A Critical Analysis on Complex Urban Systems and Complex Systems Theory

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Abstract – Deep neural complexity theory has recently received new attention, particularly in the study of climate and the environment. According to the majority of the research on urban climate resilience, cities are complex adaptive systems, and as such, urban governance and design should take cues from the study of complex adaptive systems. This means that climate change governance, in order to mitigate the problems presented by climate change's unpredictability, has to be flexible, participatory, and adaptive. This article provides a critical literature review on the topic of Complex Urban Systems, i.e., climate change governance in the context of complexity theory. The paper argues that the current hype around complexity theory exaggerates the theory's relevance. Complexity theory falls short in explaining urbanization and environmental change since they are highly contested social phenomena. However, it serves a significant purpose in bringing attention to the uncertainty realities in the process of policy-making, which are certainly fundamental in the context of climate change, including the changing ecologies on which cities rely. Many critics of complexity theory point out that it tends to showcase urban developments are happening through neutral evolutionary forces, which can be comprehended, and governed by individuals engaged in governance for a particular objective.

Keywords – Complexity Theory, Complex Urban Systems, Complex Adaptive Systems

I. INTRODUCTION

Cities are made up of interconnected parts, such as residents and buildings, and display emergent qualities that cannot be explained by looking at the parts individually. Cities cannot be understood on a macro level from a micro level of knowledge, such as the psychology or economics of an individual. Due to this, cities are a good illustration of complicated systems. Consequently, the study of complexity theories and approaches is pertinent to this field. There are "universal" reasons for the creation of cities since "cities are visible across the globe and through history". For these and similar reasons, it seems reasonable to start by comparing and contrasting the cities' shared characteristics, rather than focusing on the differences between them at first. The complexity of cities is a major contributor to the problems that arise when trying to simplify a complex city that many of its components have common processes.

Haimes et al. [1] identifies a complex system as one with numerous interconnected parts that may or may not work in concert. Climate on Earth, living organisms, the human brain, the electrical grid, complex software and electronic models, transport and communications networks, economic and social organizations (e.g., cities), a living cell, an ecosystem, and the universe are all examples of complex systems. Due to the interdependencies, competitions, linkages, and other interactions between the parts of a complex system or between an environment and its system, the behaviors of these systems are inherently challenging to define. Feedback loops, adaptability, spontaneous order, emergence, and non-linearity are only some of the aspects of "complex" systems that result from these interdependencies. Commonalities across these systems have been the focus of their own field of study due to their prevalence in so many different contexts. The nodes in such a network represent the parts of the system and the linkages between them indicate the interactions between those parts.

The term "complex systems" is typically used to refer to the research paradigm of studying the interrelationships and mutual influences among the many parts of a system in order to better understand the system's overall behavior [2]. In contrast to reductionism, the prevalent paradigm in the study of systems, which emphasizes parts and their interactions, complex systems may be considered as an alternative way of looking at how systems work. The study of complex systems draws from a wide range of academic fields, including those that investigate self-organization and critical events in physics; spontaneous order in social science; adaptation in biology, and problems in mathematics [3]. As a result of this, "complex systems" is typically used to refer to an umbrella study technique that may be applied to challenges in domains as diverse as statistical physics, biology, psychology, economics, sociology, meteorology, computer science, anthropology, non-linear dynamics, and information theory.

Cities should be seen as complex systems for several reasons. Social, physical, and virtual networks may be seen as a superposition, with characteristics and data with a grid or lattice character. Second, cellular automata and other forms of discrete dynamics have been used fruitfully to the study of urban dynamics by Park [4]. Finally, dynamical systems are another example of continuous dynamics. Finally, agent-based modeling allows for the investigation of urban residents and their social interactions [5]. As a fifth point, the lack of a defining scale raises some interesting questions. In computing, scalability is closely related to the concept of scaling. 'Space-time scalability' is defined by Li and Wheeler [6] as "the capability of a system to keep its functioning even as the number of items it includes expands by magnitudes." Cities fit this description since their populations might number in the hundreds of thousands or perhaps the millions. Therefore, city systems may be seen as a comparable scalable system. Scalability, however, necessitates some degree of flexibility; for instance, major cities often have a very effective public transportation infrastructure, such as subways. The next step is to provide some examples of the fallout from this kind of adjustment.

The following is an example that might be encountered on a daily basis: In an instance where you need to purchase 2.5 kg of potatoes with the price of a kilogram of potatoes as 1.50 Euros, then 0.75 euros will get you 0.5 kilograms of potatoes, whereas 3.75 euros would get you 2.5 kilograms. Cheshmehzangi et al. [7] demonstrated that this linear relationship is not true for numerous urban indicators. The overall urban GDP increases by 20% when city sizes are doubled or approximated around $21.152. In that case, the GDP of a single large city is more than that of two smaller cities combined. Therefore, the aforementioned real-world experiment is not applicable to urban infrastructure.

