THE POTENTIAL OF SYSTEMS DYNAMIC MODELLING IN THE SUSTAINABLE PLANNING AND MANAGEMENT OF ESSENTIAL ENVIRONMENTAL FACILITIES IN AN URBAN AREA OF SUB-SAHARAN AFRICA

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Key words: Systems Dynamic, Essential Environmental Facilities (EEF), Social-Economic Groups, Social Security Pension Fund.

ABSTRACT

In these contemporary times, the tasks of planning and managing urban environments especially in sub-Saharan Africa have become very cumbersome, arduous and costly due to a myriad of factors. For example, the large and continuous inflows of poor people from rural hinterlands, who can hardly afford basic essential urban environmental facilities, seem to compound the already worsened urban living conditions as they result to inappropriate coping strategies to survive in the urban area. Existing approaches for remedying these problems have tended to be ad-hoc, piecemeal and unsustainable and therefore have been found wanting with time.

The Systems dynamic modelling approach that is employed here attempts to conceptualise and operationalize urban development processes in a more holistic manner than previous attempts. This is realized through the integration of a series of independent urban subsystems that are deemed to operate systemically. The subsystems comprise of Population and Households, Economic Activity, Essential Environmental (EE) Facilities and urban Development Policy initiatives sectors. The model so derived is then applied on a limited scale to the Housing sub-sector of Kumasi, Ghana. The model's utility is then tested though a series of investment policy options that is based on an already existing Social Security Pension Fund in Ghana.

1. INTRODUCTION

Urban management in sub-Saharan Africa (SSA), like in other parts of the developing world, has been snarled in the tangle of urban complexities. Phenomenal population growth, heightened poverty, over-utilization of limited essential environmental (EE) facilities, persistent financial and investment constraints due to inadequate revenue and poor investment decisions and inefficient management systems, among many others, confront and stymie urban development efforts in SSA.

In a recent write up, Harsch (2001) has remarked that Africa's urban problems do not revolve only on insufficient resources and services, but also on severe social dislocations associated with the different modes of migrations that is experienced, high levels of crime and insecurity, corrupt and inefficient local government institutions, striking inequalities in wealth and especially the pervasive poverty that blights most urban settlements. While not attempting to diminish the relevance of the other causative factors, it must be highlighted that population pressures caused by natural factors (dominated by high birth rates) and social factors (due principally to immigration from the rural hinterlands) and poor economic performances have consistently generated problems of poverty and inadequate access to EE facilities and services. Related to these problems, in recent times, has been the implementation of policies on cost recovery, which has been adopted by many governments to recoup investments in EE facilities and other related services. Removal of subsidies, mass unemployment through privatisation and trade liberalization all contributed significantly towards worsening the economic plight of poor urbanites and therefore their inability to pay for urban amenities.

Against this backdrop, some studies have been designed and conducted in SSA in an attempt to ameliorate some of these problems and improve upon the living standards of the less fortunate and marginalized sections of the urban population. The output however has been far from successful. Overcoming these problems require more effective planning and management strategies involving comprehensive, integrated and holistic systems which could describe all facets of urban problems and not the 'crisis' management mode of effecting operational changes which has become so pervasive in spite of the undesirable experiences gained from them. It is within this context that an attempt is been made here to formulate a systems model that could help identify and assess the shortfalls in the provision of Essential Environmental (EE) facilities within the urban system. The model, which is essentially a predictive one, could help us anticipate the future efforts needed to ensure better planning and management of our urban systems.

Specifically, the discourse is to provide with illustrative examples, processes for urban systems model formulation, generation and testing of policy options and indication of avenues for sustained planning and management of urban areas of SSA. It is anticipated that the model so formulated would help address the myriad problems associated with population growth, economic activities, provision of EE facilities and urban development initiatives. The rest of the study is structured as follows; the next section describes the systems dynamic framework and provides a justification for its adoption. This is followed by a discussion on the model formulation and execution. Employing this model, the fourth section attempts a sectoral case study based on the Housing Sector in Kumasi city, Ghana. The final section is devoted to the articulation on the challenges and potentials of this dynamic modelling approach in the provision of vital services in urban areas of SSA.

