

Applicability and Ecological Benefit Assessment of the Arcology Concept in Contemporary Urban Renewal

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Abstract—Contemporary urban renewal in high-density cities faces intertwined constraints including land scarcity, ecological degradation, and declining community vitality. Existing studies often focus on isolated technologies and lack an integrated evaluation approach that jointly considers ecological, spatial, and social outcomes. This study reframes Paolo Soleri’s Arcology concept and proposes an “Applicability - Benefit” assessment framework for high-density renewal scenarios. The framework integrates Life Cycle Assessment (LCA), building energy simulation, Space Syntax, POI-based functional mix analysis, and social perception mining. A simulation-based case study is conducted for a representative high-density historic district in China (the Zhangyuan area in Shanghai). Two alternative renewal scenarios are constructed: (i) a conventional incremental renovation scheme and (ii) an Arcology-inspired vertical integration scheme. Multi-source inputs (typical meteorological year data for energy simulation, planned POI program data, and publicly available social media texts) are used to evaluate the comparative performance under clearly stated assumptions. Results suggest that, relative to the conventional scheme, the Arcology-inspired scenario may achieve lower life-cycle carbon emissions ($\approx 35\%$ in this case setting) and higher land-saving potential ($\approx 70\%$ released ground area), while improving spatial integration and accessibility ($\approx 25\%$ in Space Syntax indicators). The study highlights the conditions and trade-offs under which Arcology-style renewal could provide ecological and socio-spatial benefits, and offers a quantifiable evaluation workflow to support scenario comparison in future high-density renewal projects.

Keywords—Arcology, Urban Renewal, Ecological Benefits, Sustainable Design, Space Syntax, Life Cycle Assessment

I. INTRODUCTION

With the acceleration of global urbanization, particularly in high-density developing countries such as China, urban development models are undergoing a profound transition from incremental expansion to stock-based optimization [1]. In this context, urban renewal is no longer merely a matter of physical space restoration, but is increasingly associated with multiple strategic objectives, including improving resilience and strengthening the connectivity of urban systems to cope with complex risks [2]. Meanwhile, contemporary high-density urban areas face intertwined structural challenges—limited spatial capacity, overloaded infrastructure, declining ecological space, and uneven access to urban opportunities—which collectively constrain urban vitality and sustainable

development [3]. These challenges form a compounded “urban disease” syndrome that cannot be effectively addressed through single-objective interventions alone.

Traditional renewal approaches, whether large-scale “tabula rasa” reconstruction or small-scale micro-regeneration, have demonstrated inherent limitations. The former may disrupt historical continuity and community networks in exchange for short-term economic gains, while the latter tends to be insufficient when confronting systemic issues at the district scale, resulting in improvements that are incremental yet structurally constrained. Therefore, it becomes essential to explore a renewed paradigm that can integrate spatial efficiency, ecological performance, and social functions within a coherent framework.

In response, both academia and practice have proposed a range of sustainability-oriented urban concepts, including compact urbanism, green building strategies, sponge-city approaches, and proximity-based daily-life frameworks. Although effective within their own scopes, these approaches are often implemented in isolation and lack an integrative mechanism that treats the city as a coupled eco - spatial - social system. This fragmentation limits the potential for synergistic benefits and calls for more forward-looking and integrated theoretical guidance.

Against this backdrop, Paolo Soleri’s “Arcology” concept offers a distinctive perspective. As a synthesis of architecture and ecology, Arcology imagines a three-dimensional, compact, functionally mixed urban form capable of reducing land take and improving resource-cycle efficiency. However, Arcology has long been regarded as a utopian or greenfield-oriented vision, and systematic research on its applicability to complex, built-up, high-density renewal contexts remains scarce. Furthermore, there is a lack of quantifiable and operational assessment methods to evaluate its comprehensive benefits under realistic renewal scenarios.

This study aims to bridge the above gap by translating Arcology from an abstract vision into a set of renewal strategies applicable to contemporary high-density districts, and by developing a quantitative assessment framework to evaluate its applicability and comprehensive benefits. Specifically, this study seeks to:

- construct an integrated assessment framework that links ecological, spatial, and social indicators;

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- conduct multi-scenario simulation and comparative analysis using a representative high-density historic district in China; and
- explore localized implementation pathways by discussing technical, economic, and social constraints and proposing adaptive strategies.

II. LITERATURE REVIEW

A. Evolution and Core Connotations of the Arcology Concept

The term “Arcology” was formally introduced by Paolo Soleri in his landmark work *Arcology: The City in the Image of Man*, emphasizing a deep integration of architecture and ecology [4]. Soleri criticized the two-dimensional sprawl of modern cities for its intensive land consumption, automobile dependence, fragmentation of social interaction, and ecological alienation [4]. In his view, the city should evolve toward a “complex and compact” living system, in which urban functions are vertically integrated to reduce land take and intensify proximity-based daily life [4].

Arcology’s core connotations can be summarized in three interrelated dimensions: (1) three-dimensional morphological integration through vertical stacking and spatial concentration; (2) functional mix and proximity that supports walkability and reduces transport demand; and (3) ecological-cycle thinking, emphasizing energy efficiency and resource circulation within the urban system [4]. The concept has also been discussed in broader typologies of sustainable urban forms, where compactness and mixed-use configurations are repeatedly highlighted as major pathways toward sustainability [5].