There are essentially two different scaling patterns that may be seen between urban areas. First, there is a negative relationship between population and the number of cities. Zipf's rule for cities [8] reflects the fact that, on average, there are many more small cities than big ones. That is, the odds of coming across a city of size S are lower the smaller the city is. There is a broad spectrum of sizes and shapes among human settlements. Second, a lot of metrics used to evaluate cities have a non-linear relationship with population. For example, this relationship might be seen as a representation of the non-proportionality of adaptability for urban centers (also known as "urban scaling"), as shown above. One of the reasons why people are drawn to big cities despite their unfavorable qualities is because of the "extra-wealth" they represent for GDP. The term "growing returns to scale" is used to describe this pattern. Consider a farmer who can produce 5 tons of potatoes. When comparing yields per acre, the next farm is 10% larger and can thus afford more sophisticated and efficient technology and equipment, increasing yields to, say, 70 tons (other than 50 tons). "Agglomeration effects," caused by cities' high population and infrastructure density, are the basis for urban economics' explanation of both growing returns and the existence of cities.

A city has been described by Fine [9] as the "quintessential example of complexity" where responses to climate change are complicated by this complexity. City governments are finding it challenging to counteract the consequences of climate change while simultaneously lowering their carbon emissions. This is especially true in the face of increasing sea levels, increased temperatures, and extreme weather conditions. Rapid urban transformation, such as population expansion and regional and global integration, overlaps with climate change, especially in cities of the Global South. Complexity theory has recently gained popularity in the environmental change literature as a response to these "wicked" challenges. Based on the principles of complexity theory, cities may be seen as open, dynamic, multi-subsystem, and adaptive systems. The consequences of climate change on complex urban systems will be non-linear and difficult to forecast [10], and they may have a domino effect on other parts of the city's infrastructure. Complex systems theory may help urban government deal with these changes in the environment.

This paper focuses on providing an integrated viewpoint of complex urban systems, based on the complexity theory; and defines cities as cities as complex adaptive systems. Based on a critical analysis of the complexity theory and its application in this research, various limitations to the theory have been drawn. The remaining part of the paper has been organized as follows: Section II presents a critical perspective of complex urban systems where details about urban complexity cognition, and planning and complexity for adaptive urban policymaking have been provided. Section III focuses on reviewing cities as complex adaptive systems, where details (such as an overview of complex systems, understanding complex systems theory, cities as complex theory, and critiques of complexity) have been provided. Section IV provides a discussion of the limitations of the complexity theory. The last Section V summarizes the articles identifying key details and critiques in the research.

II. COMPLEX URBAN SYSTEMS PERSPECTIVES

Urban Complexity Cognition

Human cognitive abilities are tested in urban environments, and this is true not merely from the standpoint of modeling cities and the structural connections between its components. To be effective, fiction models must include findings from studies of urban dynamics into representations, actions, and evaluations of urban space navigation, usage, and governing techniques. This remarkable similarity between modeling and fiction opens up some explanation for why stories have historically been such an effective method to comprehend, portray, and express the complexities of urban settings. Communities and individual residents are just as responsible as urban planners and policymakers for this. As a result, we see urban cognition as a crucial area for disseminating and applying our results from studies of urban complexity.

Humans' inherent cognitive constraints in information processing have been known for a long time. With the growing complexity of today's highly urbanized cities, it is becoming harder for residents to engage with their surroundings. Cognitive load is a notion that connects people's lived experiences to the increasingly complicated conditions of urban living. Overloading the brain may occur when there are too many stimuli to process, or when successive stimuli come so quickly that the brain is still working on one stimulus when another arrives. When faced with too much information, people tend to rearrange their priorities and resort to simplified decision-making heuristics.

Traditional tools, such as maps, must be rethought in light of the complexity of modern urban settings. Search tools and techniques range from disseminating eye attention to following metro lines throughout the map, according to recent studies on visual search methods, which connects directly with the amount of time spent finding a route across a transportation network's map. When searching for concealed items visually, the same shift from directed to isotropic random search occurs as the number of distractors grows. Therefore, there is a ceiling on the complexity of "mental maps" that can be maintained, and only via intensive training in spatial navigation can this ceiling be raised by structural changes in the hippocampus. There may be too much information to go through in order to determine whether the transportation network service is worthwhile. A new informational perspective has been offered to assess the mental effort required for the video retrieval of a route in public transportation systems. We were able to identify and quantify the cognitive limit by linking a measurement of "information search" with a trip from a single route to the other, and this enabled us to characterize the challenges we have when navigating on a public transport map. With these constraints in mind, it may seem apparent to take a "fractal" approach to cartography; but, the "just in time" adaptive mind-set that this method requires of planners, interest groups, and people may not be so evident.

It is difficult to convey such perspectives from experts to non-specialists and requires a full rephrasing of individual perspectives, to say nothing mental perspectives, mostly if this perspective is to be applicable and beneficial to a certain problem-solving scenario. This is the prevailing concern in modern democracies, when public discourse and involvement are valued highly. Politicians and policymakers may be inclined to resort to simplified and simply erroneous responses to complicated urban concerns when citizens fundamentally lack the ability to comprehend the intricacies of urban policy problems as well as their ramifications for their interests. Achieving a middle ground requires integrating such knowledge into people's everyday lives and strengthening community institutions. This educational shift, however, calls for a serious rethinking of the established norms of the architectural and urban planning communities.

