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DATA REQUIREMENTS FOR INTEGRATING URBAN DEVELOPMENT AND URBAN WATER INFRASTRUCTURE MODELS

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This work presents an introduction to urban development models with a focus on their usage in urban water sciences. Two models are compared and described: one developed within the DynAlp project at the University of Innsbruck, the other well established and developed at the University of California, Berkeley. Data need within both models differs significantly and therefor a comparison of the outputs of both models after a coupling with a drainage model and a water distribution model will give insight on which temporal and spatial resolution is needed for planers and engineering offices.

INTRODUCTION

Urban development, especially sealing of surfaces and land use change, driven by changes in population, society and economy constitutes a long research tradition. Additionally it is a complex dynamical process driven by forces like geography, environmental situation, politics, societal behavior or economic condition [1]. A number of (computer) models have surfaced in the past 3 decades to support decision-makers, city planners, ecologists or other fields of interest. Especially in for research groups within urban water sciences knowledge and usable models for projecting changes of urban fabric and population is essential to understand the dynamics of changes in behavior of drainage systems or water supply systems.

Recently developed computer-based models are both functional and useful to analyze urban development and give an improved representation of urban dynamics. Nevertheless most models are driven by an increase in spatial data and tools for processing this data [2,3]. Yet the availability of data is still limited as well as the application of the models is rather complex and time consuming. This may be feasible and needful for city planners and governmental institutions of big metropolitan regions but is usually not an option for projections used by planners for urban water infrastructure. As a consequence the usage of urban development models is still not accustomed in the field of water sciences. To satisfy the needs of planers and stakeholders an urban development model was developed which is both minimalistic in data and calibration needs.

This work shows the integration of this urban development model and the well-established hydrodynamic model SWMM [4]. The subsequent full paper shows the interaction with EPAnet as is already demonstrated in [5] and a comparison of both water distribution and drainage networks under influence of results by the well-established urban development model UrbanSim [6].

MATERIAL AND METHODS

DynAlp-urbandevel

The DynAlp-urbandevel dynamic urban development model uses the DynaMind Framework [7] as a basis to run the dynamic modeling cycle because of the ease of development of integrated models. DynaMind is a freely available (GPL license) scientific workflow engine implemented in C++. It provides a platform for researchers and planers to combine urban water centric models, GIS (Geographic Information System) functionality including visualization. For performance reasons the urban development modules are also written in C++ instead of using Python (which would also be possible).

As indicated the model is designed to run with minimal data needs. Data is inserted into the model as GIS-data as presented in

Table 1. Files (eg. Shapefiles) or a spatial database (eg. PostGIS) can be used as an input. CITY and SUPERBLOCK are mandatory inputs, whereas for simulating urban decline also existing CITYBLOCK and BUILING data are necessary. The table gives an overview about the GIS type needed with mandatory and optional attributes. The CITY represents the city center with expected population and corresponding year as comma separated values as attributes. SUPERBLOCK represents parishes of a city which are used as spatial input. Optionally it contains a designated development year and if already developed which type: residential, commercial or industrial. A CITYBLOCK represents subdivisions of a SUPERBLOCK and is used to create a street layout within the SUPERBLOCK. Additionally the street network can be attached for the possibility to connect generated streets to the existing layout.

Table 1. Input data needs for the DynAlp-urbandevel model. M stands for mandatory, O means optional

	View	Shape Type	Attributes			
			Development Year	Area Type	Inhabitants	Height
mandatory	CITY	Point			M	
	SUPERBLOCK	Polygon	O	O		O
optional	CITYBLOCK	Polygon				
	BUILDING	Polygon			M	M

Figure 1 shows the whole dynamic development cycle. After the necessary input step, the development cycle itself is set up. This means definition of the timeframe (start year and end year), the timestep (from one to many years) and also the definition of the share of workplaces. This parameter includes 2 numbers: share of commercial workplaces and share of industrial workplaces (eg. 0.4 & 0.1) meaning that for a population growth of x there are $0.4 \cdot x$ commercial workplaces and $0.1 \cdot x$ industrial workplaces created. Within the model number of inhabitants and workplaces are used to create buildings of the related categories.

