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Diagrammatic Abstractions: Jay Forrester's Urban Dynamics and Its Contribution to Architecture and Urban Planning in the Late 1960s and Early 1970s

Anna Ulak, Institute of Architecture, The Oslo School of Architecture and Design, Norway, anna.ulak@aho.no

In the 1960s and '70s, Jay Wright Forrester (1918–2016) created a rigorous new method he called Urban Dynamics, in which he applied systems theory to urban planning by an extensive use of diagrams and computation. This article discusses how Forrester's theories migrated from business theory to urbanism in educational settings and into real-life planning scenarios in the US Department of Housing and Urban Development (HUD). By focusing specifically on how Forrester adopted systems drawings that incorporated data and the use of computation for urban planning, the article argues that Urban Dynamics marked a changing approach to urban planning, favouring general managerial knowledge over competences specific to urban design. By conducting a visual analysis of Forrester's diagrams, the article demonstrates how Forrester's diagrams for his Urban Dynamics model were instrumental in concealing political ideals that blurred the border between the real and the ideal.

Keywords: Architecture; Urbanism; Systems Theory; Mid-Century Jay Forrester; Social Housing; United States; Department of Housing and Urban Development; Computation; Design

A Systemic Shift

During the late 1960s and early ’70s, the notions of ‘environment’ and ‘built environment’ signified a shift in architectural pedagogy within architecture schools in the Anglo-Saxon West.[1] The word ‘environment’ underscored an interdisciplinary mandate associated with the social sciences (Lobsinger 2013: 653). Around this time, architectural discourse was of a tremendous interest in linguistic, behavioral, psychological, computational, mediatic, communicational, and cybernetic paradigms. Arindam Dutta refers to this as the ‘techno-social’ tendency and says it is characterized by ‘its wariness towards what it considered the vagaries of aesthetic formalism [as much as] by its aspirations to what it considered “expertise” steeped in rule-based judgments and verifiability’ (2013: 2). This moment has been well documented in architectural history; scholars such as Arindam Dutta et al. (2013), Mark Wigley (2001), Molly Wright Steenson (2017), and Felicity Scott (2013: 2016) have demonstrated how architects and planners were utilizing more instrumental, technological, and managerial knowledge. However, specialists outside the discipline of architecture also made significant contributions to the techno-social moment in architecture.

One such specialist outside of architecture was the systems theorist Jay Wright Forrester (1918–2016), a professor at MIT’s Sloan School of Management who applied systems theory to the discipline of urban planning in educational and real-life settings. In brief, systems theory analyzes and uses systems to understand complex phenomena and problems. The theory focuses on a system’s structure rather than its function, assuming that complex systems share similar organizing principles despite different purposes and that these principles can be mathematically modeled (Forrester 1968: 1). Forrester aimed to find a solution to urban problems in the United States by transforming systems theory into urban theory. The methods of Forrester’s so-called Urban Dynamics model were based on systems theory and included representing urban problems by the means of diagrams, in tandem with computational models. Although Forrester was not trained in architecture, urbanism, or any design field, his work contributed to the techno-social moment in architecture and urban planning, as this article shows.

Numerous architectural historians have cited Forrester’s work; however, none have analyzed his diagrammatic methods in particular. In *Outlaw Territories* (2016), Felicity Scott explores aspects of Forrester’s use of systems theory in environmental planning. This article builds upon Scott’s critical analysis and draws on previous research by Peter J. Taylor and Ann S. Blum (1991), in which they analyze mid-century ecological diagrams to show how graphic conventions were used to translate complex ecological relations into systems.

According to Orit Halpern (2015), Paul Emmons (2017), and others, several leading figures in a variety of disciplines were creating similar diagrams of systems to describe and study their respective fields, including architecture and urbanism. And although several architects were advocating and attempting the use of systems theory in urban design in the 1960s and '70s (for example, Buckminster Fuller, Christopher Alexander, Constantinos A. Doxiadis, and Cedric Price), their proposals rarely managed to capture the attention of policy makers. Yet Forrester's diagrams were highly operational because he used them in tandem with the computer, a device that few had access to at the time, thus affording his specific diagrams a certain level of novelty and authority. Forrester managed to convince powerful decision makers, such as the US Department of Housing and Urban Development (HUD), of the efficiency of his methods.

When we look at the context in which Forrester's Urban Dynamics emerged, we can understand the nature of his political leanings upon which he built the theory. This underlying ideology affected his drawings, which an analysis of his diagrams reveals. Moreover, the visual analysis of Forrester's diagrams unpacks precisely how he concealed his political beliefs and convinced others that the diagrams were objective. In addition, the seemingly non-political diagrams participated in a turn towards managerial knowledge in urban planning and architecture methods. Nevertheless, visual thinking was a significant component of Urban Dynamics. Therefore, Urban Dynamics affected not only the planning discipline and but also the role of visualization techniques within it, even though Forrester dismissed such techniques as futile. Finally, the implementation of Forrester's Urban Dynamics in the real-life planning scenario of the HUD-sponsored pilot project in Lowell, Massachusetts, demonstrates how Urban Dynamics transcended academic circles into political reality.

Systems Everything and Everywhere

Forrester, a pioneer in early digital computer development, invented random-access magnetic-core memory during the first wave of modern computers after the Second World War. In the post-war years, he received several awards for his books, nine honorary degrees from various universities, and the National Medal of Technology, awarded by the president of the United States (Dizikes 2015).

In 1956, Forrester founded the field of system dynamics while working as a professor at the Sloan School of Management at Massachusetts Institute of Technology (MIT). Like systems theory, system dynamics studies the relationship between all the parts of a system and analyzes those relationships' influence on the behavior of the system over time. Though system dynamics is built on systems theory, system dynamics is more detailed and uses its own graphic language and symbols to represent explicit equations

that are computed and applied to clearly defined problems in order to offer solutions. Whereas the origin of systems theory is less definitive and arguably a mixture of humanistic and rational fields, system dynamics was born out of the fields of electrical engineering and management — fields that Forrester studied and practiced prior to founding system dynamics. Practitioners of system dynamics produce actual simulation models of the subjects to which the method is applied and therefore (try) to move away from theorizing about those objects of study and toward generating applicable results.

