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REPORT

Review of Land-Use Models

Summary and Documentation

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Review of Land-Use Models

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Client

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1 Foreword

Nordregio is a leading international Nordic research institute in the broad field of regional studies. The institute undertakes strategic research with the aim of producing informed and relevant material for decision-makers at the international, national and regional levels. Nordregio also contributes to the Nordic co-operation by acting as the secretariat for four working groups under the Nordic Committee of Senior Officials for Regional Policy (EK-R). This assignment concerns a project which is part of the research conducted by Nordregio within the Nordic Working Group for green growth – sustainable urban regions (hereafter NWG).

The NWG is interested in how spatial planning knowledge and instruments can contribute to the policy goals of green growth of Nordic city-regions. Among its objectives are to contribute knowledge on, and the development of, modelling tools for urban areas to undertake spatial development in ways that contribute to green growth.

Visual representations of future urban development through modelling and scenario tools can allow for the projection and evaluation of planning policies, thereby creating continuity across the urban scale and making sustainable urban development manageable (and operational) for relevant stakeholders and decision makers.

This report is the result of an inventory and assessment of different land-use models that are (or have been) in use in different parts of the world. It reviews some of the (in the authors view) most interesting and widely used land-use models in the world at scientific academies and at planning agencies. However, one initial conclusion from our survey is that there is an abundance of different types of land-use models being developed in world, and that it is impossible to cover all of them. Therefore, this report does not claim to be a complete survey. Instead, it should be seen as an assessment of the most common and popular land-use models.

This work has been led by Ryan Weber, research fellow at Nordregio. The report has been written by Lars Berglund and Svante Berglund, senior analysts at WSP Analysis & Strategy.

2 Introduction

2.1 Why do we need to model the real world?

Planners and policy makers face a difficult task. The world they must deal with is complex, interconnected, and ever changing. Regional and urban planning, the design of policies for sustainable development and the integrated management of different types of land-use all have to deal with systems in which natural and human factors are interconnected. Understanding the processes that cause these systems to change and knowing their spatial consequences is essential in preparing effective policies. Systems such as these must therefore be understood and managed as dynamic entities. Planners and decision makers often struggle to balance the demands of growth with the desire to preserve the natural environment, unique community characteristics, and other quality-of-life attributes. Planners influence the land use change process by applying restrictions on development in certain areas and stimulating development in other areas. This is especially true for the Nordic countries, which have a very strong tradition of managing land use and transportation by comprehensive urban and regional planning.

Land-use change models are an essential component of a comprehensive approach for planners to project and evaluate the potential consequences of policy decisions and other actions on land-use patterns in their administrative areas[1]. Models are mathematical representations of the real world – typically implemented through computational simulation tools that describe, explain, forecast and evaluate the complex interactions between different elements of the land-use system.

Land-use models also serve various purposes. First, models help achieve a better understanding of the urban dynamic system (in an explanatory role). Second, they enable virtual experimentation, allowing the possible impacts of new infrastructures, technologies, or policies to be determined (in a predictive role). Third, models are powerful tools to facilitate participatory processes for collaborative decision making (in policy and design roles)[2]. Additionally, they should serve as tools to stimulate thinking and facilitate discussion, rather than to make definite statements about the future. Thus, models help in narrowing down the number of possible policy interventions, without making a predictive statement about the only (or optimal) solution.

Therefore, in this study, land-use models are primarily seen in the perspective of a *planning decision support system*, which allows for a better understanding of future impacts of different planning policies, supported by knowledge about economic theories and social behaviors. Ideally, this should be done in an iterative process, where modelled outcomes give new information for subsequently adjusting policy to reach planning goals.

