Agent Based Modeling (ABM) For Land Use Transport Integration

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Abstract. Rapid urbanisation, spatial fragmentation, and increasing mobility pressures have intensified the need for stronger land use transport integration (LUTI) in many cities. Weak coordination between housing growth, transport networks, and accessibility planning has contributed to congestion, inefficient land development, and uneven access to opportunities, particularly in rapidly growing urban regions. These challenges affect both commuters and planners, making the development of more responsive analytical tools an urgent priority.
This paper aims to examine how Agent-Based Modelling (ABM) has been used to strengthen LUTI, and to identify conceptual, methodological, and empirical gaps that affect its application in diverse urban contexts. To achieve this, the study adopts a structured review of academic literature published over the past two decades, drawing on peer-reviewed studies that apply ABM to land-use change modelling, transport microsimulation, and integrated urban systems analysis. The review finds that ABM enables the representation of heterogeneous agents and emergent spatial outcomes, offering advantages over traditional LUTI models that rely on static or aggregated behavioural assumptions (Waddell, 2002; Batty, 2005). However, persistent challenges such as data intensity, calibration difficulty, limited validation, and a concentration of studies in developed-world contexts continue to limit the transferability and operational use of ABM in planning practice (Moeckel, 2017; Crooks & Castle, 2020).
In response, the paper proposes a hybrid contribution consisting of a conceptual ABM–LUTI integration framework and an evaluation matrix to support systematic assessment and model transparency. Together, these outputs can assist planners and policymakers in selecting, interpreting, and applying ABM tools more effectively to support evidence-based urban development and integrated mobility planning.

Keywords: Agent-Based Modeling (ABM), Land Use Transport Integration (LUTI), Ur-ban Simulation, Behavioral Modeling, Urban Dynamics, Data Integration, Urban Planning.

1 Introduction

Rapid urbanisation, expanding mobility needs, and uncoordinated land development have intensified pressures on urban systems. Many cities especially in rapidly developing regions face rising congestion, increasing travel times, fragmented spatial growth, and unequal access to opportunities. These challenges stem from weak

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between where people live, where economic activities concentrate, and how transport infrastructure evolves. Residents, commuters, low-income groups, and planners are directly affected, often experiencing longer commutes, higher travel costs, reduced accessibility, and unsustainable land consumption patterns. The accelerating pace of development in cities such as Bhopal, Dehradun, and similar Indian urban regions further amplifies the need to understand how land-use decisions and mobility behaviour interact over time.

Historically, planners and institutions have relied on aggregate or equilibrium-based models such as UrbanSim, the Land Transformation Model, and classical LUTI frameworks to forecast development patterns and assess transport impacts (Waddell, 2002; Li et al., 2013). These tools have guided long-term planning by linking accessibility, density, and land-market conditions. However, they treat human behaviour as largely uniform, overlook informal mobility, and struggle to represent feedback loops between daily travel choices and land-use change (Wise et al., 2017; Batty et al., 2014).

Although several cities have introduced policy measures such as transit-oriented development, mobility plans, and zoning reforms, the analytical tools behind these interventions remain limited in their ability to simulate diverse agents or capture emergent behaviour. Efforts to model informal growth, socio-economic diversity, or rapidly changing accessibility conditions remain weak, particularly in developing-world contexts where data constraints are severe. As a result, many existing models produce stable macro-level patterns but fail to explain localised and dynamic urban processes (Torrens, 2006; Xiao et al., 2025).

While recent research increasingly adopts Agent-Based Modelling (ABM) to address behavioural limitations of traditional LUTI models, existing applications remain fragmented across regions, scales, and tools. Studies from Europe and North America report success with ABM–LUTI platforms such as MATSim and FABILUT (Horni et al., 2016; Malleson et al., 2022), yet findings often remain case-specific and difficult to generalise (Bastarianto et al., 2023; Liu et al., 2020). Research from developing contexts attempts to incorporate informal mobility and socio-economic heterogeneity (Verma et al., 2021; Jalan et al., 2016), but faces persistent constraints in data integration, calibration, and validation.

