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Accessibility equality assessment across future scenarios: contribution of isobenefit morphology and equity-oriented transport relative to classical city

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Article

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Accessibility equality assessment across future scenarios: contribution of isobenefit morphology and equity-oriented transport relative to classical city

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Abstract:

Urban agglomeration generates opportunities, interactions, economics, but also producing spatial and accessibility inequalities, especially as transport greatly enhanced mobility. Various research has identified urban inequality, but to what extent can it be mitigated by urban forms or transport. Isobenefit Urbanism (IU) envisions cities with equal proximity as basic benefit, but can urban transport extend these benefits? Future scenarios offer a way to evaluate the accessibility equality under different urban development paths aiming to opportunity equality and green equality. This study uses isobenefit city simulator to generate different urban forms: continuous compact, poly-nucleated, and punctiform dispersed. Assess accessibility equality using population weighted Gini and Atkinson indices based on reachable centralities and social interaction within 10, 20, 30 min isochrones. Then build the equity-oriented transport among centralities in isobenefit city with accessibility deficit weighted OD matrix, incremental spanning tree (IST) backbone, maximal covering network optimization (MC), and heuristic routes set selection. Besides, an equality compensation parameter P3 has been added to simulator to improve morphological equality from centrality distribution. 4 control groups have been constructed for three isobenefit urban forms to illustrate the coupling effects between morphological compensation and equity-oriented transport. 3 future scenarios are conducted to envision a better development path. The results confirm that transport expands accessibility but further concentrates benefits around centralities, undermining equality both in global and disadvantaged areas. Increasing and distribution of centralities from morphological compensation performs various in different urban forms regarding equality improvement. Coupling effect of morphology and transport in future scenario, both have greatly optimized accessibility equality compared to traditional city. Consequently, this study combines isobenefit principle of urban form and equity-oriented transport planning to further support the planning strategy for more equitable future.

Keywords: Isobenefit Urbanism, accessibility equality, transit network design problem, future scenario analysis, isochrone

1. Introduction

Global urbanization has created opportunities for population and resources gathering and infrastructure development has further accelerated urban mobility. These interaction mechanisms of sharing, matching, and learning among different urban activities have strengthened and consolidated the resources integration and economic agglomeration (Duranton and Puga, 2004). Gradually, urban centers have emerged in various ways, some inherit their historical advantages and born naturally, some as new attractive destinations which are mainly guided by regional economic development policy. In another words, city planning has further reinforced the urban agglomeration effect by deliberately reallocating the land and transport resources to achieve political achievements. As multifunctional centers attract

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population and investment, growing mobility continuously reshapes the urban spatial structure. Subsequently, continuous emergence of new city centers inevitably leads to urban sprawl and generates urban problems, including traffic congestion, fragmentation of green space, and mismatch between jobs and housing.

Against this background, inequality has been noticed, and increasing attention has been paid to spatial justice. As Anas et al. (1998) illustrated that although urban centers improve efficiency through agglomeration, they also produce spatial hierarchy by concentrating employments, municipal institutions, public facilities, education, healthcare, and especially accessibility advantages created by transport infrastructure. While Soja (2013) emphasizes that all urban residents should have equal access to resources, services, and opportunities. Urban planners are attempting to address this spatial inequality by planning more urban centers. Meanwhile Zhou and Gao (2020) also proved that advanced public transport and coordinated land policies can weaken the inequality from dominance of monocentric. Whether polycentricity automatically eliminates spatial hierarchy or accessibility inequality should be further discussed.

To envision a more equal urban future, D'Acci (2013) proposed Isobenefit Urbanism (IU) as a generative urban model in which centralities and green spaces are distributed to keep residents within almost equal distance to essential urban resources. Accordingly, the isobenefit city simulator further applied the distance benefit constraints to cellular automata and generate diverse urban morphologies with local proximity equality satisfied (D'Acci and Voto, 2023). Then, Yu et al. (2026) extend Isobenefit Urbanism principle to evaluate walkable equity in Beijing's core area, argue that whether walking accessibility of daily services, green spaces, and public transport can support livability, fairness, and sustainability in high density urban contexts. However, existing research has mainly focused on walkability and neighborhood service accessibility, while less attention has been given to how to further extend the accessibility equality beyond walk in the framework of IU, and whether the skyway as mentioned in IU could further optimize inequality, or exacerbate it?

As IU generates spatially equal reachable opportunity for centrality and green land at the walking scale, once these destinations are connected through a transport network, such as skyway, equal accessibility may be inevitably undermined by centrality hierarchy, driven by uneven served populations and the timing of centrality generation, which determines when each centrality enters the transport network. Despite the hierarchy from nodes and network topology itself, recent studies also suggest that local proximity and city-wide accessibility are governed by different spatial dynamics. Barthelemy (2026) argues that short commutes from "15-minute city" can only be realized by a certain city's economic structure which is fundamentally constrained by the internal structure of urban economies. And in Seoul, Lee et al. (2025) use real OD data to show that neighborhood level agglomeration benefits as pull effects (PE) trips exhibits a strongly hierarchical distribution, while daily life convenience as self-containment (SC) trips are diffusely distributed. Abbiasov et al. (2024) further show that, in the US, only 14% of daily trips are made locally at the median, while residents' actual activities span a much larger urban area. These findings indicate that to pursue equal accessibility in city scale, completed centrality transport in IU should be further established and evaluate the global accessibility equality among citizens.

To address this gap, at each step of centrality generation in isobenefit city simulator, an extra module is applied to construct the skyway transport system between centralities. As original IU

morphologies have realized the basic benefit of accessibility, further equality detection and equity-oriented transport resource reallocation are regarded as the basis in skyway transport construction. In doing so, Gini index and Atkinson index have been applied to evaluate the global and distribution of accessibility equality among residence cells during the whole process. First, establish the isochronic accessibility map with the threshold of 10, 20, 30min for isobenefit morphologies, calculate the excessive isobenefit score and social potential score for each residential cell which constitutes its accessibility assessment. This step demonstrates the actual equality distribution in isobenefit urban forms beyond the minimum accessibility benefit. Then, construct the equity-oriented transit network by established accessibility deficit weighted OD matrix, use centrality generation sequence-based IST as network backbone to ensure its connectivity. Next, adopt maximal covering network optimization proposed by Bucarey et al. (2022) to construct the extra paths to satisfy all OD demands under a cost constraint. Moreover, set operational routes set and frequency within the heuristic procedure of equity-controlled selection to complete the skyway transport system. To compare the contribution of IU morphology and equity-oriented transport, this study further proposed P3 as compensation parameter to redistribute the centrality in accessibility deficit area. Finally, assessing the accessibility equality among 3 future city scenarios constructed from two urban development directions: green isobenefit and centrality isobenefit.

The study is guided by the following research questions:

Main question: How do equality-oriented morphology and equity-oriented transport differ in their contributions to accessibility equality, and how do their effects interact?

RQ1: How does equal local proximity translate into city-scale accessibility equality across different Isobenefit urban morphologies?

RQ2: How does an equity-oriented transport network reshape accessibility equality across different Isobenefit urban morphologies?

RQ3: Which combination of morphological and transport conditions produces the most equal accessibility across future city scenarios?

Focusing on accessibility equality, this study contributes an equity-oriented transport network framework for Isobenefit urban forms and clarifies how equality-oriented morphology and equity-oriented transport jointly shape global accessibility equality and disparities in disadvantaged areas. Their combined effects further provide a basis for developing more equal accessibility strategies.

2. Literature review

2.1 Urban accessibility equality

Research on urban accessibility inequality generally identifies two main sources: demographic disparities, such as income and race, and spatial disadvantages associated with geographical and infrastructural marginalization. Zhang et al. (2024) use counterfactual random-walk-based embedding to reveal persistent income and racial disparities in neighborhood-level facility accessibility across US cities. Based on 102 Chinese cities, Wang et al. (2026) show that polycentricity may exacerbate inequality in green-space accessibility when high accessibility is not supported by equity-oriented planning. Zheng et al. (2026) similarly develop an analytical

framework and dual-path optimization strategy to diagnose and reduce inequality in urban green-space provision. In South Korea, Lee et al. (2024) find that densely populated areas generally achieve greater accessibility equality through shorter network distances to social infrastructure, while housing prices remain an important source of disparity.

Accessibility inequality can also emerge from uneven urban development trajectories and transport planning. However, the effects of transport investment are mixed. Loo et al. (2024) show that public transport expansion in Hong Kong can moderate social segregation, while Athey et al. (2021) identify similar inequality-reducing effects at the regional scale. Arellana et al. (2021) further demonstrate that transport-oriented planning can mitigate accessibility disparities associated with car dependence. Conversely, Baker and Lee (2019) identify transit investment as a potential driver of neighborhood gentrification, while evidence from London shows that improved public transport accessibility does not necessarily reduce disadvantages associated with income deprivation and ethnicity (Nie et al. 2024). The combined effects of urban morphology and equity-oriented transport on accessibility equality, however, remain less explored.

Accessibility inequality has been measured through several approaches. Biazzo et al. (2019) use isochrones to evaluate transport performance through velocity and sociality scores, representing reachable distance and potential social interaction. Wang et al. (2025) measure opportunities reachable within specified travel times and apply the population-weighted Atkinson index. Lee et al. (2024) evaluate network-distance burdens form social infrastructures with Gini index, while Arellana et al. (2021) apply gravity-based accessibility measures incorporating opportunities, transport networks, travel time, and impedance functions, together with horizontal and vertical equity comparisons. Building on these approaches, this study applies isochronic accessibility to compare travel modes and evaluate excessive isobenefit, while Gini and Atkinson indices measure overall inequality and disadvantaged areas.

2.2 Transit Route Network Design Problems (TRNDPs)

Network flow research has developed from the work of Ford and Fulkerson (1962), who represented network performance through capacity, flow conservation, demand, cost, and allocation rather than only topological connections. These principles were later widely applied to transportation systems, where networks must be adapted to changing travel demand (Mandl, 1979).

