M-DAB

Towards re-using material resources of the city

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If we strive for a de-carbonized future, we need to think of buildings within a city as resources that can be re-used rather than being disposed of. Together with considerations on refurbishment options and future building materials, this gives a decision field for stakeholders which depends on the current ``building stock'' - the set of pre-existing buildings which are characterized e.g. by building period, location and material composition. Changes in that context are hard to argue for since (1.) some depend on statistics, other (2.) on the concrete neighborhood and thus the space in which buildings are embedded, yet again others on (3.) future extrapolations again dealing with both of the aforementioned environments. To date, there exists no tool that can handle this back-and-forth between different abstraction levels and horizons in time; nor is it possible to pursue such an endeavor without a proper framework. Which is why the authors of this paper are aiming to provide one, giving a model of change in the context of re-using material resource of the city, when faced with numerous abstraction levels (spatial or abstract; past, current or future) which have feedback loops between them. The paper focuses on a concrete case study in the city of Vienna, however, chances are high that this will apply to every other building stock throughout the world if enough data is available. As a matter of fact, this approach will ensure that argumentation can happen on multiple levels (spatial, statistical, past, now and future) but keeps its focus on making the building stock of a city a resource for sustainable development.

Keywords: *material reuse, sustainability, waste reduction, Design and computation of urban and local systems – XS to XL, Health and materials in architecture and cities*

INTRODUCTION

The city as an organism is ingesting and excreting material resources in every year of its existence. Many of these materials have to do with the built environment, e.g. reinforced concrete as a basis for all currently-built structures, leading to a mixture of steel/concrete when demolished, bricks and mortar which form the baseline of many historical cities, and add-on materials such as styrofoam and glass wool which form the main insulation materials that are currently used.

All of these materials have different time horizons with regards to when they need to be replaced; they also differ in terms of reusability and effort for recycling or disposal. However, these factors do not influence people who are actually building; it is rather economical reasons that form the basis for most considerations in that context - which underlines the importance of policy-making in that context. To this end, we have established M-DAB, a coupled simulation/visualization that shows different building materials in the city-scape and predicts future waste resources and likely re-use/recycling paths. However, it does not simply stop at predicting these factors but also offers to enter different options for material employment during the building phase together with economic incentives, leading to less material consumption and/or better utilization of the waste material for other uses. The proposed framework works with policy scenarios, i.e. AS-IS as the baseline, and a selection of customizable future scenarios where materials can be shifted to a variety of possible re-use paths - thereby becoming the basis of a political discussion focused around "what possible future scenario provides the best overall performance for city development" as a whole.

In more detail, our contribution consists of the following parts:

- We take a thorough statistical look at the annual material output of the city ("waste" resulting from refurbishment, demolition and new building activity, which happens with a certain probability; see Section 'Material Output of the City'). Our data show that this depends largely on a building's year of construction, which implies a certain material composition.
- In a second step, we use GIS to identify buildings of different construction era and their neighborhoods, so as to act as data basis for a concrete city. We turn this data into a hierarchical representation (see Section 'City Representation') that contains all relevant data for our later simulation.
- The temporal dynamics and future scenarios are captured within a simulation that uses the statistic and representation presented earlier and computes a yearly material output depending on the probability for demolition, renovation and new building activities (also depending on the respective building era of the buildings in question). Specific scenarios such as an increase or decrease in housing need are furthermore introduced via a set of parameters that control city development (see Section 'Simulation').
- In a last step, we present the output of the simulation both as statistical visualization (charts) as well as spatially, within a city model; since our predictions are aggregated e.g. for a whole district of a city, we also present the latter data in an abstracted manner using extruded volumina rather than concrete locations (see section 'Visualization').

Our framework is intended for use by political stakeholders which may have widely different views on further development. It is therefore necessary that everyone can build new scenarii out of the given simulation parameters we offer, which implies a certain level of personalization; we have follow a User-Centered Design approach with stakeholders in which this point was a major outcome (see Section 'Discussion'). The framework is part of an ongoing research project which is still underway, the implementation is currently under development and uses the concepts presented herein.

RELATED WORK

We are not aware of any simulation/visualization/-planning efforts on this (city) scale, and thus our related work is based on previous work in material reuse (Kleemann 2018; Kohler and Yang 2007; Lichtensteiner and Baccini 2008; Swart, Raskin and Robinson 2004; van der Voet et al. 2017; Wittmer and Lichtensteiger 2007). For an introductory overview of material stock analysis, the reader is advised to consult Augiseau and Barles 2017 as well as Lanau et al. 2019. Our approach is specifically tailored around the use of GIS data, as in Kleemann et al. 2017.

MATERIAL OUTPUT OF THE CITY

In previous work (Lederer et al. 2020 [in press], Kleemann et al. 2017), the project team has collected data on the material output of construction and demolition sites, based on the year of construction. Furthermore, new building constructions have been researched by the use of BIM data, for typical housing types, which are nowadays common. In more detail, we have used IFC to extract the bill of materials and aggregate that to our specific material classes (e.g. concrete, brick, wood and so on).