Despite growing interest, there is no consolidated synthesis that systematically explains how ABM is being used for land-use and transport integration, what behavioural and computational assumptions underpin these models, and how their results vary across geographical and methodological contexts. Existing studies examine specific tools or case studies, but no structured review connects these strands to provide planners with conceptual clarity, methodological insight, or practical guidance.

1.1 Aim, objectives and research question

Aim - To evaluate the applicability of Agent-Based Modeling (ABM) in simulating Land use transport integration and developing a contextual framework in relation to Urban planning scenarios.

Objectives –

To explore the theoretical foundations, evolution, and scope of agent-based modeling in the context of urban planning.

To examine how ABM simulates the interdependencies between land use and transportation systems, incorporating individual decision-making and spatial dynamics.

To develop a conceptual/research framework for integrating land use and transport planning using agent-based simulations tailored to various urban scenarios.

2 Methodology

2.1 Review Approach

The research follows the PRISMA (2020) systematic review protocol, combining bibliometric mapping with thematic content analysis. A total of 80 papers were initially retrieved, of which 30 studies met the inclusion criteria after abstract and full-text screening.

2.2 Data Sources & Search Strategy

Search terms included:

- "Agent-Based Modelling for land use transport integration in urban planning"
- "LUTI AND simulation in urban planning"
- "Land-use change AND ABM"
- "Urban mobility AND agent-based"

Searches were conducted across Google Scholar, Scopus, and Web of Science databases.

2.3 Screening, Inclusion & exclusion Criteria

A three-stage filtering protocol was used:

1. Title–abstract screening to remove non-urban or non-modelling papers.
2. Full-text screening for methodological relevance (papers using ABM for land-use, transport, or both).
3. Quality threshold screening based on clarity of model design, data description, and stated outcomes.

2.4 Eligibility Criteria

Inclusion criteria as discussed in Table 1:

- Use of ABM in land-use, transport, mobility, or accessibility modelling.
- Empirical, conceptual, or computational LUTI-related studies.
- Published in the last 20–25 years.

Exclusion criteria as discussed in Table 1:

- Pure machine-learning transport models.
- Large-scale LUTI models without agent behaviour.
- Environmental ABMs with no spatial–mobility component.

Table 1 – PRISMA Inclusion & Exclusion of papers (Author)

Stage	Action	Records Identified / Assessed	Records Excluded (with Rationale)
Identification	Initial Search Records (from Google Scholar, Scopus, Web of Science, ScienceDirect)	120	
Deduplication	Records Removed Before Screening (Duplicates identified via DOI matching)	80 (Shortlisted)	40 (Duplicates)
Screening	Records Screened (Titles and Abstracts assessed for relevance to ABM/LUTI)	50	(Implicitly 30 were excluded in this combined step)
Eligibility	Full-Text Articles Assessed for Eligibility Exclusion Rationale (20 papers):	30	20 (Excluded during full-text assessment) 1. Computational focus only (no behavioral modeling) 2. Machine learning/neural-network studies lacking heterogeneous agent decisions 3. Generative design models without land-use–transport interactions 4. Macro-level/national-scale models lacking agent-based behavioral representation 5. Domain-specific ABMs (e.g., ecological) not connected to urban LUTI
Included	Studies Included in Final Systematic Review and Synthesis	30	

2.5 Analysis Procedure

Step 1: Systematic Coding

- Each paper was coded for study context, modelling platform, agent types, behavioural assumptions, data used, outputs generated, and validation techniques.
- A uniform coding template ensured comparability across all 30 studies.

Step 2: Analytical Grouping

Coded studies were organised into key categories such as:

- model integration approaches,
- behavioural representation,
- computational scalability,
- planning and policy applications.

This grouping helped identify dominant trends and variations across contexts.

Step 3: Thematic Synthesis

- Cross-comparison was conducted to identify recurring themes, contradictions, and missing elements.
- **Negative** evidence (what papers did not address), contextual contrasts (Global North vs. Global South), and methodological gaps were systematically noted.
- Insights from this synthesis informed the conceptual framework and evaluation matrix developed later.