2.2.1 Network structure

TRNDP studies are commonly based either on real urban networks or idealized benchmark networks such as Mandl's (1979). Despite their abstraction, idealized networks remain useful for identifying general relationships between network structure and transport performance. Hurdle (1973) optimized feeder-line density and service frequency within a parallel trunk–feeder network to balance user and operating costs. Byrne (1975) formulated a radial transit network in polar coordinates and optimized line locations according to population density and circumferential access. Tsao and Schonfeld (1983) divided the service area into transit zones, each served locally and interconnected through express corridors, while Vaughan (1986) optimized route spacing and headways in a ring-radial bus network under many-to-many travel demand. Later studies moved toward hybrid and comparative network structures. Daganzo (2010) proposed a hybrid network combining a central grid with suburban radial branches and

examined the suitability of different transit modes across these structures. Chen et al. (2015) further compared ring-radial and grid networks, demonstrating how network configuration affects transit service efficiency.

Network design has also increasingly incorporated travel demand. Magnanti and Wong (1984) used OD demand to optimize network construction cost and travel time, while Bucarey et al. (2022) developed covering-based network design models under travel-time constraints. In this study, IU urban forms provide explicit population, centrality distributions, allowing transport networks to be evaluated beyond pure topology and providing a basis for equity-oriented network design.

2.2.2 Transit route set design

Transit route set design is generally conducted on a predefined physical network. Candidate routes can be generated using shortest-path algorithms such as Dijkstra and Yen's k-shortest paths (Dijkstra, 1959; Yen, 1971), followed by exact, heuristic, or metaheuristic optimization. Exact approaches can identify optimal solutions but often involve high computational costs, whereas heuristic methods obtain feasible solutions more efficiently without guaranteeing global optimality. Metaheuristic methods as Genetic Algorithms, allow broader exploration of large solution spaces and are particularly suitable for balancing multiple objectives. Most subsequent studies adopted Mandl's network as a benchmark and developed different route-set optimization approaches to balance passenger and operator objectives, including construction cost, travel time, and transfers. To reduce the field's reliance on this relatively small benchmark, Mumford (2013) introduced four larger test networks and evaluated route sets by combining passenger travel time with operator route length.

Studies of route optimization have incorporated passenger demand, travel time, transfers, route length, and operating cost. Kılıç and Gök (2014) combined OD demand and shortest paths with Tabu Search, Islam et al. (2019) applied Stochastic Beam Search, and John et al. (2014) used NSGA-II to balance passenger and operator objectives. Kim et al. (2019) further introduced spatial and modal equity into route design, while Wang et al. (2025) showed that demand-responsive transit can reduce accessibility inequality, particularly in low-density areas. Building on these studies, this research develops an equity-oriented transit module covering physical network generation, initial route setting, and route-set optimization to improve accessibility equality.

2.3 Scenario analysis

Scenario analysis provides a useful framework for exploring how alternative planning and transport interventions may lead to different long-term spatial and accessibility outcomes. Fuglsang et al. (2012) combined spatial and socio-economic data under different transport paradigms to simulate land-use change, integrating accessibility and population distribution within a GIS-based cellular automata model. Papaix et al. (2022) examined public transport travel-time reduction scenarios in Lille and compared changes in job accessibility across social groups, showing that accessibility improvements alone may not fully reduce inequality without coordinated land-use and social policies. This approach is particularly relevant to Isobenefit Urbanism, where alternative combinations of centrality distribution, green-space provision, and transport strategies can generate different urban development pathways. Comparing these scenarios with conventional urban trajectories allows their relative performance in accessibility equality to be assessed.

3. Method

3.1 Isochronic of accessibility maps

This study constructs equality assessment based on accessibility isochrones map, calculating the number of reachable centralities and green spaces for each residence under thresholds of travel-time at 10, 20, and 30 min, to represent potential accessibility.

All urban forms are generated from isobenefit city simulator with one million population, corresponding to the OECD for metropolitan urban areas (0.5–1.5 million inhabitants) (OECD, n.d.), the rest parameters setting follow the studies of D'Acci and Voto (2023), especially for P1 and P2 which formed the typical morphology. To examine the morphology's influence on accessibility equality, three representative isobenefit urban forms are selected: continuous compact, poly-nucleated, and punctiform dispersed.

3.1.1 Excessive isobenefit index

Equal access to at least one centrality and green land is regarded as the basic benefit in IU, while some residential cells will inevitably have access to more opportunities according to the distribution of centrality, therefore creating new inequality. To demonstrate this, an excessive isobenefit index O_i is used to evaluate the match situation between population and accessible opportunity.

For each residential unit i, calculate $N_i(T_k)$ as the opportunity j (centrality and green land) can be reached under threshold time T_k (10, 20, and 30 min):

$$N_i(T_k) = \sum_{j=1}^{J} 1(t_{ij}^m \leq T_k) \quad (1)$$

Where m represents the travel mode and t_{ij}^m is travel time from residential cell i centrality j, $1(\cdot)$ is indicator function, it returns 1 once $t_{ij}^m \leq T_k$, otherwise is 0. $N_i(T_k) \geq 2$ according to IU.

Then $E_i(T_k)$ presents the actual number of extra reachable centralities. For example, if one residence cell can reach 3 centralities and one green land in limited time, $N_i(T_k) = 4$, and $E_i(T_k) = 3$.

$$E_i(T_k) = 2N_i(T_k) - 5 \quad (2)$$

While $N_i(T_k) = 2$, $E_i(T_k) = 0$ to avoid negative effects.

To simulate the real travel situation, people intend to travel less regarding the time increases. Then, $E_i(T_k)$ reached by 10, 20, and 30 min threshold are assigned with different weight, as 0.5, 0.3 and 0.2 respectively to calculate the excessive isobenefit index O_i. And $O_{normalized}$ can better compare among isobenefit cities.

$$O_i = 0.5E_i(10) + 0.3E_i(20) + 0.2E_i(30) \quad (3)$$

Normalization:

$$O_{normalized} = \frac{O_i}{number\ of\ total\ opportunity} \quad (4)$$

To examine whether high density residence cells benefit more in isobenefit city, jitter scatter plots and violin distributions are applied to identify the relation between population distribution and excessive isobenefit. The jittered points preserve the excessive isobenefit values among all the residential cells, and the violin distributions additionally summarize the dispersion, and concentration of reachable opportunity values. To support the comparison, Pearson's correlation coefficient r, the coefficient of determination R^2, and the difference in mean value between the high and medium density groups are calculated for each urban form and presented in R.

3.1.2 Social potential index

Besides the excessive isobenefit index from direct accessible opportunity, social potential index S_i is also introduced to evaluate the interaction from accessibility, which is calculated by the population that can be reached from each residential cell in weighted isochronic threshold:

$$P_i(T_k) = \sum_{j=1}^{R} p_j 1(t_{ij}^m \leq T_k) \tag{5}$$

Where $P_i(T_k)$ calculates the total population reachable for residence i, with p_j as the population in residential cell j, and R as the whole number of residence cells. Then social potential index S_i is also weighed by travel time impedance and normalized as O_i to show its social performance in daily trips:

$$S_i = 0.5P_i(10) + 0.3P_i(20) + 0.2P_i(30) \tag{6}$$

$$S_{normalized} = \frac{S_i}{total\ population} \tag{7}$$

3.1.3 Accessibility index

With excessive isobenefit index O_i and social potential index S_i, the accessibility performance A_i for each residential unit i is calculated as:

$$\mathrm{A}_i = \mathrm{O}_{normalized} + \mathrm{S}_{normalized} \tag{8}$$

Higher A_i represents residential unit i benefits more from opportunities and social interaction.

Before constructing the skyway network between centralities, equality criteria in residence level should be established to better guide the equity-oriented transport design. Therefore, use the population-weighted Gini coefficient to evaluate the overall inequality performance, and Atkinson index to locate disparity distribution. The dynamic changes between the two indices can clearly reflect how equality evolves before and after each step during the transport construction.

Population weight w_i is defined as:

$$w_i = \frac{P_i}{P_{total}} \tag{9}$$

Population-weighted mean accessibility $\overline{A_w}$ and accessibility equality Gini index G_A:

$$\overline{A_w} = \sum_{i=1}^{R} w_i\, A_i \tag{10}$$

$$G_A = \frac{\sum_{i=1}^{R}\sum_{j=1}^{R} w_i w_j |A_i - A_j|}{2\overline{A_w}} \tag{11}$$

Population-weighted accessibility equality Atkinson index AT_A:

$$AT_A(\varepsilon) = 1 - \frac{(\sum_{i=1}^{R} w_i A_i^{1-\varepsilon})^{\frac{1}{1-\varepsilon}}}{\overline{A_w}} \tag{12}$$

Where ε represents inequality aversion parameter, higher ε means more weight will be assigned to lower benefit areas in transport network construction. And this study adopts $\varepsilon = 1$ to assign a significant yet balanced weight to disadvantaged groups according to Souche et al. (2016).

3.2 Equity-oriented Transit Route Network Design Problems (E-TRNDPs)

To conduct city-scale accessibility evaluation, the transport system connecting centralities should be extended rather than walk only, in terms of network, route set, and service frequency. Building on the multi-objective framework of TRNDPs, which coordinates route structure, service coverage, travel cost, transfers, and resource allocation (Kepaptsoglou and Karlaftis, 2009), this study proposes an equity-oriented TRNDP (E-TRNDP) incorporating accessibility equality as an additional design objective, instead of transport efficiency alone, which can extend the equal-benefit principle of IU from local proximity to wilder equal accessibility. E-TRNDP is organized into three sequential modules as Figure 1, progressing from weighted OD matrix to optimized centrality network and operational service.