Forrester's books, *Industrial Dynamics* (1961), *Principles of Systems* (1968), *Urban Dynamics* (1969), and *World Dynamics* (1971), all incorporate ideas about system dynamics on a variety of generalized problems. In *Industrial Dynamics*, Forrester employs system dynamics to propose a new management method for business organizations, suggesting how corporate policies and structures can accommodate growth, enhance dynamic stability, and deal with the complexities of internal interactions to improve the function of a business. The book offers insight into how actions from management influence the dynamic characteristics of a business organization. *Industrial Dynamics* is built upon Forrester's ideas from his past work with servo mechanics and computation. He describes how information within a system changes because of its various inputs that become outputs, and how an output does not need to be very precise since the primary focus is on the way information is put together in a system while still being able to change (1961: 97).

In *Principles of Systems*, Forrester takes a more general approach to utilizing system dynamics, focusing on how the structure of a system determines its own behavior. Although Forrester uses examples from business, he presents system dynamics as universal, applicable to any topic, from the hard sciences to the social sciences (1968: 1–4). System dynamics, so Forrester suggests, has the potential to offer solutions because it is focused on the malleability of a system's structure and its use of customizable equations.

The year after *Principles of Systems* appeared, Forrester published *Urban Dynamics*, in which he develops system dynamics for urban policy and design and presents a study of a city. In it, Forrester coins the term 'Urban Dynamics' to refer to a model for applying systems dynamics for urbanism. He uses the Urban Dynamics model to analyze the forces influencing the balance of a city's population, housing, and industry. With this model, he sought to *predict* the impact of various policy proposals for cities, which he reformulated as 'systems' (1969). Following the publication of *Urban Dynamics*, Forrester was asked by The Club of Rome to conduct a similar study, but this time for the whole world. This systems approach to the entire world was published in 1971 as *World Dynamics*. To analyze the entirety of the world system and to study the limits of the world's consumption of natural resources, he employs such parameters as population, natural resources, capital investment, and agriculture.

What these four books have in common is the graphical diagrams of all Forrester's 'systems' — a business organization, a city, the entire world — with the aim of facilitating the management of such systems by relying on the benefits of computation (**Figure 1**). However, these detailed graphics were more than abstract representations; they were highly operational *visual equations*.

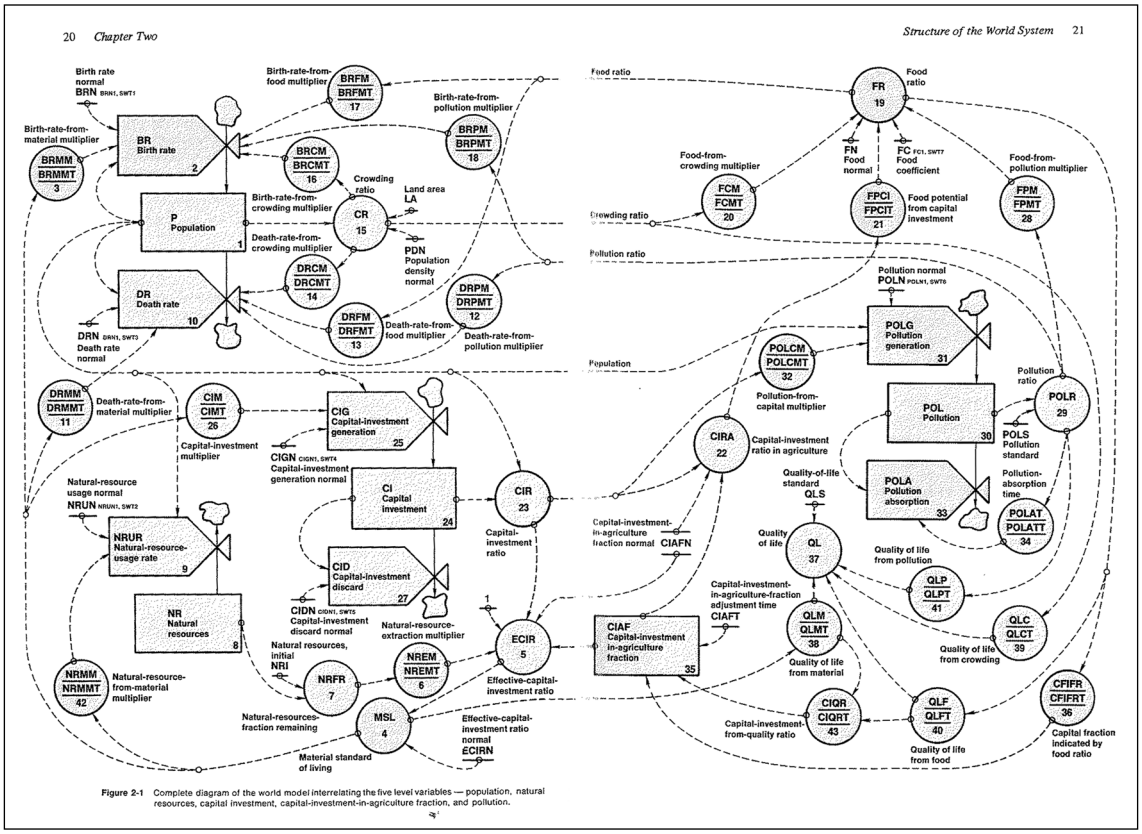

Figure 1: Forrester developed this systems diagram to study the correlations between population, capital investment in agriculture and the economy, pollution, and the natural resources of the world. From Forrester (1971: 20).

Urban Dynamics Fever

In early 1968, four schools at MIT — Architecture and Planning, Humanities and Social Sciences, Engineering, and the Sloan School of Management — formed the Urban Systems Laboratory (Annual Report [WAR] 1967–68). The aim of the Urban Systems Lab (USL) was to pool MIT's wide resources, such as the institute's 'computer and information resources', to study urban issues, work that was described as 'urban systems research' (Annual Report [WAR] 1967–68: 4). Forrester was invited to the USL by Mason Haire, the associate director of the USL, who, like Forrester, was a professor at the Sloan School of Management. Haire encouraged Forrester to participate in the

Lab's studies (Urban Systems Lab [WAR] 1968–70). Forrester's involvement with urban issues around this time was amplified by the fact that in 1968, the former mayor of Boston, John Collins, was given the office next to Forrester's, their proximity allowing discussions between the two on urban topics (Forrester 1969: ix). Collins taught from 1968 to 1981 in MIT's urban planning department. Collins also encouraged Forrester to utilize system dynamics for the sake of urbanism. Collins recommended, for example, that Forrester present the use of system dynamics for urbanism at the 1968 National League of Cities (National League of Cities [JWF] 1968). Initially, Forrester wrote a few essays on the topic of urban systems, which garnered the attention of researchers from several disciplinary fields. In October 1968, the Center for Advanced Engineering Studies (CAES) (established at MIT in 1963) and the USL held a three-part series of seminars titled 'The Cities and MIT', for which Forrester presented a paper, with Alexander L. Pugh, titled 'DYNAMO — Its Use in Urban Studies' on October 17, and another paper titled 'Urban Growth, Stagnation and Revival', by Forrester alone, on October 24 (Forrester and Pugh [JWF] 1968; Forrester [JWF] 1968). These papers discuss the use of the computer software DYNAMO in urban studies.

