

## From Self-Organization to Regulation: A Bio-Inspired Agent-Based Model for Integrated Urban Planning and Growth Management in Western Province, Sri Lanka

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### INTRODUCTION & AIM

Urban growth in Western Province, Sri Lanka, does not occur as a random spread. Commercial clusters form near transport corridors, density concentrates around established urban areas, and ribbon development follows major roads. Between 1990 and 2025, the built-up extent of the province increased from 143 km<sup>2</sup> to 787 km<sup>2</sup>, showing a major spatial transformation within 35 years.

Traditional urban growth models can reproduce urban patterns, but they often provide limited explanation of the actual mechanisms behind development.

**Problem:** Planning regulation often treats urban growth as a controllable top-down process, while real development is partly shaped by decentralized market decisions.

**Research Need:** Limited research has tested how far self-organizing growth can explain urban expansion in a South Asian planning context.

**Objective:** This study develops a bio-inspired agent-based model, based on *Physarum polycephalum*, to identify where urban growth follows self-organizing spatial logic and where stronger planning regulation is required.

### METHOD

The study uses a mechanism-discovery approach rather than a conventional prediction model. The 1990 urban edge was used as the initial development frontier, while agents allocated growth across contemporary spatial conditions until the observed 2025 built-up extent was reached.

#### 2.1 Data Preparation

Input layers included road proximity, land value, existing urban density, amenity accessibility, slope suitability, and water bodies. The 1990 built-up edge was used for agent initialization, while the observed 2025 built-up pattern was used for validation. All suitability layers were prepared at 30 m resolution, normalized, and combined into an attraction surface representing relative development pressure.

#### 2.2 Bio-Inspired Agent-Based Framework

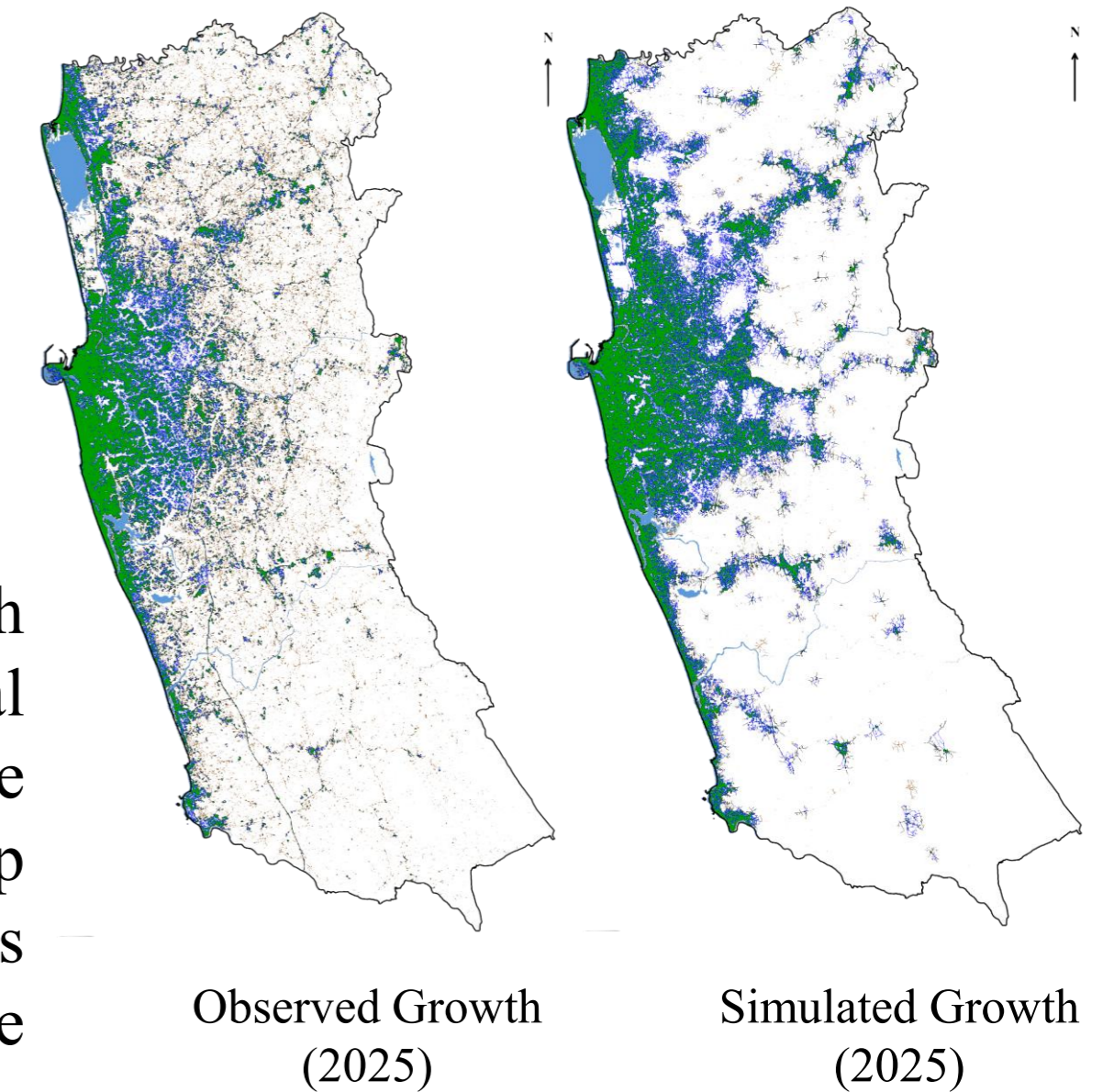
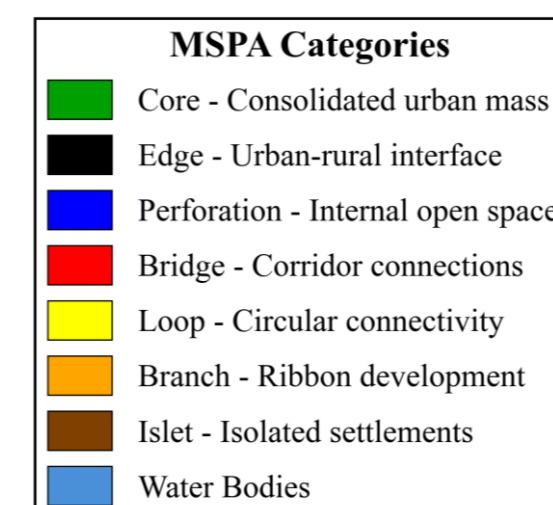
The model translates three *Physarum* mechanisms into urban growth rules:

