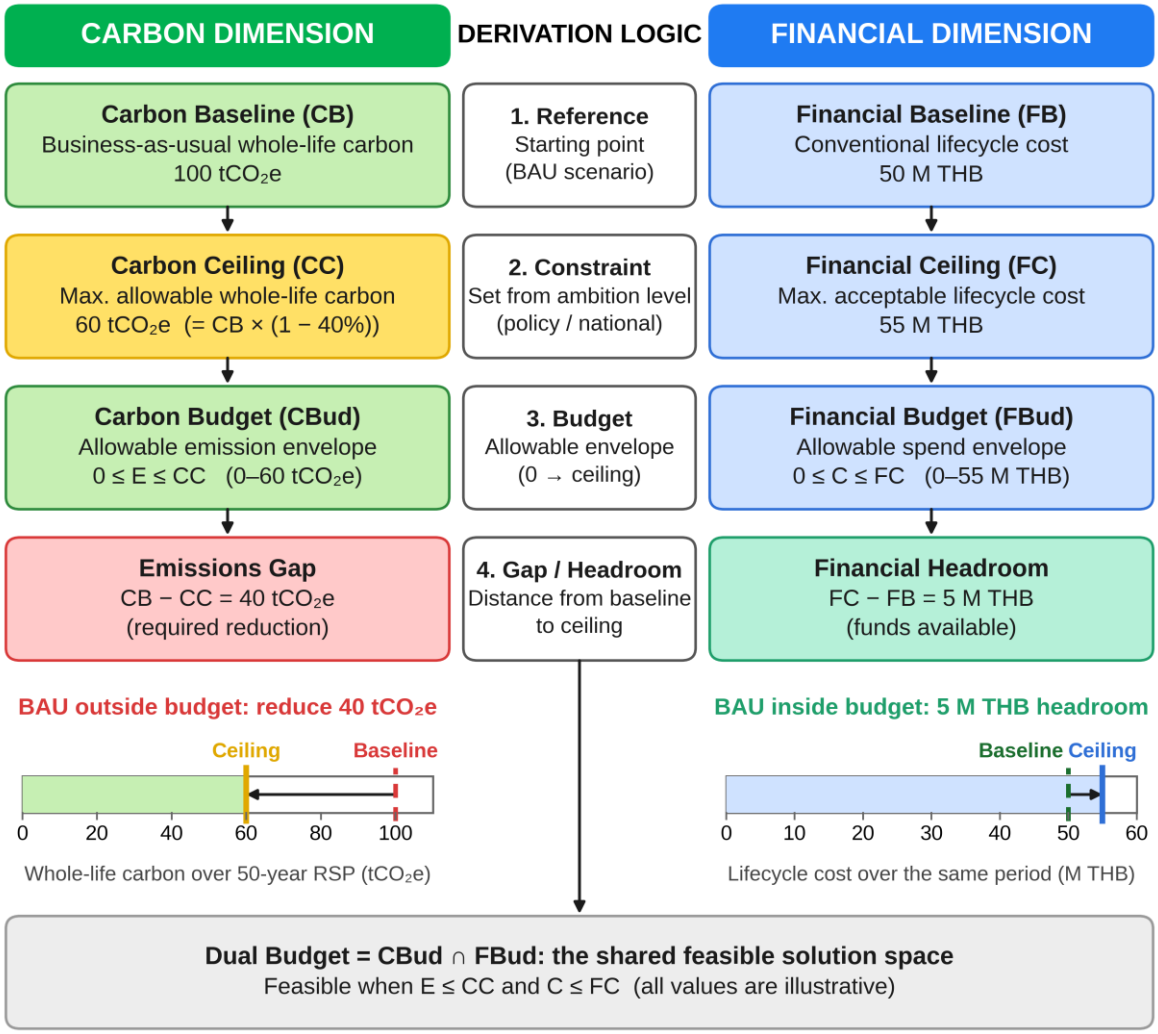

Figure 1. Derivation of the Carbon and Financial Budgets and the associated Emissions Gap and Financial Headroom from reference and constraint conditions, using illustrative values.

3. RESULTS AND DISCUSSION

3.1 Reframing Feasibility Assessment: From Financial Evaluation to Dual Constraints

A primary outcome of this study is the reconceptualization of project feasibility from a predominantly financial evaluation toward a dual-constraint perspective. Conventional feasibility studies determine viability through financial indicators such as development cost, profitability, return on investment, and market demand [4], with environmental performance assessed separately and often after major design decisions [3]. The proposed framework positions carbon performance as a binding decision constraint, expressed through the Carbon Ceiling, a science-based target, rather than solely a sustainability indicator. Consequently, feasibility is no longer determined by financial viability alone but emerges from the simultaneous satisfaction of environmental and financial requirements, transforming feasibility assessment from a single-objective process into a multi-dimensional decision structure aligned with low-carbon development.

