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Citation	40th IAHS World Congress on Housing "Sustainable Housing Construction", 16 - 19 December 2014, Funchal, Portugal International Association for Housing (2014), 10 p.
Date	2014
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SIMULATION MODEL FOR ENVIRONMENTALLY EFFICIENT DISTRICTS IN GREATER URBAN AREAS

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Keywords: System dynamics, Material flows, Urban transport, Energy allocation and distribution

Abstract *This paper presents a system dynamics simulation model of districts in greater municipal areas. The model combines in a simplified way the impacts of building material flows during their life cycle, public and private transport, and the energy use and distribution in several simultaneously simulated districts. It is designed to study the long-term effects of different policies on the combined environmental impacts from transport, energies and materials. The population aging and its effect on the dynamic movement of inhabitants across the system boundaries and between the districts is also included in the model either as a permanent relocation or a temporary travels to reach the services or work. The model will support the city authorities in the planning of new urban areas and investments into rehabilitation of existing ones. Such policies must be designed to take into account the interaction between the built environment, infrastructure, services for the inhabitants and their transport and energy needs. The dynamic interaction between several district models simulated in parallel is essential to understand the effect of the particular decision on the surrounding areas.*

Material flow analysis opens the possibility for improved building waste treatment policies such as separation, recycling and material re-use. The construction, maintenance and demolition of the buildings implemented in the model affects the attractiveness of the buildings to the inhabitants and their willingness to move into the area or stay there. The same negative effect as obsolete buildings may be caused by traffic congestion, insufficient public transport or the reduction of green areas by the infrastructure. Therefore the difficult task of city administration to keep the balance between the needs of inhabitants and the interventions to improve the environmental efficiency has to be aided by sophisticated simulation methods such as the presented model.

1. INTRODUCTION

System dynamics is a powerful modelling technique to simulate the behaviour of complex systems with strong feedback relationships. It has been used for decades to study problems such as housing development [1], energy and population [2] or traffic congestion [3]. The topic was recently tested for the urban eco-efficiency prediction [4]. The advantage of system dynamics is its modularity that allows combining more systems together or calculating similar models in parallel with their real-time interaction. At the city level these methodologies, when integrated with the decision-support systems, provide powerful tools for municipal steering and policy making. This paper presents a system dynamics simulation model of districts in greater municipal areas. The model combines in a simplified way the impacts of building material flows during their life cycle, public and private transport, and the energy use and distribution in several simultaneously simulated districts. It is designed to study the long-term effects of different policies on the combined environmental impacts from transport, energies and materials.

2. SIMULATION MODEL

The calculation of environmental impacts in our model is based on the building materials flows, energy use and on the travelled distance by various means of transport (see Figure 1). Not all of the parameters form feedback loops with temporal variation, and therefore the model consists of system dynamics part (solid lines in the figure) and the complementary calculations (dashed lines in the figure). These complementary calculations can be programmed directly in the environment from where the system dynamics model is controlled.