[1] U.S. EPA, 2000: *Projecting Land-Use Change*. U.S. Environmental Protection Agency

[2] Batty 2012: *Urban models for transportation and spatial planning*. EUNOIA Consortium

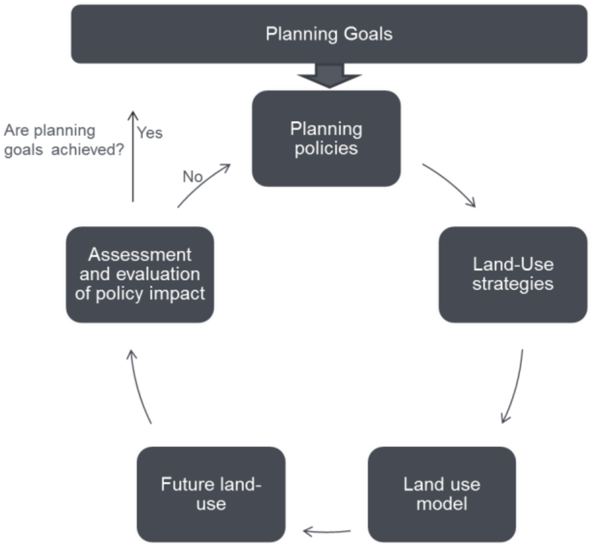

Figure 1 Typical planning process with support of land-use modeling

2.2 Typical fields of application

Based on our literature study of research papers on land-use models, the following four major thematical fields of application can be observed:

- Land-use
- Transportation
- Spatial econometrics
- Environment

Sometimes, models are combined into modular model systems. Following this, three major types of model systems can be identified:

- Single urban land use models, mainly used for planning purposes and policy analysis and assessment. Models are often detailed in terms of input data and have high spatial resolution.
- Single land use change models, mainly used in environmental sciences. Models are often detailed in terms of input data and have high spatial resolution.
- Coupled land use and transportation models (LUTI), which represent a holistic system approach of urban and transportation systems. Transport-only models require land-use inputs which are forecast exogenously, whereas LUTI models generate their own forecasts of land-use as a function of land-use policies and changes in the transport system. Land use modeling is necessary for studying traffic effects of different land use patterns. Models are often generalised in terms of input data and spatial resolution, and are often aggregated on traffic analysis zones.

2.3 Types of models

One fundamental feature of land-use models is the underlying mechanisms that rule the behaviour of the model. Therefore, land-use models can be divided into different classes according to their theoretical foundation and functional mechanisms. The following section summarises the most common types of model approaches[3].

Spatial input-output models (I/O)

Input-Output models address spatial patterns of location of economic activities and movement of goods and people between zones. They account for producers and consumers of goods and services and their interactions. They are mainly econometric models, developed by identifying the actors, conceptualising the drivers of their economic decision process, hypothesising variables that reflect those drivers, and developing statistical approaches to test hypotheses. Fitted models may then be used to make projections of land use change for the area for which they were developed. A major limitation of such models is that they often require detailed data that are not available in regionally consistent formats. These models may also lack the ability to model conditions that deviate from historic norms.

Agent-based models (ABM)

Micro-simulation models of land use are activity-based models with the individual (or household, firm, or any other agent in the urban system) as the unit of analysis. An agent-based model consists of multiple interacting agents within a simulated environment. Rules are defined for the agents' actions, and these rules affect their behaviours and relationships. Agent-based models allow the exploration and simulation of the behaviour of urban systems at a fine level of detail. Activity patterns are modelled from the bottom up. Agent-based models require more detailed information about population demographics than is usually available from surveys or census data. The lack of easy tools to generate the artificial agent-population is a major obstacle for their implementation.

Multi-Agent simulation

ABM can be extended to a Multi-agent system (MAS), which not only contains an ABM representing disaggregated decision making, but also includes a CA model (see the following section). The CA part describes the land-use changes, while the agents represent human behaviours and perform in the simulated environment. Thus the complicated interactions among agents or between agents and environment are simulated.

