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Affordable Housing: A Complex Adaptive Systems Perspective

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Abstract

Affordable housing remains a critical challenge shaped by complex economic, social, and political forces. Traditional approaches often struggle to address the deep, interconnected dynamics involved in affordable housing. These methods tend to overlook the shifting relationships between key players, such as policymakers, communities, and market actors, and how their actions influence one another over time. This study explores a different way of thinking about the affordable housing sector, by applying the concept of Complex Adaptive Systems (CAS). CAS offers a way to understand housing not as a fixed structure but as a living, evolving system made up of many different actors, like policymakers, developers, communities, and market forces, that influence each other in real-time. By applying CAS principles, this paper aims to support better decision-making and policy design. It offers a way to understand how small changes, like shifts in behaviour or policy, can ripple through the system and create broader impacts. This dynamic view helps identify real-time effects of interventions and improves how strategies are developed. The study begins by outlining the main principles of CAS, emphasizing the importance of thinking in terms of complexity rather than straight-line cause and effect. It then draws connections between these ideas and the realities of the affordable housing sector, showing how the CAS framework can be practically applied. The paper concludes that using a CAS lens opens new pathways for creating flexible, innovative policies that can better address housing shortages and promote long-term affordability.

Keywords: System Dynamics, Decision-Making, Behavioral Interventions

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Highlights

- Viewing affordable housing through a CAS lens reveals a fresh perspective on its inherent challenges and potential solutions.
- A hierarchical framework is used to systematically map affordable housing properties guiding future research and empirical studies.
- Incorporating the interplay of stakeholders helps to develop more responsive, flexible, and adaptive policy decisions.

1 Introduction

Housing is widely recognized as a basic human right and plays a vital role in supporting the health and stability of communities. According to the UN's 2020 report, more than 55% of the world's population lives in urban areas, a number projected to rise to 70% by 2050. This rapid pace of urban growth underscores the importance of Sustainable Development Goal 11, which focuses on creating sustainable cities and communities. While urban growth can generate economic and social opportunities, it also puts immense pressure on housing systems, particularly for low- and middle-income urban populations. Increased demand often drives up housing prices, making it difficult for these groups to access adequate and affordable shelter (Khan et al., 2022). Affordable housing is not only about lowering costs. It is a complex issue that involves economic conditions, social inclusion, and environmental sustainability (Gopalan, 2014). Addressing these challenges is essential for promoting an inclusive, fair, and resilient society (Moghayedi et al., 2021). Although the precise definition of affordability varies across contexts, it is commonly benchmarked at allocating no more than 30% of household income to rent and utilities (Chileshe & Kavishe, 2024).

Despite efforts to improve affordability, deep-rooted structural and policy-related barriers persist (Shen & Gao, 2020). Traditional approaches often fall short because they tend to address problems in isolation, overlooking the interconnected nature of the housing system (Moghayedi et al., 2021). Adding to this complexity, housing systems are also influenced by legal, market, and cultural contexts, which vary greatly across regions (King et al., 2017). In response to these limitations, this paper proposes the use of Complex Adaptive Systems (CAS) theory as a more holistic analytical lens. CAS theory enables a better understanding of how diverse agents—such as policymakers, developers, residents, and technology providers—interact over time, co-adapt to feedback, and influence broader system outcomes (Shen & Gao, 2020). The approach helps shift focus from isolated technical fixes to the broader network of relationships that drive housing outcomes.

To ground this theoretical perspective, this study examines the Global Housing Technology Challenge (GHTC) as a national-level case study from India. GHTC was launched to introduce and mainstream alternate building technologies (ABTs) within the public housing sector, serving as a "live laboratory" for innovation and adaptability within an otherwise rigid delivery framework (Ministry of Housing and Urban Affairs, 2021). By analyzing GHTC through the CAS lens, this paper aims to demonstrate how complexity science can offer new insights and actionable strategies for addressing the persistent and evolving challenges of affordable housing. This paper explores the analogy between complex adaptive systems and affordable housing, supported by a case study of GHTC, to offer insights into the dynamic nature of the sector, informing more effective strategies for addressing it.