3 Literature

3.1 Thematic Literature

3.1.1 Land Use Dynamics

Land use models have long provided planners with insights into spatial allocation of population, housing, and employment. Early frameworks, such as the Lowry model (1964) and its successors, emphasized aggregate spatial distribution driven by accessibility and economic forces. However, traditional land use models often rely on static equilibrium assumptions and zonal aggregation, overlooking individual heterogeneity and the micro-decisions that drive urban change (Waddell, 2002; Wegener & Fürst, 1999). Consequently, these models struggle to represent fine-scale spatial dynamics such as peri-urban expansion, informal settlements, or densification along transport corridors (Verma et al., 2021; Acheampong & Silva, 2015).

3.1.2 Transport Modeling

Transport models, on the other hand, have matured through the four-step framework—trip generation, distribution, mode choice, and assignment—providing robust estimates of mobility demand and network performance. Yet, conventional transport models typically treat land use as static input, failing to capture how accessibility changes influence long-term location decisions or urban form (Miller et al., 2004; Horni et al., 2016). As a result, feedbacks between travel demand and spatial development remain weakly represented, leading to policy misalignments where infrastructure supply precedes urban demand patterns (Zhong et al., 2014).

3.1.3 Need for Land Use–Transport Integration

The recognition that land development and mobility are co-evolutionary led to the emergence of Land Use–Transport Integration (LUTI) models. Integrated LUTI frameworks seek to represent how accessibility affects location choices and how those choices, in turn, alter transport demand and network performance (Wegener, 2004; Acheampong & Silva, 2015). Despite progress, existing LUTI approaches still face limits: weak behavioral realism, lack of dynamic adaptation, coarse spatial granularity, and difficulty testing multi-sectoral policies such as transit-oriented development (TOD) or congestion pricing (Batty, 2013; Verma et al., 2021).

3.2 Key Gaps in Conventional LUT and LUTI Models

Table 2 – Key Gaps in Conventional LUTI Models (Author)

Aspect	Limitation in Conventional Models	Evidence / Authors
Spatial Resolution	Operate at coarse zonal scale, miss parcel-level and corridor-specific dynamics.	Wegener & Fürst (1999); Verma et al. (2021)
Behavioral Realism	Assume homogeneous agents and static preferences, weak behavioral feedbacks.	Waddell (2002); Acheampong & Silva (2015)
Dynamic Feedbacks	Limited two-way interaction land use affects travel demand but transport rarely feeds back to land markets.	Miller et al. (2004); Zhong et al. (2014)
Temporal Adaptation	Equilibrium-based, cannot simulate gradual adaptation, relocation, or induced demand over time.	Batty (2013); Wegener (2004)
Policy Sensitivity	Struggle to evaluate combined policies (zoning + transport + pricing), often scenario-dependent.	Verma et al. (2021); Horni et al. (2016)

Cross-Sectoral Gaps	Exclude social, health, and environmental accessibility factors influencing spatial structure.	Rao & Patel (2018); Perez et al. (2011)
Data and Calibration Issues	Depend on extensive datasets but have limited mechanisms for spatial validation or calibration.	Acheampong & Silva (2015); Zhong et al. (2014)

3.3 Introduction to ABM (Agent Based Modeling)

Agent-Based Modeling (ABM) is a simulation method that models individual agents such as households, commuters, or developers and their interactions to capture complex system behavior (Crooks et al., 2008). These agents follow defined rules and respond to their environment, allowing the model to simulate how individual decisions lead to emergent patterns (Benenson & Torrens, 2004).