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[3] Rui 2013: Urban Growth Modeling Based on Land-use Changes and Road Network Expansion. Doctoral Thesis Royal Institute of Technology (KTH), Sweden

Rule-based/Spatial allocation models

> There is a parallel move to building simpler, faster, more visually accessible desktop tools. These tools are based on lightweight, less data-intensive and/or less theory-rich approaches (e.g. rule-based / GIS-based tools) and aim to support rapid scenario analysis, visualisation, and community engagement using state-of-the-art interactive graphics, sometimes embedded in web-based interfaces.
>
> Rule based models are useful for planning agencies for long range scenario testing, because they are easy to apply. They are often developed on economic theories and market rules, but not comprehensively enough to model the complex economic and market process. Simulation is generally based on specific policy changes.
>
> Spatial allocation models have typically been developed by geographers or planners who identify neighbourhood conditions that tend to be correlated with certain types of land conversion, usually residential and commercial development. A predicted amount of residential or commercial growth is allocated to specific locations (e.g. grid cells) to generate future land use.

Cellular Automata (CA) models

> Operate over a grid of cells. Consists of a matrix of regular cells, a set of cell statuses, a neighbourhood and a set of transition rules for individual cells. Some also have a connected time aspect. CA models are basically deterministic and rule-based as they use logical statements to determine the transition rules. CA has been widely applied to geography and related fields because of four main advantages: spatiality and affinity with GIS, dynamism, micro-simulation, and a bottom-up approach. Most often, they are not based on economic theories but rely heavily on historical trends. There are lots of applications. CA can be used as a part of a MAS-model, where a cell is considered as an agent.

2.4 The problem with complex and simple models

In general, land-use models are either complex *or* simple with respect to their theoretical foundation. Spatial input-output models, agent-based models, and most of the cellular automata models are generally complex, while rule-based models are generally simple. Both complex and simple models have their own common strengths and weaknesses. We have noted some general observations in the section below.

First, almost all complex models require some sort of calibration and validation. This is an important and often very complex process for non-experts. Also, calibration is site specific, and a model needs to be re-calibrated if it is to be used in other study areas. The simple rule-based models usually do not need any form of calibration.

Second, the rule-based models often have problems in handling the economic or market aspect of the urban system. This is probably the main disadvantage for rule-based models. On the other hand, they often handle this issue (e.g. land value/price) by pseudo-economic attractors, such as accessibility (which is shown to be strongly correlated to land value). The complex models are far more refined when it comes to capturing spatial economic phenomena.

Third, the complex models attempt to model extremely complex systems without methods that account for all the important phenomena displayed by the systems. The simple models lack the power to capture phenomena of interest, and the most complex models generally lack the data they need to statistically identify their parameters.

Fourth, a perhaps obvious but equally important observation: Theoretically complex models are complex to use (expert tool), and simple models are simple to use (planner tool).

2.5 General modelling challenges

We have identified some key challenges for land-use modelling and their application in practice. They include the following main characteristics,

- Transparency: Models will not be credible as tools for decision support unless they can be explained and understood with a sufficient degree of transparency.
- Ease of use: If a model is too complex to explain and implement, it will not succeed in practice. A model system must pass a threshold of usability that makes it possible for staff within planning agencies to be able to use it.
- Computational performance: A model has to be characterised by a good computational performance.
- Flexibility: A model has to be able to satisfy users in all cases and for all applications. Models that are too rigid can become a serious constraint, which would limit the usage. Models also need to be adaptable to different users, sites and different data.
- Data availability and quality: In implementing a model a crucial point is preparing the input data for it. The difficulty of preparing the data for a model can be a very important obstacle to consider.
- Ability to handle uncertainty: Uncertainty is becoming increasingly important in decision-making processes related to spatial planning, especially when choosing among different alternatives.

2.6 Current trends in land-use modeling

Based on our literature study of research papers, the following three trends of development of land-use models can be observed:

Trend 1:

From macro to micro-simulation (from a top-down to a bottom-up modelling approach). From static, aggregated land-use models, to complex agent based micro-simulation models. Agent-based models seem to be an increasing approach in regions with more complex planning issues.