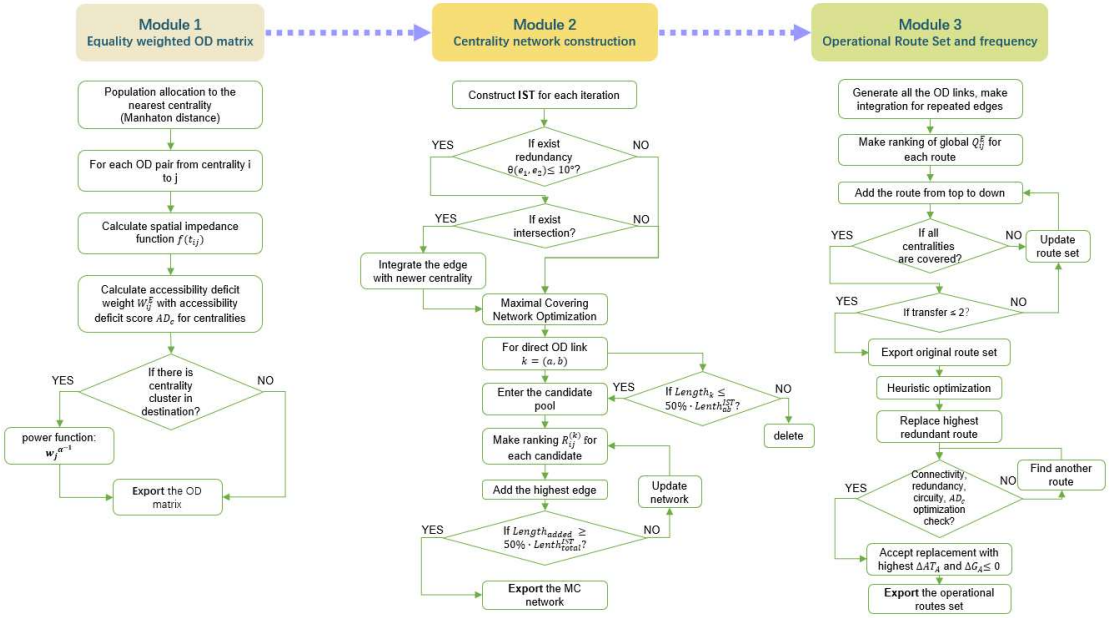


Figure 1. equity-oriented transport generation structure

In isobenefit city, each residence has been assigned equal proximity to centrality and green land. However, different served population and birth sequence of centrality produce new hierarchy and result in accessible inequality. To mitigate it, this study uses accessibility deficit score AD_c to identify the centrality with lower accessibility where to allocate more transport resources later.

Accessibility deficit score AD_c for centrality c:

$$D_i = \max(0, \overline{A_w} - A_i) \tag{13}$$

$$AD_c = \sum_{i \in \Omega_c} \frac{P_i}{P_c} D_i \tag{14}$$

D_i represents the accessibility deficit for each residential i, P_c means the total served population for centrality c, residence cells are allocated on shortest Manhattan distance. For travel mode m "walk + skyway", skyway speed is 30km/h, including acceleration, deceleration, and intermediate station dwell times (Casello et al. 2014).

3.2.1 Module 1: Equality weighted OD matrix

Equality weighted OD matrix Q_{ij}^E among centralities is the basis to generate possible mobility for skyway transport system establishment. As in isobenefit city, no observed travel data has been attached, served population for each centrality P_c is used to represent the OD demand, and the travel requests will be divided into different flows according to destination's population and inequality weight. Each OD pair concerns served population P_{c-i} in origin centrality, spatial impedance function $f(t_{ij})$, accessibility deficit weight W_{ij}^E and destination attraction w_j (population weight) raised to the power of α^{-1}, where α is the urban agglomeration index and calculated as the number of centralities reachable within 10min walk. The original accessibility deficit score AD_c for calculating W_{ij}^E adopt travel mode "walk only", representing the initial situation of isobenefit city.

$$Q_{ij}^E = P_{c-i} \cdot {w_j}^{\alpha^{-1}} \cdot f(t_{ij}) \cdot W_{ij}^E \tag{15}$$

$$f(t_{ij}) = \exp(-\beta \cdot t_{ij}) \tag{16}$$

$$W_{ij}^E = 1 + \gamma \cdot \frac{(AD_i + AD_j)/2 - AD_{min}}{AD_{max} - AD_{min}} \tag{17}$$

$$Q_{normalized(ij)}^E = \frac{Q_{ij}^E + Q_{ji}^E}{2Q_{max}^E} \tag{18}$$

Where β is distance decay parameter (set $\beta = \frac{\ln 2}{30}$, once skyway travel time from origin centrality i to destination centrality j arrives 30min, $f(30) = 0.50$, by extension, $f(10) = 0.79, f(20) = 0.63$, etc.), γ as equality sensitivity index, $\gamma = 1$ is used for original setting, higher accessibility deficit weighted OD candidate edges possess higher priority to be established. $Q_{normalized(ij)}^E$ is calculated for each centrality to inherit its original mobility demand ranking in OD matrix, to better clarified, $Q_{max}^E = \max_{i \neq j} Q_{ij}^E$, $Q_{normalized(ii)}^E = 0$.

3.2.2 Module 2: Centrality network construction

First, all the centralities should be connected after each iteration by connecting to the nearest neighbor. Incremental Spanning Tree (IST) is well suited to this basic growth mechanism as it preserves historically built sequence as real city while maintaining the lowest construction cost. However, when centrality grows by leaps in more dispersed morphology, several links will present high redundancy and intersection. Therefore, correction should be applied in this situation. Detect IST edges with an angle less than 10° and directly integrate new centrality into the original paths. Then, detect intersection inside IST network, delete longer cross link and reconstruct the shortest path to keep connectivity. Shown as Figure 2, deleting edge 1-2 and adding edge 1-3 can solve both redundancy and intersection while keeping connected.

Nevertheless, its tree topology inevitably produces hierarchy, which will be addressed in following procedure of equity-oriented network and routes design.

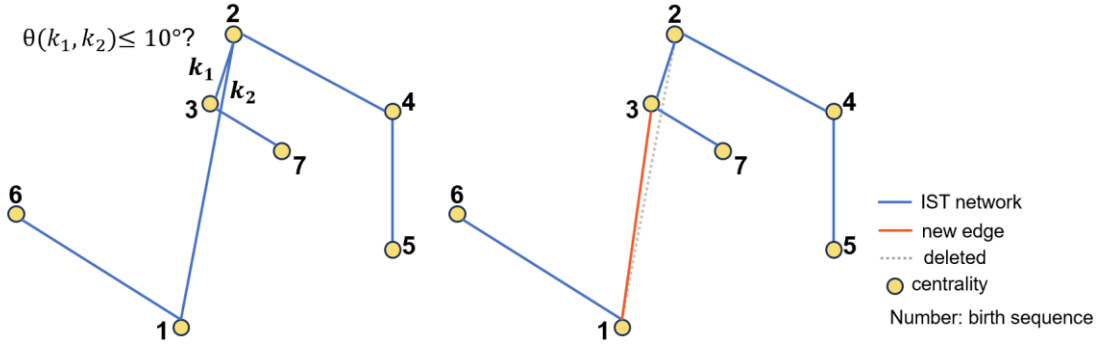


Figure 2: IST redundancy and intersection correction

Maximal Covering Network Design problem (MC) has been proposed by Bucarey et al. (2022) to optimize the network which can maximize all OD demand covered under a budget constraint. Use IST backbone as an original network and all direct OD links as the potential candidate edges. This study adopts MC model to generate the optimized centrality network before designing skyway operational route set. For each OD link $k = (a, b)$ from centrality a to b, it can be allowed to enter the final candidate pool only under the condition: direct connection k reduce the 50% detour rate of its original IST path.

$$Length_k \leq 50\% \cdot Lenth_{ab}^{IST} \tag{19}$$

Once detour demand candidate pool generated, start from adding candidate k one by one following the sequence of $Q^E_{normalized(ij)}$, then evaluate network efficiency optimization per unit of construction cost. As a new edge k may also facilitate other OD pairs and save global travel time $\Delta T_{OD}^{(k)}$. While calculating the global time saving for each candidate k, the equality weighted matrix $Q^E_{normalized(ij)}$ has been applied again to weight the time saving of each OD pair. Then follows the construction sequence with the ranking of $R_{ij}^{(k)}$ which is the ratio of global reduced travel time $\Delta T_{OD}^{(k)}$ and $Length_k$ (Euclidean distance), higher ranking $R_{ij}^{(k)}$ of candidate k represents a better influence in optimizing the transport network efficiency.

For added candidate $k = (a, b)$, travel time for each OD_{ij}:

$$t_{ij}^{after} = \min\left\{t_{ij}^{before}, t_{ia}^{(k)} + \frac{Length_k}{30km/h} + t_{bj}^{(k)}, t_{ib}^{(k)} + \frac{Length_k}{30km/h} + t_{aj}^{(k)}\right\} \tag{20}$$

Where t_{ij}^{before} is original travel time for centrality i to centrality j with IST network.

$$\Delta T_{OD}^{(k)} = \sum_{i<j} Q^E_{normalized(ij)}(t_{ij}^{before} - t_{ij}^{after}) \tag{21}$$

$$R_{ij}^{(k)} = \frac{\Delta T_{OD}^{(k)}}{Length_k} \tag{22}$$

This network optimization process uses dynamic greedy approach, recalculating $\Delta T_{OD}^{(k)}$ after each round of adding new path. For example, calculate the $R_{ij}^{(k)}$ for all candidates at round one, add only the link with top $R_{ij}^{(k)}$ and delete from candidate pool. For round two, recalculate the $R_{ij}^{(k)}$ for rest candidates, choose another edge at top $R_{ij}^{(k)}$, same with other rounds until the total length of further generated edges has arrived 50% of IST network to limit the construction cost. The cross edges generated at this time have been kept in network but constructed at different

levels in parallel, transfer only allowed in centralities. This module can be integrated into the isobenefit city simulator and update the transport network at every iteration. To facilitate calculation, this study adopts the optimized network in final iteration to finish the operation routes setting and compare among different scenarios.