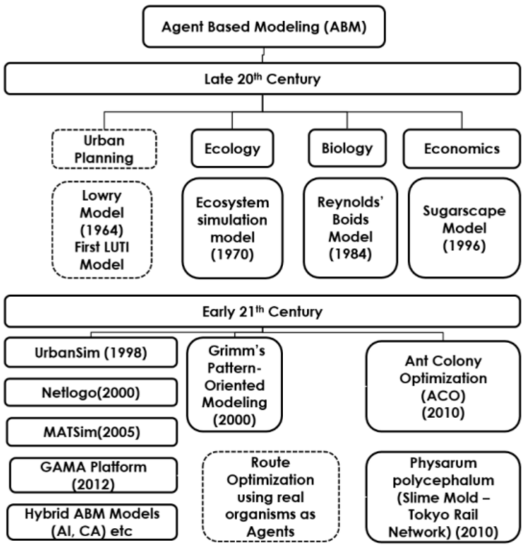

Fig 1 - Evolution of ABM in various fields (Author)

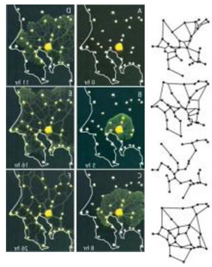

Fig 2 – Slime Mold Experiment, Tokyo (WIRED)

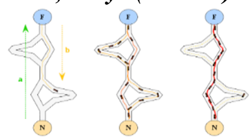

Fig 3 – Ant Colony Optimization (Dutta)

Ant Colony Optimization (ACO) and Slime Mold are both decentralized self-organizing systems that use indirect signalling. This dual principle is applied in urban planning to optimize city infrastructure, where agents (ants/slime) reinforce the most efficient paths to help design resilient transportation and utility grids.

3.4 Relevance to Urban Planning

Realistic Modelling - Urban systems require models that capture complex, adaptive behaviors rather than static zones. Studies (Waddell, 2002; Verma et al., 2021) show that coupling land-use and transport through agent-based simulations yields more realistic spatial and accessibility outcomes.

Scenario Testing - Integrated models enable planners to test zoning or pricing scenarios before real implementation. Wegener (2004) and Zhong et al. (2014) note that ABM-based frameworks simulate long-term impacts of policies under changing spatial and behavioral conditions.

Behavioral Analysis - Traditional LUTI models generalize human choices, missing behavioral diversity. Acheampong & Silva (2015) and Miller et al. (2004) highlight that agent-based modeling captures how households, firms, and commuters react individually to accessibility and cost, improving behavioral realism.

Sustainable Urban Development and Spatial Equity - Sustainable cities depend on balanced accessibility and inclusive growth. Rao & Patel (2018) and Perez et al. (2011) demonstrate that agent-based approaches reveal how local travel and land-use interactions influence low-carbon and equitable urban outcomes.

3.5 Case Studies & ABM Techniques used

Table 3 – Case studies matrix (Author)

Sr. No.	Case Study / City	Focus Area	ABM Technique / Platform	Key Outcome / Relevance
1	Dehradun, India	Land-use & urban growth	CA–ABM Hybrid (Custom)	Showed corridor-based compact growth potential
2	Bhopal, India	Infrastructure dynamics	Feedback ABM	Linked infrastructure delivery with compact growth
3	Xi'an, China	Land-use–transport coordination	Multi-agent LUTI Model	Identified accessibility-led urban form
4	Paris, France	Regional LUTI framework	FABILUT	Integrated behavioral feedback in urban modeling
5	Zürich, Switzerland	Transport behavior	MATSim	Evaluated congestion pricing and mode shift
6	Austin, USA	Autonomous mobility	Activity-based ABM	Tested SAV fleet management & emissions

7	San Francisco, USA	Integrated urban simulation	UrbanSim	Linked housing, employment, and transport
8	Berlin, Germany	Dynamic traffic assignment	ABM + DTA Coupling	Enhanced congestion prediction
9	Jakarta, Indonesia	Urban form optimization	Spatial ABM	Modeled mixed-use compact city planning
10	Jaipur, India	Urban health & ecology	Population ABM	Analyzed street dog management policies
11	Brazil	Healthcare accessibility	Discrete-event ABM	Improved hospital resource allocation
12	Delhi NCR, India	Air quality and exposure	ABM–Environment Coupled	Evaluated pollution mitigation measures
13	Seoul, Korea	Land-use efficiency	ABM + Accessibility Metrics	Analyzed 15-minute city potential
14	Milan, Italy	Cycling and cultural corridors	Agent-based transport design	Identified route optimization policies
15	Toronto, Canada	Policy impact on travel	Agent-based Policy Simulation	Predicted traveler response to fuel tax
16	Nairobi, Kenya	Informal transport systems	Multi-agent network ABM	Analyzed para-transit regulation
17	Madrid, Spain	Energy-efficient neighborhoods	ABM–Energy Coupled	Evaluated solar energy adoption
18	Singapore	Smart city mobility	Multi-agent transport ABM	Tested integrated data-driven routing
19	Chicago, USA	Housing-market simulation	ABM–Econometric Integration	Studied gentrification and accessibility
20	Beijing, China	Regional LUTI validation	ABM Calibration Model	Validated spatial policy performance