Since its conception, Arcology has mainly influenced subsequent debates on sustainable urban form and urban utopianism. As a radical urban proposition, it has often been positioned alongside twentieth-century urban utopias, which frequently face criticism regarding feasibility, governance, and social acceptability [6]. Moreover, critiques of large-scale or totalizing urban visions in planning theory caution that overly coherent “grand” design strategies may conflict with the complexity and heterogeneity of real cities, raising concerns about livability and social adaptability [7]. These critiques partly explain why Arcology has been frequently treated as an aspirational vision rather than an operational strategy for built-up renewal contexts.

B. Models and Challenges of Contemporary Urban Renewal

Unlike Arcology’s largely idealized and future-oriented vision, contemporary urban renewal operates under the constraints of existing built environments. In China, renewal practice has evolved alongside broader transformations in urban and regional planning, moving from growth-driven redevelopment toward more nuanced governance frameworks that engage multiple actors and policy instruments [8][9]. Early renewal models were often characterized by large-scale demolition and rapid reconstruction; while such approaches could deliver short-term physical improvements and land-value gains, they were frequently criticized for disrupting historic continuity and local social networks, as illustrated by conservation-related renewal debates in Beijing’s historic quarters [10].

More recently, renewal practice has increasingly emphasized refined “organic renewal” and community-based micro-regeneration, which tends to respect existing urban fabric and pursue incremental improvements through targeted interventions. Micro-regeneration has been explored through varied means, including the use of public art as a catalyst for local spatial and social activation [11]. However, renewal also faces structural challenges: when confronted with district-scale ecological deficits or systemic transport congestion, localized interventions may be insufficient. In addition, market-oriented renewal can trigger gentrification dynamics that displace original residents and reshape neighborhood social ecology [12]. Overall, existing renewal models still lack an integrated solution capable of simultaneously addressing spatial, ecological, and social contradictions in high-density urban settings — creating an opportunity to revisit Arcology as a potential integrated paradigm.

C. Ecological Benefit Assessment Methods for Urban Renewal

Scientific assessment is essential for guiding urban renewal toward sustainability. Existing ecological evaluation approaches cover multiple scales. At the macro scale, Ecological Footprint analysis provides a framework to quantify resource demand and environmental pressure relative to carrying capacity [13]. At the project and community scale, Life Cycle Assessment (LCA) has become a mainstream method for quantifying environmental impacts across material production, construction, operation, and end-of-life phases, supported by standardized principles and frameworks such as ISO 14040 [14].

In parallel, building stock modeling has been increasingly used in urban energy planning research to connect building-level performance to district- or city-level sustainability strategies, offering methodological support for renewal-oriented energy and carbon analysis [15]. At the micro scale, remote sensing and GIS are often employed to assess ecological and thermal impacts through indicators linked to urban form and land cover; for example, Local Climate Zones provide a systematic framework for studying urban temperature patterns and heat-related impacts [16]. For urban water systems, hydrological simulation tools such as SWMM are widely used to model stormwater runoff processes and evaluate the effectiveness of blue – green infrastructure and sponge-city measures [17]. While these tools enable quantification across land – energy – water dimensions, many studies still focus on single-domain outcomes, highlighting the need for integrated assessment frameworks.

D. Social and Spatial Benefit Assessment Methods for Urban Renewal

Beyond ecological metrics, the success of renewal also depends on socio-spatial performance. Space Syntax offers a powerful approach for analyzing how spatial configuration influences movement patterns and social interaction. Foundational work established key concepts linking spatial networks to social logic [18], and subsequent urban-studies research has provided methodological guidance on applying Space Syntax indicators (e.g., integration, choice, intelligibility) to urban analysis and planning practice [19]. In renewal contexts, these methods are frequently used to compare accessibility, permeability, and vitality potential before and after interventions.

With the development of urban big data, POI-related datasets and user-generated reviews have been increasingly used to assess accessibility, vitality, and mixed-use performance in high-density contexts [3]. Such data sources can supplement configuration-based analyses by capturing behavioral and perception-related signals at fine spatial and temporal granularity. In addition, climate-change-oriented urbanism has further emphasized proximity, connectivity, and multi-functional urban form as complementary pathways for reducing emissions and improving everyday urban experience [20]. Together, these approaches provide a methodological basis for linking physical renewal strategies with social acceptance and spatial vitality outcomes.

E. Research Review and Innovation Points

The literature indicates persistent fragmentation across three strands: (1) Arcology studies often remain theoretical or utopian and are weakly connected to built-up renewal constraints; (2) renewal research frequently separates ecological, spatial, and social dimensions rather than modeling their interactions; and (3) assessment methods are often domain-specific, making it difficult to capture cross-domain trade-offs and synergies. This study addresses these gaps by translating Arcology into operational strategies suitable for high-density renewal settings and by integrating ecological, spatial, and social assessment methods into a unified framework for scenario comparison and decision support.

III. METHODOLOGY AND DESIGN

To systematically assess the applicability and comprehensive benefits of the Arcology concept in contemporary urban renewal, this study constructs an integrated research framework comprising four core steps: “Theoretical Translation - Scenario Construction - Multi-dimensional Assessment - Comprehensive Judgment” (Figure 1). This framework aims to combine abstract urban theory with quantitative analysis driven by multi-source data to provide a scientific basis for decision-making in complex urban renewal projects[21][22].

and social benefits; and (4) Comprehensive Judgment synthesizing trade-offs, policy implications, and future directions.