2. PERSPECTIVE ON SYSTEMS DYNAMIC MODELLING APPROACH

2.1 Systems Framework

According to Wilson (1990) a 'System' has many meanings based on the context in which it is used. In general, it is defined as 'a set of elements standing in interrelationships

(Bertalanffy, 1951) or as an attempt at studying of ‘’wholes’’ rather than ‘’parts of wholes’’ (Johnston, 1983). Systems have certain basic characteristics worth noting for this discourse. First, they are made up of parts or subsystems and the elements within them have relationships such that a change in one of the systems will induce and affect the rest of the system, possibly putting it into disequilibria. Second, a system is also embedded in a system. For example, a city as a system can be viewed as comprising of subsystems of the various land uses or suburbs that are in interrelationships and functioning as one unit. Another feature of systems is that it is made up of two distinct types – Open systems and Closed systems. Open systems are linked to the outside environments in addition to their own internalised linkages but this is not the case with closed systems, which are without external linkages. Finally, feedback mechanisms are essential features of the model. They exert both positive and negative effects on the system (Bertalanffy, 1951).

On the basis of the above perspective, an urban system could be described as a set of elements or subsystems interacting with each other through socio-economic and spatial mechanisms of the urban area; with corresponding variables that can be used to describe the structure of the system (Robinson, 1998). In consonance with the above description and the problems usually linked to urban areas of SSA, an urban system has been conceived as illustrated in Figure 1 below.

This conceptualised framework essentially addresses a SSA situation, but its application may be more spatially diverse. Relative to other regions, SSA’s urban problems are unique with respect to the magnitude of these problems, the factors influencing each component of the urban system and the capacity for urban management, including availability of skilled manpower and financial resources mobilization. This comprehensive approach involves interaction among the parameters controlling each component of the system in a dynamic manner. It also involves a leverage at each stage of model execution for applying policy options deemed fit to re-orient the model along the most desired future trajectories. A more elaborate description of the various system components of Population, EE facilities, Economic activities and Urban Management policies and programmes has been provided below.

2.2 Model Components Description

The various components of the model (fig. 1) are as follows;

2.2.1 Population Components:

This component is classified into 3 groups based on the socio-economic profile of the urban residents. The groups are Low income, Middle income and High income. It is possible to further stratify these groups into age cohorts especially when planning for the development of different EE facilities that are age based, like education. Each of these identified groups is influenced by demographic features such as natural and social increases. Upward mobility due to changes in one’s socio- economic status as well as natural transfer of population from one age group to another with time are also recognised by the model. The recognition becomes especially important in the model as these mobilities are normally accompanied by changes in affordability levels for EE facilities. The demographic features described above, which are conditioned primarily by socio-economic factors, determine the state and levels of Urban Economic activity and EE facilities as well as urban developments programmes that take place at each point in time within the urban system.

2.2.2 Essential Environment (EE) Facilities.

This component of the system comprises of sectors considered as providing 'basic' and 'supplement' services. The basic services or sectors considered under this study are housing, education, health and water while sewerage, solid waste, parks and open space represent some of the supplementary services. Each of these services may be influenced by financial, physical, engineering and administrative factors. They are also influenced by the dominant socio-economic group that consumes most of the services provided as that gives an indication of the level of affordability for that particular service.

2.2.3 Economic Activity Component

The key sectors considered under this component relates to dominant business activities within the area whether formal or informal and the dynamics characterizing their operations. The dynamics may be precipitated by political, social and economic forces at play and their overall impact on economic activities in urban SSA has been found to be less favourable and this necessitates the evolution of measures for intervention in the sector.

2.2.4 Urban Development Policies

The basic premise underlying this model relates to the overall improvement of affordability levels of the different socio-economic groups inhabiting the urban area understudy. This can be realized through the implementation of comprehensive programmes and policies such as tax system restructuring, job creation and training programmes, financial investment or capital injection, family planning programmes and others. It is obvious that the institution of any of these programmes is intended to stimulate all the component parts of urban system and pave way for improvements in affordability levels. Financing of such programmes, which is very critical to the success of these interventions, is obtained traditionally from the difference between local revenue and expenditure. Beyond this, other ingenious sources, including extraneous ones, could be assessed. Fig. 1 provides an overview of the system relationships reviewed above.

