Land-use modelling to support strategic urban planning - the case of Dar es Salaam, Tanzania

Alexandra Hill
Christian Lindner

1. Introduction

At the beginning of the 21st century humanity entered the 'century of cities' (Kofi Annan) with the majority of the global population living in urban areas. Global urbanisation is one of the most fundamental and most radical changes recently experienced by humanity. In the last decades new so-called megacities emerged in Asia, Latin America and Africa (Kraas 2010; Kraas & Mertins 2008; Bronger 2004; Fuchs et al. 1994; Mertins 1992). The United Nations highlight that "the developing world, where megacities will be the hallmark of future urbanisation, is experiencing extraordinary spurts of growth in its largest cities" (UN 2007). Urban growth in an informal environment is neither guided by strategic planning nor zoning specifications. "Urban planners and managers have increasingly found themselves confronted by new spatial forms and processes, the drivers of which often lie outside the control of local government" (UN-Habitat 2009: xxiii). Informal urban settlements are characterised by severe deficits in basic services and infrastructure supply calling for strategic urban planning and action taken to qualify informal settlements to meet the Millennium Development Goals (MDG) of the UN and to contribute to a sustainable urban development. This contribution focuses on informal urban growth processes in Dar es Salaam, one of the most rapidly growing large cities in Africa.

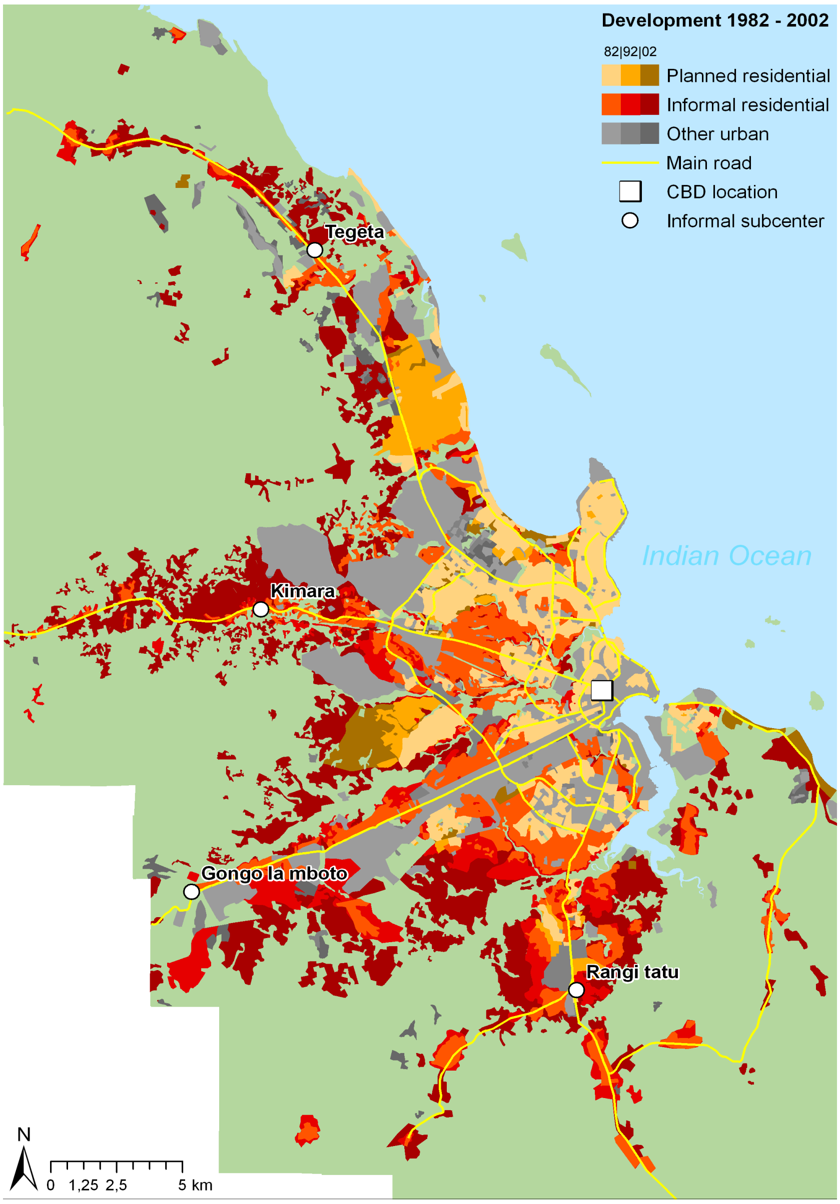
Although research has focused on informal urbanisation and many studies on megacities were conducted in the past years, knowledge about the drivers and mechanisms influencing informal urban dynamics is still incomplete. As a step towards a better understanding of the underlying processes this paper presents selected findings from research to explore, model and simulate informal urban growth processes using the modelling approach of cellular automata (CA) (Hill & Lindner 2010a, 2010b). CA models seek to reproduce development patterns and the underlying mechanisms on an aggregate cell-based level. Based on the knowledge generated, they can be used to identify suitable access points for planning intervention, to forecast likely future trends and to demonstrate the impacts to be expected from selected planning measures. Eventually the modelling exercise can contribute to a more strategic planning approach and sustainable development. A particular focus of this contribution is to demonstrate the potential of transport infrastructure as an access point for planning intervention to guide future informal development.