2 An Overview of a Complex Adaptive Systems

A CAS refers to a dynamic network made up of agents and structures that continuously interact, learn, and adapt in response to changes in their environment. What makes CAS unique is its ability to self-organize, evolve, and produce unpredictable outcomes at the macro level, a phenomenon that traditional linear models often fail to capture (Carmichael & Hadžikadić, 2019a). CAS theory has been used in a wide range of fields, including biology, economics, psychology, environmental science, and engineering (Gomersall, 2018). Rather than introducing an entirely new scientific approach, the study of CAS provides a rich conceptual framework for understanding dynamic and interconnected systems.

Many real-world organizations and policy systems can be viewed through the CAS lens, as they comprise heterogeneous agents capable of learning and adapting over time (Davis et al., 2021).

At the core of CAS theory is the idea that systems change and develop through constant interaction between diverse agents. These agents aren't just passive elements; they actively respond to each other and to their environments, shaping the way the system behaves and evolves (Haken & Portugali, 2015; Shi et al., 2021). This continuous and reciprocal interaction is what drives complexity and system growth over time. One of the early thinkers in this area, Professor J. H. Holland, identified seven features that define CAS: aggregation, flows, nonlinearity, diversity, tagging, internal models, and building blocks (Holland 1992). Later, Drazin and Sandelands (1992) introduced a multi-layered view of CAS, distinguishing between surface-level behaviors, component-level elements, and deeper structural dynamics. Although there is no universally accepted framework for CAS, most scholars agree that its key elements are agents, their interactions, and the environments they operate within (Nan, 2011). Several researchers have outlined the defining features of CAS in more detail (Geyer & Rihani, 2012; Holland, 2012; Van Dam et al., 2012), which can be grouped into four main areas:

- **Diverse Agents:** CAS includes many independent agents with unique knowledge and simple rules of behaviour. The system's behaviour emerges from its local interactions and responses to environmental conditions (Carmichael and Hadzikadic 2019).
- **Adaptiveness and learning:** Agents in CAS learn from experience. Feedback loops allow them to adjust their behaviour, leading to continuous evolution and system-level change.
- **Chaos and Randomness:** CAS often behaves unpredictably, even when following set rules. Small changes can lead to large, unexpected outcomes, what's often referred to as the "butterfly effect."
- **Emergence, self-organization, and patterns:** Order in CAS doesn't come from top-down control but from local interactions. These interactions create new patterns and behaviours that are visible only at the larger system level.

CAS offers a powerful lens for understanding real-world systems that are constantly evolving, especially where rigid or linear models fall short. Its application in academic research continues to grow, providing valuable insights into organizational behaviour, policy formation, urban planning, and more. By recognizing the adaptive, decentralized, and emergent nature of complex systems, researchers and policymakers can better respond to uncertainty and design more resilient, flexible systems (Nel et al., 2018).

3 Methodology

This study adopts a qualitative, theory-driven approach to explore the affordable housing sector through the lens of CAS. Instead of collecting or analyzing numerical data, the research focuses on interpreting conceptual patterns and drawing meaningful connections between the nature of housing systems and the foundational principles of CAS theory. The goal is not to test hypotheses but to use CAS as a way of seeing, offering fresh insights into how housing systems behave, evolve, and react to pressures from their surroundings. This approach builds upon foundational theories of CAS from existing literature (Holland, 1992, 2012; Miller & Page, 2009), aiming to generate new theoretical insights into the ways affordable housing systems evolve and respond to economic, social, and policy-related pressures. The research follows a deductive methodology, starting from established CAS properties and applying them to the context of affordable housing through structured analogies. These analogies are organized into a four-level framework that mirrors the layered complexity of adaptive

systems: the individual level, learning and adaptation level, social interaction level, and the system level (Zhou et al., 2024).

Each level serves to capture a different aspect of how housing systems function. At the individual level, the study identifies the key agents in the housing ecosystem, such as developers, policymakers, tenants, and financial institutions, and outlines their core behaviours and decision-making traits. Moving to the learning and adaptation level, the focus shifts to how these agents respond to changes in their environment, whether that involves new regulations, market shifts, or social expectations. Like infrastructure providers adjusting to technological or policy changes (Oughton et al., 2018), housing agents learn and adapt through feedback. The social interaction level explores the relationships among these agents. These connections might involve collaboration, negotiation, or competition, all of which shape how the system functions as a whole. Finally, the system level examines the broader outcomes that emerge from these local interactions, such as recurring housing shortages, affordability crises, or cascading policy effects. The study's structure follows a step-by-step process:

1. **Individual level:** Identify the autonomous agents in the housing system and define their individual characteristics.
2. **Learning and adaptation level:** Analyze how these agents learn and adapt based on experience and feedback
3. **Social level**: Explore the networks of interaction among agents, including patterns of cooperation or conflict.
4. **System level:** Draw conclusions about large-scale outcomes that arise from these interactions.