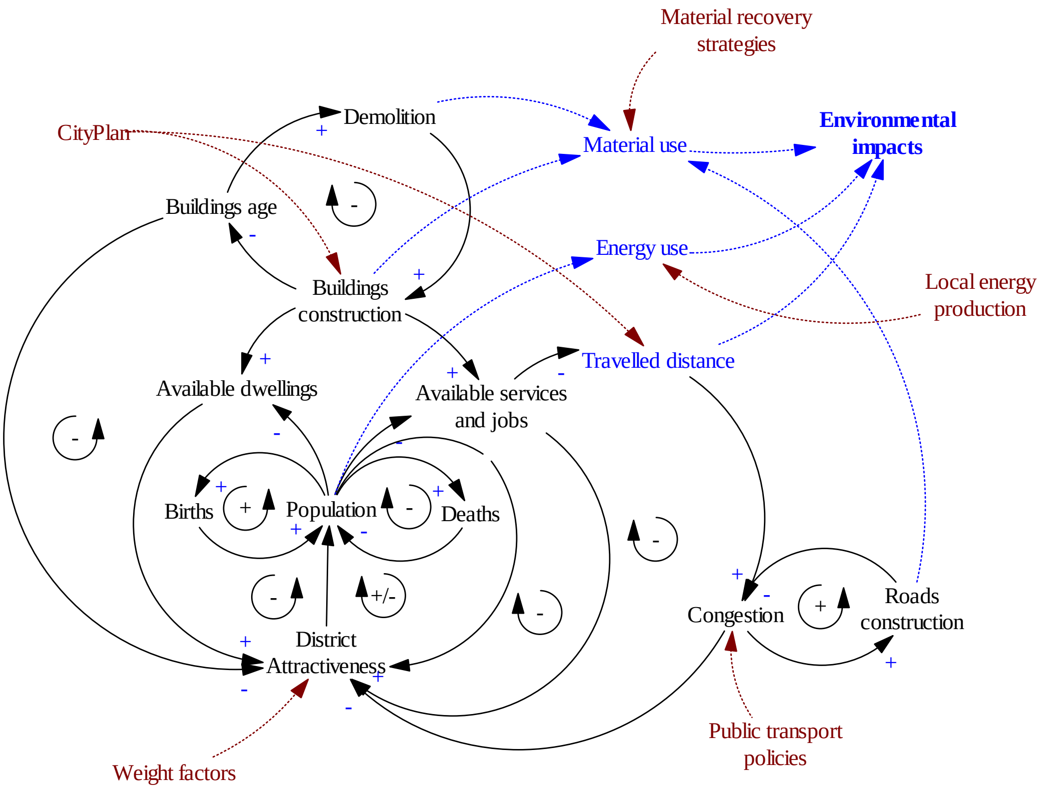


Figure 1. Casual loop diagram of the simulation model

2.1. Population dynamics

As it can be seen from Figure 1, the core of system dynamics model is the simulation of population abundance in the district. In reality, more districts can be simulated in parallel and their inhabitants can migrate between them or outside the city. They can also stay in the area and travel between the districts to reach the required services and jobs. The district population is governed by the overall district attractiveness that can be partly controlled by changing city plan or public transport parameters.

The population model adapted from MRPC Regional Energy Model [2] is divided into four age groups with the specific behaviour (see Figure 2). The population of the first group, called children (0-18 years), rises proportionally to the birth rate and the size of the second group, young adults (their parents). The crude birth rate is based on the UN population prospects for the selected area [5]. The second and third group, young adults (19-39 years) and adults (40-64 years) respectively, create the labour force pool. The last group, elders, does not have any specific feature in the model. The population aging is simulated and all of the age groups have a specific death rate calculated from the UN population prospects [5].

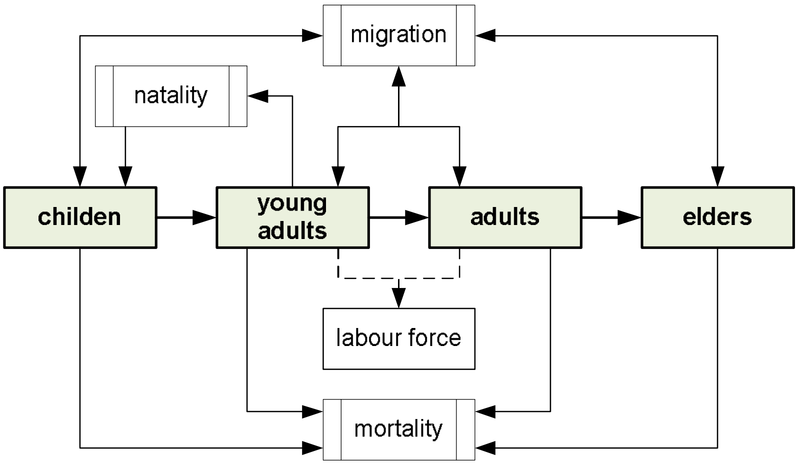


Figure 2. Age groups used in the system dynamics model

The migration between the districts and the migration outside the simulated area is controlled by the attractiveness factor A calculated in each district. This factor is the weighted average of several partial factors, each of them related to the specific model variable by so called "attractiveness function". The selection of partial factors, their appropriate attractiveness functions and weights w is subjected to the thorough research at the moment. However, it is clear that the preferences of people living in urban areas vary greatly with the location, and the whole system of functions and weights has to be flexible and modular to be able to add, remove or replace attractiveness categories according to the local habits.

