AGENT-BASED MODELLING OF URBAN SANITATION: INFORMAL SETTLEMENTS IN NAIROBI

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ABSTRACT

During the last two decades, Nairobi in Kenya has experienced a rapid increase in its urban population. With the number of houses failing to match the increase in urban population, a number of informal settlements (slums) have mushroomed. As the population of these areas continues to increase, the inability of the local authorities to provide basic sanitation services for the urban dwellers is becoming a serious problem. The unprocessed soil water being discarded into the environment is not only adversely affecting the ecosystem; it is also creating unhygienic conditions that are conducive for the transmission of diseases in the densely populated informal settlements. A number of community-based organisations (CBOs) have undertaken various initiatives to mitigate against such problems. These organizations operate largely independently and there is no evidence of an evaluation being undertaken across the board to model the social, economical and environmental impact of the existing sanitation initiatives. This paper describes a proposed agent-based model that is aimed at doing just that. The proposed system will increase the comparative efficacy in the selected domain by modeling the values and incentives for the different organisations in various scenarios.

KEY WORDS

Agent-based modelling, simulation, sanitation, impact assessment, CBOs.

INTRODUCTION

Urban sanitation has a direct impact on the environment since waste is generally discarded into the ecosystem. Depending on whether or not the waste is processed before being discarded, urban sanitation has a bearing on public health. It is estimated that at least 2 billion people in the world lack access to dependable safe disposal of wastewater; and because this problem is rather significant, the Millennium Development Goals specifically identify provision of sanitation for everyone by 2015 as one of its targets within its environmental sustainability goal (URL 1).

Poverty in developing countries is linked to increased population, which in turn leads to increased social, economic and environmental demands (Prasad and Hall 2004). The urban

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population in Africa doubles every 15 to 20 years (du Plessis et al 2001). The local authorities cannot cope with such rapid population growth. Available statistics indicate that less than half of the African population has infrastructural connections to water, sewerage and Electricity (UNCHS 2001). During the last two decades, Nairobi in Kenya has experienced a rapid increase in its urban population. With the number of houses failing to match the increase in urban population, a number of informal settlements (slums) have mushroomed (Omenya et al 2004). Such settlements have emerged largely unplanned and unregulated, and therefore lack basic infrastructure and social amenities.

As the population of these areas continues to increase, the inability of the local authorities to provide basic sanitation services is becoming a serious problem. The unprocessed soil water being discarded into the environment is not only adversely affecting the ecosystem; it is also creating unhygienic conditions that are conducive for the transmission of diseases in the densely populated informal settlements. A number of community-based organisations (CBOs) have undertaken various initiatives to mitigate against such problems. These organizations operate largely independently and there is no evidence of an evaluation being undertaken across the board to model the social, economical and environmental impact of the existing sanitation initiatives.

This paper describes a proposed agent-based model that is aimed at doing just that. Agent technology will be used to model decision making within the various CBOs. The assessment strategy will use agent-based modelling to demonstrate how such decisions affect the social, economic and environmental profile and performance of the selected informal settlements. While this approach is essentially focused on understanding the broad dimensions and impacts of Sanitation initiatives, it will also provide a framework for developing a common metrics that can be used to identify best practices. This can be used by the local authorities for strategic planning. The use of agent technology will increase the comparative efficacy by modeling the values and incentives for the different organizations in various scenarios.

RELATED WORK

Pioneer researchers in this area include Axtell and Epstein (1994). In more recent years, a number of researchers have built on their work and used agent-based modelling to exhibit naturally spatial, functional or temporal decomposition of knowledge and skill among stakeholders. This section provides an overview of agent-based modelling. For a detailed review of agent-based modelling see Alexandridis and Pijanowski (2002), Antona et al (2002) and Parker et al (2002).

Bousquet and Page (2005) reviewed the development and use of agent-based simulation and modelling for ecosystem management, specifically highlighting the strength of such an approach. The review discussed the potential for using the agent paradigm to model social sciences and spatial issues such as land-use change. Agent-based methodology was cited as being useful for problems integrating social and spatial aspects. It was also presented as being ideal for supporting collective decision-making. Bousquet and Page's review provided detailed research perspectives on individual decision making processes through the representation of different forms of organisation (spatial, networks, hierarchies) and interactions among different organisational levels.