These levels are brought together in a conceptual diagram (see Figure 1), which visually maps how CAS features unfold in the affordable housing context. Through this structured yet flexible lens, the research addresses a central question: "How can affordable housing be understood as a complex adaptive system?" The study considers the Global Housing Technology Challenge (GHTC), which was launched in 2019 in India, to study the dynamics of alternate building technology (ABT) diffusion within India's affordable housing sector. GHTC has been selected as an illustrative case because it brings together diverse technologies and stakeholders through a platform that demonstrates light-house projects designed to test, evaluate, and mainstream innovations. As a government-led initiative that links national policy with local experimentation (through Lighthouse Projects), GHTC offers a unique opportunity to observe how alternate building technologies emerge, adapt, and scale in complex environments. Studying GHTC through a CAS framework, therefore, provides not only empirical insights but also theoretical grounding to inform future housing policy and innovation strategies. By systematically mapping the hierarchical CAS features- autonomous, evolutionary, interactive, and emergent- onto the structure and processes of GHTC, the study seeks to reveal how alternate housing technologies and stakeholder collaborations unfold in practice. Through this case study choice, we gain a deeper understanding of how ABTs spread, not just as a technical solution, but as a part of the evolving system shaped by feedback, collaboration, and contextual responses. This helps highlight the enabling conditions that can facilitate wider and more effective diffusion of innovative construction technologies across diverse housing contexts. The diffusion of alternate building technologies through CAS principles moves beyond static or linear modeling in order to capture the dynamic and networked nature of large-scale housing interventions. This theoretical investigation provides a groundwork for future empirical research, while also offering a new perspective for shaping policy and guiding long-term housing strategies.