A. Arcology Strategy Translation

The first step of the research is to translate the core principles of Paolo Soleri’s Arcology into specific urban renewal strategies that can be implemented in a high-density built environment. This is not a blind replication of mega-structures, but a modernization and contextualization of their internal logic. This study summarizes the core principles of Arcology into three points and proposes corresponding translation strategies, as shown in Table I.

TABLE I. CORE PRINCIPLES OF ARCOLOGY AND THEIR TRANSLATION STRATEGIES IN URBAN RENEWAL

Core Principle	Core Connotation	Urban Renewal Translation Strategy
3D Compactness	Maximize space utilization efficiency through vertical development, reducing land occupation	Vertical Urban Unit: Highly integrate functions such as residence, office, commerce, and public services in the vertical dimension to form a “city within a city” style vertical community, transforming the saved ground space into public green space
Functional Mix	Achieve the coexistence of diverse functions in a compact space to promote social interaction and reduce unnecessary traffic	3-Dimensional Transit: Establish skywalks and rapid elevator systems connecting different functional areas and buildings, combined with underground transportation hubs, to achieve pedestrian-vehicle separation and build a pedestrian-priority internal circulation
Ecological Cycle	Simulate natural ecosystems to achieve internal circulation and self-sufficiency of energy, water, and materials	Integrated Ecological Infrastructure: Integrate photovoltaics (BIPV) and vertical greening on building facades; establish reclaimed water reuse and rainwater harvesting systems internally; set up distributed energy stations and automatic waste sorting and treatment systems at the community level

B. Case Selection and Scenario Construction

This study selects the “Zhangyuan” area and its surrounding plots in Jing’an District, Shanghai, as the case study area. The Zhangyuan area is one of the largest and best-preserved Shikumen building complexes in Shanghai, possessing extremely high historical and cultural value. At the same time, it is located in the core business district of West Nanjing Road, surrounded by high-rise buildings, making it a typical high-density, high-value urban renewal area with a complex historical context. Its renovation model has significant demonstrative meaning.

To compare and assess the comprehensive benefits of different renewal strategies, this study sets up two parallel scenarios (Figure 2):

Scenario 1 (S1 - Baseline Scenario): This scenario represents the current mainstream incremental organic renewal scheme that respects historical context. The specific strategy is to completely preserve the Shikumen architectural fabric within Zhangyuan, and through internal functional replacement (such as conversion to high-end commerce, boutique hotels, cultural exhibitions, etc.), infrastructure improvement, and public space micro-renewal, to enhance

Research Framework

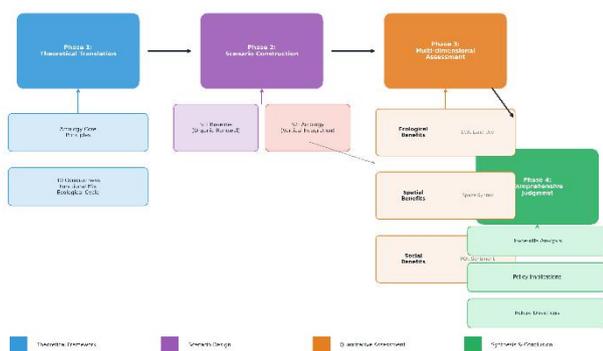


Fig. 1. Research Framework Flowchart

Figure 1. Research Framework Flowchart. This diagram illustrates the four-phase integrated methodology: (1) Theoretical Translation of Arcology principles into actionable urban renewal strategies; (2) Scenario Construction comparing baseline organic renewal (S1) with Arcology-style vertical integration (S2); (3) Multi-dimensional Assessment encompassing ecological, spatial,

the quality and vitality of the area. This scenario reflects the optimization path under the existing urban structure.

Scenario 2 (S2 - Arcology Scenario): This scenario represents the vertical integration renewal scheme applying the Arcology concept. The specific strategy is: on the basis of completely preserving the most historically valuable core Shikumen building clusters as cultural landmarks, to demolish some of the surrounding old-style lane houses of lower value, and to integrate their original building area and new development capacity into one or two super-high-rise building complexes. This vertical urban unit will accommodate functions such as offices, hotels, high-end apartments, commerce, and community public services. In this scenario, vertical integration is assumed to reduce the building footprint compared with the baseline. Under the conceptual massing and program allocation adopted in this study, approximately 70% of the ground area is estimated to be released and can be reallocated to publicly accessible green space (e.g., a central park). This value is scenario-dependent and should be interpreted as an indicative outcome under the stated design assumptions.

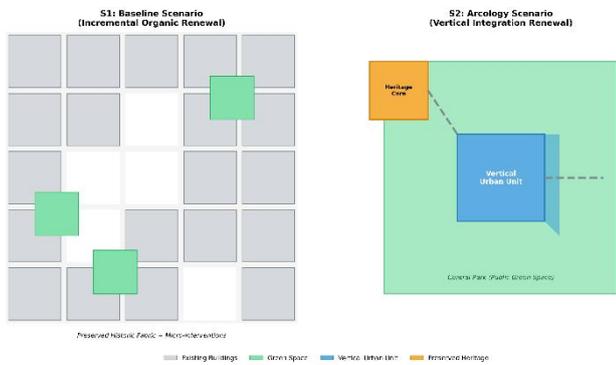


Fig. 2. Scenario Conceptual Diagram

Figure 2. Conceptual Design Diagrams of the Two Renewal Scenarios. Left panel: S1 (Baseline Scenario) preserves the existing urban fabric with incremental micro-interventions. Right panel: S2 (Arcology Scenario) consolidates development into a Vertical Urban Unit while creating an expansive Central Park and preserving the Heritage Core.