It is difficult to apply a complexity science approach to urban systems in general, but the greatest difficulty is in conceiving of the city as a complex system that evolves due to the actions of humans, who are also complex systems. Each person who contributes to this multiscale complexity receives some kind of feedback in the form of cognitive constructs. All large-scale social phenomena have a multiscale complexity, including markets, states, and online communities. The city is particularly sensitive and, in some ways, crucial to most other sorts of social phenomena since it provides the sociospatial setting that mediates most human experiences. Chai, Zhang, Sun, and Yang [11] observes that Prigogine's use of the city as a metaphor for social complexity in his Nobel talk was no coincidence. How much inhabitants' mental perceptions of the city impact their own decisions and behaviors and, in turn, reflect into certain spatial and behavioral qualities at the macroscale is, thus, equally crucial to the city's potential to perform as a complex system.

Connecting the personal and the impersonal in urban life requires taking a systems ecology perspective and creating new environmentally informed paradigms of sociospatial cognition. One such complexity-driven urban epistemology is based on the concept of "cognitive affordances," which holds that people's skills to make productive use of urban settings result from a careful balancing of their own past knowledge and the specifics of their immediate surrounds. As people and groups get more used to this form of open-ended adaptive learning, they are better able to draw on their prior experiences when making decisions about which buttons to press in novel situations. Citizens need to be able to adjust their thinking quickly and accurately in response to novel situations, since the urban environment is always changing and might provide unexpected challenges to their preconceived notions, their sense of reality, and their well-honed repertoires of behavior.

For the purpose of evaluating an affordances-based strategy to urban epistemology, it may be useful to conduct experimental experiments using animal intelligence, like in the instance of rats. By repurposing urban surroundings as "playable" places for both collective and individual use, the notion of affordances provides a natural framework for addressing the attitude-action gap that lies at the foundation of the failure of successful collective action in urban situations. If individuals can rediscover a shared sense of purpose in the city, it may be easier to understand and control urban self-organization. However, in order to facilitate more inclusive and participatory activities in the urban environment, we must significantly raise our sights to meet the rising need for a shared understanding of the world. These objectives must consequently be included as a priority in urban policymaking.

Complexity and Planning: Adaptive Urban Policymaking

The fundamental conclusion drawn by planning theory after decades of interaction with urban centers from a complexity viewpoint is the necessity for a dramatic redesign of planning methodology as an interrelationship between institution-driven architecture and urban self-organization concepts. The primary goal of urban planning is to guarantee that city services are widely available and easily accessible to all residents. However, cities may seem very differently depending on your perspective, since various locations equate to varying degrees of power and access. Thus, despite good intentions, the management of urban complexity runs the risk of being used as a smokescreen for avoiding political accountability and favoring certain special interests over others. It's feasible, however, that planning techniques that take into consideration the self-organization component of urban processes might actually spur local initiative and boost citizen engagement. In order to fully benefit from the complexity principle in planning, it is necessary to provide the basis for a reflexive strategy to planning, which means laying out the architecture for decentralized, concerted work at least as much as determining centralized, top-down planning approach.

From a planning perspective, the central issue is how to give citizens the means to exercise their right to the city and participate in the co-creative process by learning how to plan for, organize, and evaluate group efforts to achieve common goals. The urban environment may be transformed into a "playable public realm" by reenacting rituals of community enjoyment there, in the spirit of repurposing collaborative action aimed at social revolution in the vein of Gramscian philosophy. Rather of passively delegating power to organizers and high-level decision-makers, a growing number of publicly accessible public art practices are actively pushing people to adopt an aggressive, probabilistic approach toward urban complexity from the viewpoint of shared authority.

From this vantage point, gamification-based strategies stand out because they aren't designed to be domesticating forms for passive involvement and manipulative conditioning, but rather as an efficient means of deploying community resources and skills and of implementing behavior treatments that empower individuals rather than relying on external rewards. The inherent narrative potential and attraction of gamification, which, as said, may serve efficiently in presenting correct contextual information in complex urban places, has shown promise as a wonderfully practical and adaptable technique to reach tough technological and sociocultural collective purposes.

As such, the pandemic crisis and the resulting need on contact tracking applications to reduce the spread of the infection might be seen as a wasted opportunity. Despite legitimate privacy concerns, contract monitoring software has been extensively used and is helping to keep infections and deaths to a minimum, especially as compared to the more autonomous so-called "first world" countries. This is especially evident in East Asian societies, which combine a strong sense of civic awareness and a focus on social responsibility and obligation with a mature stage of the digital transformation. Despite a prevalent inclination to install contact tracking applications across most nations, studies have shown that accountable and fear-based incentive programs to adoption have not been successful in driving pro-social conduct, even under grave personal hazard.

The applications, on the other hand, were created with little more than a strictly functional logic in mind; they were only intended to serve as information and command carriers at a time when individuals were feeling the weight of the nearly total disruption of their prior social life. Given the increased strain on social incentives for communication and commerce brought on by the pandemic crisis, it is indeed possible that a more robust desire to utilize the app may have been obtained by the selection of suitable, motivationally salient signals. People might be invited to participate by downloading the app themselves and persuading their friends to do the same by being shown how the app's adoption rate will affect the likelihood that social constraints will be lifted and how that probability will alter for every additional thousand users. Alternatively, persons might be provided with a dynamic assessment of the chance to be infectious provided their social connection history as part of an "appeal to responsibility" to deter hazardous conduct.