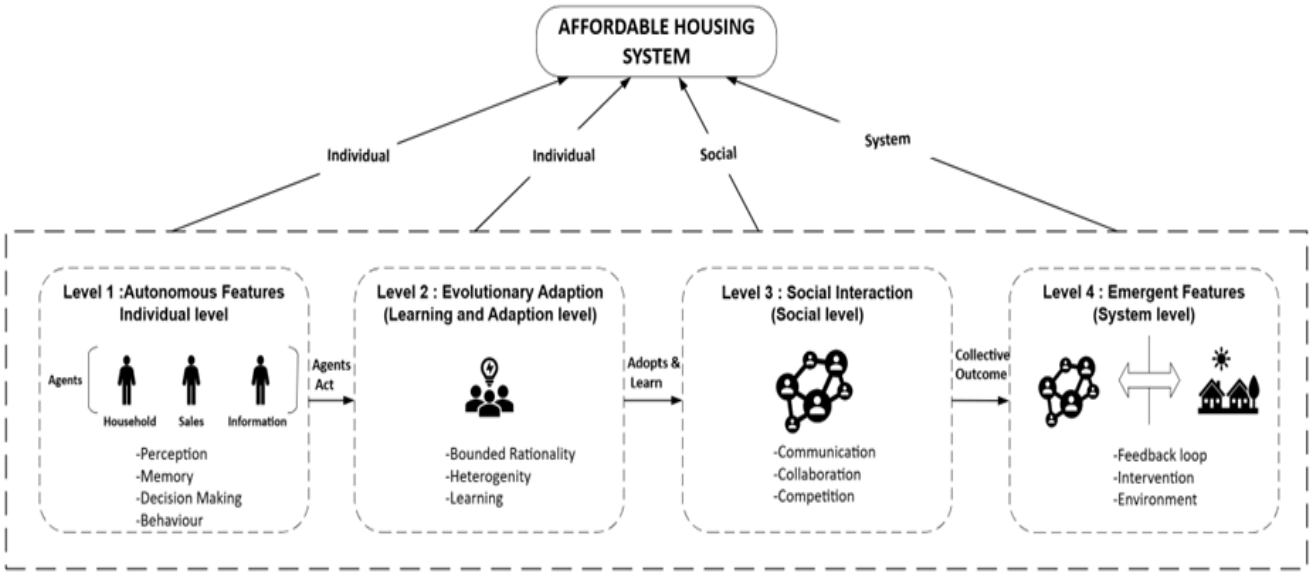

Figure 1. Hierarchical structure of the complex adaptive system

4 Applying the key concepts of CASs to Affordable Housing

As the global community faces rising challenges around housing affordability, complexity science offers a helpful way to understand how housing systems really work. Affordable housing is not just about building more homes, it involves many different people, changing conditions, and constantly shifting factors that all influence how the system works. The wide variety of definitions, policies, and viewpoints around affordable housing shows how complex the issue truly is (Cheng et al., 2024). Much like other domains, such as healthcare, education, or smart city planning, housing systems are marked by nonlinear relationships, emergent outcomes, and dynamic interdependencies (Ghosh & Roy, 2013). Affordable housing does not operate as a static, isolated entity. Instead, it evolves through the continuous interaction of multiple stakeholders, including local communities, private developers, government bodies, and civil society organizations. These agents each bring differing priorities, constraints, and capacities to the system, reflecting the diversity of needs and socioeconomic conditions across population groups. This heterogeneity is a hallmark of Complex Adaptive Systems, where agents act with partial knowledge and adapt in response to changing environments (Carmichael & Hadžikadić, 2019b).

Viewing affordable through a CAS lens helps us move beyond simple supply-and-demand explanations. For example, in some cities, there are empty houses even though many people still lack homes. This disconnect shows that the problem is not just about numbers; it also involves mismatches between what is built and what people actually need (Adabre & Chan, 2019). This suggests that challenges in affordable housing are not solely quantitative but involve qualitative mismatches, behavioural responses, and institutional constraints. Based on the methodological framework outlined earlier, this study examines the affordable housing system across four connected levels: individual, learning and adaptation, social interaction, and system-level dynamics (Zhou et al., 2024). At the individual level, different agents, tenants, landlords, developers, and information providers, act based on their own goals and limited knowledge. They make decisions shaped by personal needs, market access, and local circumstances.

The learning and adaptation level explores how these agents adjust their strategies over time. For example, policymakers (information agents) may update zoning laws in response to changing housing demands, while developers (sales agents) might pivot toward higher-end projects that offer greater profit margins. These adaptive behaviours are part of how the system evolves and restructures itself. At the social interaction level, these agents begin forming relationships. Community-led housing initiatives, partnerships between public and private sectors, and regulatory negotiations all illustrate how housing decisions are influenced by structured and sometimes conflicting interactions. These patterns shape policies and local outcomes in meaningful ways. Finally, the system level looks at the broad consequences that emerge from all these layers. Patterns such as gentrification, housing bubbles, or long-term affordability issues arise from the accumulation of many decisions over time. These aren't the result of any single actor's plan but are instead emergent outcomes of complex interactions. An example of this can be seen in large-scale housing programs in countries like India. As Ghosh & Roy (2013) note, the challenge isn't only about building homes, it also includes dealing with informal economies, trust within communities, and local cultural expectations.

Figure 2 visualizes how core CAS elements, such as feedback loops, emergence, nonlinearity, and adaptation, play out in the housing context. By mapping these dynamics across all four levels, this research helps develop a more integrated and systemic understanding of housing challenges, offering a foundation for more thoughtful and effective policy design and strategic intervention.

4.1 Integrating CAS theory application through GHTC India

The Global Housing Technology Challenge (GHTC) in India serves as a live laboratory for demonstrating and testing new and innovative building technologies in the affordable housing sector. By viewing GHTC through the lens of Complex Adaptive Systems (CAS) theory, we can better understand how different stakeholders interact, adapt, and learn from each other, leading to faster and more effective technology diffusion. Unlike traditional, linear approaches, CAS theory, especially when combined with agent-based modelling, helps capture the dynamic, networked, and self-organizing nature of technology adoption in real-world settings. This approach provides deeper insights into how innovations spread and scale in complex environments like affordable housing, making the diffusion of technology both quicker and more sustainable.

The following Table 1 presents a comparative analysis of how Complex Adaptive Systems (CAS) properties manifest across our four-level hierarchical framework when applied to affordable housing initiatives such as the Global Housing Technology Challenge (GHTC-India). This structured comparison illustrates the fundamental differences in how each CAS characteristic is operationalized under traditional policy approaches versus a CAS-based perspective. While conventional housing programs often employ linear, top-down implementation mechanisms with predictable pathways and standardized outcomes, the CAS approach recognizes and leverages the inherent complexity, adaptability, and emergent properties of housing systems. By examining these differences across autonomous, evolutionary, interactive, and emergent levels, we can better understand why GHTC's approach enables more responsive, context-sensitive technology diffusion

This comparison not only highlights the conceptual distinctions between these approaches but also demonstrates how a CAS perspective offers practical advantages for accelerating housing innovation and improving implementation outcomes in dynamic environments.