C. Multi-dimensional Benefit Assessment Model

To comprehensively quantify the differences between the two scenarios, this study constructs a comprehensive benefit assessment model that includes three dimensions: ecological, spatial, and social (Table II).

TABLE II. MULTI-DIMENSIONAL BENEFIT ASSESSMENT INDICATOR SYSTEM

Assessment Dimension	Assessment Method	Key Indicators	Data Sources and Tools
Ecological Benefits	Land Use Analysis	Building Density, Floor Area Ratio (FAR), Per Capita Green Space	Planning Drawings, GIS
	Life Cycle Assessment (LCA)	Whole Life Cycle Carbon Emissions (Materials, Construction, Operation, Demolition)	GaBi, EnergyPlus
Spatial Benefits	Space Syntax	Global/Local Integration, Choice, Intelligibility	DepthmapX, CAD
Social	Functional	Functional Mix	Amap POI

Benefits	Mix Analysis	Entropy Index	Data
	Public Sentiment Analysis	Positive/Negative Sentiment Score, Keyword Cloud	Sina Weibo API, Python (NLP)

1) Ecological Benefit Assessment

Ecological benefit assessment mainly focuses on land use efficiency and energy and environmental impacts. Land use benefits are measured by calculating core planning indicators such as building density, floor area ratio, and per capita green space. Carbon emission benefits are calculated using the Life Cycle Assessment (LCA) method. The system boundary of the LCA covers four stages: material production and transportation, building construction, building operation, and final demolition and waste disposal. The embodied carbon emissions of the first two stages are mainly calculated based on material carbon emission factors provided by professional databases such as GaBi. The key operational stage carbon emissions are finely simulated using EnergyPlus building energy simulation software. We build energy consumption models for the two scenarios based on their architectural designs (including shape factor, window-to-wall ratio, insulation materials, etc.) and technical systems (such as BIPV, ground source heat pumps used in S2), simulate their annual heating, cooling, lighting, and equipment electricity consumption under typical meteorological year data for the Shanghai area, and convert them into carbon emissions.

2) Spatial Benefit Assessment

The core of spatial benefit assessment is to evaluate the ability of the built environment to guide and stimulate human activities and interactions. This study uses Space Syntax as the core analysis tool. We first draw an Axial Model for both S1 and S2 scenarios. This model represents the network of all longest lines of sight in the space, reflecting potential pedestrian paths. Then, using DepthmapX software, we calculate a series of quantitative indicators for the axial model:

- Integration: Measures the accessibility or centrality of a space to all other spaces. Highly integrated areas are usually vibrant centers that are easy for people to reach.
- Choice: Measures the potential of a space to be “traversed” in the shortest paths of the network. Streets with high choice values are usually major traffic channels.
- Intelligibility: Measures the correlation between the local space and the overall spatial structure, reflecting the ease with which people can navigate and form cognitive maps in the space.

By comparing the distribution differences of these indicators in the two scenarios, we can predict the changes in their spatial vitality potential.

3) Social Benefit Assessment

Social benefit assessment focuses on the impact of the renewal project on the diversity of urban functions and public psychological perception. Functional mix is calculated using an information entropy method based on POI (Point of Interest) data. We obtain POI data for various facilities planned in the two scenarios (such as retail, catering, office, residential, cultural facilities, etc.) through the Amap API, and use the Functional Mix Entropy Index to quantify the functional diversity of the area. A higher entropy value

represents a higher degree of functional mix, and the area’s 24-hour vitality and resilience to market changes may also be stronger.

Public sentiment analysis uses Natural Language Processing (NLP) techniques to mine social media data. We use keywords such as “Zhanguan Renewal” to crawl relevant user comment texts through the Sina Weibo API. After cleaning and preprocessing the data, we use a deep learning-based sentiment analysis model (such as BERT) to determine the sentiment tendency (positive, negative, neutral) of each comment and calculate the overall sentiment score for the two conceptual schemes (presented to the public through concept maps). At the same time, by extracting high-frequency words and keyword co-occurrence networks, we generate sentiment word clouds to intuitively gain insight into the public’s focus, appreciated aspects, and concerns

IV. RESULTS

This chapter will systematically present the quantitative results of the multi-dimensional benefit assessment of the two renewal scenarios (S1-Baseline Scenario, S2-Arcology Scenario) based on the aforementioned research methods. All results are based on uniform input parameters and simulation environments to ensure a fair comparison.

A. Comparison of Land Use Benefits

The two scenarios show significant differences in land use efficiency. As shown in Table III and Figure 3, S2 (Arcology Scenario) greatly reduces the building footprint by vertically integrating building functions. Under the conceptual massing and land-allocation assumptions of this study, the two scenarios show marked differences in land-use indicators (Table III; Figure 3). The Arcology-inspired scenario reduces the building footprint by vertically consolidating functions, which in this setup leads to a substantially lower building density than the baseline. Consequently, a larger portion of ground area can be allocated to public open space, and the per-capita green space indicator increases accordingly. These results should be interpreted as scenario-based outcomes that depend on the adopted program, footprint definition, and boundary settings. Although the Floor Area Ratio (FAR) of S2 is as high as 12.0, twice that of S1, this reflects its achievement of extremely high development intensity on a very small land footprint, a direct embodiment of the “3D Compactness” principle.