DYNAMO was initially developed by Forrester, Pugh, Phyllis Fox, Grace Duren, and others at the MIT Computation Center in the late 1950s (Richardson and Pugh 1981). The name DYNAMO was short for 'dynamic models' and was a simulation language with an accompanying graphical notation system developed within the analytical framework of system dynamics. The new computer program was one of the elements that interested Forrester's peers at various departments within MIT and drew them to his work.

Forrester's work with Urban Dynamics transcended even more distant disciplinary boundaries in 1969 when it caught the attention of an art and design professor, György Kepes, at the MIT's Center for Advanced Visual Studies. Kepes requested that Forrester submit a chapter for an upcoming book that would form part of his Vision + Value series, two tentative titles for the book were *The Art and Science of Environment* and *Arts and Participation: 20th Century Environmental Pageantry* (Kepes [JWF] 1969). Forrester's work, especially his diagrammatic methods, was in fact a good match for Kepes's Vision + Values series of books, whose premise was to teach readers to think visually between unrelated fields, especially for those in fields typically not considered visual (Blakinger 2019: 186).

As the correspondence in the archives of Forrester's work at MIT suggests, Forrester was initially reluctant to accept Kepes's request, but he eventually wrote a chapter titled 'Planning Under the Dynamic Influences of Complex Social Systems' for the publication that was eventually called *Arts of the Environment*, in the Vision + Value series (Kepes 1972). Forrester's initial hesitance is not insignificant and is worth exploring

further as it is related to his view on architecture and visual design. In Forrester's books, managerial, planning of various systems and instrumental knowledge trumps other forms of knowledge, such as the specific fields of urbanism or business (Forrester 1961: 4); he makes this particularly evident in *Principles of Systems* (Forrester 1968: 1–4). The methods of management should guide interdisciplinary studies, he says. Therefore, although Kepes might have been interested in how Forrester's diagrams were creating a new kind of knowledge — the visual aspect of how the diagrams were bringing knowledge together and thus contributing to that knowledge — Forrester was more interested in the instrumentality of the diagrams and their managerial methods. Moreover, Forrester never mentions the significance of visual composition in his diagrams in any of his books. He only stresses the equations that such diagrams express and how their results could assist in managerial decisions.

A certain kind of interdisciplinary approach arose at MIT's architecture school in the late 1960s. As detailed by Dutta and others in their meticulous analysis of MIT (Dutta 2013), the School of Architecture was under pressure to incorporate methods from other fields and to collaborate with institutes across the school, favoring approaches related to technological and social studies over disciplines related to the arts. This interdisciplinary urge was more inclined toward managerial, social-scientific knowledge than artistic, urban, architectural, and design knowledge. MIT thus organized several events for Forrester to present his Urban Dynamics — the kind of interdisciplinary knowledge that the school wanted to promote — to the School of Architecture. In a confidential letter written circa 1970, Lawrence Anderson, the dean of architecture, wrote to the faculty members at MIT, including Forrester, regarding dissolving the discipline and artistic specificity of the School of Architecture:

> The architectural and the planning professions I think right now are especially susceptible to the introduction of new technology. I would cite advances in the application of decision theory, of modeling and simulation of social systems, and of the development of new computer languages for the use of planners and architects and clients of environmental professionals as examples of extremely productive new areas … Thus the image of the School that I am creating consists of four differing kinds of entities, some of which are shared by other institutions, thus accomplishing the kind of bridging which I believe to be necessary characteristic of the School … In this way I think the whole School could become what we were calling before the Center of the Human Environment … The strength of my proposed organization I think in part rests upon its avoiding a discipline-based organization of the School … (Anderson [JWF] 1970)

By that time, Forrester was a frequent guest within architectural circles, both within and outside of MIT. In the summer of 1968, he participated in the series of workshops MIT conducted in Berlin with the Technische Universität (Conference [JWF] 1968). The next year, he was invited to lecture at the Boston Architectural Center, where Forrester presented Urban Dynamics to great acclaim, according to Abraham Woolf, the chairman of the Boston Architectural Center and the event organizer (Woolf [JWF] 1969).

Despite Forrester's being invited to many architectural and urban planning events, his ideas underlying the Urban Dynamics model, and the book, were not without controversy. Forrester deemed a city desirable if it was economically successful, and thus his Urban Dynamics model is based entirely on how immigration, migration, and housing within a city affect its economic growth and decline. For instance, the book states that economic growth, movement of people, and housing availability are the most important for the economic health of a city — more so than government, political intervention, or even factors to do with social culture (Forrester 1969: 17). As such, the Urban Dynamics model was an attempt to counter 'slum areas, high tax rates, flight of industry to the suburbs, and mounting welfare rolls' (Forrester 1969: 51). Thus, Forrester's model was a system based on parameters to do with the economy of a city being affected by migration and served to optimize an urban problem defined in terms of tax rates, government spending, industrial flight, and inadequate housing. The slums that *Urban Dynamics* specifically mentions are those obsolete buildings once used for economic activity or housing that have fallen into disrepair, to be studied for how they affect a city's economy. The ultimate recommendation of the book is to demolish low-income (slum) housing based on economic arguments. Thus, Forrester's model undermined a key disciplinary discussion: social housing in the urban context. Instead of approaching social or political issues through design and planning, he approached housing problems in cities as economic issues that could be overcome by *management* (1961: 4; 1968: 1–3).

Levels, Rates, and Variables

The visual nature of Urban Dynamics drawings made the ideas behind them more accessible to those unfamiliar with methods of system dynamics. As the computer graphic interface was not yet an established computational feature, Forrester's computer models were complicated and demanded computational knowledge in order to be understood. While the drawings for Urban Dynamics were intended to be objective — akin to scientific graphs — not all scientific representations can be correct, because science is continually evolving, as historian of science Andrew Pickering argues. Pickering also notes that we can never fully understand scientific-like research

practice through a representational idiom because such a representation is always an interpretation of sorts. However, interrogating such representations, he says, can reveal additional knowledge about the respective topic and instigate critical reflection on how society interprets such images (2017: 136). A visual analysis of Urban Dynamics diagrams demonstrates how they functioned within the field of urbanism and how they neutralized political and ideological concerns that typically affect urban planning.