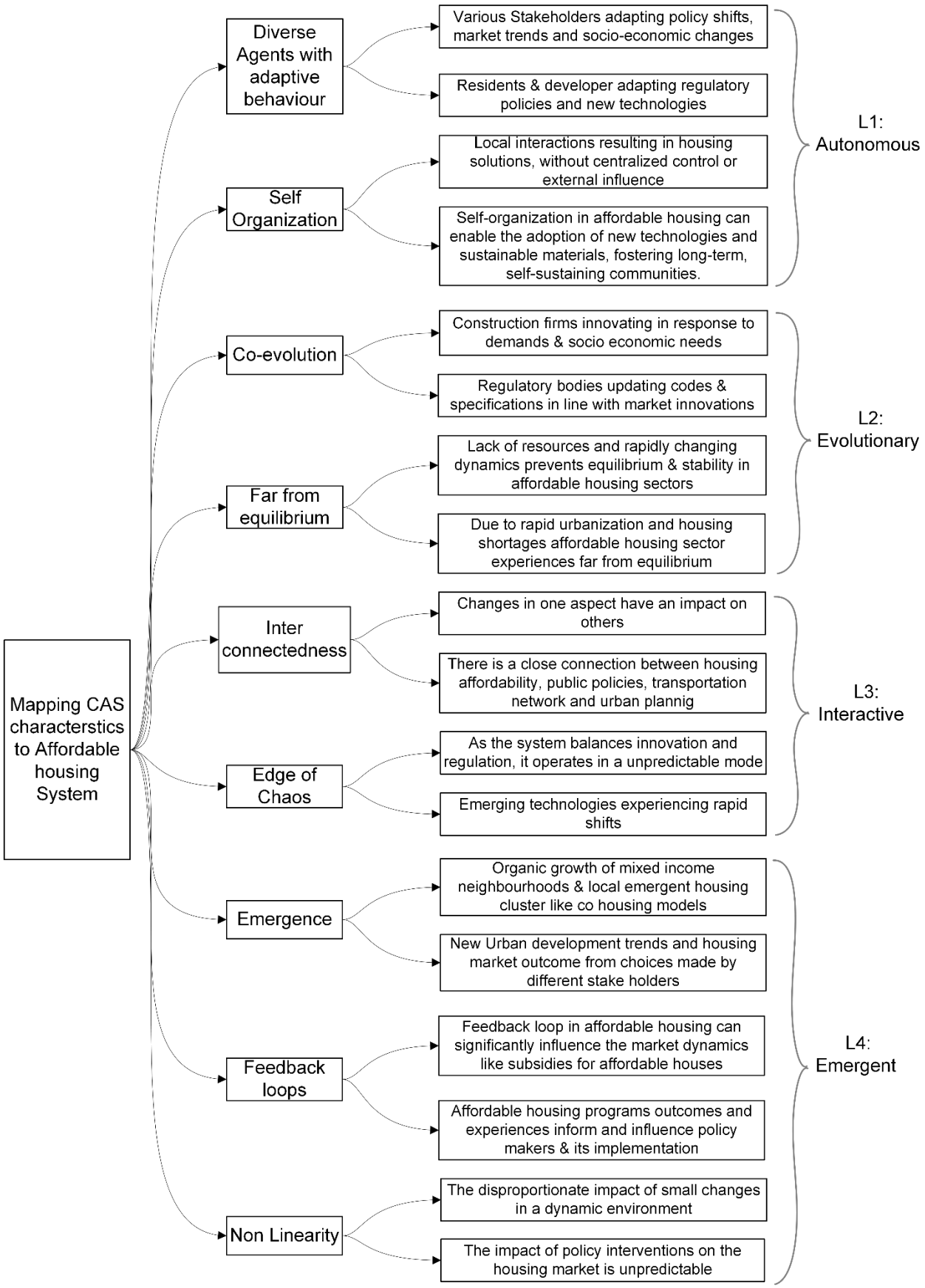

Figure 2. Mapping CAS characteristics to the affordable housing system

Table I. *Technology Diffusion Through a CAS Hierarchical Framework (GHTC case-study)(Ministry of Housing and Urban Affairs. (2019). Concept Note on Global Housing Technology Challenge-India (GHTC-India). Government of India., 2019)*