Trend 2:

Possible as a reaction to the evolution of more complex models, there is a parallel move to building simpler, faster, more visually accessible desktop tools. These tools are based on "lightweight", less data-intensive and/or less theory-rich approaches (e.g. rule-based / GIS-based tools)

Trend 3:

There is also an increasing awareness about the importance of an integrated planning approach. However, there is still a sense among practitioners that fully integrated land use-transportation models are immature with respect to institutional integration and operational policy[4].

2.7 The Use of Land-Use Models – Diffusion

Based on our survey on the development and use of Land-use models worldwide, we have found the following observations.

- Land-use models often originate from research projects at universities.
- Some models mature, and advance to commercial software or as a freeware[5].
- Development of land-use models seems to be concentrated to universities within the Netherlands, Germany, USA and Great Britain.
- Practical use (in a planning environment) seems to be concentrated mainly to planning agencies in the Netherlands and USA.
- There seems to be few implementations in the Nordic countries.
- Applications are found in two cases in Sweden (Practical use of IPM, Stockholm and Skåne regions 2006-2013 and academic tests of LEAM in 2012), one in Finland (early academic tests of MOLAND in the Helsinki region 1998), and one in Denmark (academic tests of METRONAMICA in Greater Copenhagen 2012).

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[4] Batty 2012: *Urban models for transportation and spatial planning*. EUNOIA Consortium

[5] Please see next section for the typical life-cycle of a land-use model.

2.8 The Typical Lifecycle of a Land-Use Model

To be able to make a proper risk assessment of the persistence of a land use model it could be useful to know a few things about the typical life cycle of a land use model. We will also try to evaluate the selected model candidates from this perspective.

Most land use models we know of have started as research projects at universities or governmental agencies. In research projects the aim is usually to make a contribution to the existing flora of technical modeling procedures by adding new functions. It is less common to develop a new modeling concept from scratch, but there are some few examples of this. In the case of the addition of a new function, this can be applied to an existing land use model or by programming the rudimentary core of basic general functionality and then focusing on the research topic. The intention of these models is usually not to be operational but rather to test if this feature could be integrated later in operational models or in future models. This kind of models is of secondary interest from our perspective, but they will appear in our survey. These models usually have short a life, but some of the code may be reused in other models.

In some successful cases a land use model will gain an interest outside the academic context and become implemented and even used for policy analysis. Usually, a model originating in academic research will be more or less tailor made for a specific area, thus working quite well that specific region and the questions addressed there. The drawback is the transferability of the model, which usually requires reprograming and re-calibration. This is often an overwhelming task for a non-expert. Re-programming can only be successful if the source code is made available, which is not always the case. These models are also of limited interest from an application point of view due to the – usually – large effort required for implementation.

A quite recent phenomenon is the development of software as freeware or open source projects, where different research environments in an informal fashion develop parts of the software and share their contributions as an operational model and common library of code. If such an open source project reaches a critical mass and becomes widely used, it can be a very efficient and creative way of developing and maintaining models. The organisational form in open source projects makes it possible to adopt the software to specific needs given that the competence is available and that the original functionality is close enough to the intended use. Use of open source software has become increasingly popular and there are several examples outside the area of land-use models. The most well-known example of an open source project concerning land-use models is UrbanSIM.

Another alternative path of land use models developed in a research environment is as a basis for spin-off companies that continue the development for applied purposes. If a model survives and gets a (economic) life outside the academic world, it probably has got some merits. These models are either used for selling services and implementations of the model, or sold as software. In the former case, the client will have to rely on one service provider which could be problematic. In the latter case, the option to run the model in-house is available. The disadvantage of privately owned software is of course that usage is associated with a cost, but the major advantage is that there is someone responsible for maintenance and support.