On the one hand, this gives us a mapping from historical data to material outputs, on the other hand a possible future extrapolation for current building types. This serves as a basis for computing the actual output of materials according to probabilities (renovation, demolition, new buildings) under the influence of simulated growth and the concrete building park being investigated (see next sections).

Further points for consideration in this context are:

- The neighborhood context including zoning, norms and preservation regulations
- Existing extensions of a building (including rooftop extensions), which make demolitions less likely
- Potentials resulting from unused or not fully used building volumes, since that makes further building activity more likely

All in all, we obtain material output according to three probabilities: demolition, renovation and new building activity. The first two are based on the current building park (see section 'City Representation'), the last one on our simulation (see section 'Simulation').

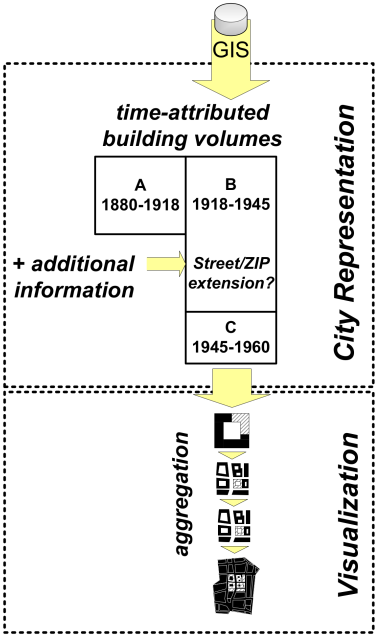

Figure 1
Time-attributed building volumes as a basic element of the city representation on which the simulation acts. For visualization, these bits are aggregated into building blocks, neighborhoods and districts.

CITY REPRESENTATION

Since we are based on the construction year of each building within the building park, we first have to obtain a spatial model where each basic entity represents a building volume with such an attribute. To do this, we extract extruded polygons from a GIS, where each such polygon represents a building part of a certain era. Further data, such as zoning regulations and preservation restrictions are then accumulated into these basic bits of information. In the next step we aggregate these volumes into building blocks, neighborhoods and districts. The simulation will happen

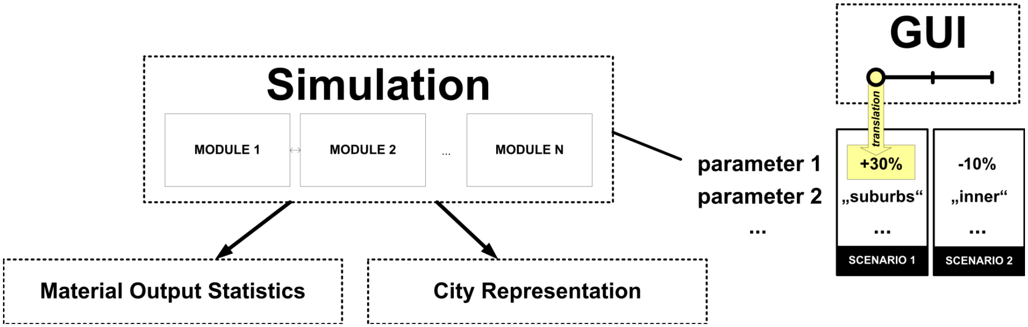

Figure 2
Different parts of the simulation

on the level of the original basic volumes; visualization uses the aggregated representation (figure 1).

SIMULATION

The simulation computes annual demolition, renovation, and new building activities and, from that, the predicted material output. During that task it references the lower layers - statistical analysis of material outputs and the city representation (see figure 2) - in order to update its state. The actual city dynamics are encoded as multiple communicating modules, each dealing with a specific aspect:

Housing demand: Computes the change in buildings depending on demographic growth (growth, decline, or stagnation).

Urban sprawl: Controls the location where changes to housing are taking place predominantly (outer perimeters, inner core, or both).

Unit size per capita: Computes the change in m^2 which an average person needs (increasing, decreasing or same).

Future material preference: Simulates development tendencies in material choice, as e.g. supported through financial incentives and policymaking. Choices include concrete, wood and bricks.

The *parameters* named above are defined on a non-technical level and presented as such to the user (see e.g. the slider "space requirement target" left in figure 3, which controls the unit size per capita named before). These settings are defined on a global level (e.g. $38m^2$ mean unit size throughout the whole city) but need to be translated to per-district values (districts have different mean unit size; if $38m^2$=100%, one can express the mean unit size per district in a relative fashion). Also, some values are "targets", i.e. they are to be reached at the end of the simulation interval (2020 ... 2050 in our case). We accordingly use linear interpolation to achieve the actual value of a parameter in a certain year. Depending on the parameter in question, we may further need to translate a parameter on the user interface according to a building's construction period and usage (residential, industrial, service or "other"). Because of the complexity of the translation process, we offer detailed documentation outlining the whole process for each parameter (see "book icon" to the left of each slider in figure 3).