Port management is often faced with many vexing problems that are complex and difficult to define. Henesey et al (2003) point out that in some cases, port policies are formed from idealized perspectives and market factors, with very little attention or understanding of stakeholder strategies. They addressed this problem using agent-based modelling. Their model enables decision makers to simulate various port policies and to analyse the multitude of 'what if' scenarios.

Achieving cooperation among competing groups, particularly in the sphere of social and ecological resources is a challenging task. Srivastava and Kaldate (2002) use a multi-agent model of the activities of two such competing groups (native farmers and logging companies) using. Srivastava and Kaldate's model shows the benefits of all the stakeholders moving into more cooperative behaviour.

The proposed agent-based modelling of Sanitation Initiatives will build on the principles developed in the works cited in this section.

A CASE FOR 'INTELLIGENT' COMPUTING IN SANITATION INITIATIVES

The working definition for CBOs is based on World Bank's taxonomy of Non-governmental organisations (URL2). This has been depicted in Figure 1:

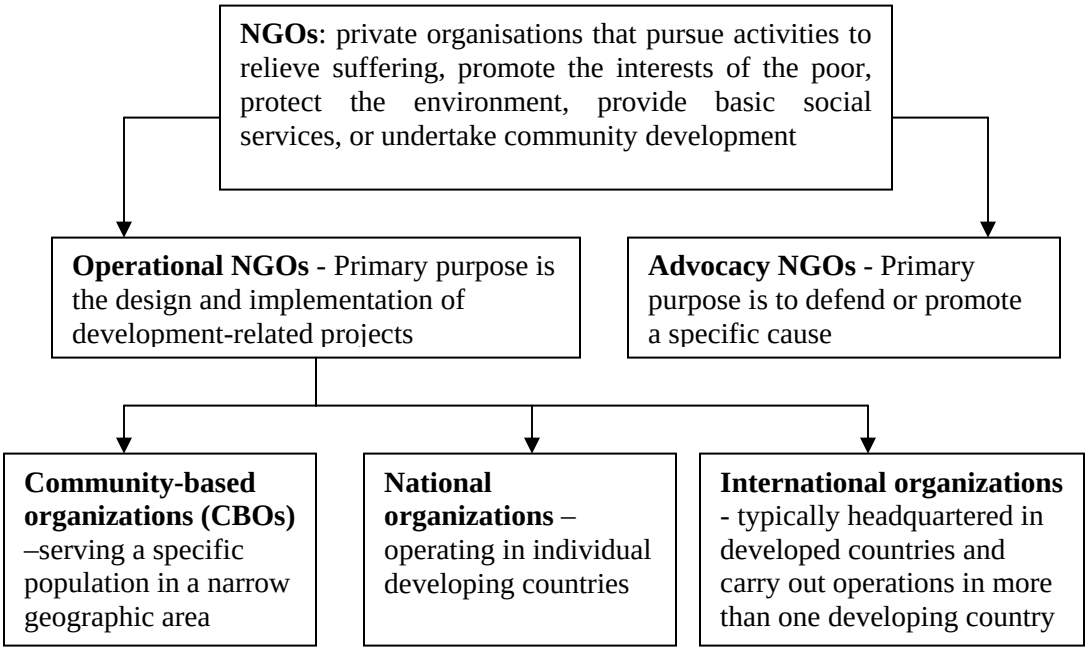

Figure 1: Classification of Non-Governmental Organisations

The CBOs executing sanitation initiative Nairobi's informal settlements focus on serving specific communities in a narrow geographical area (Omenya et al 2004). Studies have revealed a number of advantages and disadvantages of operating in such a highly localized context. These have been summarized in Table 1. The weaknesses identified in this table are

consistent with findings of du Plessis et al's (2001) assessment of the main barriers to the realization of sustainable construction in developing economies. The assessment specifically identified the lack of accurate data on which to base decisions as a key problem in developing economies. Such issues can be managed through the provision of an ICT (Information and Communication Technology) framework that can be used by CBOs to collaborate and share information with one another.