4 Results/Findings/Analysis

4.1 Bibliometric Analysis –

The bibliometric analysis was conducted manually using a structured database compiled from the 30 peer-reviewed papers shortlisted for this SLR. Publication metadata (year, authors, region, journal, and keywords) were extracted from Scopus, Web of Science, and Google Scholar records. These data were organized in Excel and analysed through frequency counts and percentage distributions to identify temporal trends, regional representation, and thematic clusters. Keyword co-occurrence and author–institution patterns were mapped conceptually following principles of co-citation and co-word analysis used in bibliometric studies as shown in **Table 3**.

4.1.1 Field of Study

Table 4 – Field of Study (Author)

Criteria	Category	No. of papers	%
Field of study	Urban/Spatial Modelling	12	40%
	Transport & Mobility Studies	7	23%
	Land-use & Environment Planning	6	20%
	Computational / Simulation Science	5	17%

Urban and spatial modeling (40%) remains the dominant domain, reflecting ABM's planning origins. Transport (23%) and land-use studies (20%) indicate growing interdisciplinary overlap, while computational science (17%) as shown in Table 4.

4.1.2 Publication Years

A clear upward trend appears annually with 50% of papers published between 2020–2025.

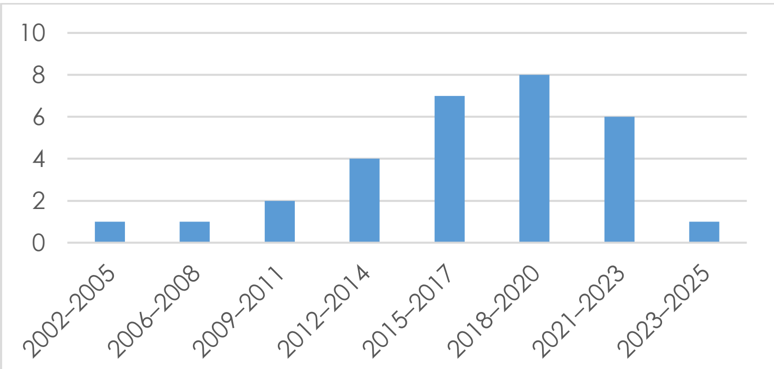

Fig 4 – Year-wise publication of papers (Author)

4.1.3 Research Methods

Table 5 – Research methods used in the research papers (Author)

Orientation	No. of Papers	%
Quantitative	14	47
Qualitative	4	13
Empirical	8	27
Theoretical	4	13

Nearly half (47%) of the studies are quantitative, focusing on simulation and scenario analysis. Empirical research (27%) highlights growing real-world calibration efforts, mainly in Europe and South Asia. Theoretical and qualitative works (13% each) provide the conceptual base as shown in Table 5.

4.1.4 Geographic Distribution of Studies

The majority (50%) of ABM–LUTI research originates from high-income countries in Europe and North America, whereas developing-country applications remain underrepresented (27%). Indian case studies such as those by Jalan (2016) and Verma (2021) are critical early contributions demonstrating the adaptation of ABM in data-scarce contexts as shown in Fig 5 and 6.