2. Informal residential dynamics in Dar es Salaam

Dar es Salaam is Tanzania's largest city in terms of population and recently the third fastest growing urban agglomerations in Africa. Like in most rapidly growing cities of the developing world urban informality has been recognised as a predominant "mode of urbanisation" (Roy 2005) and informal residential growth constitutes a major component of urban change (see Figure 1). With projected urban growth rates of about 4% between 2010 and 2025 Dar es Salaam is expected to become a megacity with a population of more than 5 million inhabitants before 2020 (UN 2010). Rapid urban growth under poverty has outstripped the capacities of planning authorities to cope with the enormous pace of urban expansion. Additionally, the impact of formal planning in Dar es Salaam is very limited as the latest masterplan approved dates back to 1979. As a consequence informal settlements absorb large proportions of the urban dwellers leading to rapid urban sprawl into the unplanned periphery and the emergence of informal sub-centres in peri-urban areas.

The urban structure of Dar es Salaam resembles a four finger pattern following the four major arterial roads. Informal urban sprawl in Dar es Salaam can be described as a diffusion process progressing in wave-like concentric rings from the city centre towards the periphery of the city in combination with broadening ribbons following the arterial roads (see Figure 1) (Hill & Lindner 2009). In Dar es Salaam, estimates assume that approximately 70% of the population live in informally developed settlements (Kombe & Kreibich 2006; A. Lupala 2002; J. Lupala 2002). Kironde (2006) reports about calculations based on property tax databases which support that even more than 80% of all buildings in the city of Dar es Salaam are located in unplanned areas. Considering the higher house occupancy rates in unplanned areas, he argues that the proportion of the city's population living in unplanned areas is likely to be higher than 80%.

Figure 1: Land-use development in Dar es Salaam in 1982, 1992 and 2002



Source: Own illustration; based on land-use and transport network data provided by ITC, Enschede; updated for 2002 by IRPUD, Dortmund

Urban growth in Dar es Salaam is mainly driven by informal residential location decisions of both, the urban poor as well as medium- and high-income groups. Despite intensive densification and consolidation processes in existing settlements, most of the urban population growth is accommodated on formerly vacant or agricultural land. Research has brought forward that informal settling is basically driven by plot availability and affordability,

thus, differing from formal markets in developed countries (Kreibich et al. 2008; Lupala 2002). The imperfect market conditions are basically related to limited availability of information, ambiguous institutional settings and financial restrictions of informal settlers. High land consumption mainly results from the fact that single storey buildings prevail and affordable large plots can only be found at the urban fringes. Although land consumption is high, there is still much vacant land available at the urban fringe.
Despite being informal, the location decision processes exhibit specific individual location rationalities. Kreibich even argues that the lack of statutory planning is to some degree compensated by “local institutions which join in social regulation trying to streamline the self interest of settlers in such a way that individual behaviour turns out to be beneficial for their community” (Kreibich 2010: 43). This invisible hand at the end of the day often actually creates functioning spatial structures of land-use allocation on a larger scale but nevertheless also creates externalities for the urban poor.
The dynamics of urbanisation under poverty in Dar es Salaam and the associated deficits in infrastructure supply highlight the urgent need for action of public authorities to reduce externalities and to qualify informal settlements if the Millennium Development Goals (MDG) set out by the UN shall be met. In the year 2000, 39% of the population of Dar es Salaam were unserviced with safe drinking water (UN-HABITAT 2003: 28). To fulfil the MDG this rate has to be halved by 2015 requiring upgrading of existing settlements and, additionally, supplying the majority of about 150,000 new dwellers per year with technical infrastructure. To guide informal settlement activities to favoured locations could help to optimise the use of scarce resources available for planning purposes, to reduce costs for investment and maintenance and to achieve affordable prices for the supply with water, electricity and public transport. Infrastructure investments have to be strategically positioned and appropriate densities have to be implemented to create adequate threshold populations for the economic supply of trunk infrastructure. This requires that public and also private stakeholders break new ground for cooperation (Hill et al. 2010). Appropriate planning tools and instruments (such as urban land-use models) could foster this process by supplying valuable information and knowledge on urban dynamics, the underlying drivers and mechanisms, future perspectives and planning opportunities.