III. CITIES AS COMPLEX ADAPTIVE SYSTEMS

Overview of Complex Systems

Studies of complex systems e.g., by Khamis and van der Weide [12] focus largely on system properties and dynamics. When several entities interact with one another or are dependent on one another, they are said to constitute a system. It is always characterized by their borders, which specifies what elements are and are not included in the system. Thereafter, things outside the system are integrated into it as ecosystem components. These system-wide or universal features and behaviors, which vary from the characteristics and actions of the parts, are elements of how the system communicates with or appears to the surroundings, or of how the system's components respond (for instance, in reaction to external stimuli). Research into systems, as suggested by the idea of behavior, necessarily requires studying events throughout time (or, in mathematics parameterization). In complex systems, the relevance of systems ideas cannot be overstated due to their extensive, multidisciplinary application.

Complex systems research is a specialization within the larger area of systems theory [13]. General systems theory, in a similar vein, explores the collective behaviours of interacting parts, but it does so across a significantly more complete class of structures, including non-complex structures where traditional reductionist approaches may still be appropriate. One of the primary goals of systems theory is to create new categories that can be used by scientists in many different disciplines to better understand and study the great variety of systems that exist in the real world. Systems theory provides insight into complex systems by focusing attention on how interdependencies and interconnections among individual components shape the whole. It also aids the quest of universal modeling techniques that can be used to complex systems everywhere they are found, which is essential given the multidisciplinary nature of the study of such systems. Emergence, feedback loops, and adaptability are just a few of the complex-system-relevant notions with their roots in systems theory.

According to Bulgarevich, Burdastykh, and Tishchenko [14], a complex system is one whose actions cannot be simply extrapolated from its attributes. Ignoring or dismissing such challenges as noise in the modeling process would inevitably lead to inaccurate and useless models. A completely general theory of complex systems has not arisen to tackle these issues, thus researchers must find solutions in domain-specific settings. To solve these issues, Khadartsev, Eskov, Bashkatova, and Vedeneev [15] focus on modeling complex systems as accurately as possible rather than simplifying them. There may not be a single, definitive definition of complexity, but there are certainly numerous paradigmatic cases that demonstrate its existence. Examples of complex systems include those having chaotic behavior (activity that demonstrates great sensitivity to beginning circumstances) or emergent characteristics (features that cannot be inferred from a consideration of the parts alone but which emerge as a result of the system's interconnections and interdependence) or those that are intractable to the system (if the system's complexity increases at an excessive rate relative to the number of parameters).

One way to conceptualize a network is as a graph with nodes representing individual components and connections representing relationships between them. Networks may be used to characterize any set of interrelated elements, whether they employees in a corporation, logic gates in a network, genes in a signaling pathway, or anything else. Often, networks may be used to illustrate the origins of complexity in complex systems. Therefore, many practical uses of graph theory and network research are made possible by studying complicated systems as networks. Complex systems are prone to displaying emergent or chaotic behavior because they share characteristics with complex networks, such as phase transitions and power-law degree structures [16]. Understanding the origin of complexity in vast networks may be made easier by the observation that the overall number of vertices in a graph increases quadratic function with the number of vertices. This is because in a network, the total number of connections quickly exceeds the total number of nodes.

Understanding Complex Systems Theory

The origins of complexity theory can be traced back to the fields of mathematics and physics, with subsequent variants being adopted by researchers in many other scientific and social disciplines. Complexity theory has been heavily criticized by social scientists, but its proponents argue that it is more relevant than ever at a time when social actors are actively engaged in governance and when global processes touch numerous sectors and scales.

Complexity theorists see the world as a system made up of many interconnected parts, each of which has its own unique set of agents, interactions, and processes. Consequently, a system-level perspective is necessary for a complete comprehension of them. We cannot separate the human and physical systems that make up our institutions, networks, bureaucracy, and policies. Consequently, they form a complex, dynamic system in which individuals and collectives (termed "adaptive agents") respond to both internal and external stimuli, often with surprising results. The principles of complexity theory argue against reducing a problem to its component parts in order to draw simple causal conclusions. This is because the whole is greater than the combination of its parts in any complex system. Instead, complexity theorists assert that they take a more holistic approach, attempting to define systems "in a non-reductionist manner" by considering all of the interconnected parts.

Many of the earliest works on complexity drew heavily from cybernetics, information theory, and general systems theory. Rather than focusing on individual parts, the general systems theory put an emphasis on the connections between them. Proponents of this theory reasoned that systems would eventually settle into a unique equilibrium as a result of the interplay of the relevant variables. One of systems thinking's major flaws was that it couldn't adequately account for system change because of the theory's emphasis on stability. Social scientists had issues with it because it was too functionalist and tautological; they claimed that the only way to explain system functions was to consider how they affected the system as a whole. Since then, complexity theory has developed in several contexts, including evolutionary ecology and biology, physics and computational theory, and most recently, the governance, organizational theory, and public administration literature.

Social-Ecological Systems (SES) theory [17] is a branch of complexity theory that has proven notably useful to studies of climate change and adaptation efforts. Built upon the work of ecologists, SES was the first framework to propose the idea that social and biological systems might be seen as Complex Adaptive Systems (CAS) composed of many interacting sub-systems of varying sizes. Rather than being fixed things that gravitated towards equilibrium, SES theorists claimed that CAS were dynamic structures that may move to alternative states if they passed critical thresholds. For instance, climate scientists have mapped thresholds and warned that if the world warms by more than 1-2 degrees Celsius, many natural systems may undergo dramatic and irreversible changes. The melting of arctic sea ice might cause biophysical systems to cross crucial thresholds over 3 degrees Celsius. Changes in precipitation and the frequency, with which forest fires occur, for instance, might have a dramatic impact on the species diversity of Amazonian forests.