Our initial finding is that the latter two organisational forms for maintaining software, open source and software companies, will be the most serious candidates for land use models to look more seriously into.

3 Disposition of review

3.1 Overview

This review is disposed in three steps:

1. Model Inventory

   Identification of potential Land-use models from all around the world. The inventory is mainly Internet-based, but information was also collected from other sources, such as scientific papers, scientific journals and personal contacts.

   The model inventory is documented in a separate document attached to this report.

2. Model Classification

   Following an initial pre-assessment, the most interesting models were classified according to their characteristics. This classification gives basic descriptive information about the models, but does not evaluate the model characteristics.

   The model classification is documented in a single ExCel-document attached to this report.

3. Model Assessment

   The classified models were also assessed with respect to different variables. The result was compiled in an assessment matrix in order to better compare the models.

   Matters that could not be fully considered and described in the assessment matrix were commented in a report (this document) with the most interesting general findings and observations.

3.2 Model Inventory

The main conclusion from this first phase is that there is an abundance of land-use models developed all around the world. There appears to be extensive scientific research being carried out at universities and other research institutes, and some scientific journals are dedicated to the subject.

Some land-use models are tightly connected to specific aspects of the natural and urban systems, answering precise questions. Others are characterised by a more open and general approach to the urban system and are therefore flexible and able to deal with a wider range of urban questions. With respect to the aim of this study, we have focused on the latter type of models, since they can be applied in a number of ways.

As mentioned before, there seem to be two main types of origins for land-use models, academic and commercial (although the latter ones most often have their origin from research at academic institutions). One common characteristic of the models that never leave the academic world is that they tend to have insufficient documentation. These models are often immature and have seldom been tested outside universities. Some scientific and almost all commercial models that have been developed over a long period of time can be referred to as mature models. These are generally well documented. Often, the model developer also has a home page on the Internet where written information can be found. Written and accessible documentation is crucial to our project in order to conduct a proper assessment of the land-use models at a later stage.

For the purpose of this study 30 potential model candidates were identified. One common feature for these models is that they all in some way consider land use, the built environment and/or settlement structure. Background information and data about each model that was found during the inventory was collected and briefly overviewed. This data consists of scientific papers, journals, any written documentation about the model from the developer, links to the models home page, etc.

The models are listed below:

1. CATLAS
2. CLUE-S
3. ICLUS
4. ILUMASS
5. I-PLACE3S
6. IPM
7. IRPUD
8. ITLUP
9. Land Change Modeller
10. Land Use Scanner
11. LEAM
12. LILT
13. LUCI/luci2
14. LUCIA
15. LUCIS
16. LUMP
17. MEPLAN
18. METRONAMICA
19. MOLAND
20. PECAS Model
21. Rapid-Fire and Urban-Footprint
22. Stuttgart University (No model name)
23. TELUM
24. TRANUS
25. ULAM
26. UPLAN
27. UPLAN
28. UrbanSIM
29. What-IF
30. Xplorah

The number of available land-use models found in the inventory phase was too large to be fully classified and assessed within the scope of this study, and a selection of the most interesting models was therefore necessary. For that reason, and after a brief read through of the documentation of each model, we have mainly concentrated on models that seem to be: widely used (popular); are flexible; are documented; at a first glance seem to have good potential; or are frequently referred to in the documentation of other models.

After this selection process, 14 models remained and proceeded on to the classification and assessment phases. These models are considered to be the most interesting for further investigation.

3.3 Model Classification

In this phase, 14 land-use models were examined in more detail. The selected models are listed below.