3. Dar es Salaam land-use model

Dar es Salaam like many other large cities in developing countries must be characterised as a data-poor environment. Public authorities lack up-to-date and accurate data and, thus, each public body basically works (literally) ‘with their own homemade’ reference datasets. Given the lack of personnel capacities and a missing tradition in database conception and maintenance even existing data created for instance in the course of international co-operation projects gets lost after those projects end. Consequently, appropriate data for the modelling exercise was lacking. The compilation of the model database turned out to be quite demanding particularly concerning spatial coverage, multi-temporal availability, reliability and spatial resolution. Finally, initial datasets, e.g. land use and transport network, have been acquired from a partnering European research institution (ITC, Enschede, The Netherlands) and were subsequently updated and extended where possible based on aerial imagery. Based on these datasets a calibration database was compiled which included variables covering the following drivers: current land use, natural conditions, accessibility and neighbourhood relations.

3.1. Cellular automata models

The CA-based modelling approach aims at reproducing the outcomes of underlying micromotives as macrobehaviour (Schelling 2006) by means of an aggregated, cell-based simulation model on land-use transformation. Most cities are characterised by a permanent transformation reflecting demographic, economic or technological changes. “Almost all cities are undergoing continual growth, change, decline, and restructuring - usually simultaneously” (White & Engelen 1993: 1176). Moreover, cities show the typical features of complex systems as they exhibit several of the characteristics of complexity: fractal dimensionality, self-similarity, self-organisation, emergence and non-linearity (Barredo et al. 2003; Torrens

2000; Torrens & O'Sullivan 2001) in accordance to von Bertalanffy's notion that "the whole is greater than the sum of the parts" (1968: 18).

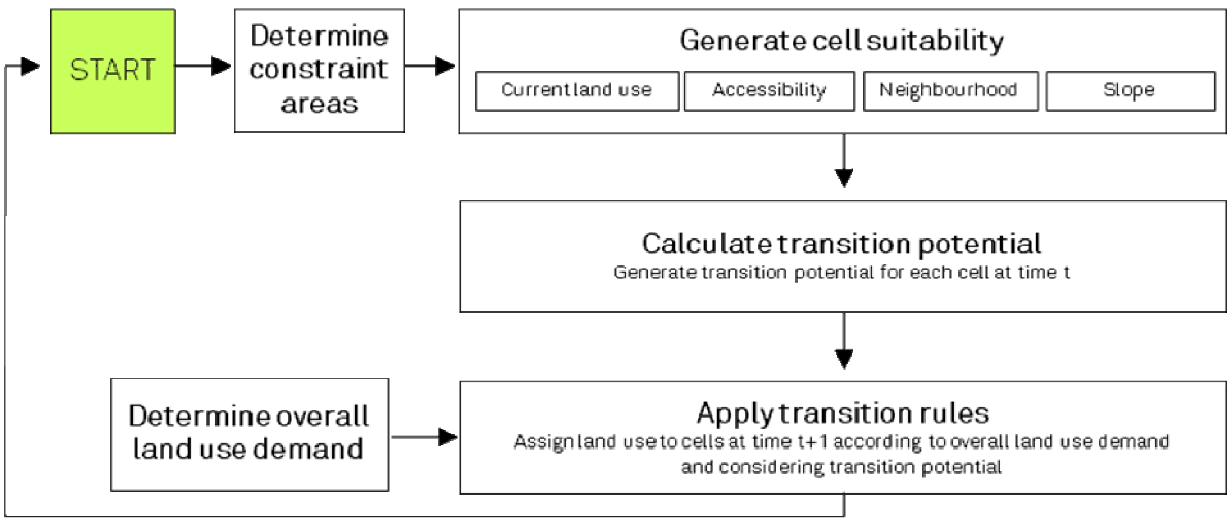
CA-based models are highly suitable for modelling land-use development in environments that are characterised as being data-poor and experiencing rapid urban growth and informal development. As the CA modelling paradigm is largely oriented towards simplicity such models do not require a highly sophisticated database - a feature which is of significant advantage considering the application in data-poor environments typically found in developing countries. Incorporating neighbourhood effects CA intrinsically allow for reproducing dynamic and complex processes, particularly those that are strongly influenced by local-scale factors.