Duggan [18] demonstrates a complex SES as a panarchy, a pyramid model characterized by the interdependence of various scales that undergo independent but interacting evolutionary phases of transformation, re-organization, and regeneration (for visual depiction). In relation with other complex adaptive systems, SES has the following characteristics (in **Table 1** below):

Table 1. Social-Ecological Systems (SES)

SES Characteristics	Brief Description
Nonlinearity	Relationships among dynamic elements (humans, plants, animals, and things) are the building blocks of complex systems. Complex relationships, e.g., negative and positive feedback loops and multi-scalar process, describe system change, as opposed to the linearity and predictability of change where x directly affects y. Change is prompted by positive feedback, while negative input keeps things in check. An example of a positive feedback in climate research is the ice-albedo feedback loop. For instance, when a glacier recedes, it reveals soil of a deeper color. This is because dark surfaces absorb more heat from the sun than the white ones do, speeding up the melting process on snow and ice. Moreover, systems are subject to threshold effects, which imply that little perturbations may set in motion chain reactions that are difficult, if not impossible, to undo at later stages.
Emergence	Over time, localized interactions between actors and system components "emerge" as the behavior of a complex system. Actors on a local level act in accordance with local norms and based on the data at their disposal. Over time, they learn and evolve to better suit their surroundings, a process known as "adaptation." The new roles and relationships between actors are shaped by the decisions and occurrences that occur on a local level. The term "emergence" refers to the phenomenon in which the whole of a system exceeds the individual parts. However, in a panarchy, higher-scale processes condition local behaviors.
Self-organization	In addition, decentralization is not the rule in complex systems, which is another aspect of emergence. Although there may be a small number of essential processes that ensure the smooth functioning of the system as a whole, no one entity has command over it. Specifically, "the interaction of individuals, institutions, and structural systems results in an efficient and well-organized distribution of goods and services," according to complexity theorists, hence markets are a good example of self-organization.
Connectedness	One of the most important aspects of change in a system to comprehend is its connectedness, or the degree of connectivity between its internal variables and processes. Systems and subsystems that are highly interconnected and dependent on one another may be more resilient to external change because of these connections, but they may also become inflexible as a result. Self-sufficiency and mastery over one's own fate are enhanced when a system is increasingly dependent on its own components. On the other hand, pieces may "produce mutually supporting interactions that give rise to sustaining systems and processes that promote their own development and utility." The "conservative, sustaining power" of institutional memory is one example; another is the social path dependence or "lock-in" that might result from the use of certain technologies. Tightness in a natural system may indicate the degree to which some species are dependent on a limited number of nutrients. Tight coupling may be seen, for instance, in the dependence of urban dwellers on their city's network of linked utilities.
Cascade effects	The intensity of the connection also has an impact on the magnitude of the cascading consequences. The "cascade effect" is the phenomena by which the effects or consequences of a specific threshold level "cascade" across multiple scales, time periods and/or complete systems. Cascading effects are more likely to occur in closely linked systems because they are less adaptable and more immune to normal levels of external fluctuation.
Uncertainty	Unpredictability in system behavior is a result of several factors, including, self-organization, and emergence, non-linear and cascading effects.

Particular emphasis in the field of climate change studies and policy has been paid to another quality of SES: resilience. While it is beyond the scope of this study to go further into this hotly contested term, resilience is generally understood to represent a system's capacity to continue functioning in spite of disturbances. The value of a function to be maintained may be defined in terms of either the maintenance of environmental services or the enhancement of human well-being. In light of environmental and economic shifts, some scholars (e.g., Li, Villasante, and Zhu [19]) stress resilience as an end goal of governance processes. Governments and development agencies have recognized resilience as an encompassing policy or developmental target [such as ICLEI-Local Governments for Sustainability; Rockefeller Foundation; and the city of Johannesburg], despite the fact that the implications of the phrase remain contentious and usually ill-defined.

Cities as Complex Systems

Complexity is defined by the fact that it may be seen from several, often conflicting, perspectives. It is one of many ways to describe cities as complicated systems. Cities can be as small as a square mile or as large as many smaller countries; they can expand and change over time; they can be both real and virtual; they can be located anywhere; they can be networks; they can be spatial and transcendental; they can be about places and people; they can be as big as many small nations or as small as a square mile.

Cities have been adjusting to and driving the growth of ICTs for quite some time and they have done so without the help of urban researchers, managers, or strategists. Publications on the subject have been accumulating for years, and they reveal that urban uses of ICT have yielded mostly unsatisfactory outcomes, with few groundbreaking breakthroughs and few replicable best practices. As we leave the city of yesterday and go toward the city of future, there are also numerous issues: the emergence of supra-local and global actors, as well as new political coalition governments of any scale; the adaptive reuse of urban buildings and facilities for different purposes at different times; the anticipation of divisions of labor, new urban decision-making routes and new forms of urban administration, in which information technologies corporations progressively make the decisions; and the onset of future technology that we have yet to even imagine. This issue is anticipated to emerge in the next twenty to thirty years due to unstoppable growth of information and communication technologies (ICTs) all over the world.