$$A = \sum_i A_i w_i \text{ where } \sum_i w_i = 1 \tag{1}$$

As can be seen from Figure 1, we use five attractiveness categories called "*Available dwellings*", "*Available jobs and services*", "*Buildings age*", "*Traffic congestion*" and "*Population density*". The proposed attractiveness functions are presented later in this paper.

2.2. Material flow analysis

The environmental impact of building materials or products is based on the standardized rules in EN 15804:2012 [6] where the contribution of product stage, construction process, use (including material renewal during the regular maintenance), deconstruction and material recovery is taken into account (see Figure 3). Special focus is on the different recovery options including recycling and re-use. The structure of the recovery process is adapted from specified directions of future development in waste recycling [7].

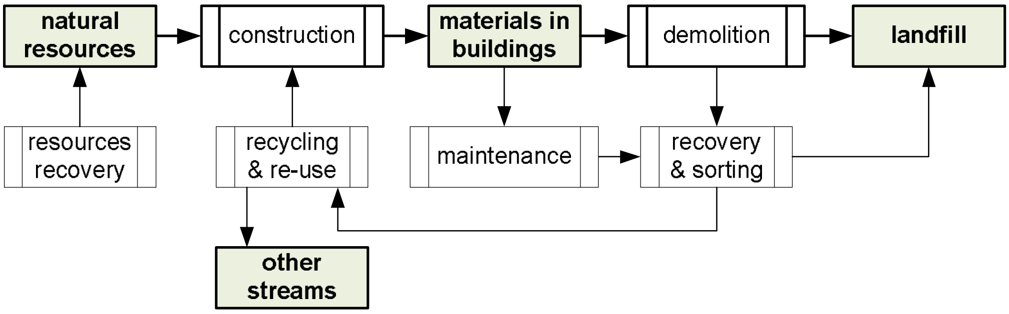


Figure 3. Material flows in the model

2.3. Urban transport

Transport system dynamics model is adapted from the one developed in the simulation of transitions towards emission-free urban transport [8]. Here it is extended to work independently in each district. This robust system dynamics model provides the fractions of different transport means that is used in the environmental impacts evaluation. It also calculates the road congestion which serves as one of the attractiveness parameters for the population dynamics. These are among the crucial parameters in highly populated urban centres. The travel distance is calculated from the estimated number of leisure trips, commuting to work and to reach the services inside or outside the districts. While the young adults and adults are always travelling to work (unless unemployed), the need of services has to be specified separately for each age group. For instance, the education is important to children and the healthcare may be required more by the elders.

2.4. Energy use

The calculation of energy use in the district is straightforward and does not include any feedback loops in our model. However, it is rather complex and computationally demanding because the hourly data of energy demand and supply are utilized while the rest of the model is calculated in yearly steps. Such data has to be provided (e.g. calculated by external software) for a typical reference year. Then the demand and supply is scaled separately to match the yearly average used in the system dynamics model and combined. The provision for energy storage and re-distribution is also implemented. It should be noted that electricity and heating are for convenience treated separately on the district level (e.g. to simulate street lights or pavement heating) and per square meter of floor area of different buildings. In the future the load balancing within the district and the interaction with the grid (including energy brokering dynamics) are variables to be considered.

3. MODEL IMPLEMENTATION

The core system dynamic model used in the presented study was programmed in software package Vensim [9] as shown in Figure 4. The use of commercial software was convenient in our case because of the simple and fast model building, but it has also certain challenges. For instance the number of districts, materials, building types, services, transport means and environmental impact categories is limited to the pre-defined amount. Using open-source environment such as Simantics [10] can break such limitation and, therefore the model will be converted.