Integrated land-use transport modelling has a forty years long tradition (Wegener 2004) with CA-based applications for the urban context emerging mainly since the 1990ies (see for instance White & Engelen 1994; Batty & Xie 1994; Batty 1997). Although informal urban growth processes in developing countries seem to be particularly suitable to be reproduced as diffusive processes using CA-based approaches, surprisingly, so far only few examples applying CA-based models in developing countries and their rapidly growing cities exist such as those for Lagos, Nigeria (Barredo et al. 2004), or for Yaoundé, Cameroon (Sietchiping 2004).

3.2. Model design

As CA-based models partition the observed space into regular grid cells, Dar es Salaam land-use data has been divided into 1 ha (100 by 100 m) cells. Thus, the study area comprised about 97,000 cells of which about 11,900 cells had transformed from vacant cells into informal residential land use between 1982 and 2002. The set of variables tested as independent variables for the applied logistic regression model approach reflects data restrictions on the one hand but on the other hand reflects the aim to test a broader range of variables which all may have explanatory power concerning informal development. The calibration run results illustrate that the overall spatial growth patterns between 1982 and 2002 can be adequately reproduced by the model based on the selected parameter set. The model's prediction power was checked using a hybrid approach of quantitative degree of fit measures and visual interpretation of calibration results in comparison to real world development. In order to validate the model subsequently to the calibration two validation runs have been conducted confirming the model's ability to adequately reproduce urban development for the tested periods (Hill & Lindner 2010a).

Figure 2: Land-use transformation process



Source: Own illustration

At the beginning of each model run the vacant cells being subject to the modelled transformation process of informal urbanisation are determined. For each one of these cells suitabilities are calculated based on the factors identified during model conception and calibration. Furthermore, cells located in constraint areas, i.e. swamp areas, river valleys and forests reserves, are excluded from the transformation process since no development is assumed to take place in these areas. Subsequently, the transition potential for each cell is calculated based on the suitability factors. Based on population projections by the UN (2008) the future demand for residential land, i.e. the demand for new informal residential cells, has been computed exogenously. The model assigns as many vacant cells as needed to satisfy the demand in the subsequent time-step. Transition rules define that the respective number of transformation cells is selected considering those cells with the highest transition potential. The model iteration ends when the demand for cell transformations is satisfied. The remaining vacant cells are not subject to transformation.

4. Scenario application

4.1. Modelling and strategic planning

Spatial models are increasingly employed as decision support tools in urban planning in order to inform planners and decision makers. So far cross-sectoral and co-ordinating planning is largely missing in Dar es Salaam. Accordingly, the model could contribute to overcome planning obstacles pioneering the way forward towards a more co-ordinated urban future and, thus, sustainable development. A prerequisite for informed and co-operative planning and the development and implementation of a sustainable urban policy is good knowledge of the status quo situation and the major trends and drivers of urban development. Here, urban information and decision support systems come into play.

Moreover, simulation models serve to forecast future states of urban systems illustrating the needs for future planning and investment. They can be used to demonstrate the possible impacts of different planning measures and, thus, support participatory approaches in urban planning. As the “future orientation of planning is unique to the field’s identity (...) the very substance of urban planning is founded in time” (Myers & Kitsuse 2000: 225) so that urban planning and urban models have to be discussed jointly. Couclelis has argued that connecting these two spheres could “amplify the positive synergies between the two domains and enhance the ability of spatial planning to prepare for the future” (2005: 1353). Thus, a sound claim for more strategic planning has been revitalised during recent years by various scientists (e.g., Albrechts 2004; Friedmann 2004; Salet & Faludi 2000). But still planning and modelling practices exhibit a clear separation as “earlier hopes of creating a stronger, more scientific urban land-use planning practice through integration with models did not materialize” (Couclelis 2005: 1355). In this context Couclelis demands that appropriate urban models have to be developed that are suitable to step into place when it comes to support this strategic and co-ordinating function of planning.