1. CLUE-S
2. ICLUS
3. I-PLACES3s
4. IPM
5. Land Change Modeler
6. Land-Use Scanner
7. LEAM
8. LUSIS
9. METRONAMICA
10. MOLAND
11. TELUM
12. UPLAN
13. UrbanSIM
14. What-IF

In order to achieve a better understanding of the selected models, all written documentation for these models were examined in detail and classified according to their characteristics. The aim of the classification is to provide basic descriptive information about the models. The classification variables consist of the following typology:

Technical Platform/software
Data types (raster, vector etc.)
Dependency on other software (if any).
OP system
Ownership, diffusion and any legal issues
Modular or monolithic software
Age, year of development
Number of implementations (if any)
User Manual/Support?
Main field of application
Input data: Spatial, thematic
Input data: Non-Spatial
Output data: Spatial representation
Output data: Non-spatial
Evaluation possibilities
How are planning goals and policies treated?
Time scale
Spatial scale, resolution and scalability of model
Model engine and behavioural assumptions (CA, Agent based, Rule Based etc.)

The typology above follows the classification scheme proposed by Silva and Wu[6].

We have noted some general observations from the classification in section 4 of this document. The full model classification is documented in a single Excel-document attached to this report.

[6] Silva A. and Wu N. (2012), Surveying Models in Urban Land Studies, Journal of Planning Literature 27(2).

3.4 Model Assessment

The previously classified 14 models were also assessed with respect to the assessment variables below.

- General strengths and limitations of the model
- Software
- User friendliness/ease of use
- Quality of user manual/support
- Theoretical and practical complexity
- Transparency (can the planning profession understand how to apply this tool?)
- Evaluation capabilities/ability to compare scenarios
- Model flexibility
- Generality (ability of model to be transferred to other environments)
- Data need (availability and quality)
- Data preparation for model setup
- Computational performance needed
- Communicability and ability for understanding model input-output for non-technical experts (e.g. public participation)
- Relevance of the model in a Nordic planning perspective
- Initial effort required for model implementation
- Operating costs (€, own staff)
- Maintenance costs (€)
- Training costs (€)
- Organisation stability

The first assessment variable, "General strengths and limitations of the model", is probably the most important and is intended to capture general qualitative evaluations that do not fit under the other variable headings.

The other variables are mainly assessed by a four gradation scale; "Low/Poor", "Moderate", "High/Good" and "Excellent". It should be noted that this gradation is not an exact science, but represents our best judgement of each assessment variable. Text-boxes where an assessment is not possible (e.g. due to lack of information) is denoted as "Unclassifiable" or "n/a". Additional information is also written in the text-boxes to comment and clarify the assessment, but due to the large amount of information (in total, about 230 unique assessments were performed), the comments are kept short and concise.

We have summarised the most important observations from the assessment in section 4 of this document. The full model assessment is documented in a single Excel-document attached to this report.

3.5 Documentation and summary of findings

This report represents the documentation and summary of findings.

4 Conclusions

The most important findings of the study are summarised in this section.

4.1 Summary and comments on the classification

- Most of the models use the ESRI produced software ArcGIS (five models) or are developed in specialised software (six models). Two of the models are web-based.
- All models have relatively high degree of spatial resolution, ranging from 30x30 m grids up to 500x500 m grids. Most common is one hectare grids (100x100 m).
- Seven models are a part of a modular model system (e.g. they are combined together with a transport model, a demographic model, economic model or other sub-model), and six models are stand-alone monolithic models.
- There is a mix of different model types: four rule-based models, two cellular automata models, one agent-based model, one input-output model, two hybrid models, two unclassifiable models and one multi-criteria model.
- One common characteristic for all models is that they can all in some manner for regional or urban planning purposes.
- In general, a majority of the models handle planning policies as an initial input for scenario testing.
- In general, most models need some sort of additional future population or housing forecasting, which the model allocates spatially according to a specific planning policy. Some models create this input data within the model system (e.g. UrbanSIM), but most models rely on exogenous forecasts.
- All models produce some sort of spatial representation (maps) of future land use according to a specific planning scenario.
- Evaluation of model results is treated in different ways. Some models have a pre-defined evaluation function, while others have a more flexible approach where it is up to the user to create a set of evaluation indicators.