However, there is cause for optimism: the data, tools, infrastructure, and analytical techniques of the informatics revolution may now be ready to construct hitherto unimaginable potential for the benefit of cities. Like ecosystems, cities, say proponents of the urban complexity theory, are dynamic, adaptable, and open to their surrounding environment. It is said that the self-organizing, evolutionary, and adaptive behaviors of cities may be seen in the striking similarities between the urban forms of various cities throughout the globe, to provide just one example. There was a paradigm shift in how cities were seen in the scientific community when socialecological research was applied to them. However, cities are often characterized as socio-technical systems to emphasize the importance of linked networks of infrastructure, knowledge, and institutions in mediating human-ecosystem interactions inside cities.

The legal limits of a city are sometimes used as a way to establish an urban structure. Multiple institutional and environmental subsystems make up urban systems, interacting with one another and with external systems to display behaviors that neither would display alone. Merchandise, services, and data all pass freely in and out of cities thanks to their permeable "boundaries". Urban systems rely on and have an impact on systems outside its physical borders, such as agricultural systems, and are affected by organizational, administrative, and socio-economic components outside of city confines, which together are referred to as the "appropriate environment" of an urban system.

Complex systems theorists usefully focus on the relationships between the many "sub-systems" and procedures that keep cities running well. According to Lewis [20], this encompasses not just the physical infrastructures (such as water and electricity) and the built environment, but also the institutions that assure supply and moderate demand for services. Understanding how systemic processes in urban areas react to external disturbances like climate change is a major concern for urban systems theorists. The consequences of climate change will be felt indirectly via urban system failures and the cascading impact of human-made and natural catastrophes; therefore a systems approach is helpful for comprehending them. Indirect system failures may occur in a variety of industries, including those that rely on transportation, power, water systems, waste management, telecommunications and food distribution.

For instance, in highly linked infrastructure systems, disturbances in one system might have repercussions for the whole network. If major roads are flooded, for instance, commuters may be unable to get to and from work, which might have a knock-on effect on their ability to put food on the table. Cities dependent on hydroelectricity are particularly vulnerable to the impacts of drought, which may cause shortages of water and energy, as well as ripple effects across the economy. Using data collected by Zhao and Fang [21], several systems theorists have also tackled the topic of the interrelationships between the technical and social aspects of infrastructure systems. The extent to which system shocks affect people is contingent on the specifics of the institutions in question, such as the status and rights that provide them access to certain services.

Akkiah [22] have a hard time figuring out how to accurately depict complex metropolitan structures. There has been a lot of work made into developing computational models to depict these intricate interconnections; these models are then used to forecast the emergent consequences of the interactions between various system linkages, which in turn aids in planning. In most cases, the social and geographical structures of people are accounted for in such models by modifying ecological models.

Schiavo and Magalhães [23] were able to test out various climate projections and other potential future states of the system with the help of these models. Metabolic assessments of cities have been a popular issue in urban modeling because to the increased focus on sustainable development that began in the 1990s and has continued with the advent of global climate change and the push toward low carbon development. From a systems perspective, a city's "metabolism" refers to its material production, which includes water, energy, resources, and trash. The metabolism of a city may be determined by tracking the amount of energy and matter it consumes and expends over time. Tu et al. [24] have utilized urban metabolism to quantify the city's carbon footprint and guide decarbonization efforts.

Critiques of Complexity: Alternative Methodology of Conceptualizing Cities

It is because of urban systems theory that we have begun to pay more attention to the complex network of interconnected systems that sustains cities, including the dynamic ecological processes upon which they rely. Some of the ways in which these connections affect climate change are negative, such as when they lead to increased greenhouse gas emissions or when they cause changes in urban land use that lessen the amount of carbon that can be absorbed by vegetation. Complex systems theory, which has its roots in ecology, has been criticized for trying to provide an explanation for industrialization as a complex social-ecological dynamic inside a unified model. It has certain limits in assessing governance and influencing governance actions, as stated in section two, since it does not effectively interact with the intricacies of human behavior.

According to Hager and Beckett [25], a major flaw in complexity theory is the underlying assumption that economic and social systems operate similarly to ecosystems. This obscures the reality that input and learning in social structures is shaped by conscious human activity, enabling adaptation and change in contrast to the neutral evolutionary change that insure "maximum fit" with the environment. Therefore, sound theories of social structure and agency are necessary for comprehending the causes and outcomes of urban transformation. Key ideas from the social science literature, particularly those pertaining to social power, have been largely absent from this literature, however.

Complexity theory, which emphasizes emergence and self-organization, gives less weight to political forces, such as social fights at different scales, and more to the idea that cities and urban infrastructure systems arise from neutral system behavior or evolutionary processes. Urban planning and development are often elite-driven, violent and exploitative, with the perspectives of the poor and oppressed seldom represented. Instead of analytically engaging with how different social groupings "interact with ecosystems," existing models portray humans as "anonymous generating units of pollution and urban development," making it difficult to understand how "actor organizations may be relied upon in management processes" to promote sustainability or resilience.

IV. LIMITATIONS OF THE COMPLEXITY THEORY

After surveying the relevant literature, we identify three main gaps in our current understanding of the political ecological dynamics of urban settings and urbanization that complexity theory fails to address. The first is an unwillingness to consider the past, namely the different urban development patterns that have existed in the global North and South. The second is that diverse players' vantage points are not properly considered when attempting to comprehend and depict (e.g., demarcate, characterize, and map) systems and explain goals like resilience. The third is a failure to take seriously the interconnectedness of these issues.