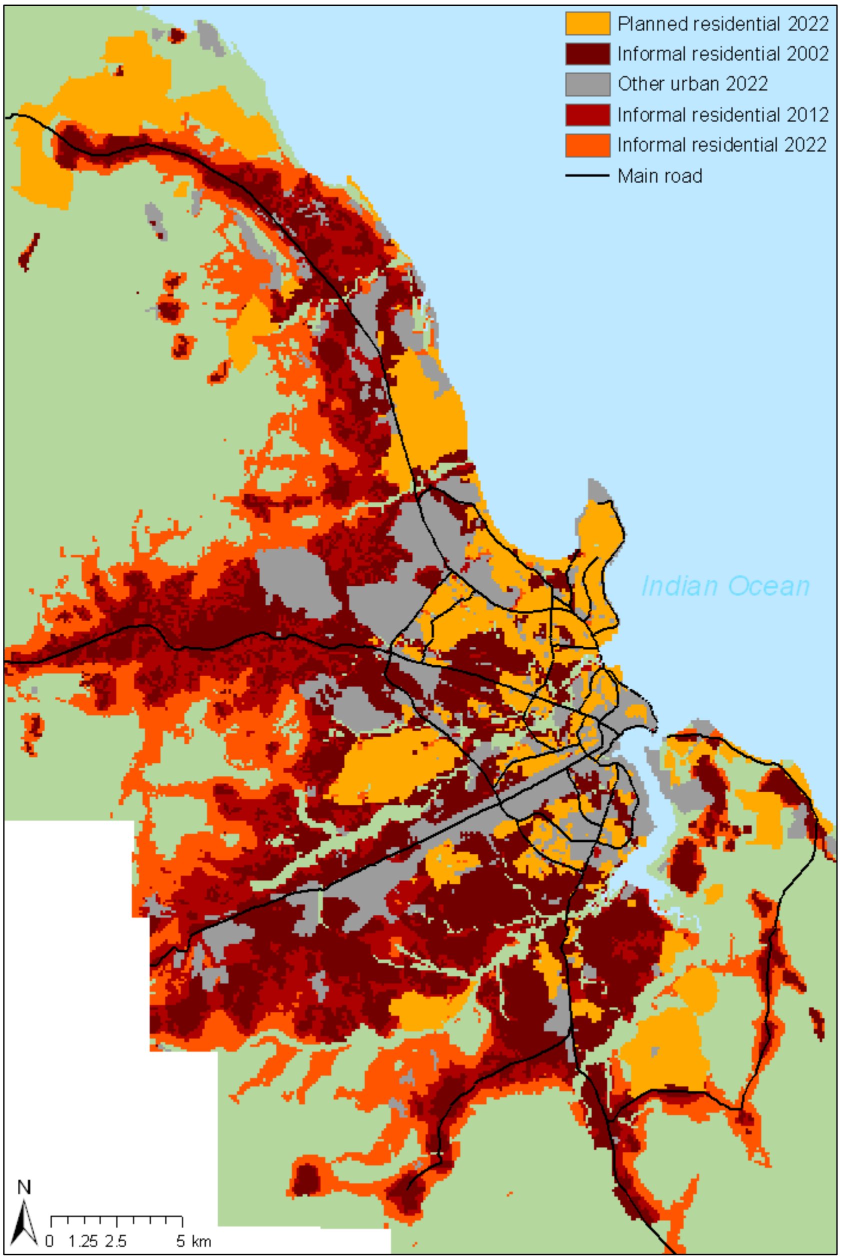
For developing countries tools such as the presented land-use simulation model could be of particular importance. There, the questions of how to plan strategically and how to implement plans are challenging. Suitable access points and supportive instruments need to be identified and to be made applicable. Moreover, the constraints imposed by scarce resources available demand to be addressed strongly strategically and in a co-ordinating manner with infrastructure investment of both the public hand and private utility suppliers.

4.2. Baseline scenario

To demonstrate likely perspectives of future urban growth the simulation model was applied to forecast informal urban expansion. The simulation results can be seen in Figure 3 showing the land-use distribution for the year 2022. The urban expansion is mapped as projected to take place until 2022 implied by adding 21,322 ha of informal residential use and 4,296 ha of formally designated residential to the urban fabric of the study area. The demand for newly developed informal residential land was derived from UN population projections (UN 2008) and assumptions made on population densities in informal and planned settlements.

The baseline scenario results clearly illustrate the spatial dimension and distribution of settlement pressure which Dar es Salaam is likely to face in the near future. The basic development trends can briefly be described as a continuous urban expansion of the ribbons alongside the main arterial roads towards the urban periphery and increasing encroachment of the so far less developed hinterlands between the arterial roads filling up the interstitial areas. The forecasts of the baseline scenario confirm the assumption that Dar es Salaam will continue to rapidly expand its urban borders.