The main diagram of the Urban Dynamics model reveals a structure that consists of 'levels' and 'rates' (Fig. 2). The nine rectangles are referred to as levels. These represent the aspects of a city most relevant to the Urban Dynamics model — business, housing, migration/immigration of people — and how they affect economic growth. The nine levels are laid out in a three-by-three grid. The flow moves left to right, from the top down. The top row, which Forrester calls 'business' in his text, represents industry and the respective need for land and buildings; the middle row, 'housing', represents three different housing types and their respective need for land; and the bottom row, 'labor', represents the different classes of people within the city that contribute to its economic health. The numbers in the lower right hand corner of each level are equation numbers to be referred to in the appendix; therefore, they are not particularly relevant in terms of the graphical composition of the diagrams. Although the three rows are visualized as distinct in **Figure 2**, they are interconnected in other diagrams, as will be explained below; according to Forrester, 'Mathematically the levels are integrations' (1969: 30). The symbols that Forrester calls valves (rectangles with triangles attached) are the rates, which represent various factors that affect the levels, such as premium housing construction or worker housing obsolescence. The rates contain values that plug into the levels and affect their outcome.

Some problematic assumptions come to light when this diagram, the basis of Forrester's model, is scrutinized. At first glance, there appears to be no hierarchy, since all levels and all rates appear the same, especially because they are set out in a grid-like fashion — each level is equally distanced from each other horizontally and then again vertically with an increased equidistance. However, Forrester places the most valuable level (be it in dollars or potential) generally on the left side of the page, each level and rate decreasing in value as it moves closer to the right side of the page. In addition, considering that in Urban Dynamics, the economic health of the city is the deciding factor in its success, the level containing the factors with the most monetary value is also presented at the top, where a reader naturally begins reading a diagram. When examining both levels and rates in the top row, 'business', it appears that the older a business, the more its value declines. In the middle row, 'housing', it appears that the older a building gets, the more its value declines. The type of housing, Forrester

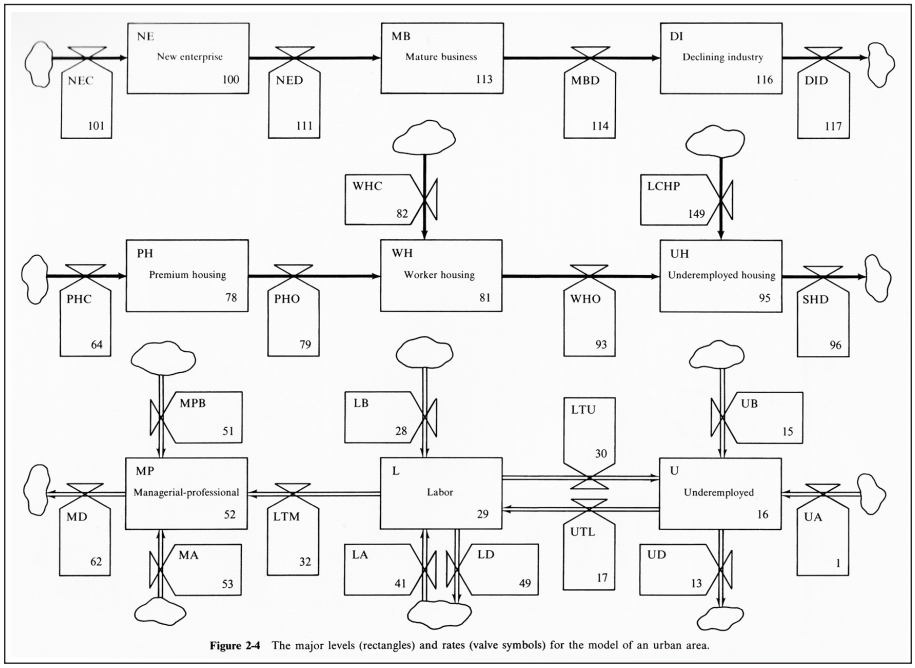

Figure 2: Forrester's basic diagram of the Urban Dynamics model, captioned, 'The major levels (rectangles) and rates (valve symbols) for the model of an urban area'. The abbreviations are explained below. The number on the lower right hand corner of each symbol is the equation number assigned so the system can be studied, and the cloud graphics are the sources or destinations of flows from or to the outside environment. The lines represent flows from or to the outside and are only controlled by conditions within the system. From Forrester (1969: 16, 31–36, Figures 2–4).

Rate legend for Figure 2

Rows are identified, from top to bottom, as 'business', 'housing', and 'labor'.

Business row	NEC: New-Enterprise Construction NED: New-Enterprise Decline MBD: Mature-Business Decline DID: Declining-Industry Demolition
Housing row	PHC: Premium-Housing Construction PHO: Premium-Housing Obsolescence WHC: Worker-Housing Construction WHO: Worker-Housing Obsolescence LCHP: Low-Cost-Housing Program SHD: Slum-Housing Demolition
Labor row	MD: Manager Departures MA: Manager Arrivals MPB: Manager-Professional Birth Rate LTM: Labor to Manager LB: Labor Birth Rate LA: Labor Arrivals LD: Labor Departures LTU: Labor to Underemployed UTL: Underemployed to Labor UB: Underemployed Birth Rate UD: Underemployed Departures UA: Underemployed Arrivals

explains, is directly related to who can afford the various housing types: premium housing is for the managerial professional class, worker housing for the labor class, and underemployed housing for the underemployed (Forrester 1969: 34–35). In the last row, 'labor', the class of people is also categorized from most valuable to least valuable. Thus it becomes clear that while Forrester would have the reader begin with the categories with which they might most readily identify — the high-value levels and rates at the top and right-hand side of the diagram — the focus is on the mid to bottom right-hand side of page, generally where the least valuable levels are located. This is evident since it is the Underemployed Housing (UH) and the Underemployed (U) levels that have the most rates (the valve-like symbols) plugged in. This means that the general concern of the Urban Dynamics model was the relationship between the Underemployed Housing (UH) level and the Underemployed (U) level, as will be discussed further.