3.2 Carbon Constraint Dimension

The first dimension concerns environmental feasibility. Carbon Baseline (CB) represents the expected whole-life carbon performance of a business-as-usual scenario and serves as the starting point for reduction. Carbon Ceiling (CC) represents the maximum allowable whole-life emissions over the reference study period; it is treated as a science-based target derived by downscaling a carbon budget

to a chosen climate-ambition pathway, so that its stringency reflects the level of ambition adopted [11, 12]. The ambition level is therefore determined at the policy or national level before the ceiling is set for the project. Where no downscaled budget is available, CC is set as a required reduction below the baseline, as specified in Section 2.4 and Table 2.

The Carbon Ceiling (CC) sets the upper limit of the Carbon Budget (CBud). The Carbon Budget is the range of emissions a project is allowed to produce, from zero up to the ceiling ($0 \leq E \leq CC$), where E is the project's whole-life emissions in tCO_2e. Any feasible design must keep its emissions within this range [11]. The distance from the baseline down to this envelope is the Emissions Gap ($CB - CC$), the reduction required for compliance. A business-as-usual design whose emissions exceed the ceiling lies outside its budget, a stranded, infeasible starting point [2, 14]. Framing the budget in this way shifts carbon from a post-design reporting metric toward a predefined boundary that actively constrains early design decisions [5, 11].

3.3 Financial Constraint Dimension

The second dimension concerns financial feasibility and is structured identically. Financial Baseline (FB) represents the expected cost of a conventional development scenario, while Financial Ceiling (FC) represents the maximum acceptable spend set by investors, lenders, or affordability requirements [4].

The Financial Ceiling (FC) sets the upper limit of the Financial Budget (FBud). The Financial Budget is the range of spending a project is allowed to incur, from zero up to the ceiling ($0 \leq C \leq FC$), where C is the project's lifecycle cost in THB over the same reference study period. Any feasible design must keep its cost within this range. Because conventional cost typically sits below the ceiling, the slack between them is the Financial Headroom ($FC - FB$), which is the additional resources available to fund decarbonization while the project remains financially feasible. Carbon-reduction strategies are therefore evaluated not only on environmental effectiveness but on whether their cost fits within this headroom [3, 19].

3.4 Dual Budget Concept

A key contribution of this study is the Dual Budget, defined as the intersection of the Carbon and Financial Budget envelopes ($CBud \cap FBud$). It represents the joint decision space in which an alternative simultaneously satisfies both ceilings (carbon $\leq$ CC and cost $\leq$ FC), where CC is the Carbon Ceiling and FC is the Financial Ceiling. The two budgets are complementary: the Emissions Gap expresses what must be reduced, while the Financial Headroom expresses the capacity available to reduce it.

Unlike single-objective optimization, the Dual Budget treats development decisions as bounded by multiple interacting limits. A design satisfying the financial budget but exceeding the Carbon Ceiling is infeasible, and an environmentally preferable design exceeding the Financial Ceiling is equally infeasible. Feasibility thus shifts from isolated performance optimization toward balanced decision-making within both envelopes.

3.5 Shared Feasible Solution Space and the Dual-Constraint Feasibility Framework

The intersection of the two budgets produces the shared feasible solution space, the set of development alternatives whose carbon and cost both fall within their respective envelopes (Figure 2). Alternatives inside this region are feasible; those beyond either ceiling are infeasible regardless of performance in the other dimension. The business-as-usual design lies outside the space on the carbon axis and must be brought into it by closing the Emissions Gap while keeping any additional expenditure within the Financial Headroom.