4.2 Summary and comments on the assessment

- Models that use standard GIS software (such as ESRI's ArcGIS) have an advantage over models that rely on specially developed software. Most often, a planning authority will already have some sort of GIS software and staff to handle it. New software will initially take some time to learn and understand. The use of standard software also facilitates spatial data preparation and graphical post processing of model results, since all land-use models need some sort of spatial data.
- Some models are easier to use than others. This is often the case with models that are web-based or have a graphical user-interface (such as IPLACE3s, IPM, LEAM, UPLAN, What-IF). Most of these models can, after some preparation, be handled by non-technical experts.
- A comprehensive user manual and user support is important when a model is set up in a region or municipality. This is often the case for commercial or widely used models. Good examples are Land-Use Scanner, LEAM, METRONAMICA, UrbanSIM and What-IF.
- Most models have good evaluation capabilities for comparing different scenario results.
- Monolithic models often rely on exogenous data from other models, such as population forecasts or travel times. This might be a disadvantage, but on the other hand, many planning authorities already have established demographic models or transport models. Modular models often create parts of this data themselves (such as UrbanSIM).
- The ability to transfer a model from one study area to another is a very important aspect. Most of the cellular automata and agent-based models need recalibration and revalidation when they are moved to other locations. This is often a complex and time-consuming task, and requires technical expertise. This is the case for Land Use Scanner, METRONAMICA, MOLAND and UrbanSIM. Rule based models generally do not need any calibration.
- Common to almost all models are that they all require quite extensive amount of spatial data, sometimes very specific, but some models are especially data-hungry (e.g UrbanSIM, Land Use Scanner and LUCIS). In certain cases access to data might be limited and therefore make it difficult to transfer a model to a new location. Extensive data preparation is also a factor to consider.
- One major limitation with most cellular automata models, and also some other models, are the exclusive states of individual cells, which only can assume one value/class. Therefore, they poorly handle an important aspect of smart/green growth, namely densification of already built-up areas. This often tends to create a radial urban growth pattern at the fringes of the urban areas.

- Relevance of the models in a Nordic planning perspective is difficult to assess, but one general observation is that many of the models have their origin in the USA. Here, land use is probably more market driven as compared to the Nordic countries (which all have a very strong planning tradition). In some models, assumptions are made that future land use will be strongly determined by economic market decisions, rather than planning initiatives. Examples of this are LEAM, UrbanSIM, and TELUM. Since most of the Rule-based models do not explicitly handle economic and market theory, they might be better suited for Nordic conditions.
- Costs and resources are always a limiting factor when a planning agency must choose a land-use model. Most of the reviewed models are free, but some are commercial products and come with a license fee, ranging from € 50 to € 15 000. Even if a model is free of charge, there will always be a cost for data, implementation, operating, training and maintenance of the model. Typical costs for model implementation (listed in this review) and creation of one scenario is approximately €30-40 000, but the cost range is large (from €20 000 to €400 000).

4.3 Can the assessed models be used in planning for sustainable/green growth?

The overall objective of this study is to investigate how spatial planning knowledge and instruments can contribute to the policy goals of green growth of Nordic city-regions. It should contribute to knowledge on, and development of, modeling tools for urban areas to undertake spatial development in ways that contribute to green growth.

Common to the assessed models in this review is that they all, in different ways, can be used for this purpose.

In the model world, spatial planning policies and strategies are the operational translation of overall planning goals. Most models optimize the allocation of future urban land use according to a specific planning policy or strategy. Thus, they do not directly optimize the allocation according to overall planning goals. By testing and evaluating the spatial impact of different planning policies, the model can illustrate if a specific planning policy reach the desirable planning goals or not (Figure 1 on page 6). This means that a model-oriented planning process usually is an iterative procedure, where model output leads to changes in planning policies and strategies, which again are tested in the model and so on, until planning goals are achieved.