The progressions in each row are all clearly based on classist assumptions. Most of these assumptions can easily be challenged, such as whether a building depreciates in value over time. Curiously, throughout *Urban Dynamics*, Forrester never supports any of his assumptions with secondary literature. This is a constant throughout all the diagrams within the Urban Dynamics models, and applies to the values implicitly assigned to the rates and levels — thus all the values are hypothetical. Moreover, by not showing any equations in the diagrams (they are instead encapsulated within the graphics that stand in for rates and levels), a barrier is created to cross-referencing the data. The neutral appearance of the black and white graphical language for all the levels and rates makes them *look* the same. This obscures the hierarchical assumptions and sterilizes the controversy made by Forrester's suggestions. Finally, the graphical style of Forrester's diagram projects an objective, scientific appearance, suggesting logic and managerial objectivity.

The Value of Housing

Housing is divided in Forrester's diagram into three types, as **Figure 2** shows: premium housing, worker housing, and underemployed housing. The valves represent various rates, from the rate of Premium-Housing Construction (PHC) down to the rate of Slum-Housing Demolition (SHD) (Forrester 1969: 34–35). In Forrester's Urban Dynamics diagrams, the Low-Cost-Housing Program rate (LCHP) is directly plugged into the underemployed housing stock. According to Forrester, the LCHP rate is 'not a normal city process, it is an externally generated program which can be activated in the model to observe the response of the urban system to the construction of housing directly for the underemployed' (Forrester 1969: 35). Thus, according to Forrester's logic, the LCHP directly feeds into building housing for the underemployed (UH level). Moreover, not only is LCHP described as *not* a normal city process, but Forrester also uses the term 'low-cost housing program' for any social rental housing funded by the government. It is important to clarify that according to **Figure 2**, the LCHP would have

to be fully funded by the government, seeing that it is directed for the underemployed. There are varying degrees and types of government-funded rental housing that Forrester either disregards or is unaware of. In addition to this problem, while the LCHP is shown in **Figure 2**, neither the Worker-Housing Construction Program (WHCP) nor the Premium-Housing Construction Program (PHCP) are present, although both exist in other more detailed diagrams later on in the book. However, they are given not as a level or a rate but only as an input (out of three or four) that would affect the levels of Premium or Worker Housing; the WHCP and the PHCP are thus assumed to receive three to four times less public financing in comparison to the LCHP. Excluding these two programs from the main diagram when the LCHP is included and its financing discussed in the subsequent pages obscures how the WHCP and PHCP are funded. Moreover, it is not entirely clear if the WHCP or the PHCP would receive any government financial support, since this is never discussed anywhere in the book. It is therefore apparent that the role of the LCHP in the urban economy seems to have been a particular target for Forrester, as will be argued further.

The most controversial aspect of **Figure 2** is the Slum-Housing Demolition (SHD) rate. Forrester explains this rate as follows:

> Worker housing ages and declines into the underemployed-housing category. The rate of obsolescence from worker housing to underemployed housing again depends on time and on the demand for worker housing. If a low-cost-housing program exists, it creates underemployed housing directly. The underemployed housing disappears through the slum-housing-demolition rate, which depends on the age of the underemployed housing and on the occupancy ratio. (1969: 19)

Without providing any sources for the suggestion, Forrester gives the SHD a 50-year life span as the norm for the Underemployed-Housing category, which effectively implies a normal demolition rate of 2% per year (Forrester 1969: 35). Thus he presents the demolition of housing as somehow *natural* and even normalizes the idea that only housing for the low-income class is destined to be demolished. *Urban Dynamics* proposes that only the Underemployed Housing gets demolished, and not the Worker or Premium Housing, which would have to depreciate into the Underemployed Housing category to be demolishable.

Labor and Class

The last row of levels in **Figure 2** represents the different classes of workers — managerial-professional, labor, and underemployed. According to Forrester, the underemployed category includes, 'in addition to the unemployed and unemployable, people in unskilled jobs, those in marginal economic activity, and those not seeking employment who

might work in a period of intense economic activity' (Forrester 1969: 19). Therefore, the underemployed include those who are employable but who, for whatever reason, are unemployed. The rates that plug into these levels range from Managerial Arrivals and Departures to Underemployed Arrivals and Departures. The rates feeding into this row are the most dynamic, meant to represent the movement of different types of people in and out of a city. In terms of movement from one level to the next, Forrester tried to demonstrate the potential for the upward and downward economic mobility of different people. Thus, there is a two-way movement between the underemployed and labor categories, but only a one-way movement from labor to the professional-managerial, suggesting that no manager could get demoted to a labor job (1969: 19). Other implied assumptions are embedded in this explanation: 'A higher ratio of managers to total population implies a more favourable social climate and increases the arrival-rate multiplier. Increasing taxes depresses the arrival rate and housing affects the manager-arrival rate, encouraging arrivals when it is adequate and discouraging arrivals as housing congestion increases' (1969: 33). According to Forrester, the flow rates depend on the population mix, available housing, and jobs provided by industry. Again, this data is difficult to cross-reference since it is encapsulated within each rate, level, and auxiliary variable, since the data is only seen in the corner of each symbol and one must flip to another page to see how all the data is calculated that affects their respective flow rates. Therefore, if the flow rate for the underemployed coming into a city is high because of more favorable social conditions, it is hard to visualize the actual data of this in the diagrams or even from where the data is sourced. This is due to the muted graphic language of black and white boxes that obscures the specificities of Forrester's assumptions.

The struggle to model the last row is graphically evident, because it has the most rates and movement between levels. Since Forrester literally could not fit all of the desired information onto one page, he made another diagram in an attempt to tackle the issue of the Underemployed Arrival rate (**Figure 3**). In *Urban Dynamics*, many such secondary diagrams exist that function as additions to the main diagram. These additional diagrams typically consist of auxiliary variables (circles) and information flows (dashed lines), to demonstrate that they contain background information to one of the levels. In **Figure 3**, the Underemployed Arrival rate and the additional AMMP level, which stands for 'attractiveness-for-migration multiplier perceived' (1969: 23), are rendered with a bold line-weight to highlight their significance, whereas everything else has a lighter line-weight. Since these diagrams contain feedback loops, in which information feeds into levels, back into the auxiliary variables, and back to the levels again, there is a progression from the linear network of **Figure 2** to a more circular one in **Figure 3**. Making the model even more dynamic is the fact that multiple variations are possible. For instance, Forrester could change the values of each component (level, rate, or auxiliary variable) and then model this via the — at the time — non-visual computer.