Inadequate Political Economy Attention and a Proclivity for "Methodological Cityism"

First, complexity theorists have a tendency to naturalize transformational movements as the adaptation action of self-organizing individuals and organisations, which obscures structural disparities and the mechanisms that sustain them via coercion and violence. Second, focusing on the size of the city as defined by jurisdictional bounds makes it hard to detect the deeper political and economic drivers of urbanization. Angelo and Wachsmuth [26] have used the term "methodological cityism" to describe this strategy for studying urban areas. Cityism is the perspective of complexity theorists who regard a city as an independent system that must adapt to its "enabling" external environment. By contrast, conventional geographical theories of space and place emphasize the mutual production and constitution of global linkages and processes in particular local locales, such as cities.

According to Barth and Harvey [27], the urbanization process—including the building of the urban built infrastructure and urban environment—is crucial to the reproduction of global capitalism because it absorbs excess capital and so prevents issues of over-accumulation. The latter is what happens when investors have accessibility to rewards that are higher than their costs. The economies of scale that result from the concentration of capital in metropolitan areas also encourage capital accumulation. This transformation is very asymmetrical, with some individuals and cities becoming more deeply embedded in the global economy in less desirable ways (for example, electronic wastes from the Global North).

The emergence of capitalist (urban) areas is neither neutral nor inevitable, but rather the result of deliberate political choices and, at times, violence. Therefore, contrary to the claims of certain complexity theorists, capitalist markets cannot be seen as an instance of self-organization that originates from the bottom-up actions of individuals. The confinement of common property assets and the regulation of social and labor formations are only two examples of the extra-economic coercion that has always been necessary for "free" economic fundamentals to function. This is especially true in cities of the Global South, where elite-led urban growth is often based on the eviction of low-income residents and the suppression of minority populations by the armed forces and law enforcement. Some have argued that the "right to the city" concept popularized by Henri Lefebvre is destined to fail in a capitalist society because "exchange rate" (— economic investment returns) takes preeminence over "use value systems," or the products and services required and preferred by the numerous urban residents whose daily workforce makes a significant contribution to building a city.

Using these concepts as a starting point, Marxist Urban Political Ecologists (UPE) argues that urbanization under capitalism is also an environmental process that alters the natural world in ways that benefit the wealthy at the cost of the poor. According to this theory, cities are neither entirely natural nor social, but rather a "hybrid" of the two. When seen through the lens of the social-ecological systems approach, nature and society are seen as more than just interconnected; they are co-constituted. This is a remark made by urban political ecologists using Marx and Engels' concept of metabolism, which has a distinct connotation in the field of complexity research. Metabolism in complex systems models is often conceived in terms of carbon or garbage throughput in a metropolis, with the aim of quantifying the efficiency of such fluxes as a foundation for legislation. In contrast, the term "metabolism" is used to describe the way in which human labor changes both the human body and the biophysical environment. Most productive activities in capitalist cultures are structured around a divide of capital and labor, with people's means of subsistence embedded in and shaping wider gender and racial power dynamics.

The above demonstrates a critical gap between complexity theory and UPE's views on the nature-society interface. Political ecologists disagree with those who subscribe to the complexity approach because they see social power and authority as being produced by the appropriation, creation, and management of material flows (such as carbon or water) rather than as working over them. Various "geometries of power" emerge at various levels of resource management and environmental protection due to disparities in race, socioeconomic position, gender, and citizenship. It is possible that racial, class and gender inequalities are constructed in spaces of governance, notwithstanding their importance as sites where identities are formed and maintained.

Therefore, political environmentalists go beyond complexity theorists' emphasis on inputs and outputs to understand the power-laden character of these metabolic pathways, notably how "'natural metabolic rates and alterations become discursive practices, politically, and commercially deployed and socially exploited to generate ecosystems that reflect and embody perspectives of social power. Proponents of urban government are left wondering "who regulates these metabolic circulatory flows within and outside the bounds of the city, for what motives, and with what outcomes" Research on adjusting to climate change from a political ecology vantage point is particularly useful since it highlights the interconnected nature of vulnerability. Some people are more likely to feel safe in cities, while others are more likely to feel helpless and dependent on others as they adapt to environmental and other forms of urban transformation. This holds true both inside metropolitan regions and between urban cores and their surrounding suburban and rural communities.

Marginalized communities in cities sometimes have to live in areas developed for the rich, which puts them at greater danger. These practices reduce the permeability of urban surfaces, which may lead to increased flooding risks. Some people's lives have improved as a result of the eradication of the coastal mangrove in Mumbai for real estate development (such as investors and middle class residents), whereas the lives of others who live in slums along the shore have become even more perilous since they no longer have the woods to protect them from storms. Bangkok's floodwalls, intended to safeguard the city's core, have instead diverted water to the city's periphery, putting peri-urban and rural populations at greater risk [28]. When people do not have access to clean water, those in power can take advantage of their dependence on others by charging them exorbitant rates, as has happened in some places with severe water shortages or by forcing those in need to rely on their wealthier neighbors.