Table 1: Strengths and Weaknesses of CBOs

Strengths	**Weaknesses**
• Strong grassroots links; • Field-based development expertise; • The ability to innovate and adapt; • Process-oriented approach to development; • Participatory methodologies and tools; • Long-term commitment and emphasis on sustainability; • Cost-effectiveness.	• Limited financial and management expertise; • Limited institutional capacity; • Low levels of self-sustainability; • Isolation/lack of inter-organizational communication and/or coordination; • Small scale interventions; • Lack of understanding of the broader social or economic context.

Etta et al (2001), Thioune and Sène (2000) and Thioune (2003) highlight the expectations of CBOs as far as ICTs are concerned. CBOs perceive ICTs as the main media for establishing networks between community members or with the outside world that would improve the institutional context of these organisations. In one South African community, Internet technologies, are expected to allow access to new communication tools and to provide a medium for discussion and exchange among different CBOs. More specifically, the communities expect ICTs to: 1) Build their knowledge about the environment and development; 2) Lead to the creation of new organizations and development of active partnerships between these organisations and other institutions and 3) Enable them to influence development policies and encourage the changes needed to ensure improved natural resource management within their region. In Senegal, ICTs are considered as development tools that will facilitate access to information and make recent information available to expand the knowledge base of local populations.

In general terms, these expectations have been matched by several facets of ICT. However, it would be misleading to suggest that the mere adoption of ICT would guarantee that the right stakeholders in the planning process have 'real' access to the key information. Although a number of studies including Lanvin and Qiang (2003), DFID (2002), Gerster and Zimmermann (2003), Harris (2004) and OECD (2005) have identified the potential benefits of ICT in developing countries, they have also exposed the growing problem of information

overload: officials are beginning not to read their emails, and websites which draw attention to vital lessons learned are buried. Many decisions makers are overwhelmed by the sheer volume of data being directed at them. Clearly, there is a need for 'intelligent' computing systems that can process data and simplify the viewing of information during decision making. The proposed agent-based model aims to do just that.

AN OVERVIEW OF AGENT-BASED SYSTEMS

There are many divergent views on the exact definition of software agents. It is therefore necessary to develop a working definition for this paper. Software agents have been explored in this context from the viewpoint of leading researchers, who have focussed on defining agents using general characteristics. Brustolini (1991), Ferber (1999), FIPA Architecture Board (2001), Jennings et al (1998), Jennings and Wooldridge (1998) Lieberman (1997) and Maes (1994) have defined software agents using the following characteristics:

- Software agents exist in an environment;
- They can sense the conditions in the environment and such senses may affect how they act in future;
- Software agents are adaptive and capable of learning;
- They are proactive, exhibiting goal-directed behaviour;
- They execute their tasks autonomously (that is, without human intervention).