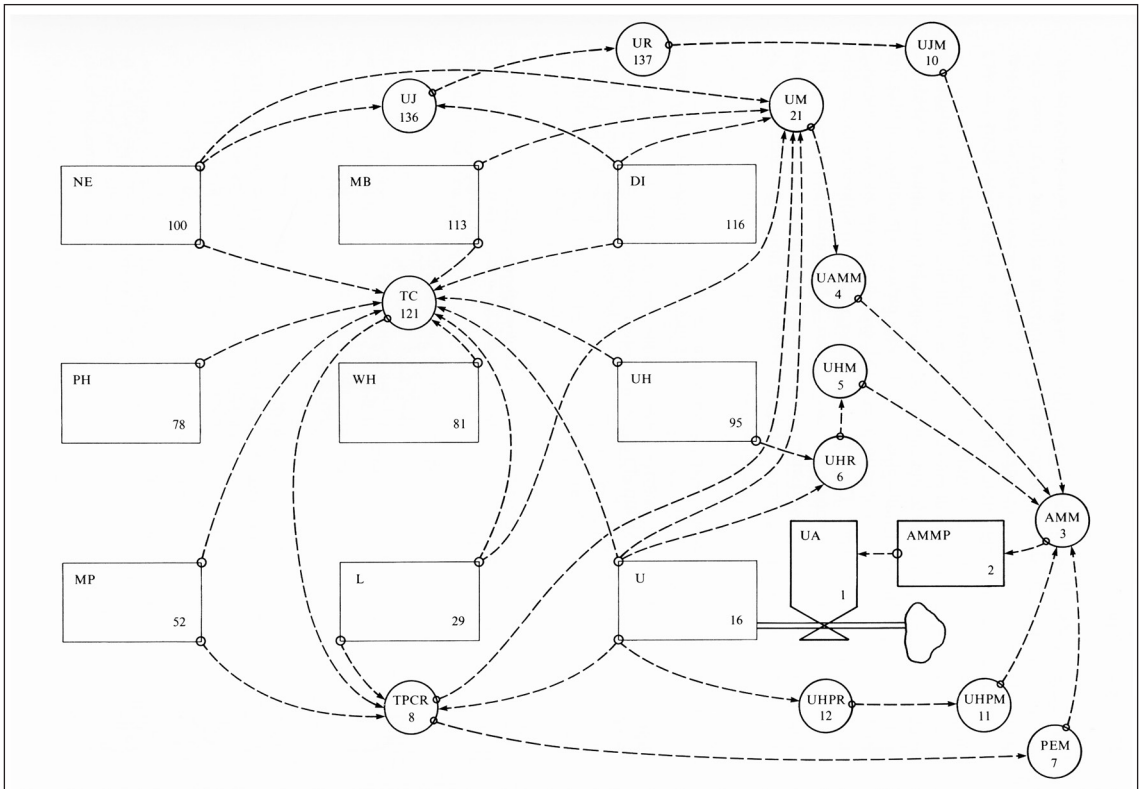

Figure 2-5 A typical set of influences controlling a flow rate. Shows how the system levels determine the underemployed-arrival rate UA. (Letter groups are the symbols in the equations and numbers identify the system equations, as in Appendix A.)

Figure 3: An example of a feedback-loop drawing that tackles the issue of the rate of underemployed arriving in a city, which Forrester captions as 'Auxiliary variables, levels and underemployed arrival rate referred UA'. From Forrester (1969: 21).

Legend for Figure 3

Rate	UA: Underemployed Arrivals
Level	AMMP: Attractiveness-for-migration-multiplier perceived
Auxiliary Variables	UAMM: Underemployed-arrivals mobility multiplier UHM: Underemployed/housing multiplier PEM: Public-expenditure multiplier UJM: Underemployed/job multiplier UHPM: Underemployed-housing-program multiplier UJ: Underemployed jobs UR: Underemployed job ratio UM: Underemployed mobility TC: Tax collections UHR: Underemployed housing ratio TPCR: Tax per capita ratio UHPR: Underemployed-housing-population ratio AMM: Attractiveness-for-migration-multiplier

In **Figure 3**, once the values were keyed into the various components, Forrester would run the model in the computer and make a graph that would represent the level of study. Thus *multiple temporalities* were modeled in the diagrams, all depending on the various inputs. **Figure 3** is the most elaborate version of the feedback-loop type of drawing in *Urban Dynamics*. This diagram in particular demonstrates how Forrester's political biases are revealed in his representations of movement of specific types of people and its effects on the city. Arguably, the AMMP level was of major concern for *Urban Dynamics*. The topic is controversial as Forrester made implicit choices in modeling why certain people, in this case the underemployed, move in and out of a city, such as for social programs or social climate. One small example is that, according to Forrester, an abundance of the managerial class made a city more attractive to those outside. Yet the simple visual language of **Figure 3** suggests a univocal answer to such a problematic topic and masks the far from obvious hypotheses that Forrester was forced to make in modeling something as complex, political, and challenging to understand as labor mobility.

From MIT to National Politics

As explained within *Industrial Dynamics*, Forrester's work with system dynamics attempted to produce specific results to broad questions on a wide range of topics. During the 1960s and early '70s, Forrester was frequently solicited by the White House, CIA, and the FBI to advise on and study such important issues as the US economy, national security, and global natural resource studies via the use of system dynamics (Scott 2016: 185–96). In each case, he made similar diagrams/models to that of Urban Dynamics. As a result, not only did Forrester become an influential figure within educational institutions, but his methods also influenced real-life politics. Collins, the former mayor of Boston who became a close colleague of Forrester at MIT, had connections to other US mayors and to the National League of Cities. In December 1968, Forrester was invited to present at the National League of Cities conference in New Orleans. There, as at several similar events, he demonstrated his use of system dynamics applied to cities, essentially, the Urban Dynamics model (National League of Cities [JWF] 1968). Thus, Urban Dynamics captured the attention of not only architects but policymakers and specialists from adjacent disciplines, including the politicians and urban planners who shaped cities via policy design and political influence.

The interest of policymakers in Forrester's Urban Dynamics coincided with the escalating housing crisis in America. Due to the popularity of suburbanization for both housing and industry, urban industrial economies contracted, causing a loss of industrial jobs and tax dollars and exasperating the existing crisis for low-income households in cities, as detailed by historian of urban planning Nancy Kwak. Kwak

points out that years of housing instability contributed to one of the first government programs to assist with home financing for low-income families, enabled by the Home Mortgage Interest in the Housing and Urban Development Act of 1968 (Kwak 2015: 200). As Forrester's Urban Dynamics directly addressed the housing crisis in these various aspects, his propositions were of significant interest for policymakers.