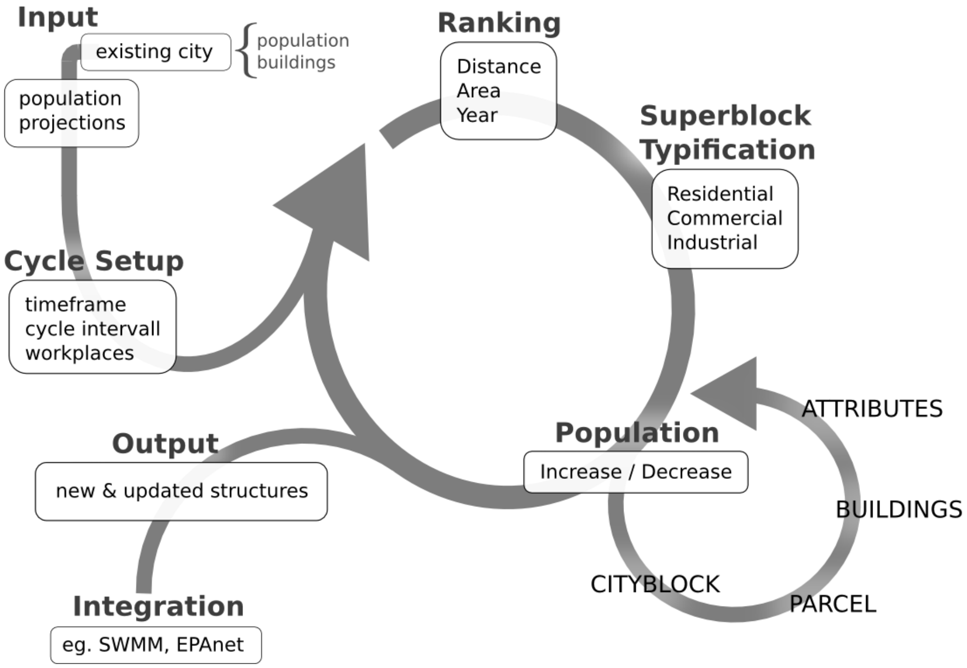

Figure 1. Dynamic Urban Development Cycle

After the initialization step the cycle itself starts with the ranking of available areas. They are ranked according to their distance to the defined city center, the size of the area and (if applicable) the set development year. For ranking distance and area the user can decide for a linear or an exponential function. The rank values are afterwards distributed from 0 to 10 depending on the minimum and maximum values determined. Year ranking happens according to the actual development year and the year set for an area. If no year is set this module does not affect the rank of an area. All ranking functions influence old rank values set (if existing) according to a weight value w between 0 and1 as a parameter. Typification also works on basis of distance to areas where the type is known and designates areas for residential, commercial or industrial usage. In addition the average building height is also set according to nearby existing buildings, if no buildings are used the value is taken from existing SUPERBLOCKs.

UrbanSim

UrbanSim is an Open Platform for Urban Simulation which integrates numerous models to resemble an urban system on household level. Providing high quality input data and reasonable model coefficients is crucial to get viable results. Due to the extensive use (and need) of data (several GB even for a midsize city with 100k inhabitants) coupling of UrbanSim with a spatial enabled database management systems (eg. PostgreSQL with PostGIS) is recommended in order to handle the data and keep a desirable speed during simulation [8]. The models of the simulation include the transportation system, the labor market and real estate markets which are closely interacting and in a state of dynamic equilibrium. Maximum likelihood methods are used to estimate the parameters of the multinomial choice models [9].

Currently a simplistic UrbanSim simulation of Innsbruck is set-up to estimate city growth and dynamics on a parcel based level. Around 15 mandatory (e.g. the parcels, households, buildings) and another 10 recommended tables (e.g. race, counties, cities) are needed to run the program with a total of ~40 parameters needed for each parcel (e.g. land value, residential units, distance to the nearest highway, how many people are living on a parcel including age distribution, income and work places / schools, sectors of employment and their location). Time-consuming processing of information from secondary data and computation of “offline” data is compulsory for the task [8].

Scenario Explication

It has been shown that calibration of land use and urban development models is only partially possible and also a portability of calibration practices is difficult [10,11]. As urban growth or decline is impacted by many influences (economic situation, immigration, emigration, etc.), a reliable prediction is hardly possible. Especially when we are looking into a small spatial scale, subjective decisions of urban planners and city stakeholders highly influence the future urban fabric. While, reproduction of past urban change is possible, reliable and exact future predictions are highly improbable. Therefor a scenario analysis of urban development is best way to cope with uncertainties of future situations.

