



*Review*

**A review of urban resilience frameworks: Transferring knowledge to enhance pandemic resilience**

**Yue Sun<sup>1,\*</sup>, Ryan Weightman<sup>2</sup>, Anye Shi<sup>1</sup>, Timur Dogan<sup>1</sup> and Samitha Samaranayake<sup>1</sup>**

<sup>1</sup> Cornell University, Ithaca, NY 14853, USA

<sup>2</sup> Center for Computational and Integrative Biology, Rutgers University-Camden, Camden, NJ 08102, USA

\* **Correspondence:** Email: [ys954@cornell.edu](mailto:ys954@cornell.edu).

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**Supplementary**

**Table S1.** Typical measures grouped by physical resilience assets and attributes.

Attribute	Measure	Physical asset	Description and calculation	Ref.
Diversity	Block sizes	Block, Plot	Statistical distribution of block sizes including average and standard deviation of block area.	[1]
	Gini-Simpson index	Plot	Estimate how different plots are in terms of sizes within a certain reach. If the index is close to 1, a plot is surrounded by a greater variety of plot-sizes. If close to 0, the plot is surrounded by plots of only one plot-size category. $\lambda_{200} = 1 - \sum_{i=1}^c p_i^2$ $\lambda_{200}$ : Plot heterogeneity score within 200-meter distance (Euclidean or Manhattan). $C$ : Total number of plot size categories. $p_i$ : Proportion of individuals in the $i$ -th category relative to the total number of individuals.	[2]
Connectivity	Closeness centrality	Block, Plot, Street	Measure how close a node is to all other nodes in the network. It is defined as the reciprocal of the sum of the shortest path distances from a given node to all other nodes in the network. The idea is that nodes with lower total distances to all other nodes are more central. $C_i = \frac{V - 1}{\sum_{j \in V, i \neq j} d_{ij}}$ $C_i$ : Closeness centrality of node $i$ in the network. $V$ : Total number of nodes. $d_{ij}$ : Actual shortest path distance between nodes $i, j$ .	[3,4]
	Average degree	Block, Plot, Street	Average number of ties to other nodes in the network. $\underline{d} = \frac{\sum_i^V k_i}{V}$ $\underline{d}$ : Average degree of the network. $k_i$ : Number of nodes adjacent to node $i$ . $V$ : Total number of nodes.	[5]

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Attribute	Measure	Physical asset	Description and calculation	Ref.
	Degree centrality	Block, Plot, Street	<p>Measure the importance of a node in network. Based on the idea that important nodes have the largest number of ties to other nodes in the graph.</p> $DC_i = \frac{k_i}{V - 1}$ <p><math>DC_i</math>: Degree centrality of node <math>i</math>.  <math>k_i</math>: Number of nodes adjacent to node <math>i</math>.  <math>V</math>: Total number of nodes.</p>	[3]
	Permeability	Block	<p>Connectivity suffers from the presence of large impermeable blocks. A low score indicates high permeability within the measured area.</p> $Per = \sum_{k=0}^n p_k * \frac{A_k}{A}$ <p><math>n</math>: Number of blocks.  <math>p_k</math> and <math>A_k</math>: Perimeter and area of block <math>k</math>.  <math>A</math>: total area of all blocks.</p>	[6,7]
	Square compactness	Block	<p>Measure how different a block is from an equivalent squared block with the same area. If the index is close to 0, the block is highly irregular shapes. If to 1, square shape. If higher than 1, circular shapes.</p> $SC_k = \left( \frac{4\sqrt{A_k}}{p_k} \right)^2$ <p><math>SC_k</math>: Square compactness of block <math>k</math>.  <math>p_k</math> and <math>A_k</math>: Perimeter and area of block <math>k</math>.</p>	[8,9]

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Attribute	Measure	Physical asset	Description and calculation	Ref.
	Straightness centrality	Street	<p>Measure the extent to which a place can be reached directly, on a straight line, from all other places in the network.</p> $S_i = \frac{1}{V-1} * \sum_{j \in V, i \neq j} \frac{d_{ij}^{eucl}}{d_{ij}}$ <p><math>S_i</math>: Straightness centrality of node <math>i</math> in the network.  <math>V</math>: Total number of intersections.  <math>d_{ij}^{eucl}</math>: Euclidean distance between nodes <math>i</math> and <math>j</math>.  <math>d_{ij}</math>: Actual shortest path distance between nodes <math>i, j</math>.</p>	[3,4]
	Betweenness centrality	Street	<p>Quantify the number of times a node acts as a bridge along the shortest path between two other nodes. A node is more central when traversed by more shortest paths connecting all couples of nodes in the network.</p> $B_i = \frac{1}{(V-1)(V-2)} * \sum_{j=1, k=1, j \neq k \neq i}^N \frac{n_{jk(i)}}{n_{jk}}$ <p><math>B_i</math>: Betweenness centrality of node <math>i</math>.  <math>V</math>: Total number of nodes in the network.  <math>n_{jk}</math>: Number of shortest paths between nodes <math>j, k</math>.  <math>n_{jk(i)}</math>: Number of these shortest paths that contain node <math>i</math>.</p>	[3,4]
	Accessible plot density	Plot	<p>Quantify density of plots reachable from a plot within a defined threshold distance. The score ranges between 0 and 1. Higher value (close to 1) is associated to the plot surrounded by a greater density of destinations.</p> $D_{200} = \frac{P_{200}}{P_{eucl,200}}$ <p><math>D_{200}</math>: Accessible plot density within 200 metric distance on street network.  <math>P_{200}</math>: Number of plots within 200 metric distance on street network.  <math>P_{eucl,200}</math>: Number of plots within 200 meter Euclidean distance from the plot.</p>	[2,10]