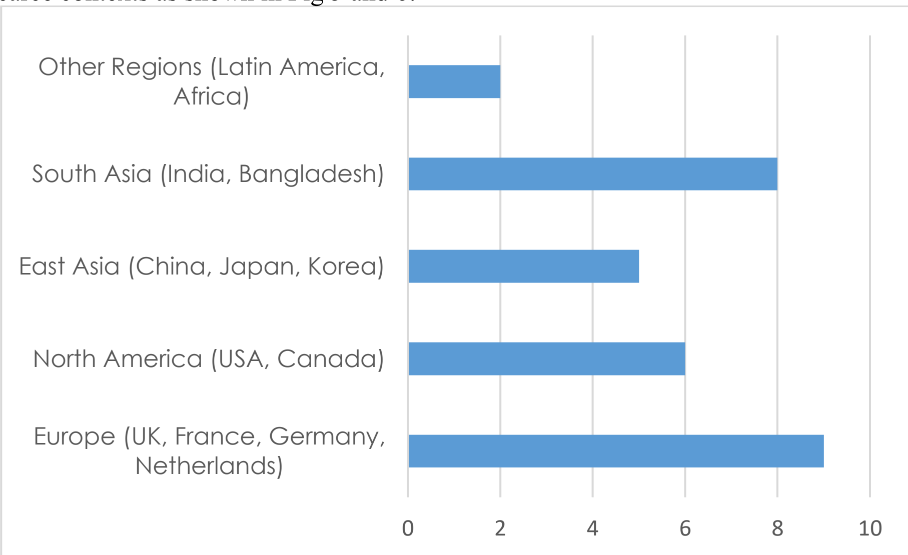

Fig 5 - Geographic Distribution of Studies (Author)

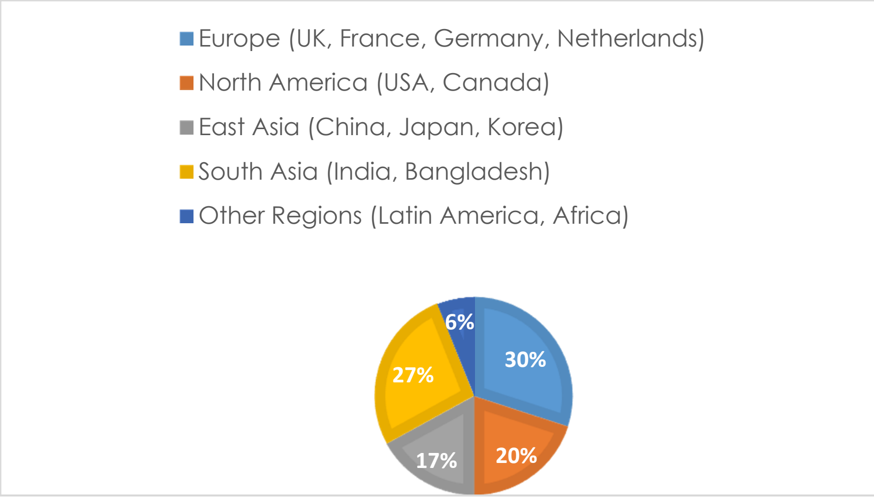

Fig 6– Percentage of Geographic Distribution of Studies (Author)

4.2 Thematic synthesis

Studies were organized thematically into five major categories:

1. Model Coupling and Integration
Nearly 60% of reviewed papers focus on coupling land-use and transport models through ABM, highlighting progress from CA-based frameworks toward hybrid ABM–LUTI systems (e.g., Raimbault, 2022; Waddell, 2002). Recent work emphasizes bidirectional feedback between accessibility and location choice, yet many models still treat land use or transport as secondary submodules rather than fully co-evolving systems.

2. Behavioral Representation and Decision-Making
About 70% of studies emphasize behaviorally rich modeling, representing individual decision-making in travel, housing, or location choice (Horni et al., 2016; Batty, 2014). However, differences persist in representing bounded rationality while some use data-calibrated decision trees, others rely on simplified rule-based behavior, revealing a methodological divide between empirical realism and computational efficiency.

3. Scalability, Calibration, and Validation
Roughly 43% of studies include formal validation, often through sensitivity analysis or limited real-world calibration (Verma et al., 2021; Jalan et al., 2016). Few models demonstrate scalability to large metropolitan systems due to computational and data limitations, especially in developing contexts. Standardized validation protocols and benchmarking datasets remain critical research gaps.