3.2.2 Module 3: Operational Route Set and frequency

After the construction of skyway network between centralities, operational route set and frequency are divided into three steps:

(1) Original routes sets: Find the shortest route for each OD pair, short repetitive paths are integrated into longer one to generate all the candidate routes. Add the first candidate to original route set from the ranking of $Q^{E}_{normalized(ij)}$, stop when all centralities are covered and at most two transfers to satisfy all the OD demands (connectivity check). Calculate the maximum redundancy for each line compared to any single existing route in original routes set, start to delete from the highest redundancy route, if connectivity is broken, keep it and evaluate the next route until reached the minimum set number.

(2) Heuristic procedure: run the iteration with locating highest redundancy route in recent set first. Delete it, then find a new route from candidate pool to replace it which must satisfy following requests:

a. connectivity check: all centralities are covered and no more than 2 transfer;

b. redundancy check: the redundancy among any two in route set is less than 50%;

c. circuity check: circuity for new candidate route is less than 1.5 compared to the shortest path;

d. AD_c optimization check: at least 10% centralities passed by the new candidate route are from top 20% AD_c value;

Next, for all satisfied candidates, calculate their Gini index G_A and Atkinson index AT_A, accept only the route with highest ΔAT_A and $\Delta G_A \leq 0$. For every original route, keep it once no candidate can satisfy.

(3) Frequency service: Frequency setting conducts less influence for inequality distribution than network and routes design, therefore, to facilitate the calculation for accessibility equality index among different scenarios, simply set waiting time as 3 min for depart centrality and each transfer punishment as 5 min.

Finally, with the establishment of equity-oriented transport system, more completed isochronic maps of accessibility index for each residence cell could be further developed with the travel mode of walk + skyway.

3.3 Equality compensation parameter P3

In land-use–transport interaction (LUTI) models, land-use patterns shape travel demand, while transport accessibility influences the subsequent spatial distribution of households, employment, and urban activities (Wegener, 2004). Such interaction can reinforce the concentration of activities in highly accessible areas. In contrast, IU seeks equal access to centralities and green space while limiting excessive concentration. Its centrality distribution is primarily controlled by P1 and P2, which determine whether new centralities emerge adjacent to built-up areas or at isolated locations, producing morphologies ranging from compact to dispersed. To introduce an accessibility-based feedback mechanism into centrality generation, this study therefore adds an equality compensation parameter P3 to the original IU simulator.

The value of P3 represents the probability to relocate the new centrality candidate selected by P1 toward to areas with high AD_c. For every generation opportunity from P1, create random number from [0, 1], if it is below P3, then locate the new centrality to the 1km area around top 30% AD_c centralities. Meanwhile, all the candidate positions from P3 must be an empty cell with at least one adjacent residential cell and satisfy the original isobenefit urbanism constraints of nature continuity and equal proximity benefit. If no candidate position has been identified from P3 selection, the new centrality stays at the original site chosen by P1. Thus, $P3 = 1$ means every eligible P1 will be reconsidered whether satisfy P3 condition, and some of them will be redirected. While $P3 = 0$ fully preserves the original isobenefit city form. To be noted, accessibility deficit value AD_c for each centrality will be recalculated at each iteration, allowing centrality allocation and urban morphology coevolve dynamically to compensate for emerging accessibility inequalities.

However, in classical mode of isobenefit city simulator, as P1 only transfers high density residence cell into centrality which also requires to be adjacent to existing centrality, P3 will look for the candidate location for each generation opportunity selected by P1 and give priority to high AD_c area.

3.4 Isobenefit future scenarios construction

Isobenefit city simulator offers an experimental platform to generate urban forms across different future scenarios, which can be used to explore the accessibility equality produced from divergent urban trajectories. This study adopts a normative comparative scenario analysis under different urban planning strategies and transport referring to core target of isobenefit urbanism: centrality equality and green land equality. To better describe different stages of urban evolutionary snapshots, matrix cards are positioned along the coordinate axes to highlight how urban patterns change under varying intensities of planning guidance as Figure 3, and the urban life narratives associated with the three scenarios are illustrated in Figure 4.

Scenario A represents a conventional and radially dependent development pattern, characterized by fragmented green provision and substantial spatial variation in access to urban activities. This scenario will be constructed by classical urban form generated by isobenefit city simulator with setting from D'Acci and Voto (2023): P1=1, P2=0.01, P3=0. The radial transport network is designed manually, but the operational routes set constructs on section 3.2.2.

Scenario B retains low density, dispersed urban morphology as traditional city but introduces a partial compensation effect of equality-oriented centrality redistribution, and an equity-based transport construction. This can be simulated by the classical mode in IU city simulator with $P3 = 0.5$ as equality compensation in morphology. And equity-oriented transport will also be constructed from the weighted OD matrix, optimized MC network and operational routes set to further minimize the inequality.

Scenario C is regarded as an ideal isobenefit situation, complying with equal proximity to green space and centrality, while also equipped with equity-oriented transport and the strongest equality compensation setting, $P3 = 1$, which therefore provides both local benefit and better city-scale accessibility equality.

Evaluating accessibility deficit score AD_c for each centrality is the basis to build transport. As isochrones of travel mode "walk-only" at 10, 20, and 30 min leave certain parts of the classical city with no reachable opportunities, an additional control group is simulated with "car + skyway" travel mode, with car speed at 20 km/h instead of walk to better simulate the real

mobility in classical city. For transport construction in classical city, centrality clusters are considered to join the transport network instead of each single centrality, clusters defined form an eight-neighbor connectivity rule. The scenario comparison reveals the co-evolution of equality-oriented urban planning and equity-oriented transport in accessibility equality performance over time.

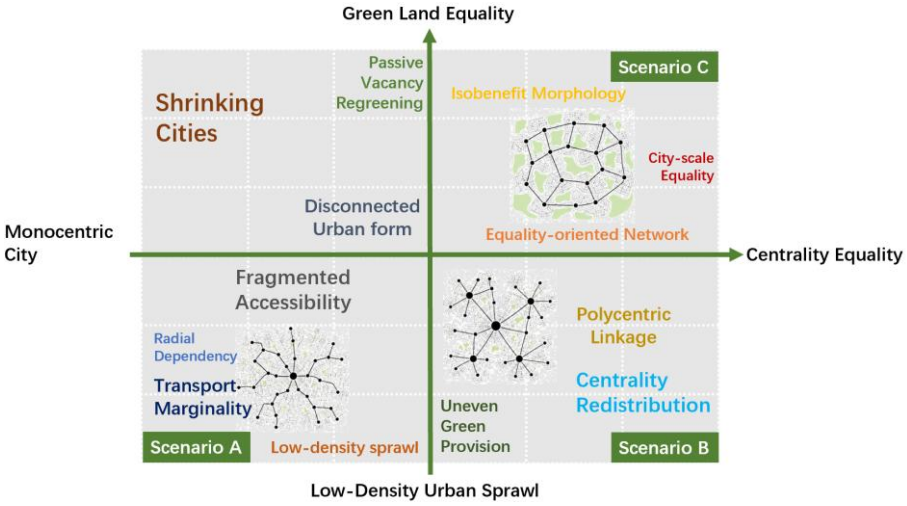


Figure 3. Narrative Scenario Matrix construction of Isobenefit urbanism for future city

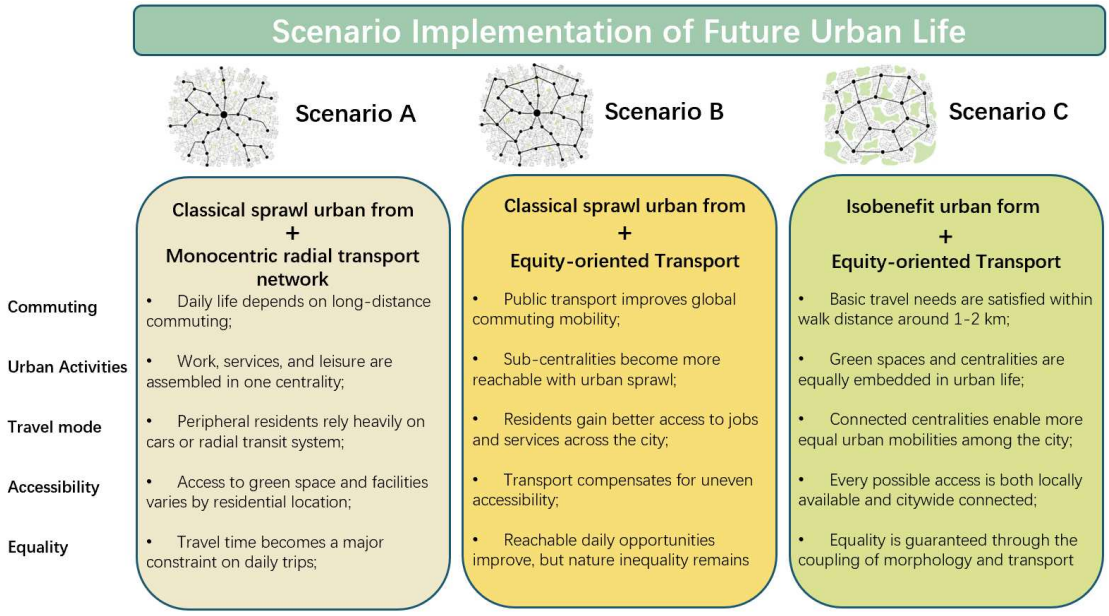


Figure 4: Scenario drivers and implementation of the narrative future life

4 Results

4.1 Opportunity-population mismatch in isobenefit cities

Following the Isobenefit Urbanism principle, all simulated isobenefit cities have guaranteed a minimum benefit of equal proximity to both green land and at least one centrality. However, the excessive isobenefit index O_i introduced in Section 3.1.1 reveals substantial variation beyond this baseline. Within the same travel time threshold setting, residential cells differ markedly in the maximum number of opportunities they can reach. Figure 5 illustrates the

growth trajectories for isobenefit city under different spatial structures: continuous compact, poly-nucleated and punctiform dispersed. As the cities expand with centralities generation, more residents benefit from access to multiple centralities. While more compact monopoly performs better than punctiform urban form concerning the sharing of urban resources. These results indicate that, despite the minimum benefit principle from IU, inequalities in cumulative resource accessibility still emerge and intensify during urban growth, exhibiting a pattern similar to traditional cities where greater spatial compactness leads to greater benefits.