Soon after Richard Nixon and his Republican party won the US election in 1968, George Romney was appointed head of the Department of Housing and Urban Development (HUD). By the early 1970s, Forrester's methods from Urban Dynamics were seriously considered as a potential planning tool by the HUD. On October 6, 1972, the Systems Dynamics Group, led by Forrester, received a grant from the HUD of approximately $210,000 for the span of 18 months to put Urban Dynamics to the test (HUD Contract [JWF] 1972). The objective of the grant was to increase the usefulness of Urban Dynamics, and confidence in it, and to help urban administrators decide on policies to manage cities. The contract also focused on extending the model and applying it to the specific case of Lowell, Massachusetts, to improve local decision making. One of the commitments was to identify other groups who were attempting to refine and apply the Urban Dynamics model to metropolitan and city areas. By May 1973, the Harvard-MIT Joint Center for Urban Studies was negotiating a crash program with the HUD to study national housing needs. The program received $85,000 for four months, with the intent to be evaluated by the HUD for inclusion in the US president's National Housing Policy report (MIT, HUD [JWF] 1972). Such grants for the implementation of Urban Dynamics into real-life policy reveal just how seriously Forrester's methods were taken by policymakers who wanted to test out his ideas.

However, some within the HUD had issues with applying Urban Dynamics to Lowell due to its methodology in general. According to the document 'Discussion of City-Suburb Interactions' written by Louis Alfeld, a colleague who worked closely with Forrester, HUD did not trust the data or parameter sensitivity of the data fed to the computers (MIT, HUD [JWF] 1972). Alfeld noted that the HUD had neither the time nor the inclination to study the utility of Urban Dynamics, most likely because every single parameter within each level, rate, and auxiliary variable is based on assumptions. To cross-reference and check all of the parameters would be a considerable task. As such, the HUD would not accept any of the model relationships (i.e., population growth to jobs) without support from solid literature references or published data (Alfeld 1995: 3).

Moreover, some within the HUD were also concerned that Urban Dynamics did not address the interactions between the city and its suburbs (MIT, HUD [JWF] 1972). Crucially, Forrester's Urban Dynamics and the graphic language of the diagrams could not illustrate that the majority of Americans benefiting from job training, financial aid, and low-income housing were typically located in urban centers and were people of

color (Scott 2016: 190). Racial integration was skirted by not including the suburbs into any diagrams or equations. By avoiding the suburbs, Urban Dynamics equations — in terms of tax revenue and economic output — were rather flawed. The outcome would be very different if the suburbs were included, since higher-income Americans and businesses were located in these areas. Forrester brought this point into critical relief in his testimony before a Subcommittee on Urban Growth:

> A low-cost housing program alone moves exactly in the wrong direction. It draws more low income people. It makes the area differentially more attractive to the poor who need jobs and less attractive to those who create jobs. In the new population equilibrium that develops, some characteristic of the social system must compensate for the additional attractiveness created by the low-cost housing. (Forrester [JWF] 1970b: 8–9)

Forrester made the same conclusions within *Urban Dynamics* and when applying Urban Dynamics to Lowell. Building low-income housing would attract low-income people, requiring more services and thus an increase in the taxation of businesses. Getting rid of low-income housing was therefore better, Forrester advised, than building it (Forrester 1969). This kind of argumentation effectively sets the stage for anti-immigration sentiment. This worried some within the HUD, who felt uncomfortable about the proposal to demolish low-income housing where the residents were predominantly people of color (Alfeld [JWF] 1972). Some of the reviewers of *Urban Dynamics* also commented on its anti-immigrant sentiment, as demonstrated in the heading of one anonymous review in the *Toronto Star* on January 16, 1973: 'Urban Expert Says City Can Exclude "Immigrants"' (p. 9).

Compounding the problems inherent in the unstated biases was the fact that applying Urban Dynamics to a specific case such as Lowell was not straightforward. Months before the HUD awarded the Systems Dynamics Group the contract to study Lowell, a proposal to tear down slum housing to make room for a highway and commercial buildings was rejected by city council members due to strong protests from the residents, which was documented in the right-leaning *Lowell Sun*. The reason for the protests against these plans was that the city, years earlier, had displaced residents in an adjacent neighborhood to make way for a highway, which infuriated locals (Giacomo 1972a: 43). Since the System Dynamics Group received the grant from the HUD a few months after this course of events, their involvement was suspected to be a pretext for yet another effort to implement plans to tear down slum housing. This happened during the rare tenure of a Republican mayor in Lowell, Ellen A. Sampson (Giacomo 1972b: 6). However, Sampson would not remain mayor for long; coincidentally, the HUD's contract with The Systems Dynamics Group was never extended.

Forrester's ideas went against concerns for social justice and equal relations in urban planning. In Urban Dynamics, the recommendation to tear down social housing was based on economic arguments, in tune with politicians on the conservative side. As Kwak reveals, while conservatives argued against government financial aid for low-income housing, they never argued against it for private homeownership (even though aid for private homeownership far surpassed low-income housing). Thus, unequal homeownership rates, for instance, between whites and non-whites, were masked as a result of a market function (Kwak 2015: 174). Tellingly, unlike in *Industrial Dynamics*, the lines of flow in *Urban Dynamics* do not specify the flow of money, just people, information, and capital/equipment. When viewing **Figure 3**, the lines between the auxiliary variables of Tax Collections (TC) and Tax Per Capita Ratio (TPCR) represent information. Therefore, how or how much the worker, premium, or low-cost housing programs are funded by tax dollars is not specified visually on any diagram but are instead buried within equations throughout the book. Not only did Urban Dynamics use the language of free market economic ideology, but by visualizing this with curated diagrams and equations, the visual language of systems diagrams was co-opted to subdue the controversial conclusions of Urban Dynamics.

Forrester's point of view expressed within his Urban Dynamics model was rather troubling, in that it was premised on the idea that the behavior of complex urban systems should inform policy, even though their implications are often counter to ethical norms and social justice concerns. Forrester dismissed any perception of a need to invest in social housing, job training, or financial aid as simply being the result of humanitarian impulses in response to short-term political pressures (Scott 2016: 190). He believed Urban Dynamics should be directing government policy rather than elected politicians, with their ethical and social justice concerns. According to Urban Dynamics models, politics are counter-productive to their intended results. Moreover, Forrester's private notes reveal that not only was he uncomfortable with social equality, but he held controversial ideas about how far the social realm could be regulated (or deregulated) for the sake of experiment — ideas that he incorporated intentionally within his diagrammatic abstractions of the city. After attending the Bellagio conference, Forrester noted,

> Social experiment is handicapped by a tradition requiring equality to all persons ... We must develop the willingness to allow a city or any other political subdivisions to operate as an experimental social system and where necessary to be exempt from certain specified laws of the country until the experiment can be evaluated. (Forrester [JWF] 1970a: 7)

Therefore, according to Forrester, politics and social equity had become obsolete (see also Scott 2016: 189–92).