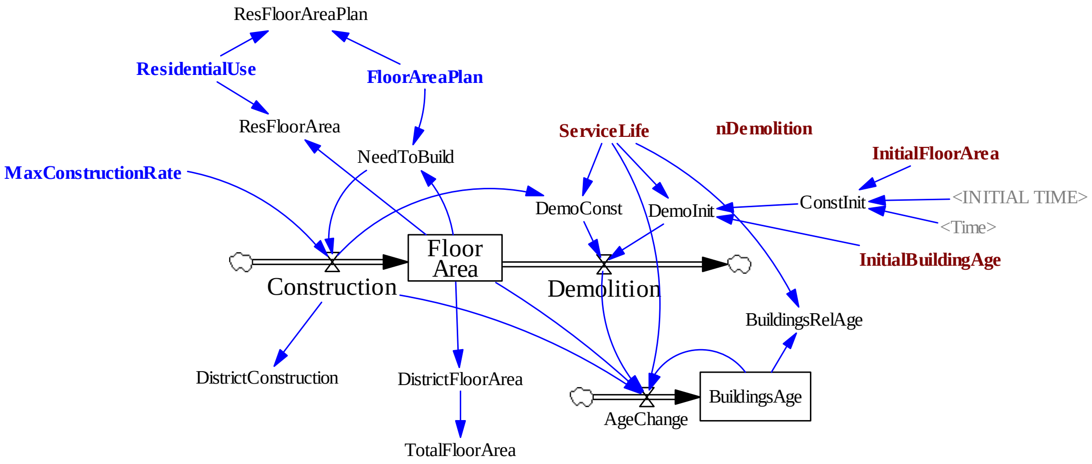
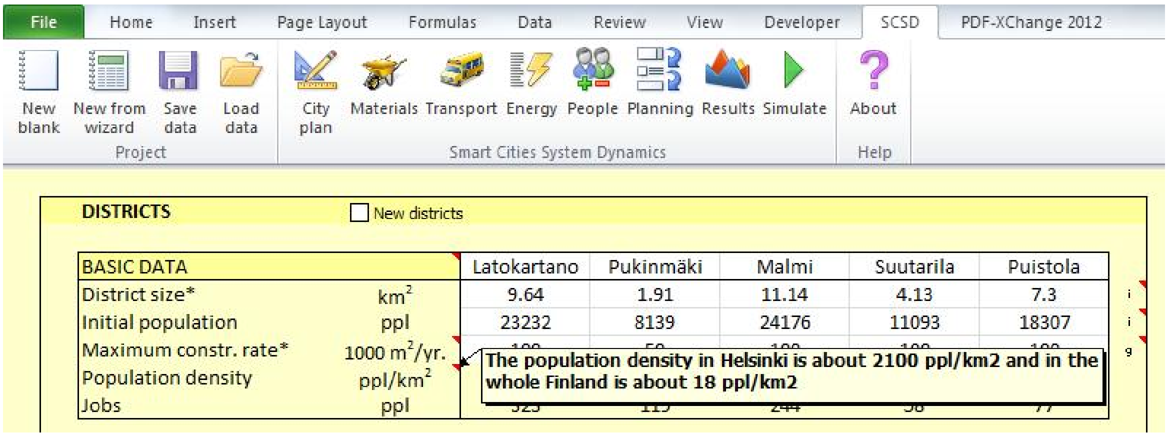


Figure 4. Example of model structure in Vensim: the buildings construction and demolition cycle

The basic model calculation is in yearly steps. Different software, connected to the Vensim model, was used due to the energy distribution and allocation procedure that is calculated hourly. We have created VBA code for that purpose and implemented in MS Excel spreadsheet editor which serves also as the user interface and controls Vensim system dynamic model automatically in the background. The user interface includes a ribbon that can easily navigate to the appropriate input forms and results or it can execute the system dynamic calculation (see Figure 5).