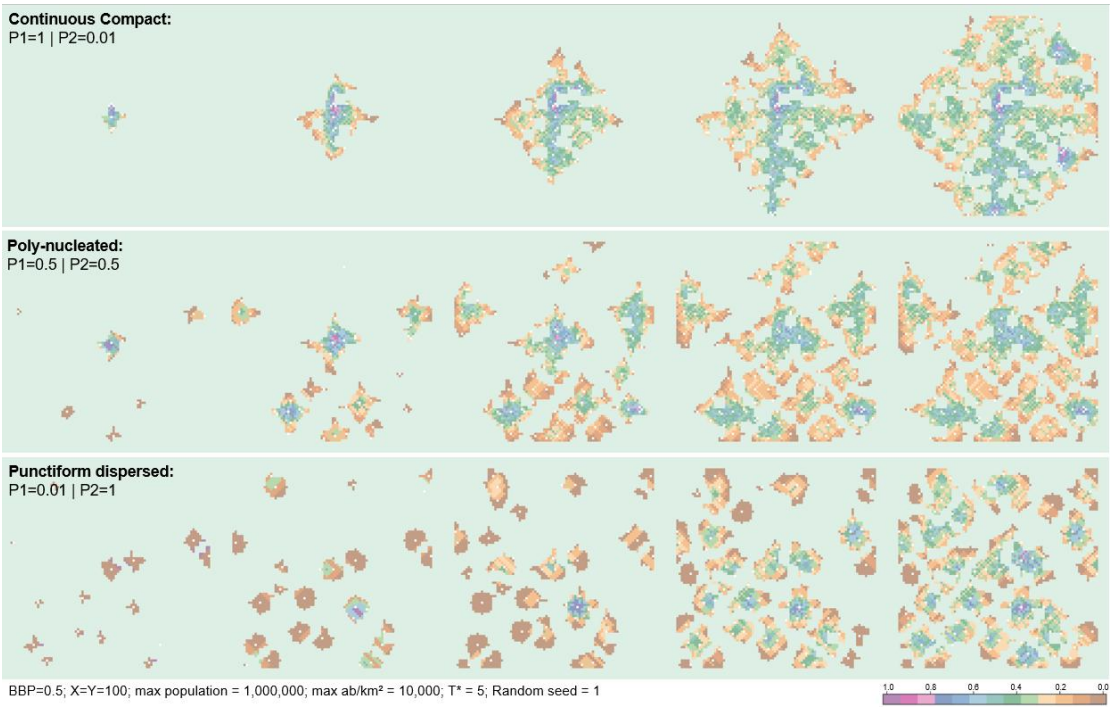


Figure 5: the growth trajectories of excessive isobenefit performance in isochronic map

Then, compare the excessive isobenefit index O_i with the population density classes (1,000ab/km^2 as medium and 10,000ab/km^2 as high) of residential cells in jittered scatter plot, centrality cells are excluded as no residence has been assigned to this cell. Across all three morphologies, higher density residential cells do not systematically correspond to higher levels of urban opportunity accessibility. As both the Pearson's correlation coefficient r and the coefficient of determination R^2 are near zero, and the differences between average excessive isobenefit of high and medium density cells also remain extremely small. By contrast, urban morphology again exerts a much clearer influence. Under the same isobenefit baseline requirement, more compact and continuous urban forms allow a larger percentage of residents to attain higher benefit accessibility. As the urban form becomes more dispersed, access to excessive isobenefit declines significantly, leaving most residents only able to reach fragmented urban resources, which has declined almost half as before within the same isochronic time threshold. Thus, the spatial configuration of the isobenefit city appears to matter more than the density features.

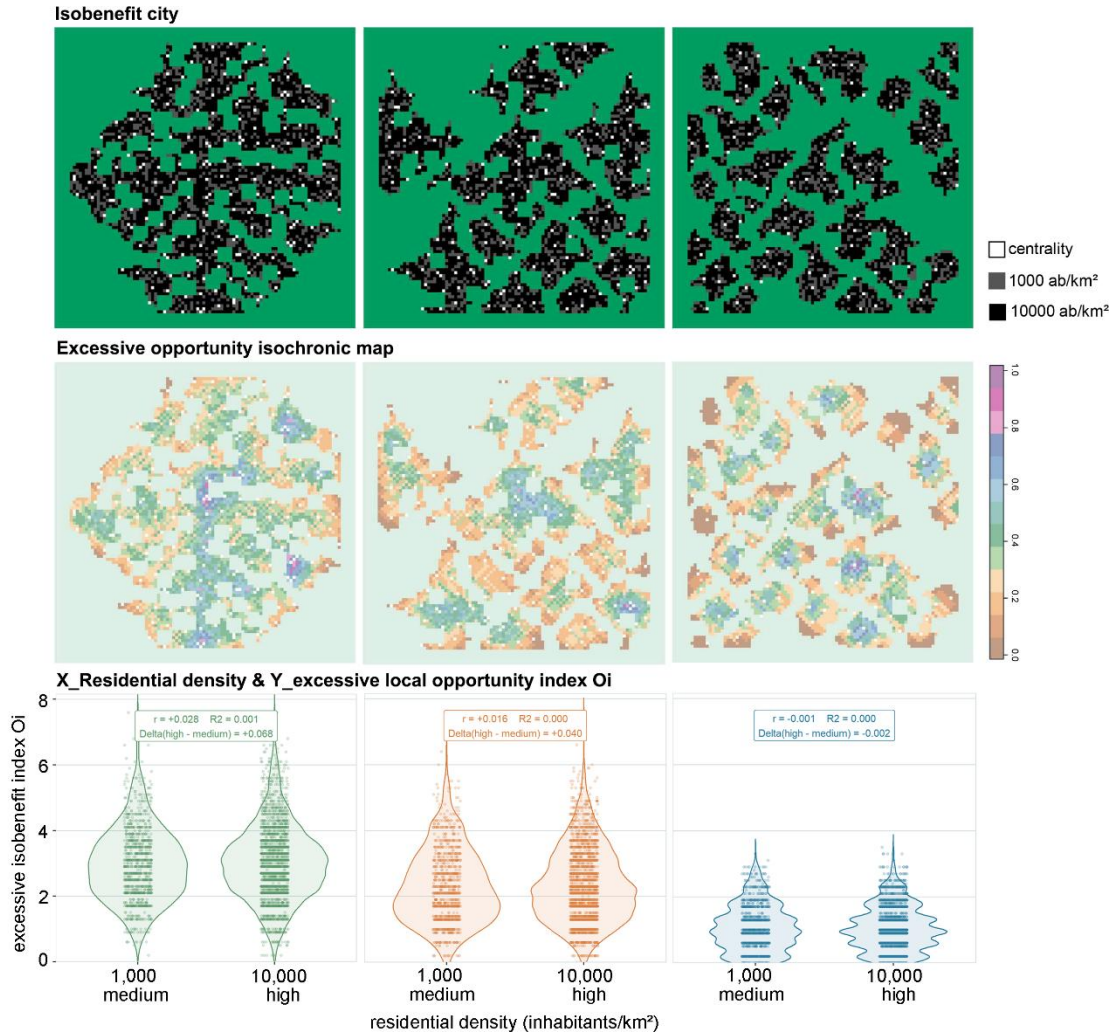


Figure 6: mismatch between opportunity and population density across isobenefit urban forms

4.2 Equality oriented Centrality network Effects

As networks are not spatially neutral, topology generates hierarchic along multiconnected nodes and transport corridors (Porta et al. 2006). To investigate whether centrality network has mitigated inequality or further exacerbated it in isobenefit city, and to compare the network effects under different isobenefit urban form, this study has applied equity-oriented transport to the three typical isobenefit morphotypes from section 4.1. The construction of transport system is divided into 8 steps shown as Figure 7, illustrate the procedure with punctiform city as an example:

a. Centrality served population allocation: in the case of punctiform dispersed city generated in 4.1, one million citizens were assigned to 114 centralities according to Manhattan distance, with the smallest served range at 1,720 residents and the largest serving 18,400 people.

b. IST backbone network: following the generation sequence of centralities, redundancy and cross optimization, 113 links were generated for IST backbone, total length is 170.99km.

c. Accessibility Deficit AD_c map under IST (walk + skyway): with basic network to keep all centralities connected, travel mode switches to walk and skyway, as no operational routes are designed yet, simply set 3min waiting time for each trip and recalculate the accessibility equality for each residence cell. The diameter of circle presents the average travel distance in

centrality served residence cells within 30 minutes, which is form 3.09-5.82km . Data illustrates the average number for reachable centralities augments from 5 to 20 with skyway system. And from the accessibility deficit map among centralities, previous nodes and their neighbors show a better accessibility benefit, which also obtain longer average travel distances in 30min.

d. Equality weighted OD Matrix: for 114 centralities, 6,441 valued OD pairs are set. Even with accessibility deficit weight W_{ij}^{E}, the OD matrix still shows a strong attraction among previously born centralities regarding the population distribution. But in punctiform city, minimum walk time between nearest centralities exceed 10min, therefore α conduct no agglomeration effect.

e. Maximal covering network optimization: 42.77% OD links can satisfy the detour demand, and with the ranking of $R_{ij}^{(k)}$ after each round of selection, 41 edges are finally added to MC network with the length constraints, and the average length of added link is 2.07km. Only two crosses the IST network, these will be constructed at different levels to ensure transfer only in centrality.

f. Original routes set: after integration of shortest OD paths, 872 candidates are selected. With the sequence of global Q_{ij}^{E} for each route, until the 146th candidate can satisfy the covering and transfer demand, after the redundant detecting, only 15 lines left and contribute to the original route set.

g. Heuristic procedure optimization: in the heuristic process, 4 original paths were replaced, and global length of routes set has reduced 10%,

h. Accessibility map A_i (walk + skyway): with 3 min waiting time and 5 min transfer time for each trip, calculate the 10, 20, and 30 min weighted isochronic accessibility map. It shows that the transport system not only significantly expanded the travel scope but further enhanced the accessibility benefits for centrality surrounding area, exhibiting a clear radial spatial effect.