Hierarchical Level	CAS Characteristics	Technology Adoption (Traditional Approach)	Technology Adoption (CAS Approach – GHTC Case Study)
L1: Autonomous	Diverse Agents with adaptive behaviour	Limited stakeholder participation, Centralized decision making.	Multiple stakeholders (tech firms, govt. agencies, academia) co-create solutions; autonomy in decision-making
	Self-Organization	Linear diffusion, Identify-test-scale. Relies on top-down mandates	Local teams autonomously coordinate and refine solutions in real time to implement and refine technologies in lighthouse projects.
L2: Evolutionary	Co-evolution	Static guidelines, one-way policy update, and linear scaling; slow adaptation to new technologies.	Policies and technologies mutually adapt; policies adapt as new solutions emerge. GHTC's projects test and refine technologies, and the norms co-evolve with respect to the technology adopted.
	Far from equilibrium	Seeks stability and predictability. Resistance to disruptive changes.	Embrace change and uncertainty and enable the system to adapt, restructure, and generate new solutions when disrupted or challenged. GHTC intentionally disrupts old methods, pushing the system to adopt new, better technologies.
L3: Interactive	Inter connectedness	Siloed actors, limited collaborations	Strong cross-sector interconnectedness. Knowledge sharing between multiple agencies in the lighthouse projects accelerates diffusion.
	Edge of Chaos	Overly rigid or controlled systems suppress experimentation, limiting innovation and adaptability.	The capability to operate at the edge of chaos allows for experimentation and innovation, thereby enabling more efficient response times and wider adoption of new technologies. GHTC balances regulatory standards with space for innovation, enabling the system transformation and resilience.
L4: Emergent	Emergence	Sum-of-parts thinking. Standardizes solutions enforced nationwide.	The whole is greater than the sum of its parts. The interaction between technologies, implementing agencies, and policy outcomes exceeds the sum of individual components.
	Feedback loops	Delayed or absent feedback loops.	Multiple feedback mechanisms. Real-time feedback from lighthouse projects shapes future policy and tech adoption.
	Non linearity	Straightforward cause-and-effect relationship. If X occurs, Y will be ensured.	Outcomes cannot be predicted through simple cause-effect relationships. Small changes (e.g., new material) can lead to large and rapid improvements in cost, speed, or acceptance

5 Conclusions

This paper has illustrated how the dynamics of affordable housing systems behave in ways that closely reflect the features of Complex Adaptive Systems. These systems are marked by qualities such as non-linear, cause-and-effect relationships, the emergence of unexpected outcomes, self-organization, and the ability to adapt continuously under the influence of social, economic, and political change. By mapping these CAS properties to the context of affordable housing and illustrating these dynamics through the GHTC in India, this study demonstrates that housing systems are not fixed or purely reactive. Instead, they evolve over time, shaped by the environment and the interactions of key agents such as policymakers, developers, communities, and institutions. These agents do not operate in isolation; rather, their choices and interactions create patterns and outcomes that can't always be predicted through traditional policy models. The GHTC example highlights how adaptive policy and collaborative experimentation can foster innovation and resilience in affordable housing. This insight underscores the need for adaptive, flexible policy mechanisms that can respond to evolving community needs and systemic feedback. What emerges from this analysis is not a prescriptive solution, but a call to reconceptualize affordable housing policy through the lens of complexity. Such a shift challenges static, target-driven approaches and instead supports iterative, context-sensitive strategies aimed at long-term resilience and equity. Yet, the application of CAS theory in the domain of affordable housing remains underdeveloped. Compared to its broader use in

fields like ecology, public health, and organizational theory, housing systems have received limited attention in complexity research. This study represents an initial step toward addressing that gap. As computational modelling and system simulation tools become more accessible, future research could extend this work through empirical testing, dynamic modelling, and cross-sectoral comparison. Embracing complexity is not about abandoning structure, it is about recognizing that structure must evolve. Understanding affordable housing as a living, adaptive system can guide us toward solutions that are not only more inclusive but also more sustainable in the long run.

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Some or all data that supports the findings of this study are available from the corresponding author upon reasonable request

Conflicts of Interest
There is no conflict of disclosure.

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