4. Urban Policy and Planning Applications
Almost half of the reviewed papers (47%) apply ABM–LUTI models for policy simulation examining transport accessibility, zoning, and density regulation. These studies demonstrate how agent-based frameworks can forecast impacts of TOD, congestion pricing, or redevelopment strategies.
Yet, policy translation remains limited, as most models are confined to research environments rather than decision-support systems.

5. Cross-Domain and Emerging Integrations
An emerging stream links ABM–LUTI with domains such as environmental assessment, energy demand, and public health (Liu et al., 2020; Chapuis, 2023). These cross-sector models highlight ABM's flexibility but also expose integration challenges between spatial and non-spatial datasets.
Such models pave the way for holistic urban simulations in the context of smart and sustainable cities.

4.3 Limitations & gaps

- Limited Empirical Validation – Nearly half of the reviewed models lack real-world calibration or post-simulation verification, relying instead on theoretical or sensitivity analyses (Horni et al., 2016; Moeckel et al., 2018). This undermines confidence in their policy applicability and transferability across contexts.
- Data Constraints and Contextual Bias – Most validated models originate from high-income regions with rich datasets, while developing-country studies remain sparse and data-limited (Verma et al., 2021; Jalan et al., 2016). This results in methodological imbalance and limited representation of informal mobility patterns.
- Fragmented Integration Between Land Use and Transport Modules - Many models simulate land-use or transport subsystems independently rather than as co-evolving feedback systems (Waddell, 2002; Raimbault, 2022). This partial coupling restricts dynamic understanding of urban evolution.
- Lack of Standardization and Benchmarking Frameworks – The absence of unified validation metrics, open datasets, and reproducible workflows hampers comparative evaluation (Taillandier et al., 2019; Chapuis et al., 2023). This gap limits knowledge accumulation and collaborative model improvement.

5 Discussions

The synthesis of 30 peer-reviewed studies reveals that the evolution of ABM–LUTI research has been both methodological and conceptual. Earlier studies primarily focused on theoretical exploration and small-scale model demonstrations, whereas recent works emphasize empirical realism, computational efficiency, and hybrid frameworks that couple land-use and transport systems in more dynamic ways (Raimbault, 2022; Moeckel et al., 2018). Despite this advancement, methodological fragmentation persists due to the absence of standardized validation protocols and interoperable data structures across regions.

Furthermore, the growing intersection between ABM–LUTI and emerging domains such as smart mobility, energy use, and environmental assessment represents a promising research frontier. Integration of behavioral data from mobile sensing, open transport datasets, and participatory modeling can enhance predictive accuracy and policy relevance. Future research must focus on context-sensitive model calibration, participatory validation with planning authorities, and open-access model repositories to ensure replicability and inclusiveness in urban decision support.

6 Conceptual Framework

Table 6 –Conceptual Framework for LUTI Modeling (Author)

Stage	Key Tasks	Outputs
1. System Setup & Data Preparation	• Define study area, modelling horizon, and spatial boundaries. • Collect land-use, transport (road + GTFS), household, OD, and socio-economic datasets. • Standardize coordinate systems, clean missing values, generate accessibility and density baselines.	Baseline urban dataset + diagnostic maps of current LUT dynamics
2. ABM Design & Behavioural Logic	• Specify agents (households, commuters, developers, institutions). • Encode decision-making: mode choice, route choice, relocation, investment, activity scheduling. • Introduce heterogeneity (income groups, constraints, informal mobility) and behavior triggers.	Functioning agent set with realistic behavioural rules
3. LUTI Feedback Integration	• Model interactions: accessibility → land value → location attractiveness. • Integrate travel demand update → congestion → network performance cycles. • Implement iterative co-evolution loops to simulate dynamic city growth.	Co-evolutionary land-use–transport interaction engine
4. Scenario Development	• Construct future interventions: TOD intensification, PT expansion, pricing, zoning modifications. • Define assumptions for population growth, network changes, and activity patterns. - Prepare simulation-ready scenario datasets.	Policy scenarios ready for simulation