DISTRICTS ☐ New districts

BASIC DATA		Latokartano	Pukinmäki	Malmi	Suutarila	Puistola
District size*	km^2	9.64	1.91	11.14	4.13	7.3
Initial population	ppl	23232	8139	24176	11093	18307
Maximum constr. rate*	1000 m^2/yr.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Population density	ppl/km^2					
Jobs	ppl	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The population density in Helsinki is about 2100 ppl/km2 and in the whole Finland is about 18 ppl/km2

Figure 5. Model user interface in Excel

4. CASE STUDY

We have selected five districts from the Helsinki north-eastern area (Latokartano, Pukinmäki, Malmi, Suutarila and Puistola) with total 34.5 km^2 land and nearly 90 thousands inhabitants (see Figure 6). Two recently populated districts Latokartano and Pukinmäki with most of the dwellings in modern panel houses are in contrast with the traditional areas like Suutarila and Puistola, where older single family houses clearly dominate. Malmi is the central and largest part with the airport and it has balanced ratio of panel houses and single family houses. The population data, unemployment rates, cars usage and building stock information are adapted from the city of Helsinki urban facts data [11]. The default recovery (sorting, recycling, re-use) rates for steel, concrete and wood are adapted from the specified directions of future development in waste recycling [7]. Energy profiles (hourly demand and production) were pre-calculated for typical buildings by the software tool Apros [12].

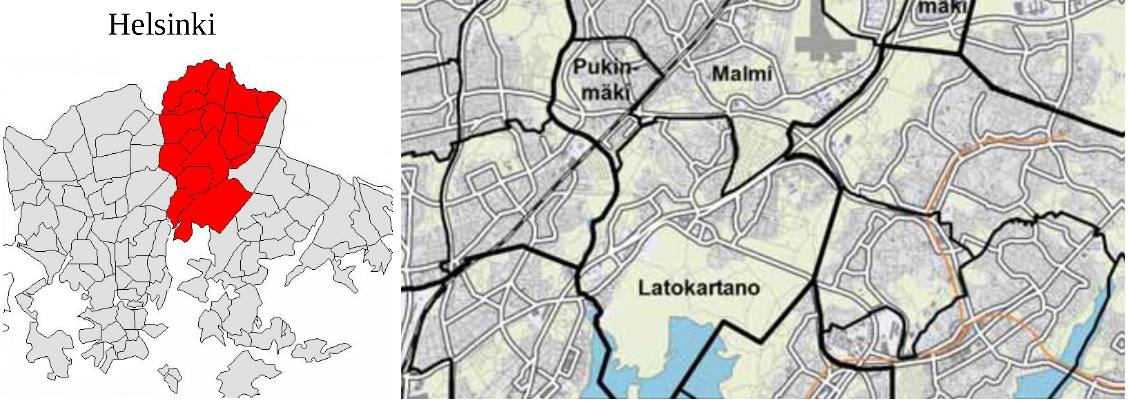


Figure 6. Studied districts [11]

The pre-defined maximum number of districts, materials, building types and services was 5, and therefore the boundary conditions of the study had to be clearly defined. For instance the building categories were (1) small houses, (2) blocks of flats, (3) offices, schools and kindergartens, (4) halls and churches and (5) shops. The weighting factors of the attractiveness parameters have not yet been calibrated and were considered equal 0.2 for all five categories.

The attractiveness functions were formulated with the following assumptions:

- The optimum population density is 1500 ppl/km^2.
- The attractiveness of services and jobs grows linearly with the increasing

availability or decreasing need of those services and jobs.

- The area with at least 1000 dwellings available for rent or sale has always the highest value of attractiveness related to the housing availability.
- The relation between buildings age and area attractiveness is linear as well as the relation between traffic congestion and area attractiveness.

It is out of the scope of this paper to present the whole set of inputs and assumptions in detail, and therefore the results should be regarded as illustrative examples of the possible outcomes of such dynamic calculations.

Our simulation model provides overall values of environmental impact combined from the transport, energy and buildings material use (see Figure 7). Since the impact of materials during the use phase was not defined in the model, the only contribution the GWP indicator from materials was during the re-building of obsolete housing that started about 2050 in our model.