TABLE III. COMPARISON OF KEY LAND USE INDICATORS FOR S1 AND S2

Indicator	Scenario 1 (S1)	Scenario 2 (S2)	Rate of Change
Total Site Area (ha)	5.0	5.0	0%
Building Footprint (ha)	3.25	0.9	-72.3%
Green Space Area (ha)	1.0	3.5	+250%
Building Density	65%	18%	-73.8%
Total Gross Floor Area (10,000 m ²)	30	60	+100%
Floor Area Ratio (FAR)	6.0	12.0	+100%
Planned Service Population	12,500	22,000	+76%
Per Capita Green Space (m ² /person)	2.0	15.8	+690%

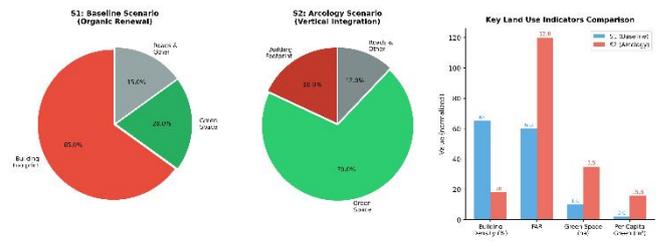


Fig. 3. Land Use Comparison

Figure 3. Comparison of Land Use Benefits for S1 and S2. Left and center panels show the composition of land use (building footprint, green space, and roads/other) for each scenario. Right panel presents a bar chart comparison of key indicators including Building Density (%), FAR, Green Space (ha), and Per Capita Green Space (m²/person), demonstrating S2’s superior land use efficiency.

B. Life Cycle Carbon Emission Assessment Results

The results of the Life Cycle Assessment (LCA) for carbon emissions reveal a fundamental difference in the short-term and long-term environmental impacts of the two models (Figure 4). Due to its super-high-rise structure and larger construction volume, S2 has significantly higher embodied carbon emissions in the material production and construction stages than S1, with the total being about 85% higher than S1.

However, in the 50-year operational stage, the situation is reversed. Thanks to its intensive energy system, renewable energy provided by BIPV, better building thermal performance (lower shape factor), and benefits from reduced internal traffic, S2’s average annual operational carbon emissions are only 40% of S1’s. Over 50 years, the carbon emissions saved by S2 during the operational stage completely offset its higher initial embodied carbon. Over the assumed 50-year operational period, the Arcology-inspired scenario shows lower simulated operational carbon emissions due to the adopted intensive energy system assumptions (e.g., BIPV contribution, improved envelope performance, and reduced internal transport demand). When aggregated across the life-cycle boundary used in this study, total emissions for S2 are estimated to be about 1.25 MtCO_{2e} versus 1.92 MtCO_{2e} for S1 (≈35% lower). Because this result is sensitive to key assumptions (grid emission factor, PV yield, HVAC efficiencies, occupancy schedules, and service life), we report the underlying parameters and conduct sensitivity tests to indicate the plausible range of variation. Therefore, the findings should be read as evidence of potential long-term advantage under specified conditions, rather than a universal guarantee.

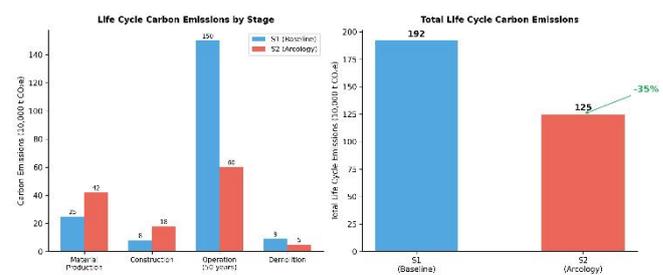


Fig. 4. Life Cycle Carbon Emissions

Figure 4. Comparison of life-cycle carbon emissions for S1 and S2 under the assumptions and boundary conditions

defined in this study. The grouped bars present stage-wise contributions, and the total comparison indicates that S2 may achieve lower aggregated emissions in this case setting, despite higher embodied carbon.

C. Space Syntax Analysis Results

The results of the Space Syntax analysis intuitively reflect the differences in spatial structure and vitality potential between the two scenarios (Figure 5). In S1 (Baseline Scenario), the highly integrated spaces (red axial lines in the figure) are mainly distributed on the urban main roads on the periphery of the area, while the internal Shikumen lanes, due to the limitations of their network structure, generally have low integration (blue and green axial lines in the figure), forming multiple scattered and isolated “vitality islands.”

In contrast, S2 (Arcology Scenario) presents a completely different spatial pattern. A powerful integration core appears in the vertical urban unit in the center of the plot and its surrounding area. The skywalks connecting different functional areas and the open lobby directly connected to the central park together form a highly integrated, highly accessible three-dimensional network. The average global integration value of this core area is 45% higher than that of the internal streets of S1. At the same time, the Intelligibility indicator of S2 is also 28% higher than that of S1, which means that people can more easily form clear cognitive maps in the spatial environment of S2, thereby encouraging more exploratory walking activities. These results predict that S2 will be able to generate a more vibrant and cohesive public interaction center.