This in turn means that most of the models are flexible with respect to the fields of application and can be used for numerous planning purposes. In the case of planning for green growth, a model can for example give indications to the questions; Is it possible to combine economic growth with sustainable development? Which planning policies reduce land consumption? How do we minimize the loss of green areas? Which policies have large potential for cuttings carbon-dioxide emissions?

4.4 Which types of models are most useful?

The somewhat boring answer to the above question is: "It depends". The choice of model for a planning organisation is dependent on several factors, mainly connected to the organisations capabilities in terms of staff, experience, and available resources. The planning agency will probably also have to be committed for some time when investing in a new model system. Another important aspect is the potential needs for a land-use model, which mainly is determined by the complexity and size of the region or municipality. A small municipality (in terms of population and employment) with moderate population growth will probably have less benefit from the results of a land-use model than a larger municipality with higher pressure on land use.

Complex or simple models?

A mainly econometric approach for modeling (which is the case for most of the complex models such as Agent-based models or spatial I/O-models) the future urban land use will probably be of less interest in a country with strong planning traditions. I these cases, new development will mainly be directed according to general plans, rather than allocation based on purely market behaviour. This is probably the case in all of the Nordic countries.

On the other hand, complex models can probably capture several aspects of the urban system in a more accurate way than simple models.

Integrated or not integrated models?

There are different benefits with stand-alone land-use models and modular model systems. Most often, a planning agency has already compiled projections of regional future population and employment. In this case, there is no need for an integrated population and employment forecasting module within a model. Also, another important aspect is that larger planning agencies often have a functional and established transport model in use. This will also reduce the need for a built-in transportation module within an integrated land-use model. In summar, this implies that a planning agency often does not need a complex, "do-all" model. A simple, less data hungry model will probably be sufficient for their needs.

The above section leads us to the following recommendations:

4.5 Recommendations for land-use model for planning purposes

A planning authority (regional or municipal), who wishes to implement a land-use model within its own organisation but does not have substantial experience with land-use modeling should, in our view, consider the following recommendations:

1. Do not use a complex and all-encompassing, theoretically rich model that attempts to capture the complexity of the urban-development process.
2. Do not aim to precisely predict an unknowable future. Instead, use an explicitly policy-oriented model that suggests what might happen in the future if clearly specified public policies are adopted and assumptions about the future are correct.

3. Use a relatively simple, rule-based model that does not attempt to duplicate the complex spatial interaction and market-clearing processes that shape the urban system. Instead, incorporate a set of explicit decision rules for determining the relative suitability of different locations, projecting future land use demands, and allocating the projected demands to the most suitable sites. These concepts and their implementation can be readily understood by planners, elected officials, and the public.

This review gives a brief overview of the, in our opinion, most interesting and useful land-use models available. It does not aim to give a complete and full description of all models. Based on the information in this project, we therefore recommend a feasibility study where one or two models are studied more in detail.

4.6 Four Simple Truths about Modeling

Last, but not least, it could be useful to consider these statements:

1. All models are wrong – Some models are useful

Any model is, by definition, a simplification of reality and thus inevitably is wrong in the sense that it leaves out some aspects of reality.

2. Prediction is hard, especially about the future

It is particularly difficult to be “correct” about the future. Forecasts are inevitably wrong, often embarrassingly so. Planners should therefore abandon the unrealistic goal of exactly predicting an unknowable future and, instead, prepare a range of forecast scenarios based on different policy choices which describes a number of possible futures.

3. Keep it simple, stupid!

Planners must recognize that their models are more likely to be useful in a policy context if policy makers and the public understand and trust them. In this context, planners should attempt to develop models that are as simple – rather than as complex –as possible.

4. Use it Because it is “BAD”

Information that is available in professional practice is always bad, i.e. incomplete and inaccurate. It is also the Best Available Data (BAD). This suggests that computer models that are developed to support planning should not require extensive data sets that are difficult, if not impossible, to obtain or create synthetically.