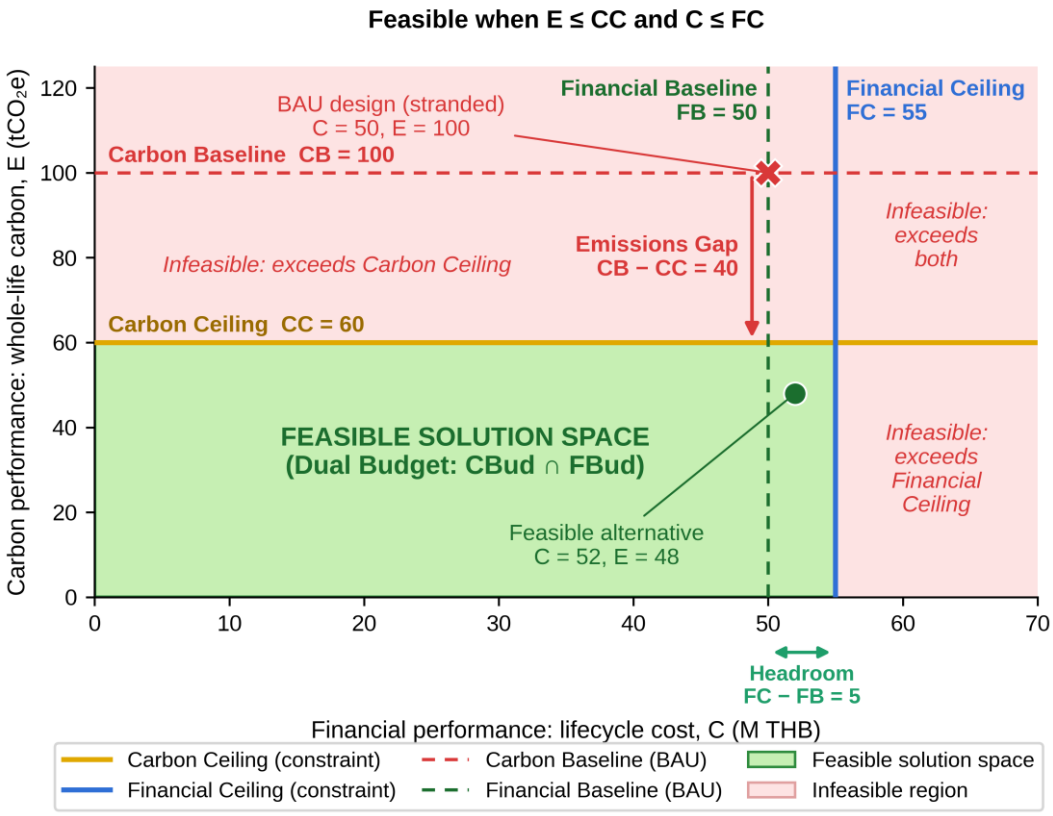

Figure 2. Shared feasible solution space under dual constraints. A development alternative is feasible only if its carbon performance and cost both fall within the Carbon and Financial Budgets; values are illustrative.

Building on this, Figure 3 presents the Dual-Constraint Feasibility Framework (DCFF) as an iterative process. The ambition level set at the policy or national level and the requirements of investors and lenders first determine the Carbon Ceiling and the Financial Ceiling, which, together with the Carbon Baseline and Financial Baseline, establish the Dual Budget and the feasible space. The design team then develops design scenarios, and each scenario is integrated with BIM, LCA, and LCC to calculate its whole-life carbon and lifecycle cost. The results are plotted on the feasibility graph to show which scenarios lie inside or outside the feasible space. Scenarios outside the space are redesigned or their costs adjusted, and the recalculated results are plotted again until a feasible design is identified. Feasibility is conceptualized as an emergent condition arising from the interaction of environmental and financial constraints rather than the optimization of a single objective. The framework thus provides a foundation for decision-support systems capable of transparent, traceable, and climate-aligned development decisions.

3.6 Implications for Sustainable Cities and Infrastructure

The framework has implications beyond individual projects. Because buildings collectively account for a significant share of global energy-related carbon emissions, resource consumption, and infrastructure demand, decisions made at the early design stage influence not only project outcomes but also broader urban sustainability trajectories [2]. By integrating carbon and financial considerations within a common feasibility structure, the framework supports balanced decision-making aligned with climate-mitigation objectives and sustainable development goals [20]. It is particularly relevant to emerging green-finance initiatives, climate-risk management, and low-carbon infrastructure development, where environmental performance and economic viability must increasingly be considered together. The framework therefore advances feasibility assessment toward a more

integrated, systems-oriented perspective supporting sustainable cities, climate-resilient infrastructure, and long-term decarbonization [19].