5. Simulation & Evaluation	• Run baseline + policy scenarios using ABM engine. • Analyse results: travel times, mode share, congestion changes, density redistribution. • Map spatial outcomes (hotspots, accessibility gains, displacement risks).	Quantified and spatially visualised scenario outcomes
6. Validation & Robustness	• Validate model using observed travel times, modal split, trip length frequencies, land-use patterns. • Conduct sensitivity testing for rule variations and parameter adjustments. • Identify stability issues and refine behavior rules accordingly.	Verified model performance and improved reliability
7. Planning Recommendations	• Translate results into TOD opportunities, corridor priorities, zoning updates, PT improvements. Prepare actionable guidance based on accessibility equity, growth suitability, and network efficiency. • Propose policy pathways aligned with master-plan and mobility-plan objectives.	Evidence-based planning strategies & decision-support insights

This matrix presents a structured conceptual framework showing how land-use patterns, transport systems, and agent behaviors interact within an ABM environment. By linking inputs, decision processes, feedback loops, and policy scenarios, it demonstrates how micro-level actions collectively shape city-wide land-use and mobility outcomes. This framework provides the foundation for analyzing and improving land use–transport integration in rapidly developing urban contexts.

7 Recommendations

- Build Reliable Data Foundations
  - Establish a minimum data pipeline related to land-use maps, transport networks, household/mobility patterns to enable credible ABM calibration.
  - Use low-cost sources (OSM, GTFS, mobile traces) where detailed datasets are unavailable.
- Represent Local Behaviour Realistically
  - Incorporate heterogeneity in income, mode choice, relocation behaviour, and informal mobility typical of developing contexts.
  - Avoid generic behavioural rules, design agents grounded in local travel habits and constraints.
- Integrate Land Use and Transport Feedbacks
  - Ensure accessibility updates influence location decisions and density shifts.
  - Set iterative feedback loops so land-use change continuously reshapes travel demand.

- Use Hybrid Modelling Approaches

  - Combine ABM with GIS accessibility tools and activity-based demand models for balanced behavioural and spatial realism.
  - Leverage machine-learning or statistical models only for calibration not as replacements for agent logic.
- Test Multiple, Policy-Relevant Scenarios
  - Evaluate TOD, transit upgrades, densification, congestion pricing, and parking reforms through comparable simulation runs.
  - Present results through clear maps and indicators to support decision-making.
- Validate Model Outputs Transparently
  - Use observed travel times, trip lengths, land prices, or density patterns to check model accuracy.
  - Apply sensitivity analysis to monitor stability when assumptions change.
- Document Assumptions and Limitations Clearly
  - Provide transparent reporting of agent rules, datasets, scenario parameters, and model boundaries.
  - Use standardised documentation templates to improve comparability with other cities and studies.
- Make Models Scalable & Adaptable
  - Design the ABM in modular form so components (agents, rules, networks) can be updated for future years.
  - Ensure the model can run efficiently with different data quality levels.
- Enhance Institutional Capacity for ABM Use
  - Train planning teams to interpret ABM outputs rather than treat them as black boxes.
- Support Policy Practice with Clear Outputs
  - Use ABM-LUTI to identify hotspots, accessibility gaps, and density-transport mismatches.
  - Provide visual scenario comparisons to help planners justify interventions.

8 Conclusion

This systematic review establishes that Agent-Based Modeling has transformed the analytical landscape of land use–transport studies by shifting from aggregated equilibrium models to dynamic, micro-level behavioral simulations. Across the last decade, ABM–LUTI research has evolved into a more interdisciplinary field linking urban planning, geography, and computational science.

However, despite these methodological advances, the field still faces persistent barriers limited empirical validation, contextual imbalance, and inadequate data infrastructure particularly in the Global South. Overcoming these limitations requires moving toward open, collaborative, and standardized modeling ecosystems that allow inter-city comparability and incremental refinement.

Ultimately, the integration of ABM within LUTI frameworks offers a pathway toward evidence-based urban policymaking, capable of simulating multiple spatial, social, and environmental outcomes. The next generation of research should focus on developing context-adaptive, computationally efficient, and participatory ABM–LUTI tools to guide sustainable urban transitions, especially in rapidly urbanizing cities like those in India.

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