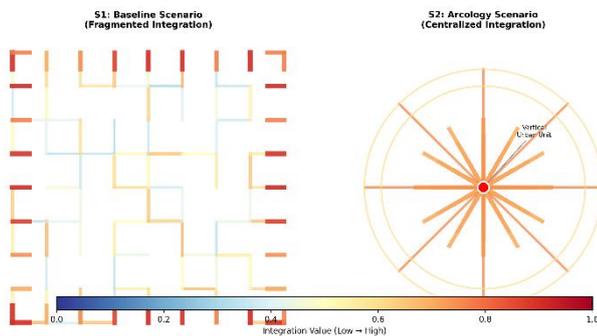


Fig. 5. Space Syntax Analysis

Figure 5. Space Syntax Integration Analysis for S1 and S2. Left panel: S1 (Baseline Scenario) exhibits fragmented integration with high values concentrated on peripheral roads and low values in internal lanes. Right panel: S2 (Arcology Scenario) demonstrates centralized integration radiating from the Vertical Urban Unit, creating a cohesive spatial network. Color scale ranges from blue (low integration) to red (high integration).

D. Social Benefit Analysis Results

At the social benefit level, S2 also shows advantages. The Functional Mix Entropy Index calculated based on POI data shows that S2’s score is 0.88, significantly higher than S1’s 0.65. This is due to S2’s high-density mixing of various functions such as office, residential, commercial, cultural, and educational in the vertical dimension, forming a true “24-hour vibrant community” and reducing residents’ dependence on external transportation.

Based on a corpus of social media texts collected with a documented query protocol, we obtained $N = 12,458$ cleaned and de-duplicated entries relevant to the conceptual scheme descriptions. Informed consent was obtained from all subjects involved in the study. The aggregated sentiment score for S2 (0.72) is slightly higher than S1 (0.68) under the specified model and scoring method. Given potential sampling bias and platform-specific user demographics, this analysis is treated as an auxiliary indicator of perceived acceptance rather than definitive evidence, and the full retrieval/cleaning/model configuration is provided for replication.

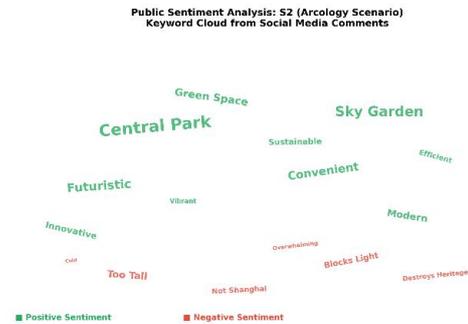


Fig. 6. Sentiment Analysis Word Cloud

Figure 6. Public Sentiment Analysis Word Cloud for the S2 (Arcology Scenario) Concept. Keywords are sized by frequency and colored by sentiment polarity: green indicates positive sentiment (e.g., “Central Park,” “Sky Garden,” “Futuristic,” “Convenient”), while red indicates negative sentiment (e.g., “Too Tall,” “Blocks Light,” “Not Shanghai,” “Destroys Heritage”). The analysis reveals public enthusiasm for green space and modern amenities alongside concerns about scale and cultural continuity.

E. Comprehensive Benefit Radar Chart

To intuitively compare the comprehensive benefits of the two scenarios, we normalized the key indicators of the above dimensions and plotted them into a radar chart (Figure 7). It can be clearly seen from the chart that S1 (Baseline Scenario) has an absolute advantage in the dimension of “historical context preservation.” In contrast, S2 (Arcology Scenario) comprehensively surpasses S1 in multiple dimensions such as land conservation benefits, per capita green space, operational carbon reduction, spatial integration, and functional mix. This intuitively reveals the fundamental trade-off between the two models: S1 is an optimization within the existing framework, while S2 is a systemic, exponential improvement of urban ecological, spatial, and social benefits at the cost of sacrificing some non-core historical fabric.

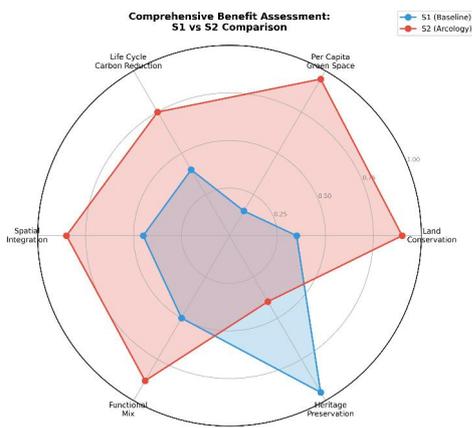


Fig. 7. Comprehensive Benefit Radar Chart

Figure 7. Comprehensive Benefit Assessment Radar Chart Comparing S1 and S2. The six dimensions evaluated are: Land Conservation, Per Capita Green Space, Life Cycle Carbon Reduction, Spatial Integration, Functional Mix, and Heritage Preservation. S1 (blue) excels in Heritage Preservation, while S2 (red) demonstrates superior performance across all other sustainability and efficiency metrics, illustrating the trade-offs inherent in each renewal approach.

V. DISCUSSION

The quantitative results of this study clearly reveal the immense potential and complex challenges inherent in the Arcology concept in contemporary high-density urban renewal. This chapter will provide an in-depth interpretation of the research findings, engage them in a dialogue with existing theories and practices, and explore the trade-offs, challenges, and limitations that may be faced in their real-world application.