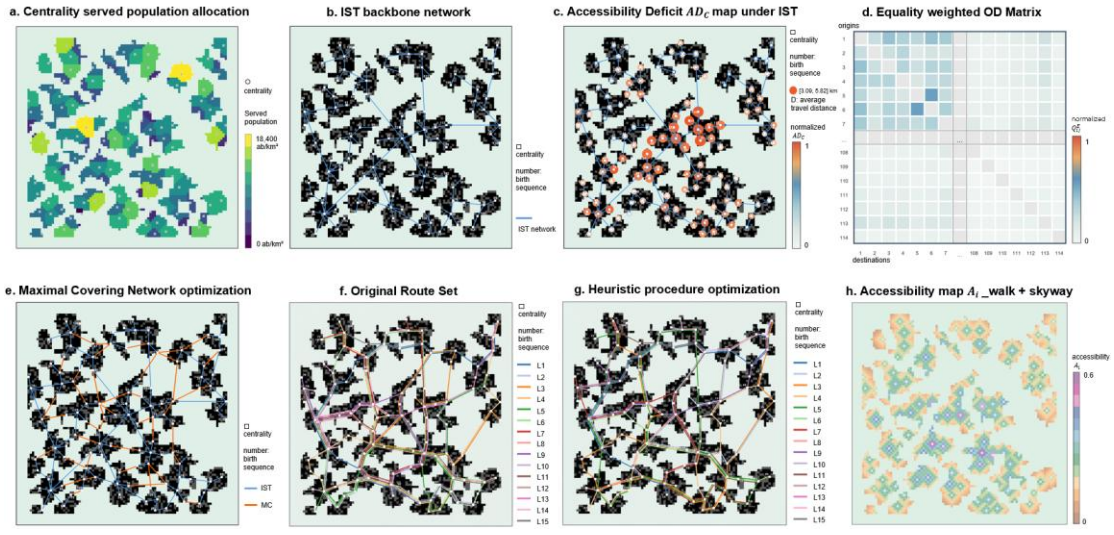


Figure 7: procedure of skyway transport network construction

Next, with completed equity-oriented transport system construct, recalculate the accessibility equality index A_i for three urban forms under the travel mode of “walk + skyway”, shown as Figure 8. As the transportation will significantly improve the accessibility, two different value range [0,0.06] and [0,0.6] were set to “walk only” mode and “walk + skyway” mode separately

to better present the spatial accessibility equality distribution. The accessibility map for "walk only" mode has a great similarity to the excessive isobenefit isochronic map as Figure 6, as more reachable centralities and green land naturally generate more social interaction as well. Besides, more continued and compact areas benefit more in walk mode, and previous generated areas also show a privilege to opportunity and social interaction. Under the "walk only" mode, accessibility declines gradually from certain compact areas toward the periphery and disperses continuously with the urban form. By contrast, under the "walk + skyway" mode, accessibility becomes strongly concentrated around centralities, followed by a distinct radial pattern away from these skyway stations.

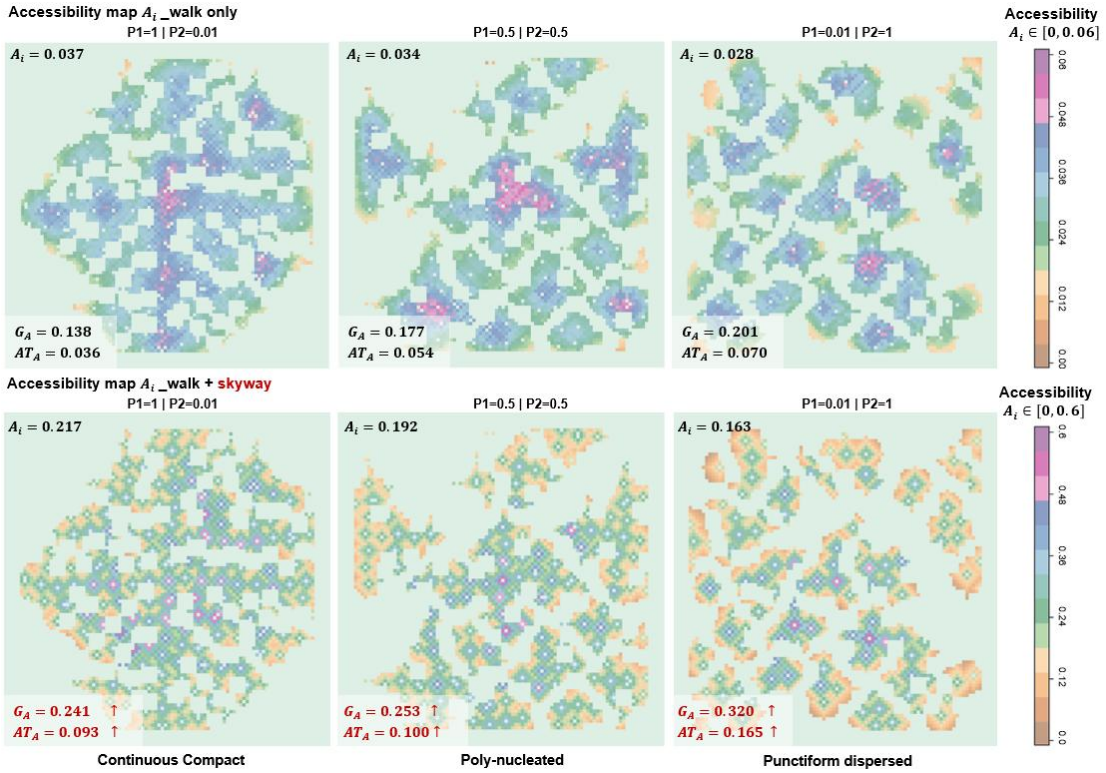


Figure 8: accessibility evolution under different situations

As for the inequality evolution, compare the Gini index G_A and Atkinson index AT_A with three urban forms under two travel modes presented in Figure 8. Apparently, both G_A and AT_A have shown an increase after the construction of skyway transport system, which means urban public transport will further exacerbate inequality, even though the centralities with lower accessibility were allocated more priority to competing the transport resource in every step. Despite the moderate increase in global inequality, AT_A rises markedly, especially for continuous compact urban form. Moreover, improvements in daily mobility range and speed further amplify accessibility disparities, leaving low-accessibility areas increasingly marginalized.

4.3 Accessibility-Compensated Morphological Evolution

From sections 4.1 and 4.2, the distribution of centralities has been proved to have essential influence on accessibility inequality. Despite the parameters P1 and P2 in isobenefit urbanism which limit mainly the continuity of urban forms. Ideally, with introduction of compensation parameter P3, the new centrality will locate in low accessibility areas, therefore, to promote equality which can be observed by the decrease of G_A and AT_A. Before constructing the future scenarios, adapting P3=1 to three typical isobenefit urban forms, to illustrate the centrality

compensation effect on city morphology and performance of reducing inequality, the results shown as Figure 9. Apparently, urban morphologies are more determined by P1 and P2 to control with the same random seed RS=1 as original group, centralities generating through either contiguous or leapfrog growth. While centrality reallocation from P3 has another internal random seed from the compensation mechanism, it can also change urban boundaries to some extent. Taking continuous compact urban form as an example, for 203 original centralities, after P3's morphology compensation, only 12 centralities have been kept at previous location, the rest 94% centralities have been replaced by new position, besides, P3 even generated 27 new centralities, which resulted in more centrality clusters compared to before other two situations. Regarding the more dispersed urban form, the compensation effect from P3 is more clearly with less overlapping area and more centralities kept. To be compared, P3 has further generated 30 centralities in poly-nucleated city, and only 12 centralities in punctiform dispersed one, nevertheless as table 1, P3 has not changed the original isobenefit morphotype.