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Attribute	Measure	Physical asset	Description and calculation	Ref.
Redundancy	Cyclomatic number (or Meshedness coefficient)	Street	<p>Represent number of circuits in the network. It indicates the number of possible alternative routes between two different destinations in the network.</p> $CN = L - V + 1$ <p><math>L</math>: Total number of links.  <math>V</math>: Total number of intersections.</p>	[11–13]
	Cyclicity	Street	<p>Number of times random walks within a network lead to a cycle back to a previously visited node/number of random walks. It indicates the portion of random walks that end up with cycling back to a visited node. The value is between 0 and 1.</p> $\hat{C} = \frac{\sum_{i=1}^n Cycle_i}{ R }$ <p><math>\hat{C}</math>: Cyclicity of the network.  <math> R </math>: Number of random walks.  <math>\sum_{i=1}^n Cycle_i</math>: Number of walks that return to visited nodes.</p>	[5]
Modularity	Sanctuary area granularity	Block	<p>Number of blocks per district normalised by total size of district, producing a value of block density per hectare.</p> $G_{Dis} = \frac{N_{Dis}}{A_{Dis}}$ <p><math>N_{Dis}</math>: Number of blocks in the sanctuary area.  <math>A_{Dis}</math>: Total area of the sanctuary area.</p>	[8]
Efficiency	Network efficiency	Street	<p>Average normalized efficiency of all possible couples of nodes in the network.</p> $E = \frac{1}{V(V-1)} * \sum_{i,j \in V, i \neq j} \frac{d_{ij}^{eucl}}{d_{ij}}$ <p><math>E</math>: Global efficiency of network.  <math>V</math>: Total number of intersections.  <math>V(V-1)</math>: Total number of possible directed pairs of different intersections.  <math>d_{ij}^{eucl}</math>: Euclidean distance between nodes <math>i</math> and <math>j</math>.  <math>d_{ij}</math>: Actual shortest path distance between nodes <math>i, j</math>.</p>	[12,14,15]

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Attribute	Measure	Physical asset	Description and calculation	Ref.
	Information centrality	Street	<p>Measure the importance of a node. The metric is defined as the relative efficiency drop in the network caused by the removal of the node from the network. The network performance, before and after the node is removed, is measured by the above metric, Network Efficiency <math>E</math>.</p> $IC_i = \frac{\Delta E}{E} = \frac{E - E_{removed}}{E}$ <p><math>IC_i</math>: Information centrality of node <math>i</math>.  <math>E</math>: Network efficiency before node <math>i</math> is removed.  <math>E_{removed}</math>: Network efficiency after the removal.</p>	[12,14,15]
	Average Shimbel index	Street	<p>Average of the sum of the lengths of all shortest paths connecting all pairs of nodes in the network.</p> $A_i = \sum_{j \in V, i \neq j} \frac{d_{ij}}{V-1}$ <p><math>A_i</math>: Average Shimbel index of plot <math>i</math>.  <math>V</math>: Total number of intersections.  <math>V-1</math>: Total number of possible O-D pairs.  <math>d_{ij}</math>: Actual shortest path distance between nodes <math>i, j</math>.</p>	[5]
Density	Floor area ratio	Block, Plot	<p>Floor Area Ratio (FAR) is a measure used in urban planning to determine the density of a building or development. It is calculated as the total floor area of all buildings on a block or plot divided by the region's area. FAR is used to control the intensity of land use, influencing urban density, building height, and open space availability:</p> $FAR = \frac{\text{Total Floor Area of Buildings}}{\text{Land Area of the Region}}$	[16]
	Population density	Block, Plot	<p>Population density is calculated as the number of people living per unit area of land. It is typically expressed as inhabitants per square kilometer or square mile. This measure provides insights into the concentration of people within a given urban area, influencing infrastructure demand, public service efficiency, and environmental impact:</p> $\text{Population Density} = \frac{\text{Total Population}}{\text{Land Area of the Region}}$	[16,17]

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