A. Interpretation of Results and Horizontal Comparison

The core finding of this study is that the Arcology-style vertical integration renewal model (S2), at the cost of sacrificing part of the built fabric, achieves a systemic leap in ecological, spatial, and social benefits. Behind this phenomenon are the synergies driven by the inherent logic of “three-dimensional compactness” and “functional integration” of the Arcology concept.

First, the ecological benefit of Arcology is not a simple superposition of “green technologies,” but a structural transformation. Unlike the “green building” approach of adding photovoltaic panels or green roofs to traditional buildings [6], Arcology fundamentally changes the spatial form of the city by vertically stacking urban functions. This extreme compactness in form directly brings two core ecological benefits: one is land conservation, freeing up valuable urban center land from building occupation and converting it into public green space with ecological service functions; the other is reduction in operational energy consumption. The mega-structure has a lower shape factor (surface area to volume ratio), which reduces the heat exchange between the building and the external environment, thereby lowering heating and cooling demands. Coupled with the reduced energy consumption from internal transportation systems, it is able to offset its higher initial embodied carbon with significant long-term operational benefits on a life-cycle scale [18]. This confirms that

Arcology is an urban development model with “positive externalities,” whose systemic advantages far exceed the sum of single-building technology optimizations.

Second, the spatial benefit of Arcology stems from its redefinition of “distance.” In a traditional two-dimensional city, spatial vitality is highly dependent on horizontal accessibility along the street. The results of the Space Syntax analysis show that Arcology, through an efficient vertical transportation system and skywalks, creates a three-dimensional, highly integrated internal public space network [22]. This not only greatly shortens the time-space distance between functions such as living, working, and consumption, giving rise to a higher functional mix, but more importantly, it creates a pedestrian environment that is independent of ground traffic, all-weather, and barrier-free. This environment is predicted to stimulate more social interaction and community activities, forming a “vertical community” with a strong centripetal force, thereby reshaping the city’s social and geographical landscape at the micro level.

Comparing the results of this study with the “Compact City” theory in the literature [10], it can be found that Arcology is its more radical and thorough expression. The compact city mainly advocates for achieving functional mix at medium to high densities, but its form is still basically limited to the traditional block model. Arcology, on the other hand, pushes compactness and mix to the three-dimensional extreme, thereby obtaining land replacement benefits and internal circulation efficiencies that are difficult for traditional compact cities to achieve. It can be said that Arcology provides a more imaginative and potential paradigm for the practice of the compact city theory in high-density core areas.

B. Trade-offs and Challenges of Applicability

Although the simulation results show the significant advantages of the Arcology model, its applicability in the real world still faces multiple trade-offs and severe challenges. The results of the public sentiment analysis have already revealed this contradiction: people yearn for the central park and the sense of the future it brings, but they are also worried about the potential impact of its super-high-rise form on the historical style and features.

First, the challenge of economic feasibility. The mega-structures, complex three-dimensional transportation systems, and integrated ecological infrastructure involved in the Arcology model undoubtedly require huge initial investments. Its construction cost is much higher than that of traditional renovation projects. Although our research predicts its long-term operational cost savings and the increase in commercial value due to enhanced spatial vitality, under the current development model, how to balance the high initial investment with the long-term, public-good-like social and ecological benefits is a difficult problem that developers and governments must face. This may require innovative financial instruments and public-private partnership (PPP) models to jointly share risks and benefits.

Second, the challenge of technical implementation. From structural engineering, fire safety, vertical transportation to internal circulation systems for energy and waste, Arcology places extremely high demands on existing building technologies. For example, how to design a vertical and horizontal transportation system that can efficiently and safely carry a large number of people? How to ensure the

evacuation safety of super-high-rise buildings in extreme situations such as fires? How to achieve stable and efficient operation of energy, water, and waste treatment systems within the mega-structure? These all require cross-disciplinary technological integration and innovative breakthroughs.

Third, the challenge of social and cultural integration. This is the most controversial point of the Arcology concept. A highly integrated, functionally self-sufficient vertical community, while improving internal efficiency, also runs the risk of being disconnected from the surrounding urban fabric, forming an “enclave in the sky” or a “gated community” [12]. In addition, how to respect and continue the local historical context and collective memory while pursuing a sense of the future and technical efficiency is a core issue that must be addressed in the localized application of the Arcology model. The S2 scheme in this study attempts to respond to this challenge by preserving the core historical building clusters, but this is only a preliminary attempt. Future designs need to handle the relationship between the new and the old more delicately, for example, by establishing a meaningful dialogue between the modern mega-structure and the historical blocks through materials, spatial sequences, and public art, to avoid creating a homogeneous space lacking identity and a sense of belonging.

C. Research Limitations

As an exploratory simulation analysis, this study has the following limitations:

- **Simplicity of simulation:** Although we have used a variety of quantitative tools, scenario simulation is essentially a simplification of complex reality. The model could not fully cover all the variables that affect the benefits of urban renewal, such as detailed microclimate changes, social dynamics during the project implementation process, and long-term market fluctuations.
- **Data limitations:** The assessment of social benefits relies heavily on existing data. For example, sentiment analysis based on social media, while providing valuable insights, may have biases in its user base and expressed content, and cannot fully represent the views of all citizens. A more reliable assessment requires a combination of broader social surveys and participatory workshops.
- **Limitations of assessment dimensions:** The assessment framework of this study mainly focuses on the three dimensions of ecology, space, and society, and has not conducted an in-depth quantitative assessment of the more “soft” factors involved in urban renewal, such as policies and regulations, community governance, and cultural heritage. These factors also play a crucial role in the actual success or failure of the project.