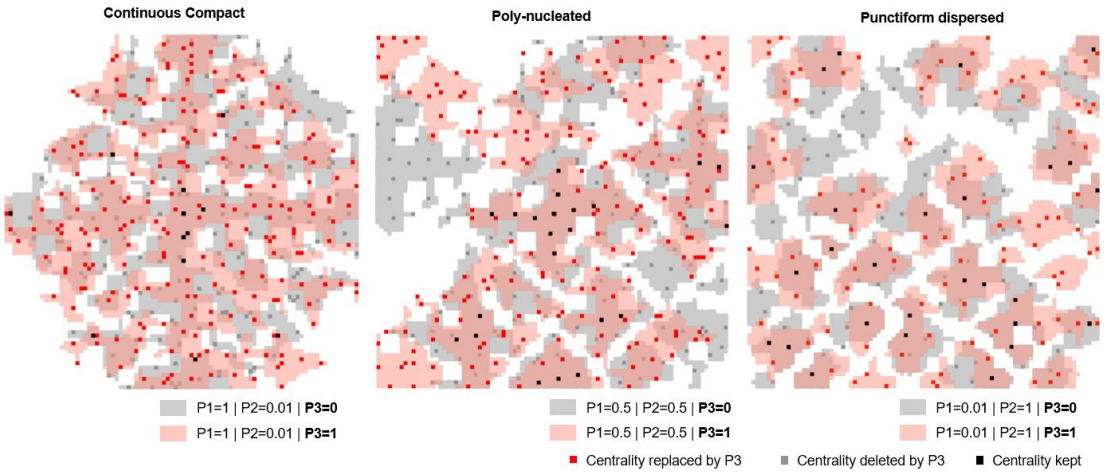


Figure 9: centrality redistribution by compensation parameter P3

Table 1: Distribution of centralities in isobenefit urban forms with or without compensation effect of P3

	Continuous Compact	Poly-nucleated	Punctiform dispersed
Original centrality number	203	175	114
Centrality number with P3=1	229	205	126
Centrality added	+27	+30	+12
Centrality kept	12	22	27
Overlapping area / original form	60.4%	53.4%	58.9%

Then, as for the results of accessibility and equality performance under "walk only" mode in each compensated isobenefit morphology shown as Figure 10, it can be observed that in the situation of "P3=1", the compensated accessibility map shows a stronger concentration of high accessibility areas among three isobenefit city forms, and lower accessibility zones become less marginalized. However, the inequality values of G_A and AT_A have shown some differences. In a more separated morphology such as poly-nucleated and punctiform dispersed isobenefit city, the compensation parameter P3 has improved the global accessibility equality and reduced the disparity between advantaged and disadvantaged areas. While contrary to expectations, inequality has increased under the compact urban form, with G_A rising from 0.138 to 0.169 and AT_A from 0.036 to 0.049. Even from the overlapping analysis of figure 9, the changement is the lowest in this continuous compact city. However, the new distribution of centralities generates more concentration of central clusters, which greatly improved the residence accessibility in

certain areas while exacerbated inequality, as average value of A_i in Figure 10 almost kept the same before and after the compensation.

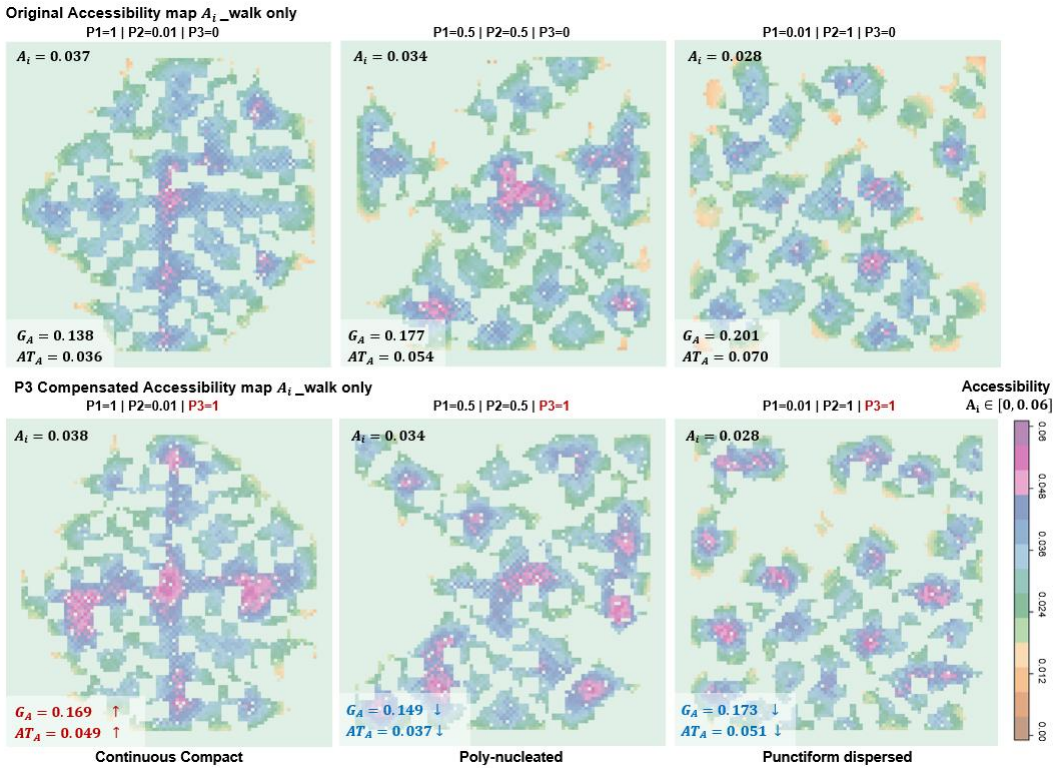


Figure 10: Accessibility equality comparison across compensated Isobenefit cities

4.4 Accessibility equality across future city scenarios

According to the future scenario settings from section 3.4, the corresponding urban forms and transport systems are generated, and accessibility equality distributions are evaluated as Figure 11. Considering that in classical city, walking to centralities is not feasible in most of residence cells, this study also set the car situation to compare its equality influence.

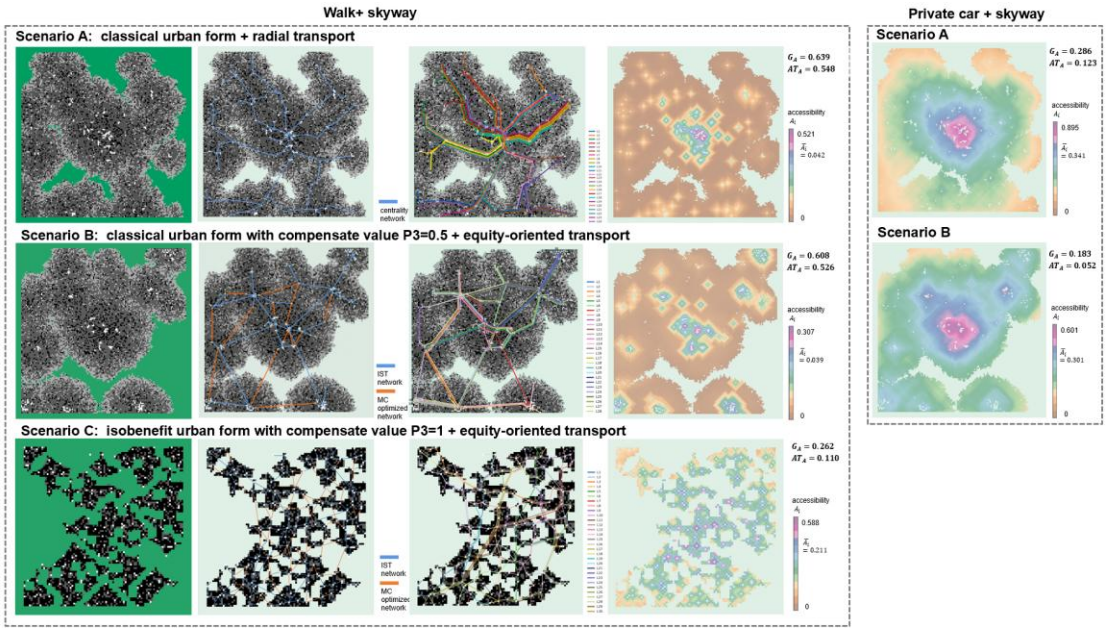


Figure 11: accessibility equality performance in future scenarios

In scenario A, original classical city has divided 193 centralities into 89 clusters according to its continuity, calculating accessibility deficit score for each cluster and building the equality-weighted OD matrix, then run section 3.2.2, 24 original routes were set which can satisfy all OD pairs and 2 transfer at most. Regarding the accessibility map with transport system, accessibility remains highly concentrated around centrality clusters and declines sharply away from them. Like a real traditional city, the urban center forms a distinct high accessibility core, whereas most peripheral areas retain relatively low accessibility levels, with high value of $G_A = 0.698$ and $AT_A = 0.675$.

In scenario B, with compensation parameter P3=0.5, it has generated 207 centralities, 80 among which selected by P1 have been replaced, the rest following the generation rule of P1 and P2, then finally resulted in 78 centrality clusters. According to the birth sequence, with IST backbone and MC network optimization, equity-oriented network has been built, and final optimized routes set consists of 28 optimized lines. Compared with scenario A, both G_A and AT_A have declined, even though it's not as much as A_{i_max}, which decreased almost 40%. It means that compensation value of centrality distribution and equity-oriented transport can improve the accessibility equality in classical city, especially in reducing the monocentric urban effect. However, in the travel mode of "walk + centrality", as the basis of accessibility calculation is 10, 20, and 30min isochronic map, almost one-third of the residence are unable to reach any opportunities within 30 minutes' walk both in scenario A and B, representing in plenty of brown area in accessibility map. While transferring the walk period into private car, from 4.6km/h to 20km/h, the average accessibility has increased nearly tenfold in both conditions, and A_{i_max} has doubled in scenario B. Apparently, in car mode, both G_A and AT_A have reduced a lot, almost reached the equality level of isobenefit morphology in Figure 10, but also further exaggerate the monocentric concentration effect.

In scenario C, based on the results of 4.3, poly-nucleated isobenefit urban form has shown the best accessibility equality after the compensation modification, therefore following section 3.2 to further build its equity-oriented transport which has resulted in 30 operational routes in MC optimized network. In isobenefit city, this study only adopts "walk + skyway" travel mode, and obviously, it has shown the best accessibility equality with $G_A = 0.262$ and $AT_A = 0.110$ in Figure 11. It has shown an increase of 3.6% in global equality and 10% in welfare sensitive equality compared to the "walk + skyway" mode in original poly-nucleated isobenefit city, even though the new distribution of centralities has decreased the inequality after the compensation mechanism.

Therefore, to better compare the difference equality effect from compensation parameter P3 and equity-oriented transport, the four control groups have been calculated among all the three isobenefit cities shown as Table 2. Transport has exaggerated greatly in accessibility and inequality in all situations. While compensated morphology effect only improves the inequality in poly-nucleated and punctiform dispersed cities, more centralities and generated clusters increased the inequality in continuous compact form. Co-effect of compensation in morphology and equality-oriented transport has shown that it cannot always reduce the negative effect in equality from transport, only punctiform dispersed isobenefit city has present a decrease of inequality compared to original urban form with transport, but its accessibility has also been influenced, shown as Figure 12.