Figure 3: Baseline scenario results for 2022

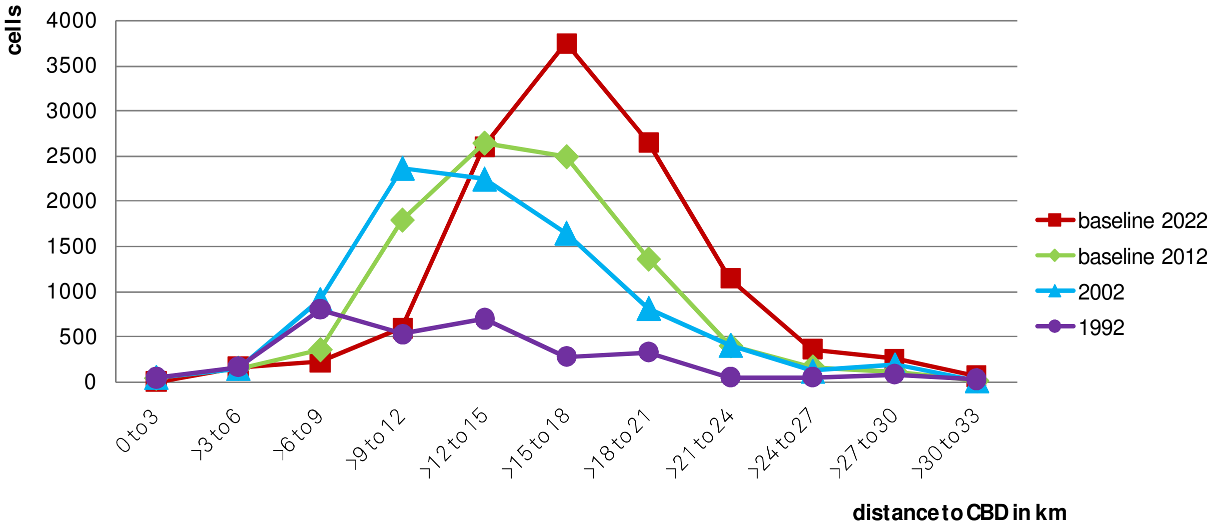


Source: Own illustration

0 demonstrates the general trend of acceleration of urban expansion and the temporal shift of peaks of informal urban dynamics according to concentric rings around the CBD. In the decade between 1982 and 1992 the largest dynamics could be observed at distances between 6 and 9 km from the CBD. During the next decade locations at this distance continuously experienced rapid development but the peak of transformations shifted to

distances between 9 and 12 km. A similar effect is forecasted for 2012 and 2022 relocating the peak to distances of 12 to 15 km and to 15 to 18 km respectively.

Figure 4: Number of newly developed informal residential cells during the previous decade for 1992, 2002, 2012 and 2022 along concentric rings around the CBD



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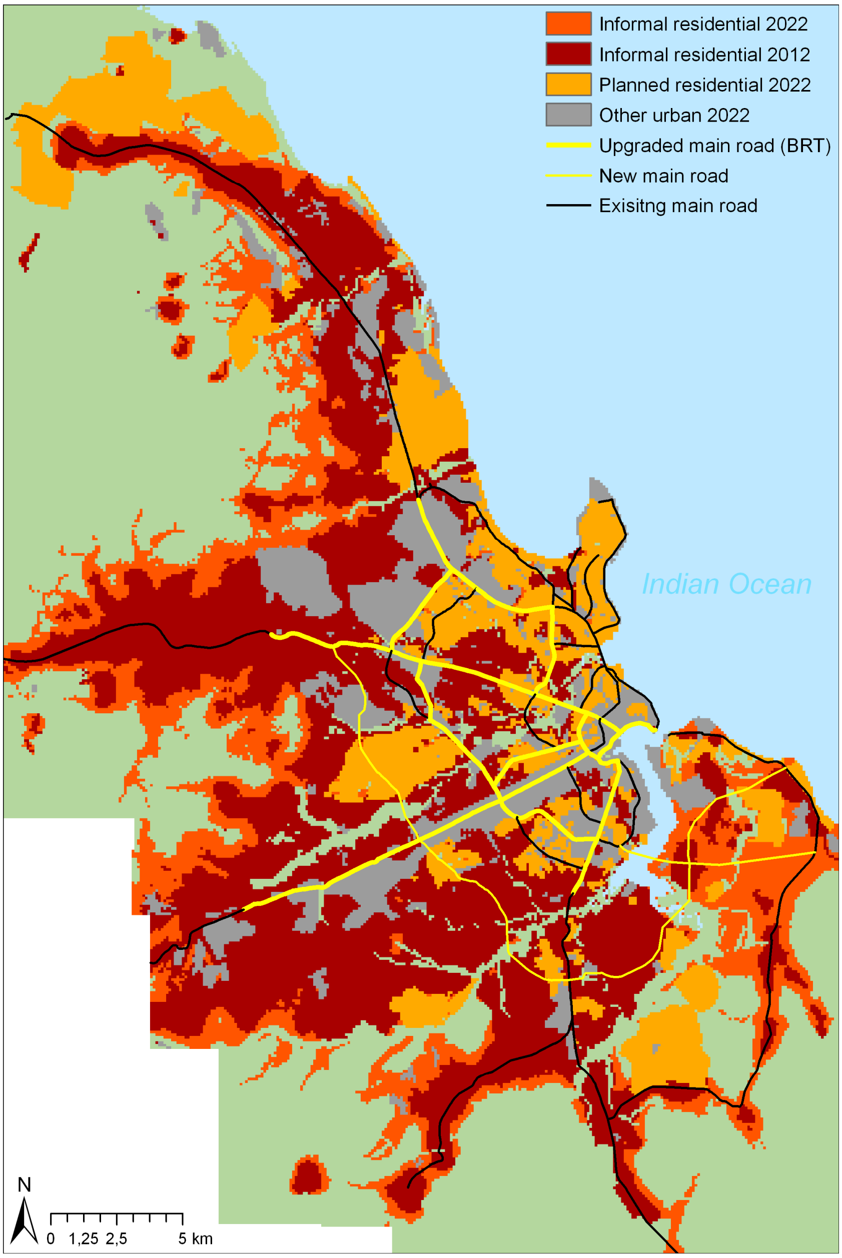
4.3. Transport scenarios