Despite these limitations, this study, through a specific case simulation, has clearly outlined the application profile of the Arcology concept in contemporary urban renewal and confirmed its great value as a potential solution. This lays a foundation for more in-depth and refined research in the future.

VI. CONCLUSION

A. Core Conclusions

By constructing an integrated research framework of “Theoretical Translation - Scenario Construction - Multi-dimensional Assessment,” this study systematically and quantitatively assessed the applicability and comprehensive benefits of the Arcology concept in contemporary high-density urban renewal. Through a case study simulation and comparative analysis of the “Zhangyuan” plot in Shanghai, this study draws the following core conclusions:

- The Arcology concept has the feasibility of being translated into practical urban renewal strategies. By transforming its core principles into specific strategies such as “Vertical Urban Units,” “3-Dimensional Transit Networks,” and “Integrated Ecological Infrastructure,” Arcology is no longer just a utopian concept, but can become an operational, radical renewal paradigm for addressing the systemic challenges of high-density urban areas.
- Overall, the Arcology-inspired renewal scenario exhibits consistent advantages in several indicators within the case setting and assumptions of this study, including land-use efficiency, green space provision, simulated operational carbon reduction, spatial integration potential, and functional mix. At the same time, the baseline scenario retains comparative strengths in heritage continuity and morphological compatibility. These findings suggest that Arcology-style renewal may deliver synergistic eco-spatial-social benefits when carefully localized, but its net advantage depends on boundary conditions, technology assumptions, and cultural/contextual constraints.
- The advantages of the Arcology model are the result of a trade-off at the cost of “high initial investment” and “partial sacrifice of context.” Its higher initial construction costs, technical thresholds, and greater impact on the existing urban fabric are the core challenges that must be faced in its practical application. Public sentiment analysis also reflects the public’s general concern about its super-high-rise form and the issue of cultural context protection.

In summary, this study confirms that, after contextualized translation and design optimization, the Arcology concept is not only theoretically applicable to contemporary high-density urban renewal, but can also bring revolutionary ecological and socio-economic benefits far exceeding traditional models in practice. It provides us with a systematic solution that transcends planar thinking, “seeking space from the sky and ecology from within.”

B. Theoretical and Practical Implications

The findings of this study have important theoretical and practical implications for the fields of urban planning, architectural design, and public policy.

At the theoretical level, this study expands the application boundaries of Arcology theory, successfully introducing it from a future concept mainly applied to “new cities” into the more complex and realistic field of “urban renewal.” At the same time, the multi-dimensional, multi-method integrated assessment framework proposed in this study provides a set

of effective methodological references for future empirical research on forward-looking urban theories.

At the practical level, this study sends a clear signal to urban planners, architects, and decision-makers: when facing the increasingly severe spatial and environmental pressures in high-density core areas, one should have the courage to break through the constraints of the existing framework and explore more radical and three-dimensional solutions. Specific practical implications include:

- Embracing “3D planning” thinking: In the planning and design of urban renewal, one should shift from two-dimensional land use control to the refined design of three-dimensional spatial capacity and functional integration to maximize the utilization efficiency of urban space.
- Valuing “life cycle benefits”: In project decision-making, a whole life cycle cost-benefit assessment system should be established to include long-term operational benefits and ecological and social values in consideration, in order to balance the higher initial construction investment.
- Seeking a balance between “context and future”: When applying forward-looking models such as Arcology, the protection and inheritance of historical context must be placed at the core position. Through careful design strategies, the coexistence of the new and the old can be achieved, creating an urban space that is both futuristic and has a local identity.

C. Future Research

As a pioneering exploration, this study also opens up several directions for future research. Subsequent research can be deepened in the following aspects:

- More refined multi-physics coupled simulation: Future research can use more advanced simulation tools to conduct refined simulations of the microclimate environment (such as wind environment, lighting, heat island effect) under the Arcology model, in order to more comprehensively assess its environmental impact and human comfort.
- More immersive social perception experiments: Combined with virtual reality (VR) and augmented reality (AR) technologies, immersive virtual environments of the two renewal scenarios can be constructed. The public can be invited to experience them, and through eye-tracking, physiological index monitoring, and other means, the impact of different spatial designs on people’s psychological perception and behavior patterns can be assessed more scientifically and intuitively.
- Optional computational extensions: Future work may explore computational optimization (e.g., rule-based parametric design or lightweight heuristic search) to improve scenario exploration under constraints (FAR, carbon targets, spatial integration goals). This study does not require large-scale model training or cloud-scale computation; any advanced AI-based generative workflows, if used, should be presented as optional tools with open parameters and reproducible pipelines.

- Research on governance and policy models: In response to the high-investment, high-risk characteristics of the Arcology model, future research needs to delve into the matching public policies, investment and financing models, and community governance frameworks to clear the obstacles for its implementation in the real world.

Through continuous exploration in these directions, we hope to gradually transform Arcology, an urban ideal containing profound ecological wisdom, into a realistic path for building future sustainable, high-density, and humanized cities.

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Jiansheng Chen: Conceptualization, Methodology, Formal analysis, Data curation, Visualization, Writing - original draft.

Guozhong Cai: Supervision, Project administration, Funding acquisition, Writing - review & editing, Validation.

COMPETING INTERESTS

The authors declare no competing interests.

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