Table 2: Accessibility equality performance in isobenefit cites under equity-oriented transport and morphological compensation

		Original Isobenefit urban form (walk only)	Compensated Isobenefit urban form (walk only)	Original Isobenefit urban form + equity-oriented transport (walk + skyway)	Compensated Isobenefit urban form + equity-oriented transport (co-effect) (walk + skyway)
Continuous Compact	G_A	0.138	0.169	0.241	0.280
	Δ/G_A	/	+22.5%	+74.6%	+102.9%
	AT_A	0.036	0.049	0.093	0.126
	Δ/AT_A	/	+36.1%	+158.3%	+250.0%
	A_i	0.037	0.038	0.217	0.251
	Δ/A_i	/	+2.7%	+486.5%	+578.4%
Poly-nucleated	G_A	0.177	0.149	0.253	0.262
	Δ/G_A	/	-15.8%	+42.9%	+48.0%
	AT_A	0.054	0.037	0.100	0.110
	Δ/AT_A	/	-31.5%	+85.2%	+103.7%
	A_i	0.034	0.034	0.192	0.211
	Δ/A_i	/	0	+464.7%	+520.6%
Punctiform Dispersed	G_A	0.201	0.173	0.320	0.310
	Δ/G_A	/	-13.9%	+59.2%	+54.2%
	AT_A	0.070	0.051	0.165	0.152
	Δ/AT_A	/	-27.1%	+135.7%	+117.1%
	A_i	0.028	0.028	0.163	0.149
	Δ/A_i	/	0	+482.1%	+432.1%

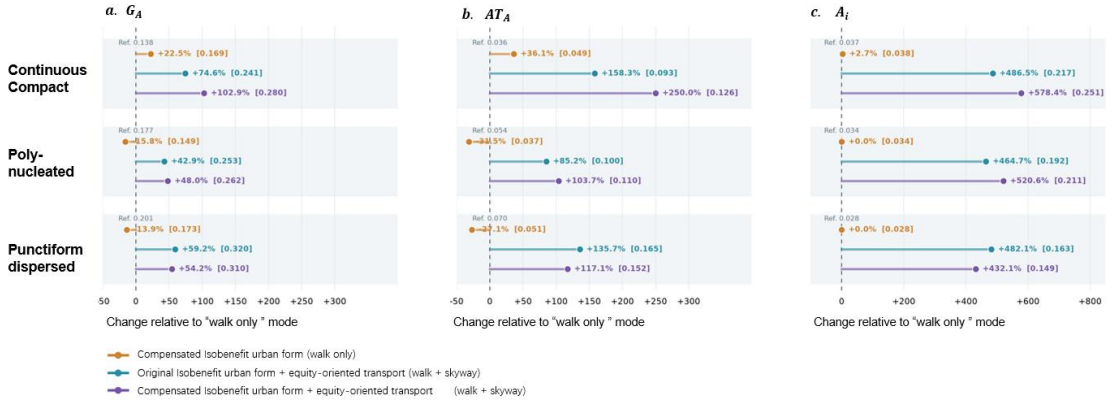


Figure 12: Accessibility equality performance in isobenefit cites under equity-oriented transport and morphological compensation

5 Discussion

5.1 Equal proximity does not ensure accessibility equality in city scale

The local proximity is the foundation of Isobenefit Urbanism, while considering the mobility in city scale, or even just comparing the actual reachable benefit of each residence cell, the excessive opportunities have shown the inequality distribution. According to Figures 5 and 6, which reveal substantial differences in excessive isobenefit performance, as residential density explains little of this variation, whereas the distribution of accessible opportunities changes markedly from continuous compact to punctiform. Compact morphologies generate greater overlap areas between neighboring centralities, allowing residents to access a larger shared pool of opportunities, whereas dispersed forms benefit less from this cumulation of centralities. The results therefore qualify the assumption that equal proximity can well protect the basic needs equality for citizens, while showing its limitation in producing a wider range of equality. Consistent with Lee et al. (2026), from case study in Seul, macro-scale connectivity and micro-

scale everyday service accessibility are not well coincided. This study further illustrates that the distribution of centralities or opportunities under urban structure shown as a stronger accessibility inequality producing mechanism relative to residential density.

5.2 Urban transport extends accessibility but further exaggerates inequality

From Figures 7 and 8, even though with a wilder accessibility and more reachable opportunities, the inequality has increased among all isobenefit morphologies, which reveals a network amplification effect. As walking accessibility is spatially continuous, declines progressively away from centrality, while with skyway transport, residence closer to the transport station greatly improved mobility within the same time constraint, which means the distance between home to centrality becoming an essential factor to further exaggerating the accessible inequality.

Then, during the network construction, IST backbone inherits the generation sequence, same as OD matrix and MC optimization, earlier and more populated centralities have occupied the strategic positions in network, with more connections and efficiency of reducing travel time, formed another factor producing hierarchy. Even though accessibility deficit weights are incorporated throughout the whole transport construction, efficiency-oriented mechanisms remain dominant over equality-oriented balancing, reflecting the inherent hierarchical and agglomerative characteristics of transport network itself.

5.3 Compensation in morphology performs various in different urban forms

The effect of compensation parameter P3 further demonstrates that equality interventions can be moderated from morphology as shown in Figure 9. With similar morphology of compensated urban forms, substantially different centrality distributions can only be observed by overlaying, which results in divergent accessibility equality outcomes, yet not casting a uniform equality effect in Figure 10, even with an increase of centralities in all compensated urban forms. In a dispersed morphology, poorly accessible areas are spatially distinct, and centrality overlapping areas are limited. Redirecting new centralities towards accessibility deficit areas therefore introduces new opportunities and reduces marginalization. While in the compact form, as the original configuration already benefits from substantial overlaps and continuous accessibility, relocation and new centralities can disrupt previously even distributed layout and simultaneously create new local concentrations from centrality clusters. Therefore, when applying an equality compensated morphological intervention, repeated trials should be conducted to explore the better balance distribution of centrality, avoiding excessive separation and over concentration that may result in fragmentation in urban development, as experiments of this study, poly-nucleated has presented the best compensation effect on equality.

5.4 Coupling effect of equality-oriented morphology and mobility in future performs better compared to traditional city

The future scenario comparison provides a narrative framework for integrating these equality-oriented mechanisms. Scenario A reproduces a monocentric classical form with a radial network where accessibility remains concentrated around the main centrality cluster and falls rapidly towards peripheral areas. Scenario B introduces medium centrality compensation and equity-oriented transport which has weakened the monocentric pattern, but large low accessibility areas remain according to walking distance limits. Scenario C combines IU morphology, strong morphological compensation and equity-oriented transport and produces the most equal city-scale accessibility distribution. The private car experiment in classical city illustrates another possibility, as the increasing travel speed markedly raises accessibility and

reduces inequality, but the accessibility field remains strongly concentrated around the principal center area, despite the morphological compensation effect. Although the simulated car experiments show improved accessibility equality, differences in car ownership are not considered, while reliance on private cars also raises sustainability issues.

Urban morphology sets the initial distribution of accessible benefits, while transport determines how far these opportunities can be reached. If the initial urban form is highly unequal as classical city, an equality-oriented network can reduce some of the accessibility inequality, but it cannot fully overcome the constraints of the existing disadvantages of urban spatial structure. In contrast, even a morphology designed from equal proximity as isobenefit city, may also develop inequality with further mobility in a city scale, especially under the support of transport system, such as skyway, which will reproduce the hierarchy in many ways. With the coordination of isobenefit morphology, equality compensated centrality distribution and equity-oriented transport, iterative accessibility equality evaluation may offer a pathway toward a more equal urban future.

6 Conclusion

This study develops an isochronic accessibility equality assessment to examine how the proximity principles of Isobenefit Urbanism translate into a city scale accessibility outcome, which demonstrates that equal proximity does not necessarily lead to equal mobility among the city, as inequalities can still emerge from the distribution of centralities across different isobenefit morphologies. While transport further extends the unequal mobility by converting geometric proximity into network-based hierarchal accessibility, where centrality birth sequence, served population, and network topology all exacerbated this inequality by influencing accessibility distribution. More importantly, the pursuit of transport efficiency has often obscured a parallel erosion of spatial equality, as accessibility improvement become increasingly concentrated during the optimization process.

Redistributing centralities toward accessibility deficit areas can partially compensate for morphology related inequality, but its effectiveness depends on the original urban form, or the degree of spatial balance in centrality distribution. Dispersed morphologies benefit more from this mechanism as additional centralities fill existing spatial gaps. In contrast, continuous compact forms, where centralities are already relatively evenly distributed, further redistribution and excessive concentration in previously disadvantaged areas may instead create new centrality agglomeration and result in inequality. Through the comparison of future scenarios, both equality balance effect of morphology and transport has shown its superiority of reducing inequalities. Therefore, IU provides the morphological basis for a more equal urban future, while equity-oriented transport can further preserve its intended equal accessibility benefit rather than allowing efficiency-driven transport development to undermine it.

This study needs to further address several limitations. Firstly, all the simulations are based on isobenefit simulator, even it reflects the spatial patterns from classical cities, but it simplifies the complexity from conventional development. Then, the OD matrix built from population, distance, accessibility deficit is origin from isobenefit generated urban forms, further work could use the observed OD data to conduct an equity-oriented transport optimization in real city. Moreover, with random seed setting in isobenefit city simulator, more morphologies should be created to compare the coupling effect of equality-oriented morphology and transport.

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Data Availability Statements

The datasets generated and analyzed during this study are publicly available in the Figshare repository at DOI: 10.6084/m9.figshare.33734248.

Ethical Approval

This article does not contain any studies with human participants performed by any of the authors.

Informed Consent

Informed consent was not required because this article does not contain any studies with human participants.