Forrester's notes from the Bellagio conference also demonstrate his particular view on planners and urban planning knowledge. He wrote that

> planning activity is often an end in itself ... the group is advisory; it does not contain people of great insight and stature. It is located far from positions of power, and even if its advice is sound there is little influence on decisions which are molded by political pressures. (Forrester [JWF] 1970a; Scott 2016: 189–92)

In statements such as these, it is clear that Forrester essentially dismissed urban studies — its history, methods, and politics — as external to the choice of parameters and systems operations in Urban Dynamics. He intended Urban Dynamics to be a way to offer more rational, less biased solutions than what the current methods in planning and urban studies could provide. Highly political and social questions about urban problems were thus transmuted from the planning discipline into the domains of computation, economics, and management.

Conclusion

Because Forrester believed the planning and design fields lacked direct political influence, his Urban Dynamics focused on politics and stakeholders rather than design or its educational circles. This approach was geared toward real-life impact, and Forrester even managed to test Urban Dynamics in real scenarios, exemplified by the HUD's use of Urban Dynamics in Lowell and Forrester advising the US government on the urban crisis of the late '60s and '70s (Forrester [JWF] 1977; New York [JWF] 1972; Forrester [JWF] 1972; HUD Washington, DC [JWF] 1970; HUD [JWF] n.d.). Although its application in Lowell was rather unsuccessful, Urban Dynamics did contribute to turning the general attitude *against* the utility of social housing (and programs) being beneficial to the city and society as a whole within the American context. The main suggestions from Urban Dynamics were that any form of government support (i.e., social housing or job training programs) was detrimental to society and that rather than building social housing, it should be demolished (Forrester 1988: 05:20–12:30). In his 1988 Killian Lecture at MIT, Forrester directly discussed how the logic of Systems/Urban Dynamics opened the consideration that social housing and programs could be harmful to the economy and therefore to society (1988: 40:30–43:00, 43:50–51:05, 1:07:00–1:07:45). During the lecture, Forrester even said that it had become acceptable to freely advocate against social housing and programs: 'Now if you were in the late 60s and

suggested that low-cost housing was not a good idea — I think it's come to be rather much more widely accepted now than it was, maybe not wholly, but at that time, it was a very emotional subject' (1988: 42:00).

Along with the influence of his work with Urban Dynamics, the specific graphical composition of the system structure of Forrester's diagrams are of interest because he adopted a particular form of representation and general approach that affected urban design and practice. This new approach visually expressed mathematical ideas and systems or sets of relationships, such as population growth, the need for housing, and industrial buildings. Urban Dynamics diagrams explicate that these factors are not isolated but rather affect one another — formally and ideologically linking systematic thinking, drawing, and computing. Furthermore, Forrester's drawings express a non-linear state of time because they were visual equations of computer models; most computer models have multiple temporalities since numerous possible futures can always be simulated when the information that feeds the model can be updated — what John May refers to as statistical thinking (May 2017). Moreover, Forrester abstracted each component to either rectangles or circles to highlight the structure of the system, thereby separating the system from its individual components and directing architectural thought away from the form and style of each building and instead to its relation within a system. In this sense, analyzing Forrester's contribution to the techno-social moment also broadens the historical context in relation to today's urban discourses about smart cities and e-societies (see Deleuze 1992; Halpern and Mitchell 2017; Gethmann 2017; Krivý 2019).

In the case of Lowell, the Urban Dynamics diagrams and their subsequent equations were an attempt to sterilize the social gravity of proposing to tear down low-income housing. This was in part achieved by the clean, black-and-white objective-looking grid and loop types of diagrams, a different way of presenting information than relying only on plans and models. This helped distance decision makers from the results of their propositions. Furthermore, it was an attempt to persuade city council members to support a socially precarious proposal, especially since it was similar to a proposal that they had voted against previously (Giacomo 1972a: 43).

More generally, the diagrams do not include the category of space, because the various components that make for urban systems' spatial locations are arbitrary (Blum and Taylor 1991). This is problematic since Urban Dynamics drawings highlight the amount of low-income housing in a city while completely ignoring the location of such low-income housing and how homes are distributed in each neighborhood. Spatial arbitrariness was a vast omission that affected urban planning and in the 1960 and '70s became a central issue in encounters of systems theory with architecture. The Greek

architect Constantinos Doxiadis, for instance, utilized concepts from systems theory to inform his planning projects, but he always considered the spatial allocation of building types and infrastructure in planning cities. In the case of the Islamabad master plan, because Doxiadis had to translate his systems ideas to tangible plans, the socio-political aspects of his systems, such as where the different classes of people would live, had to be explicitly addressed (Doxiadis 1959). However, like Forrester, some architects turned away from space and scale when it came to using systems theory for planning. Cedric Price, for instance, conceived of design problems in their performativity, as a process, rather than arising from a formal repertoire of objects and spaces (Mathews 2006: 42). This was problematic because it effectively blinded Price from seeing the negative consequences of his design proposals. For instance, when designing the Fun Palace in London 1964, the planning team focused on interaction and adaptability, and derived the design from mathematical models based on statistics, psychology, and sociology (2006: 46). Thus, a questionable mathematical model slipped into the planning, which was the determination of what is likely to induce happiness — which put the project in danger of becoming an experiment in cybernetic behavior modification (2006: 46). Doxiadis gave 'space' a place in the encounter of systems theory and architecture, whereas Price and Forrester intentionally rejected any spatial dimension in their work. When utilizing systems theory to its maximum, the spatial dimension can be easily neglected.

Forrester's drawings were made by and for systems theorists with specific knowledge on how to read such diagrams. Because Urban Dynamics was viewed on printed paper when it was published, and all the components were grouped, flattened, and framed, the drawings were not an objective study but rather highly curated, aesthetic, and subjective. With his Urban Dynamics, Forrester created a new form of urban politics and the authority to mask his socially conservative ideals as scientifically founded truths that few fully understood. Forrester intended his diagrams, like his verbal expressions, to illuminate a reality in terms of systems. Consequently, normative principles were presented as facts. But in reality, these drawings were giant abstractions pretending to be real.

Note

[1] Key educational institutions involved in the architectural environmental turn included Massachusetts Institute of Technology; University of California, Berkeley; Yale University; University College of London; and University of Cambridge.

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