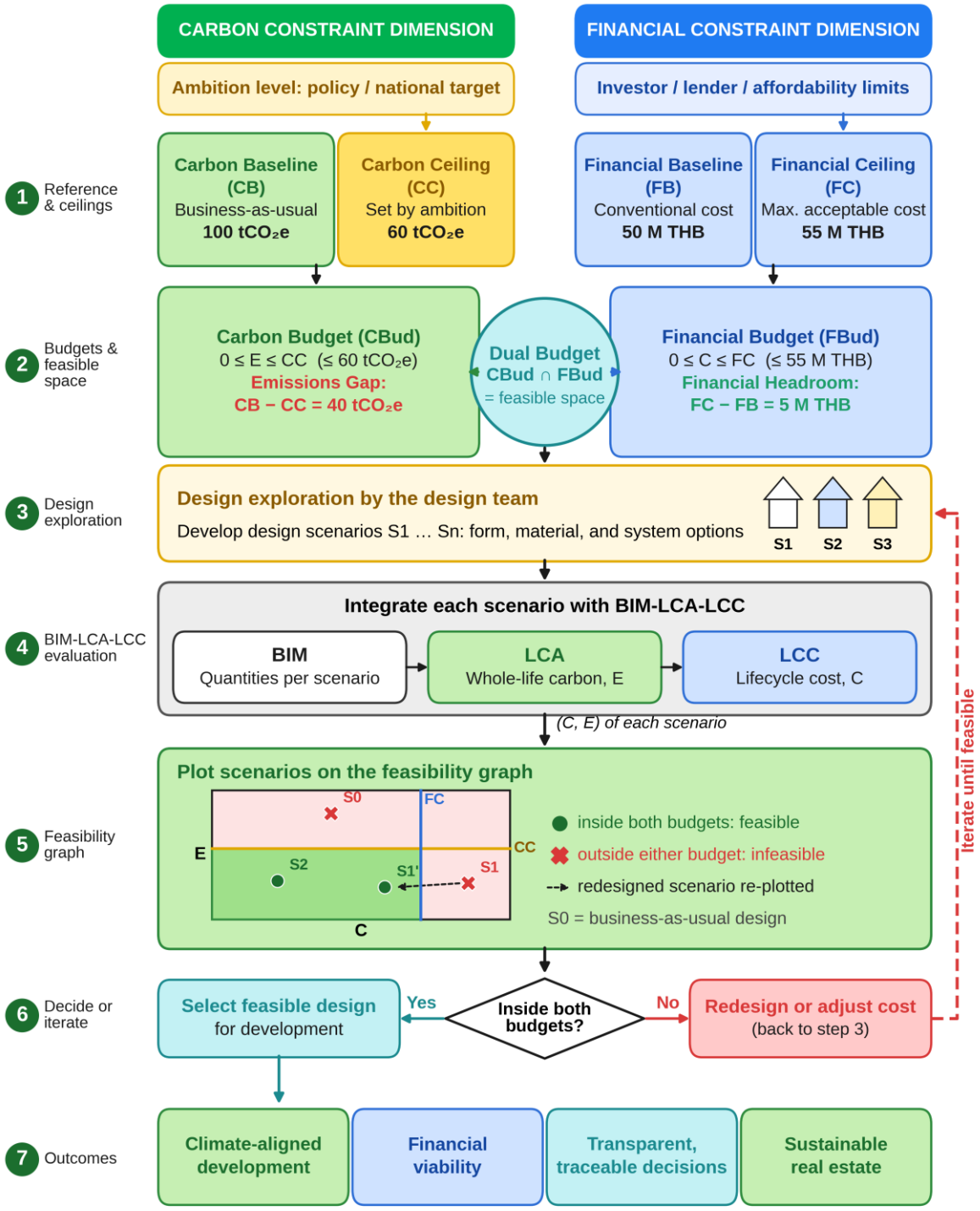

Figure 3. Iterative process of the Dual-Constraint Feasibility Framework in early-stage real estate development: setting the constraints, design exploration, BIM-LCA-LCC evaluation, and plotting of design scenarios against the feasible space until a feasible design is found.

4. CONCLUSIONS

This study proposed a conceptual Dual-Constraint Feasibility Framework (DCFF) for integrating carbon and financial considerations within early-stage real estate feasibility assessment.

The framework defines the Carbon Ceiling, expressed as a science-based target, and the Financial Ceiling as project-level constraints, each bounding an allowable budget: the Carbon Budget and the Financial Budget, respectively. The Carbon Ceiling is operationalized as the maximum allowable whole-life carbon of a project in tCO_2e, covering embodied and operational carbon over a 50-year reference study period. It is set in two levels: an ambition level is first determined at the policy or national level and is then translated into a project-level ceiling either from a downscaled carbon budget or from a required reduction below the Carbon Baseline, so that it can be calculated for an individual project. It distinguishes the Emissions Gap, the reduction required of a business-as-usual design, from the Financial Headroom available to fund it. Their intersection forms the Dual Budget, a shared feasible solution space in which alternatives must satisfy both constraints simultaneously; a design exceeding either ceiling is infeasible. BIM, LCA, and LCC serve as complementary enabling tools supporting transparent, traceable scenario evaluation.

By incorporating carbon directly into feasibility assessment, the framework extends conventional financial evaluation toward a systems-oriented decision-support approach and contributes to low-carbon development and sustainable cities. Future research may operationalize it through simulation models, empirical case studies, and BIM-LCA-LCC-based decision-support systems.

Acknowledgement

The authors would like to acknowledge Chulalongkorn University for academic support and guidance throughout this research development process.

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