From the planning perspective the overall goal considering the issue of rapid urban growth is to influence and direct future informal location decisions. The capacities of public authorities to act are limited not only in terms of their financial resources but particularly in terms of implementing formal plans. Thus, the question arises where suitable access points for local planning authorities exist. Research has demonstrated that one approach to provide more favourable conditions to informal urban settlers is to provide trunk infrastructure (Hill et al. 2010) and in particular road infrastructure as accessibility is one main driver of informal urbanisation (Hill & Lindner 2010a). Consequently, transport infrastructure scenarios constitute an adequate approach to demonstrate consequences of planning interventions and alternative development opportunities (not least because public authorities are responsible for the provision of road infrastructure).

Four alternative development scenarios were applied in the research study. They assume the following changes in transport infrastructure supply: i) establishment of a bus rapid transit (BRT) system; ii) construction of a new ring road; iii) construction of a new bridge traversing the creek south-east of the CBD; and iv) joint implementation of all three aforementioned infrastructure projects. All these measures are part of the Dar es Salaam Transport Masterplan. It aims at formulating short-term actions to alleviate current traffic problems and provide a long-term perspective for urban transport policy and development in the Dar es Salaam metropolitan area until 2030. Most of the following specifications concerning infrastructure projects are based on the draft final report for this plan (DCC 2008).

The so-called combined scenario integrates the joint establishment of the three stand-alone transport projects. The routing of additional road sections and modified classification of specific sections in terms of improved travel speed induced by the BRT system can be seen in Figure 5. The simulation run forecasts the concomitant land-use distribution for 2022 as illustrated in the map on the left-hand side. On the right-hand side the likely changes in land-use transformation compared to the baseline scenario are displayed.