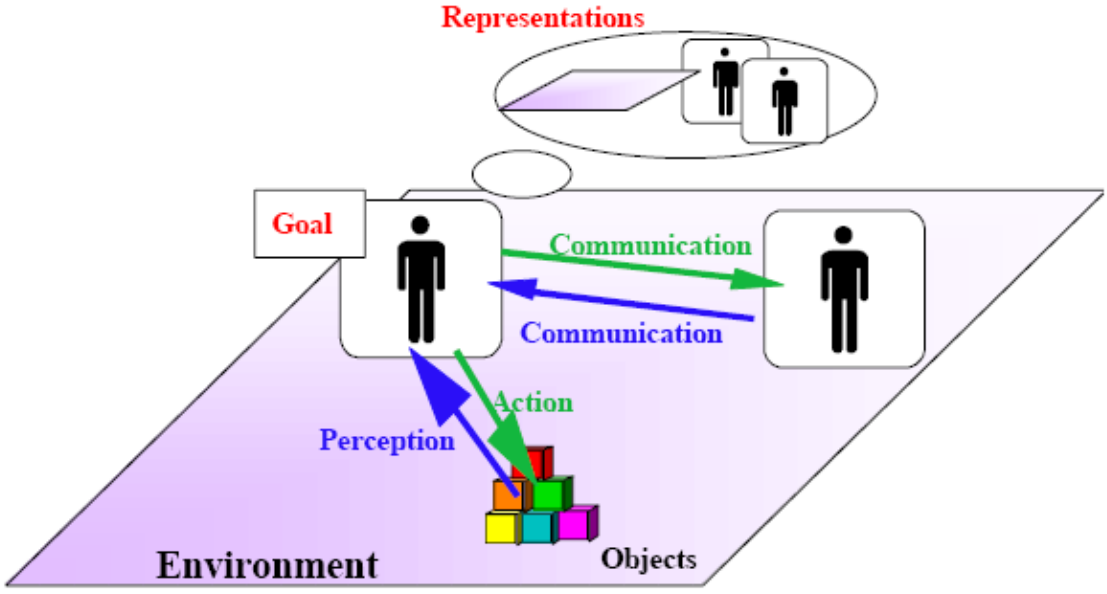

Figure 1: Principles of Multi-Agent Systems

The adopted definition based on a synthesis of these characteristics is: 'Agents are systems capable of autonomous, purposeful action in the real world.' Multi-agent systems are based on the principles of distribution and interaction (Ferber 1999) and comprise collections of agents. The principles of multi-agent systems have been shown in Figure 2.

Agent-based modelling uses the agent paradigm to represent complex phenomena in real life systems. User groups such as ecologists and sociologists have used agent-based modeling to create 'virtual laboratories' for monitoring and analysing simulation trials. Grimm and Railsback (2005) present a detailed analysis of the application of agent-based modelling. Their analysis addresses the full cycle of designing, testing, using, and publishing agent-based models. The proposed task of using agent-based modelling techniques in the assessment of social, economic and environmental impacts of Sanitation Initiatives will be based on the works described in this section.

PROPOSED STRATEGY

The proposed system will be deployed using the CORMAS tool (Cormas 2003). CORMAS provides a set a heuristics for thinking about common-pool resources management in a decentralised and distributed way. CORMAS also provides a framework that enables people to develop new ways of thinking. A UML class diagram of the CORMAS kernel has been depicted in Figure 3. The CORMAS tool has been used in the development of numerous models in applications such as

- The management of a renewable resource (water, wild fauna, tree and wood, soil and erosion and pastures);
- The economic exchanges of agricultural products and natural resources, and;
- Land-use dynamics.

The next phase of the project will involve conducting a series of workshop with the stakeholders in the Sanitation Initiatives in Nairobi's informal settlements. The results of these workshops will be analysed using a framework developed by Montgomery (1996). The main objective of this task will be drawing out the interests of the various groups. The main facets in Montgomery's framework are:

- The stakeholder's expectations of the project;
- The likely benefits for the stakeholders;
- The resources the stakeholder wishes to commit (or avoid committing) to the project;
- Other interests the stakeholder has which may conflict with the project;
- How the stakeholder regards other stakeholders.

The stakeholders' interest will be mapped using either the problems which a given project is seeking to address (if at an early stage of the project), or the established objectives of the project (if the project is already under way).