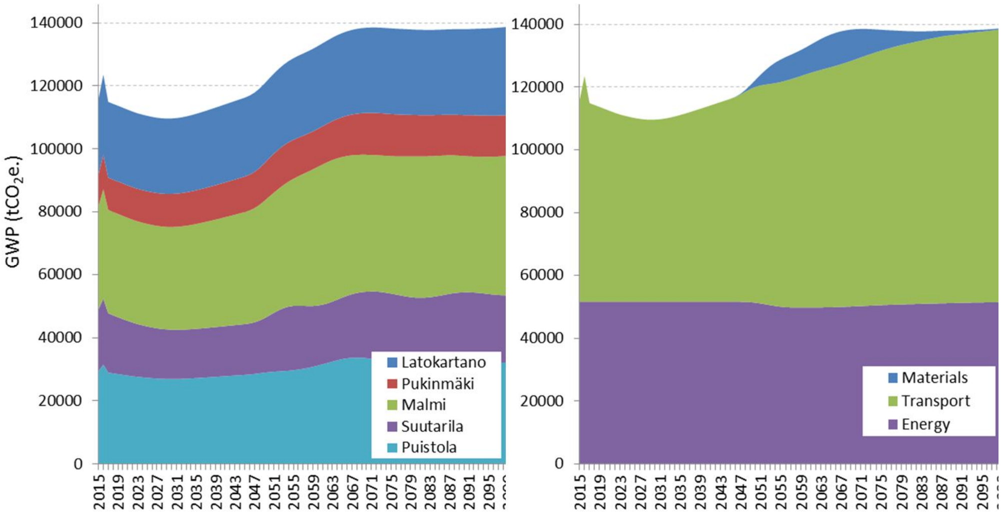


Figure 7. Global warming potential by district (left) or type (right)

Moreover, changes in simulation parameters are possible during the calculation, and therefore different urban policies, strategies and proposals for future development or interventions can be studied in more detail. The following example shows how the system dynamics model can be used to study a particular change in the urban plan.

In the test area of Latokartano the capacity of nursery and elementary schools is not sufficient and children have to commute to another district. We have simulated the effect of increasing total number of those buildings twice in 2020. It can be clearly seen on Figure 8 that the abundance of children and young adults has increased in the area. That was mostly because it became more attractive for young families than the surrounding districts. Similar effect could be observed in other neighbourhoods due to the decreased commuting from Latokartano. The emissions from transport decreased only slightly.

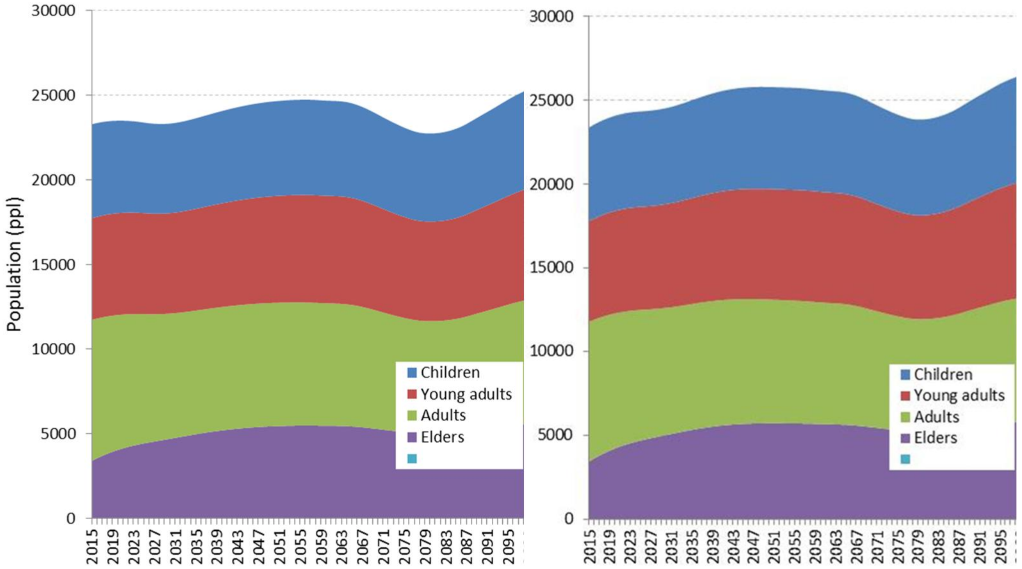


Figure 8. Population development in Latokartano district with current number schools and kindergartens (left) and after the intervention in 2020 (right)