Inappropriate Consideration to Knowledge Production Politics in Modeling Systems and Defining System Goals

A political ecology perspective highlights how knowledge of nature or the "system" is generated via and reproduces uneven social interactions. However, this approach is more positivist than the complexity theory one. Complexity theorists hold the belief that everything happens according to a preset system, which can be readily manipulated via a solid grasp of its empirical foundations. Post-structuralist and "non-dogmatic" Marxist perspectives, on the other hand, understand that there is no a priori or universally acknowledged structure or nature distinct from civilization, and that all such structures are defined from the viewpoint of an observer who is socially positioned in certain ways. Furthermore, such characterizations of the system conduct political work by promoting structures that favor some groups over others. Because political ecologists see nature and society as inextricably intertwined, they also believe that the concepts of "environment" and "nature" are fictitious and arbitrary inventions of human. This does not discount the reality of biophysical/ecological processes that occur outside of our comprehension.

Instead, it recognizes right off the bat that things have been drastically modified by people in pursuit of various ends and in accordance with various conceptions of what nature is and should be. Second, it emphasizes the need of human ideas, concepts, and languages for knowing and understanding biophysical processes, all of which reflect and produce unequal social connections. When and why various aspects of nature are prioritized in conservation efforts might change throughout time. Carbon, for instance, has made new inroads into public debate and policy due to rising worldwide concern about climate change. As a result "carbonization of urban governance," new ways of measuring carbon have had to be developed, and the power and influence of public and private actors who claim the ability and skill to regulate carbon have been bolstered. In light of this, it is crucial to assess claims of "system" knowledge in light of the political job they do and the outcomes they create. Political ecologists question what is to be maintained, why, and for whom, rather than seeing such concepts as neutral, natural, or with a single meaning. These are important problems of governance that are often overlooked in the literature on complexity.

Inappropriate Consideration to Local Process, History and Context of State Formation

Finally, it has been claimed by critical urban researchers that the relevance of many local history of urban development is minimized by complexity's emphasis on self-organization and emergence. Poststructuralists and urbanists, especially those based in the Global South, have drawn attention to the many different forms of "being urban" throughout the world, illustrating how even seemingly uniform global processes like global capitalism are punctuated by differences, splits, and schisms. Due to their exclusive focus on the city, the complexity and resilience literatures have glossed over important contextual factors like the distinct local histories of state formation highlighted by postcolonial urban scholars. The emphasis complexity puts on self-organization means that it is more important to look at horizontal types of social organization (such as networks, unstructured or community-based organizations) than vertical ones (such as the state). This is a particularly serious issue in Southeast Asia, where many governments are still highly centralized.

Scholars of "southern urbanisms" (Razavi et al. [29]) argue that current patterns of citizenship and the urban form are nevertheless informed by relations of governance with colonial antecedents. Not everything can be reduced to neutral, adaptable behavior, and this work considers the many daily ways in which people join together to live and build the urban landscapes they wish. In this context, "practices" refers to the inventive ways in which people engage in daily life to connect with one another, fight for what they need, and survive.

V. CONCLUSION

This article defines the term "complex systems" as a research paradigm of studying the interrelationships and mutual influences among the many parts of a system in order to better understand the system's overall behavior. In contrast to reductionism, the prevalent paradigm in the study of systems, which emphasizes parts and their interactions, complex systems may be considered as an alternative way of looking at how systems work. This paper starts by discussing the perspectives of complex urban systems defining urban complex cognition. It is therefore noted that human cognitive abilities are tested in urban environments, and this is true not merely from the standpoint of modeling cities and the structural connections between its components. To be effective, mental models must include findings from studies of urban dynamics into representations, actions, and evaluations of urban space navigation, usage, and governing techniques. This paper also discusses complexity and planning in adaptive urban policymaking. The fundamental conclusion drawn by planning theory after decades of interaction with urban centers from a complexity viewpoint is the necessity for a dramatic redesign of planning methodology as an interrelationship between institution-driven architecture and urban self-organization concepts.

Secondly, the article presents a critical depiction of cities as complex adaptive systems. In this, the article presents an overview of complex systems by reflecting on the previous researches on complex systems. Studies of complex systems focus largely on system properties and dynamics. When several entities interact with one another or are dependent on one another, they are said to constitute a system. It is always characterized by their borders, which specifies what elements are and are not included in the system. Thereafter, things outside the system are integrated into it as ecosystem components. The origins of complexity theory can be traced back to the fields of mathematics and physics, with subsequent variants being adopted by researchers in many other scientific and social disciplines. Complexity theory has been heavily criticized by social scientists, but its proponents argue that it is more relevant than ever at a time when social actors are actively engaged in governance and when global processes touch numerous sectors and scales. Complexity is defined by the fact that it may be seen from several, often conflicting, perspectives. It's one of many ways to describe cities as complicated systems.

Lastly, this paper presents the critiques and limitations of complexity by presenting an alternative methodology of conceptualizing cities. It is because of urban systems theory that we have begun to pay more attention to the complex network of interconnected systems that sustains cities, including the dynamic ecological processes upon which they rely. Some of the ways in which these connections affect climate change are negative, such as when they lead to increased greenhouse gas emissions or when they cause changes in urban land use that lessen the amount of carbon that can be absorbed by vegetation. The limitations of the complexity identified in this article include (i) Inadequate Political Economy Attention and a Proclivity for "Methodological Cityism" (ii) inappropriate consideration to knowledge production politics in modeling systems and defining system goals, and (iii) inappropriate consideration to local process, history and context of state formation.

Data Availability

No data were used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

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