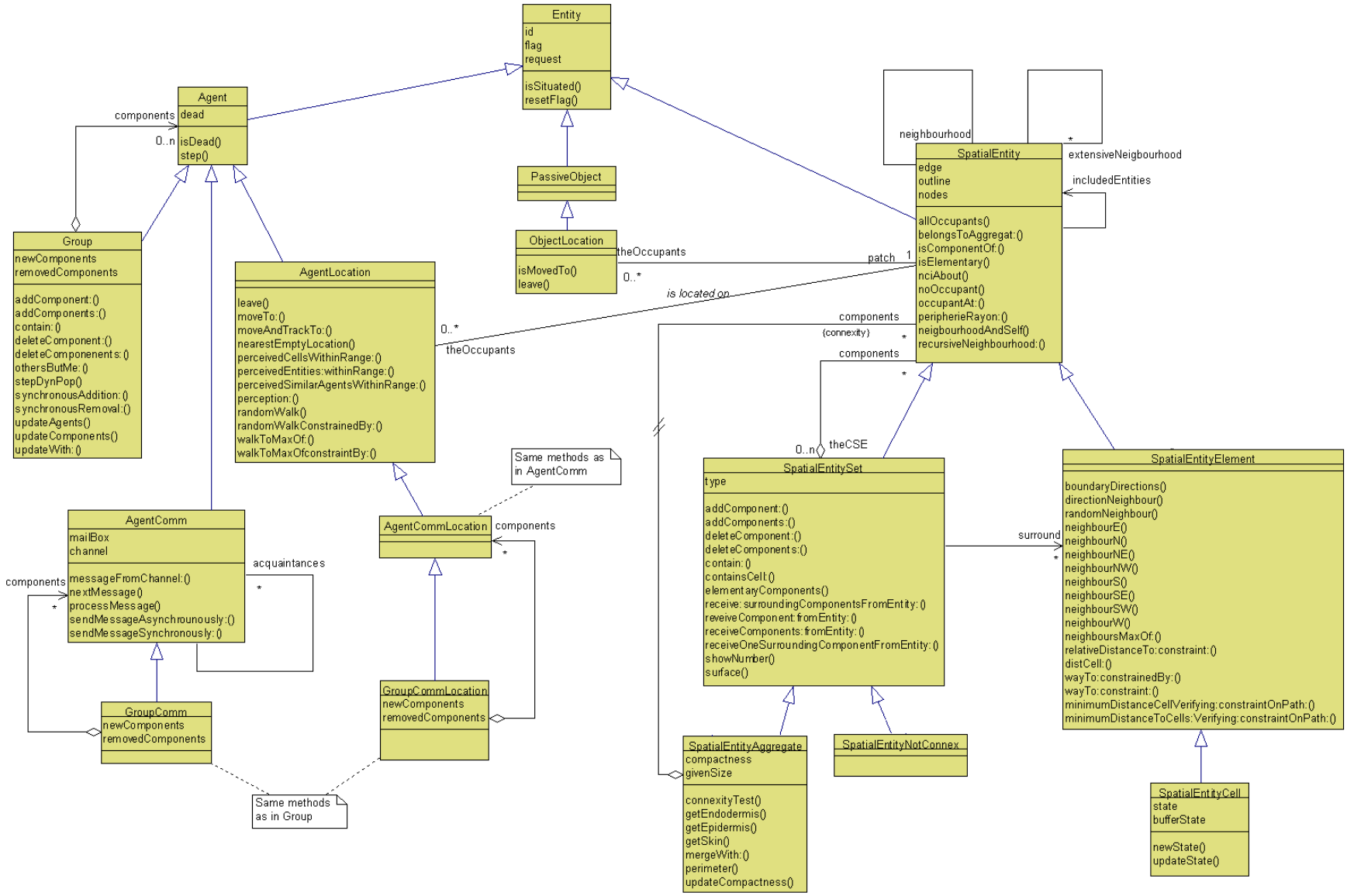

Figure 3: The Kernels of the Proposed Agent-based Model

CONCLUSION

Agent-based modelling enables the development of new theories and supports the formalization of existing theories in any complex setting. This paper has proposed the deployment of such a system to model the complex interactions and influences in the provision of Sanitation in Nairobi's informal settlements. Presently, such initiatives are executed by highly localized CBOs. A review of the expectations of CBOs has revealed that such organisations are acutely aware of the disadvantages of executing localized operations and they have adopted ICTs to facilitate the sharing of best practices across different organisation. It is important to bear in mind the fact that the adoption of ICTs does not necessary translate to enhanced knowledge sharing. There is in fact a direct correlation between the growth in volume of electronic content and an increase in decision makers' reluctance to make use of the information held in such content because of time constraints; and even where time constraints can be overlooked, without a careful analysis that can take into account the social, economic and environmental impacts simultaneously, it may be impossible to identify the most promising practices in a given setting. The used of agent-based modelling in the provision of Sanitation by CBOs domain will increase the comparative efficacy by modeling the values and incentives for the different organisations in various scenarios. The results of such comparison will not just benefit the CBOs: they can also be used to inform policy decision makers in the regulatory authorities.

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