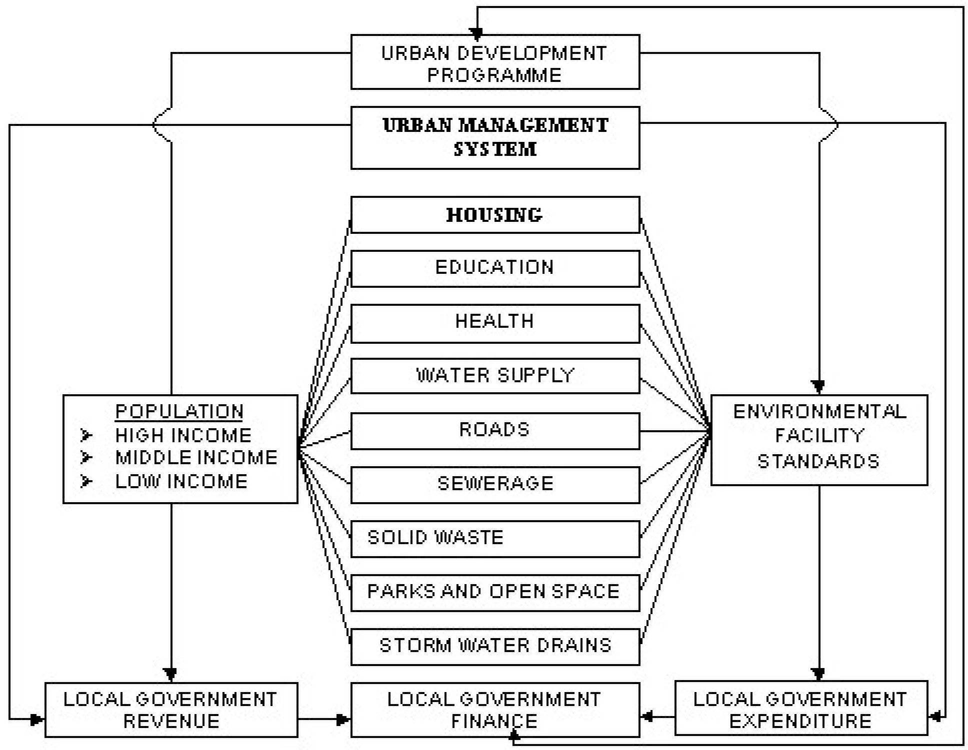

Figure 1: Urban Systems Model: Interaction of Model Components

3. MODEL FORMULATION AND EXECUTION

Jay Forrester (1969) is credited with the initial application of the systems dynamic (SD) principle in urban and regional studies. His main preoccupation was the promotion of the theory of urban dynamics that revolved around the concept of systems and which lead to the growth phase, the stagnation phase and the revival phase in the development cycle of an urban area.

As a simulation modelling approach, SD produces behaviour overtime and therefore values of all variables under consideration are calculated at each point in the simulation period. Three kinds of equations, Level, Rate and Auxiliary equations are customarily employed. Two others, constant and delay equations are also used sparingly.

The level equations represent accumulations or integrations within the system. They are the flows or changes that come in and go out of the system overtime. Housing stock, manpower pools, cash balances are levels respectively for housing, people and money flows. For example housing stock accumulates housing constructed minus housing demolished while manpower pools reflect hiring minus firing and/or quit rates in a labour turnover system. The method for formulating Level equations conforms to the method for calculating integral equations in dynamic models as shown below;

$$\text{Level} = \text{Level} + {}^{t}\!\int_0 \{INR_{(t)} - OUTR_{(t)}\}\, dt$$
$$t = 0$$

The above equation represents a discrete time approximation for the level. The left-hand side of the equation represents the future state of the previous level (t), plus the difference accompanying the changes in the rates INR and OUTR over the time duration (0).

The second equation type is the Rate, which represents a flow or a behaviour that changes overtime as a result of influences acting upon it. Housing constructions and demolitions, job hiring and firing as well as cash receipts and expenditures are examples of tangible flows that are represented as rates in system dynamic models.

The third type, auxiliary equations, is sometimes referred to as information variables and is used as information inputs to aid rate equation decisions. Constant equations or terms are values in the models that are assumed to remain unchanged throughout a particular computer simulation while delay functions are employed in some models to help transform certain input rates at a particular point in time into an output rate over an extended period of time.

Various model simulations are conducted to determine outputs for the various future time periods. The model as explained above was operationalized using data from Kumasi Housing sector in Ghana. It is important to clarify here that all the EE facilities mentioned in Fig 1 could individually be subjected to this kind of analysis and the fusion of all these sectoral systems could constitute the comprehensive system model for the entire urban area. The use of the housing sector in the discussion below on Kumasi is therefore a matter of convenience.