5. CONCLUDING REMARKS

Urban areas account for 70% of current global CO_2 emissions and hence heavily contribute to the threats of global climate change, while simultaneously being highly vulnerable to the impacts of it. This causes extensive challenges, for example regarding air pollution, congestion, waste management and human health [13]. There is a strong need for new, efficient, and user-friendly technologies and services, in particular for energy, transport, and ICT with interoperable and integrated approaches: ‘smart’ solutions. In this context scenarios simulation and performance analysis are becoming important tools in assessing cities and aiding decision-support systems. These will support planning and procurement processes allowing the stakeholders to access and compare different solutions and scenarios and thus impacting on the deployment of the most suitable ones. The system dynamics simulation model presented can be integrated into city operating systems as one of these smart solutions.

It is convenient to build such simulation model that predicts the behaviour of smaller areas because most of the cities are divided into several administrative parts, districts or neighbourhoods, and therefore it is possible to take into account the interaction with the surrounding ones. Then the effect of implementation of a particular strategy in one district can be observed also in a wider scope and in the holistic dynamics of the city. Even though the model is primarily developed for the city administration, many private institutions, facility managers and even inhabitants may benefit from its calculation results. In particular it will be interesting when used for applications targeting citizens interactive collaborations into city planning. Therefore it will be convenient to convert the calculation to easily accessible online service as we are planning to do in the future projects. In addition, in, future developments will target the real time data and integration in city operating systems.

REFERENCES

[1] J.W. Forrester (1969): Urban dynamics, Cambridge, Mass. The MIT Press, USA.

[2] M.P. Vaudreuil, D.R. Guerin, M.R. Arnold, B.S. Timms, “System dynamics computer simulation modeling to forecast the energy demands for the Montachusett region under a variety of simulations and scenarios”, Montachusett Regional Planning Commission, USA, 2011.

[3] F.A. Armah, D.O. Yawson, A.A.N.M. Pappoe, “A systems dynamics approach to explore traffic congestion and air pollution link in the city of Accra, Ghana” *Sustainability* vol. 2, pp. 252-265, 2010.

[4] P. Hradil, P. Lahti, A. Haapio (2011): Urban eco-efficiency and system dynamics modelling, Research report VTT-R07173-11, VTT Technical Research Centre of Finland, Espoo, Finland.

[5] United Nations population prospects, accessed online at http://www.un.org/en/development/desa/population/ , 2014.

[6] EN 15804 + Ammendment 1, Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products, CEN, Brussels, Belgium, 2012.

[7] M. Meinander, U.-M. Moueh, Eds. (2012): Directions of future development in waste recycling, VTT Technology 60, VTT, Technical Research Centre of Finland, Espoo, Finland.

[8] S. Ruutu, H. Auvinen, A. Tuominen, T. Ahlqvist, J. Oksanen, “Simulation of Transitions Towards Emission-Free Urban Transport”, in Proceedings of The 31st International Conference of the System Dynamics Society Cambridge, Massachusetts, USA, 2013.

[9] Vensim, Documentation Revision May 2014 by Ventana Systems, Inc. accessed online at http://www.vensim.com/documentation/index.html, 2014.

[10] Simantics System Dynamics, accessed online at http://sysdyn.simantics.org/, 2014.

[11] T. Tikkanen, P. Selander, Eds. (2014): Helsinki by district 2013, City of Helsinki Urban Facts, Helsinki, Finland.

[12] Apros, the Advanced Process Simulation Environment, brochure by VTT, Technical Research Centre of Finland, accessed online at: http://www.apros.fi/filebank/68-Apros_overview.pdf , 2014.

[13] OECD Environmental Outlook to 2050, OECD Publishing, 2012.