A *scenario* is the set of all parameters with their specific values. Each scenario has a name (e.g. "Sustainable materials") and can be compared to a baseline scenario that represents the status quo. The user may change individual parameters on the user interface and save the changed parameter set as a new scenario (further see section 'Discussion').

VISUALIZATION

The results of the simulation are visualized both *spatiotemporally* as well as *statistically*:

- For the spatiotemporal case, a 3D city model with a time slider shows extruded volumes according to districts and neighborhoods. These volumes represent spatially aggregated simulation data for a specific year (also see section 'City Representation').

- For the statistical case, we show results as a chart, one category at a time. We depict the whole time axis (in our case until 2050) and can make use of several chart visualization techniques (e.g. line and bar charts).

The ability to compare scenarios (e.g. with the current baseline) and to define own scenarios gives stakeholders a powerful tool for discussion. Such a comparison can be achieved by a side-by-side visualization (scenario A vs. scenario B) or by depicting relative differences in the produced values.

DISCUSSION

Our framework was developed using a user-centered design approach. In more detail we hosted a workshop in which potential stakeholder could state their expectations and their views on such a simulation/visualization. The main observation from that activity was that

- Users need to change and adjust parameters without having to know the exact technical (underline) details.

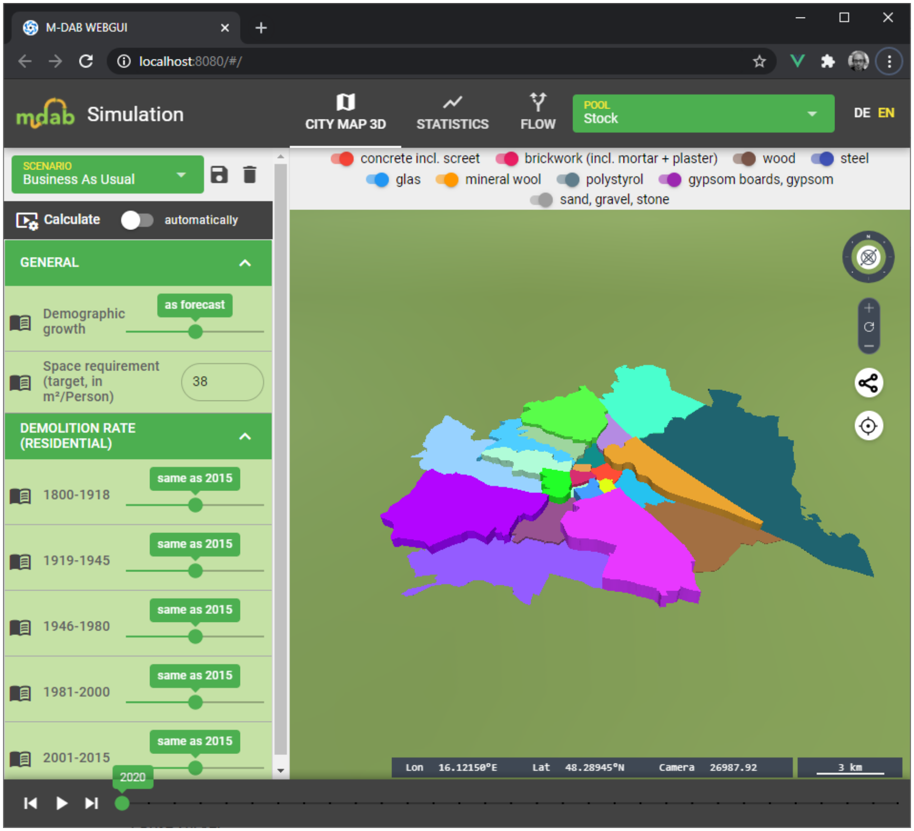

Figure 3
Preliminary implementation.

- Users wanted to save and compare their parameter sets, in order to be able to asses the performance of the outputs.

This has led to the introduction of scenario, logically modelled after the "euCALC" project [1]. So far, we are implementing the model described herein and will present first results on user-tests at the conference. One of the questions in this context is whether the spatial-temporal visualisation makes sense for our stakeholders, who are more used to see statistics as charts. Nevertheless, we feel to superimposing projected outputs from the simulation onto the cityscape might be a way to show results also to a wider public who are not trained in reading statistics.

CONCLUSION

We have presented a framework that combines visualization and simulation for predicting material outputs of a city. The goal is to shift material use to more sustainable modes, e.g. re-use instead of disposal. To make that possible we are simulating several directions of development that can be parameterized by political stakeholders easily. Results can be compared either to a baseline or to other "scenarii", which are sets of parameters that are stored under a logical name.

In future work we will further look at the gap between political actions and their translation into the formalized parameters of the simulation. Political actions include taxes and incentives, which must be translated into concrete annual increases/decreases concerning the "building stock", which forms the basis for our approach.

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