4. THE KUMASI HOUSING SECTOR CASESTUDY

4.1 City Features

Kumasi is Ghana's second largest city. According to the 1984 national population census, the city's population stood at 759,109 and this includes all the areas that presently constitute the Kumasi metropolitan area. The annual population growth rate from 1960 to 1984 averaged 7.42% and this is high even by Ghanaian and Third World Standards (Asiedu, 1991). Housing stock levels on the other hand, rose from 10,709 in 1960 to 23,700 in 1984, representing an annual increase of 3.06%. The large disparity in the growth levels between population and housing stock accentuates the stress that is imposed on housing facilities in the city.

In the context of the system dynamics approach expatiated above, the following distinguishing features of the study area are worth stating for the purpose of the housing model formulation. First, is the ever-increasing population that is youth biased. As a result, resources for the provision of housing and other EE facilities are provided by the relatively small adult population. Second, the role of migration in the city's population is noteworthy. In-migration constitutes the single largest factor for population increases.

Third, the existence of different affordability levels for the various housing environmental facilities by different households must be accorded the right attention and incorporated into policy formulation.

4.2 Housing Model Formulation

The task at hand here involves, first, isolating the factors or variable that appears to interact to generate housing as a system in the city. The next task involves using this interacting mechanism to determine the following (a) future housing needs of households with the 3 socio-economic groups, (b) the cost of meeting these housing needs. In a summary therefore, the model seeks to demonstrate the dynamic behaviour of the city's housing sector through the framework of segregated housing markets.

As illustrated in fig. 2 below, four main sectors were delineated for the purpose of this study. These were Population and Household, Housing Stock, Housing cost and Investment Decisions sectors.

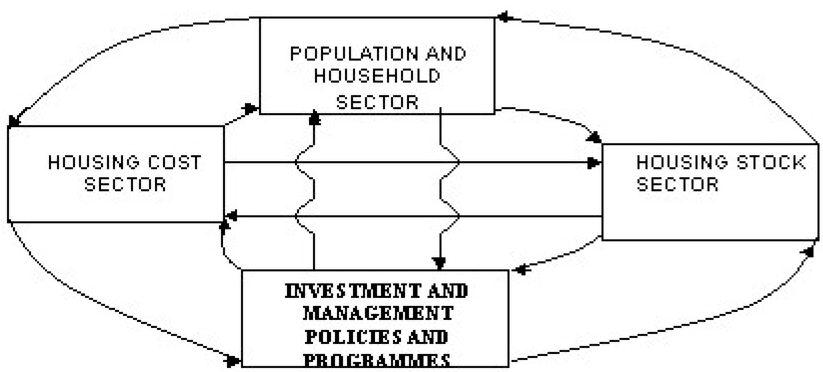

Figure 2: Kumasi Housing Sector Study Concept

The city's population was classified into 3 socio-economic groups of households – high, middle and low. Areas of residence were taken as proxies to represent the different socio-economic groups; reflecting the generally accepted view that in third world urban environments, households with identical socio-economic backgrounds tend to agglomerate in suburbs with similar housing environmental characteristics. Affordability levels for housing and other facilities and services; household formation rates, migration and upward mobility rates were also posited for the various groups along the above line of reasoning that is based on environmental determinism concept. Finally, it was also postulated that even though these identified groups operate within different sub-markets, they were nevertheless linked together in a system-like fashion. These linkages exert influence on housing needs, housing stock and housing investment policies overtime. For example, a low-income earner could experience upward mobility into the middle-income bracket. This may result in higher affordability level for EE facilities in response to his new socio-economic status. Similar dynamics could be effected in the Population and Household sector through in-and-out migration and births and deaths and also in the housing stock sector through constructions and demolitions as already indicated.

On the basis of the above insights, it becomes clear that this approach is capable of coping with the dynamic behaviour inherent in complex urban systems. It also has an effective capacity to accommodate variables in which both positive and negative feedback processes manifest themselves in both growth and regulatory action.

The first step in the analytical procedure involved the transformation of the above framework (fig. 2) into dynamic flow processes and the subsequent formulation of system equations involving level, rate auxiliary, constant, and delay equations.

4.3 Simulation and Policy Options

The model as outlined above was simulated over a duration of 20years, that is from 1984 to 2004. It employs existing data on the above-described variables on Kumasi city. The first simulation was based on a no-change option to capture future changes in these essential variables, as they relate to the 3 socio-economic groups. The results obtained for deficits in the future levels of housing provision for the various socio-economic groups have been indicated on Table 1 below to exemplify some of the model outputs.