**Gradient-following:** agents move toward locations with higher development attraction.

**Path reinforcement:** locations receiving repeated visits accumulate stronger development pressure.

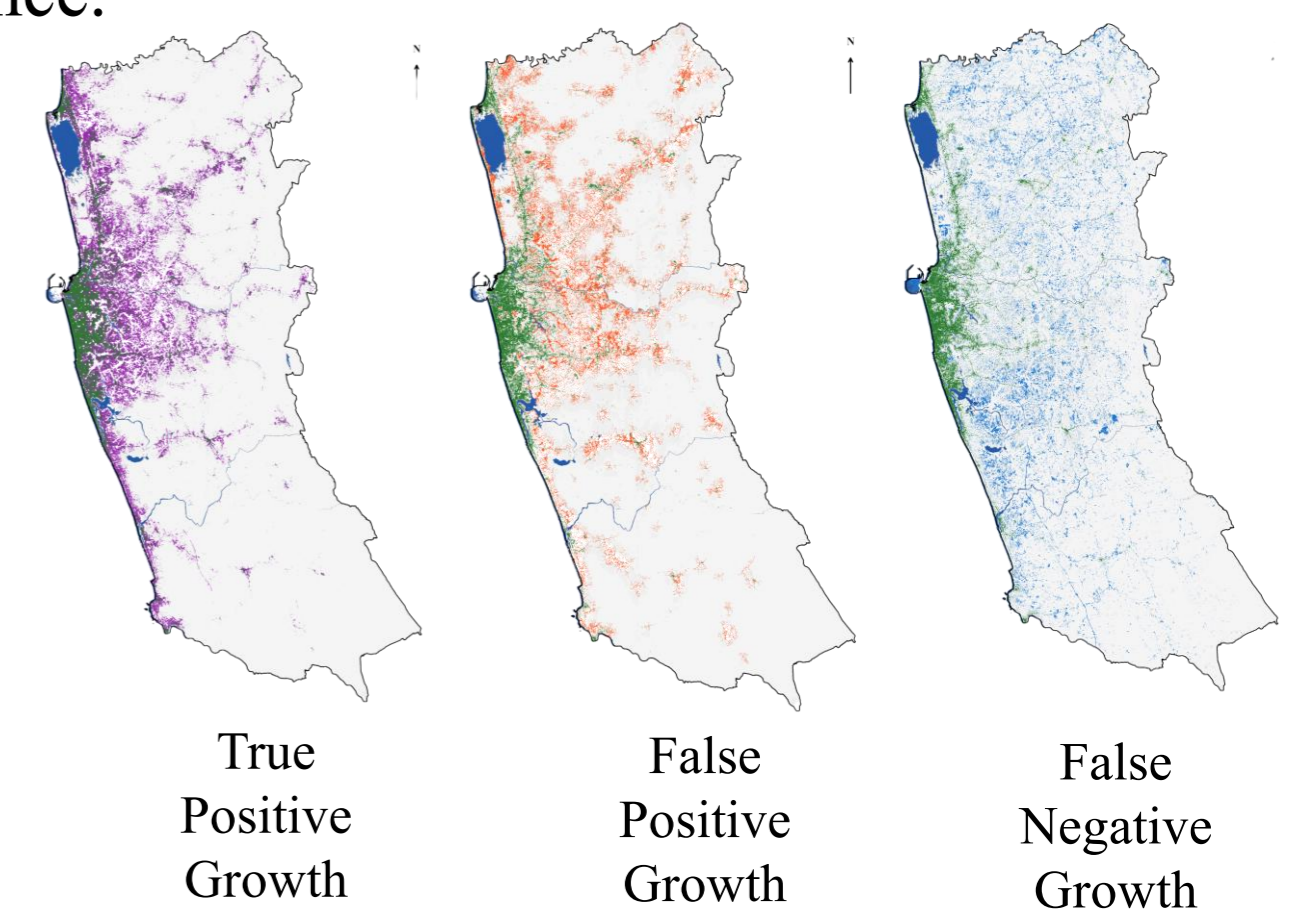
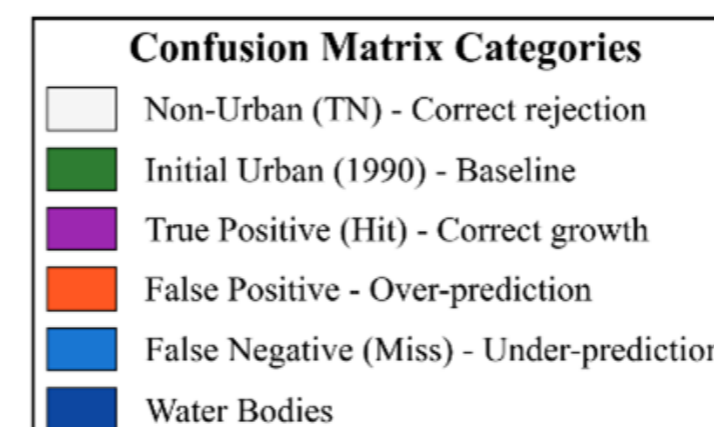
**Decay and threshold conversion:** weak pressure fades over time, while sustained pressure converts into simulated built-up growth. Model calibration was carried out by comparing simulated growth with the observed 2025 built-up pattern using spatial accuracy measures, including Figure of Merit and Kappa coefficient.

### RESULTS & DISCUSSION



The simulated growth pattern shows partial spatial correspondence with the observed 2025 built-up expansion. Agreement is more evident around the Colombo urban core

and along several transport-oriented growth corridors. The model allocated 49% of the observed built-up expansion, with a Figure of Merit of 0.428 and a Kappa value of 0.574. Within the calibrated model, road proximity received the highest weight, suggesting that accessibility plays an important role in shaping urban growth pressure in Western Province.



Morphological analysis showed that 62% of false negatives occurred as isolated fragments,

indicating scattered development less consistent with gradient-following logic. These areas may reflect informal settlement, public-sector intervention, land-tenure conditions, or other local processes beyond the model scope. False positives may indicate locations with high modelled attraction where observed development was limited by regulatory, tenure, or infrastructure-related constraints.

### CONCLUSION

#### Contribution:

Interprets the spatial limits of self-organizing urban growth through a bio-inspired allocation model.

#### Implication:

Fragmented unexplained growth indicates areas where closer local investigation and regulatory review may be required.

### REFERENCES

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