Figure 5: Combined transport scenario results for 2022

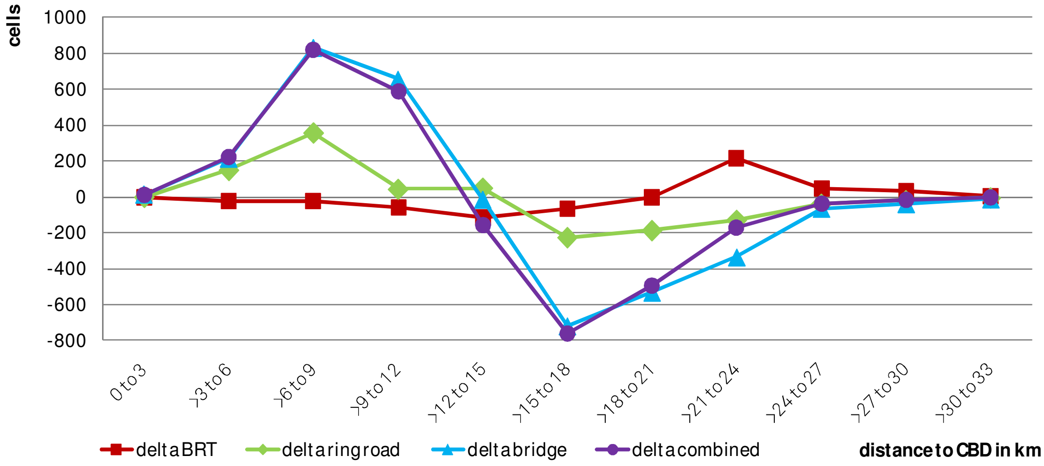


Source: Own illustration

The transport scenario reveals a clear trend of redistributing development dynamics towards the areas south-east of the creek relieving urban pressure from large parts of the city's peri-urban areas. Accessibility improvements for the area south-east of the creek will be realised basically through the construction of the bridge and the new ring road as they significantly amplify accessibility. In combination with those settlements planned formally the area south-east of the creek is projected to be almost completely transformed to urban uses.
In addition Figure 6 illustrates the impacts of transport projects according to airline distance to the CBD. The BRT scenario causes redistribution of newly developing cells to more remote locations with a peak of development at 21 to 24 km. The ring road scenario redistributes development from areas of 15 km on outwards to nearer distances with a peak at 6 to 9 km. The bridge scenario and the combined scenario show similar patterns strongly shifting land-use transformations from remote locations at 12 km and more to locations

closer to the CBD. This figure reveals the strong impacts of the bridge construction even on the outcomes of the combined scenario.

Figure 6: Distribution differences between the combined scenario and the baseline scenario results in 2022 along concentric rings around the CBD



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5. Conclusions and the way forward to a strategic spatial planning in Dar es Salaam

The future development perspectives for Dar es Salaam sketched out above and the projected continuous rapid informal expansion call for more strategic spatial planning interventions. So far a co-operative and co-ordinating planning is not in place. However, the research presented has revealed that some promising access points for planning intervention exist which may enable guidance of informal urban growth. Urban models like the simulation model presented may become a suitable tool or platform to overcome some of the existing co-ordination gaps and to strengthen strategic planning.

The modelling exercise has identified key drivers for informal residential growth in Dar es Salaam. Accessibility factors have been identified to be important determinants. Although access to CBD is definitely relevant the analysis shows that rather a multi-facetted combination with travel time to informal sub-centres and the airline distance to next road explains the observed development patterns. The neighbourhood factor has proven to account for some social aspects of informal land-use dynamics which cannot be captured explicitly. The neighbourhood factor, therefore, seems to be highly suitable to compensate for data gaps and to account for local-scale dynamics that influence the informal land and housing markets and drive urban expansion to take place in a highly diffusive manner representing bottom-up urban development processes. Whereas the closeness to existing informal settlements is largely attractive, planned settlements tend to repulse informal development which can be assumed to be related to i.a. higher land prices. Moreover, neighbourhood effects seem to be interwoven with structural urban features and patterns both on the sub-centre and city-wide level. In essence, it becomes evident that informal dynamics are of a complex and non-linear nature. The CA-based model has succeeded in reproducing these relatively complex socio-spatial dynamics with a set of simple rules and limited data. Out of the list of variables accessibility and transport infrastructure make up the key access point for planning intervention. Transport projects clearly reveal strong impacts on informal urban development and should, thus, be perceived as a guiding instrument and one strategic point for investment particularly considering the scarce resources available to planning authorities in Dar es Salaam.

Research revealed that innovative tools can support to overcome the deadlock caused by disempowered public authorities and ineffective planning regulation and the resulting information deficit of public utility suppliers, particularly trunk infrastructure providers. It can be assumed that plausible information on future perspectives of urban growth, especially its spatial distribution, could provide a common platform for the exchange of information and subsequent co-operation of stakeholders. A model to simulate urban development capable of responding to strategic variables seems to provide an adequate tool. The presentation of a prototype of the Dar es Salaam land-use model and its discussion with local experts including representatives of most utility suppliers and municipal as well as regional authorities supported the underlying assumption that the generated information has strategic value (Hill et al. 2010).
Further research is needed on how to integrate such expert systems into planning practice with the aim to employ it as practical decision support systems. This would require establishing adequate structures both in organisational and institutional as well as in technical terms to allow for a useful and effective integration and maintenance of the model. For sound analyses and interpretation of the model outputs capacity building is one fundamental prerequisite. Involving public, private and academic stakeholders into a model-led planning discourse could further enhance the integration of academic science and planning practice and, thus, support rational plan-making at city level.

Authors

Dr. Ing. Alexandra HILL Researcher Institute of Spatial Planning (IRPUD) School of Spatial Planning TU Dortmund University August-Schmidt-Strasse 10 44221 Dortmund Germany E-mail: alexandra.hill@tu-dortmund.de	Dr. Ing. Christian LINDNER Researcher Institute of Spatial Planning (IRPUD) School of Spatial Planning TU Dortmund University August-Schmidt-Strasse 10 44221 Dortmund Germany E-mail: christian.lindner@tu-dortmund.de

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