Table 1: Anticipated Deficits in Housing Stock (1984 – 2004)*

Households	**Number of Units of Deficit**	**% increase in Deficit from 1984**
All Households	48,432	49.4
Higher Income	10,113	11.4
Middle Income	15,793	42.8
Low Income	23,214	82.6

*Based on Option 1 Simulation Output.

In addition to the above simulation, two other policy options were developed and tested using this model. These options, 2 and 3, posit an infusion of additional investible financial resources into the city's housing sector from a Social Security Fund, which is a publicly operated pension fund in Ghana. This fund is generated from workers and employers contributions. These 2 options are based on a scenario, which envisages the utilization of 50% of all future contributions into the fund for housing development activities. The use of part of the proceeds from this fund for housing development has attracted considerable discussion in Ghana in recent times.

Option 2 as formulated here recommends that 50% of all contributions to the fund by a specific socio-economic group, i.e. high, middle and low, be used to provide housing solely for that group. Option 3 on the other hand envisages the creation of a special housing development fund with the 50% of the contributions and allocated to the 3 groups for housing development as follows; 10% for High income housing, 30% for Middle income housing and 60% for Low income housing development.

This distribution mechanism is to promote social equity in the city. The model estimates for deficits in housing investment due to option 3 is as shown in Table 2 below.

Table 2: Estimates of Deficits in Housing Investment (in million cedis) 1984 – 2004*

Items	**High Income**	**Middle Income**	**Low Income**	**All Households**
Cost of Satisfying Housing Needs	1,167,700	1,399,200	1,158,900	3,725,800
Estimated Levels of Housing Investment	252,350	398,650	195,190	846,190
Deficit in Housing Investment	915,350	1,000,600	963,710	2,879,600

*Based on Option 3.

Some aspects of the results obtained from the simulation exercise can be summarized as follows;
First, household housing needs are expected to rise considerably in the future alongside rapid increases in population due primarily to immigration. Second, the cost of housing provision is also expected to undergo considerable increases of similar magnitude. Against this background, the expected increases in housing stock as forecast would be grossly inadequate in meeting the needs of the people. An anticipated deficit has been reckoned at 49.4% at the end of the planned period based on option 1. Finally, forecast for future levels of housing investment based on the other policy options did not contribute much towards alleviating the low levels of housing investments in the city, calling more innovative and diversified approaches.

5. MODEL'S POTENTIAL AND CHALLENGES

Some of the potentials envisaged for the model, especially for SSA, include the following;

(i) It provides an alternative approach to the conventional disaggregated, ad-hoc modelling approaches. The computer simulation approach is simple to operate and user friendly and learning procedures are less cumbersome than other applications. Thus it is convenient to apply it in the SSA environment.

(ii) It provides useful and relevant information on a wide range of parameters crucial for the development of long-term strategies for the urban environment. If effective monitoring mechanisms are instituted to check model performance, it is likely that the process could enhance the attainment of long term growth targets and therefore facilitate the sustainable planning and development of EE facilities and services in cash strapped SSA urban environments.

(iii) With increasing decentralization of public offices and expansion in the activities of NGO's in development activities in SSA, more data is increasingly becoming available. The expectation then is that data sources for this model is expanding and this is very welcoming for prospective modellers.

However, several challenges need to be overcome to ensure the model's expanded use in the region. Some of these challenges include:

1. The large data set requirements make it less suitable for application in SSA where data sources are usually limited
2. The cumbersome assumptions related to the model puts it in a situation where it is likely to attract a number of criticism from a lot of professionals involved in urban development in SSA, though this is an issue not necessarily limited to the region.
3. Finally, computing facilities, both hardware and software, needed for operationalizing such a modelling exercise are lacking in most of SSA and this may constitute a hindrance to model application.

6. CONCLUSION

This study has been attempted to investigate one possibility for conceptualising holistically the numerous development problems confronting urban areas of SSA. The study further assessed a computer simulation procedure for highlighting both the future trends of these problems and the impact of interventionist policies.

The potential of this approach for ensuring the sustainable planning and management of EE facilities in urban areas of SSA could be immense if steps are taken to provide all the relevant inputs needed to facilitate its smooth operation

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BIOGRAPHICAL NOTES

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