As a test-case the city of Innsbruck, Austria was chosen. For this case study a calibrated, hydrodynamic, sewer model in SWMM (5358 nodes. 4528 subcatchments, 4696 links and 53 outfalls) and also historical data about city development and population projections are available. By the end of 2013 population counts 125,431 with an expected increase to about 135,000 until 2050 ([12]).

Two different population growth scenarios (increase to 135,000 and 145,000 inhabitants respectively) were chosen in combination with three different spatial development scenarios (Table 2). This results in a total of six scenarios tested. As the table shows scenario A resembles the projected population increase whereas scenario B doubles the increase of 10,000 to 20,000. Scenario 1: distributed uses small, discontinuous available areas throughout the city. Scenario 2: east focuses on large areas in the east of the city north of the river. Scenario 3: west concentrates on the area of the airport which is simply removed and its space used for development.

Table 2. Scenario definition for the urban development model

Scenario		Population Projection	Spatial Description
Population	Spatial		
A	1: distributed	135,000	Fractions throughout the city
	2: east		the north eastern rims of the city
	3: west		at the area of the ‘former’ airport
B	1: distributed	145,000	Fractions throughout the city
	2: east		the north eastern rims of the city
	3: west		at the area of the ‘former’ airport

Model Integration & Hydrodynamic Simulation

To demonstrate the model integration, an existing SWMM5 model (5358 nodes, 4528 subcatchments, 5695 links and 58 combined sewer outfalls) is adapted according to the results from urban development. Newly developed areas and their calculated impervious fraction are connected to the nearest sewer node. Afterwards the SWMM simulation is automatically executed. Each of the 6 development scenarios is simulated with a real rainfall event as rainfall input. An event from July, 17 2010 was chosen, as it caused severe flooding in the city center

(240min, peak intensity 98.4mm per hour, additional hail showers).. For all simulations the increase in flooding volume due to urban development is evaluated.

RESULT AND DISCUSSION

In Table 3 shows preliminary results for all urban development scenarios run with the DynAlp-urbandevel model. There are obviously differences in sealed areas for the scenarios, although population growth is the same. This results in the spatial differences of the scenarios, mainly the calculated average building height. Especially the eastern scenario differs significantly as there are up to 18-stories buildings around the target areas. In contrast the western scenario sticks to a maximum height of around 5 to 6 stories. Situation is the same for the distributed scenario: as there are lot of low-rise buildings near the city center and surrounding areas population is distributed over a larger area which consequently induces more sealed area. In addition to the changes in effective impervious area the changes in number of flooding nodes, total flooding volume and CSO volume for each scenario is presented. It shows that there is no clear correlation between increase in effective impervious area and increase in flooding nodes. Scenario east, followed by west, show the lowest increase in number of flooding nodes, flooding volume and CSO volume. These numbers seem to be independent from location and consequently the distance to the wastewater treatment plant at the eastern rims of the network. In contrast the distributed scenario shows a much higher increase of flooding nodes, flooding volume and CSO volume. Surprisingly both, flooding volume and CSO volume, are significantly higher even though the areas are spread throughout the city and therefor network storage effects should be effective. After a detailed view at the results an explanation is that areas are connected to small sewer trunks within the city, whilst there are already big pipes around the areas of the scenarios west and east.

Table 3. Changes in effective impervious area, flooding nodes, total flooding volume and CSO volume for each scenario compared to the base year 2000

Scenario		Δ effective impervious area (%)	(2010-07-17 Event)		
Population	Spatial		Δ Flooding nodes (%)	Δ Flooding volume (%)	Δ CSO volume (%)
A	1: distributed	9.6	3.4	21.4	9.3
	2: east	3.6	0.2	13.3	2.2
	3: west	4.2	0.6	13.4	2.6
B	1: distributed	11.9	4.3	25.5	11.5
	2: east	5.1	0.6	12.4	2.8
	3: west	7.0	0.8	14.8	4.3

CONCLUSIONS

As has been demonstrated it is crucial to use a set of differing scenarios for simulating urban development for the purpose of using resulting data for urban water models. The results suggest that every possible city planning scenario should be tested in order to identify weaknesses and sensitivity in the water system network. This enables for pro-active adaptation or (if possible) the option to put a higher development priority on areas which put less stress on the existing network. Traditional methods which just analyze a single option of urban development may miss critical weaknesses in the system.

As mentioned this paper gives a glimpse at the final paper where UrbanSim runs are included and also water distribution network generation coupling to both urban development models is finalized and presented.

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