Exploring urban scenarios that facilitate individual waste sorting in cities: Embedding the Theory of Planned Behavior (TPB) into a spatial Agent-Based model.

Keywords: Theory of planned behavior (TPB) – Agent based model – Waste sorting – Urban areas – Circular economy

Extended Abstract

Every year, in urban areas a significant number of resources is being lost due to individual behavior of poor sorting of waste. Wastes such as plastics, glass and carboard are discarded incorrectly and therefore important materials for the economy are lost. Even in the case of Sweden, perceived as a one of the most advanced countries in relation to waste management performance, it is reported that over *60% percent of the contents of household rubbish bags could be recycled* [1]. Such inefficiencies result in environmental and economic costs that can be minimized with better waste sorting at source. Therefore, the aim of this study was to develop a simulation of waste sorting in urban residential contexts and evaluate different scenarios that can support decision making to improve the waste management system in cities.
When it comes to the study of behavior towards waste management, and in particular sorting or recycling, the Theory of Planned Behavior (TPB) is found to be one of the most studied psychological conceptualizations [2]. TPB contributed to understand how individuals define their behavior by using a set of constructs which are called: Attitude (ATT), Subjective Norm (SN), Perceived Behavioral Control (PBC) and Intention (INT) [3], [4]. Usually, information is collected using self-reported structured equations and using Structural Equation Modelling (SEM), TPB is evaluated the importance of the constructs is evaluated.
Simulations, and more specifically Agent Based Model (ABM), are also used to analyze and evaluate potential scenarios in the presence of phenomena that are complex or exhibit nonlinear interactions between its components. The development of an ABM offers researchers and policy makers the opportunity to visualize and explore different scenarios to make informed decisions. Waste management solutions require the use of a variety of tools and techniques such as Geographic Information Systems (GIS), Statistical Modelling and Decision Support Systems (DSS) to improve waste management [5], that can be combined in an ABM.
To date, a limited number of studies have explored how to integrate both frameworks. The work done in [6] contributes a fundamental building block for this research, since it demonstrates the feasibility and convenience of integrating the TPB into ABMs. In the field of energy consumption and adoption of cleaner energy sources, the integration has been proven doable [7], [8]. In [7] different formalizations of the same theory are evaluated, and highlight the importance of considering PBC to mediate behavior.
Regarding waste sorting, [9] uses simulations to understand how recycling participation might change when a new policy is introduced. The model was developed in Netlogo and the situation explored was spatial, but not explicit, meaning that the space was represented as abstract and coarse. [10] incorporates standardized coefficients found in [11] and describe how these can be taken into consideration.
It is important to notice that in both cases, agents are households, but the information extracted from the survey is at individual level. Second, although the survey collected information from specific areas, the urban environment was not incorporated into the ABM. Finally, TPB has been adapted and simplified from its original form. These simulations work with intentions

instead of behavior and PBC is not found to mediate the behavior. This study provides two main contributions. First, we present preliminary findings of an ABM of individual waste sorting in an explicit urban area. Secondly, the paper presents a methodological contribution by describing how the TPB can be successfully embedded into agents.

To develop the ABM this study followed two main phases, as shown in Figure 1. When developing such a simulation it is critical to clearly define the behavior that needs to be modelled. Subsequently a survey was conducted to collect empirical behavioral data, and the TPB statistically modelled using SEM (phase 1). This paper focuses on the ABM (phase 2), where the standardized coefficients of the SEM were used as inputs for the agent's behavior. Each agent in the simulation represents a resident and the TPB constructs values were generated using the survey and their relationship with the environment. For instance, PBC is a function of distance to the waste bins and SN is a weighted average of the behavior of their friends and household members. The waste sorting behavior is determined by a stochastic process based on these values and eventually the agent will behave in 4 different ways (Very bad, Bad, Good and Very good). Each of these levels will determine the percentage of waste miss sorting that they will do. The model was developed using GAMA and Figure 2 shows the dashboard developed to follow specific Key Performance Indicators such as total waste and miss sorting waste per group. The simulation uses shape files as input representing different spatial layouts. In this case, a specific area of Gothenburg was modelled in two scenarios (Figure 3). The yellow dots represent the residents, the black and grey polygons represent residential and productive buildings, and the three squares (red, green, and violet) represent the waste bins that are typically located outside the residents building.

By developing a spatial simulation, this study proposes a method to stablish a direct link between the TPB constructs and the built environment. The simulation can be used as tool to expose how the TPB affects the amount of waste that is being properly sorted.

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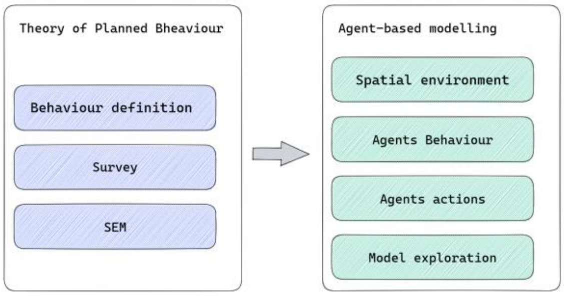


Figure 1. Two phases proposed to develop an ABM with TPB

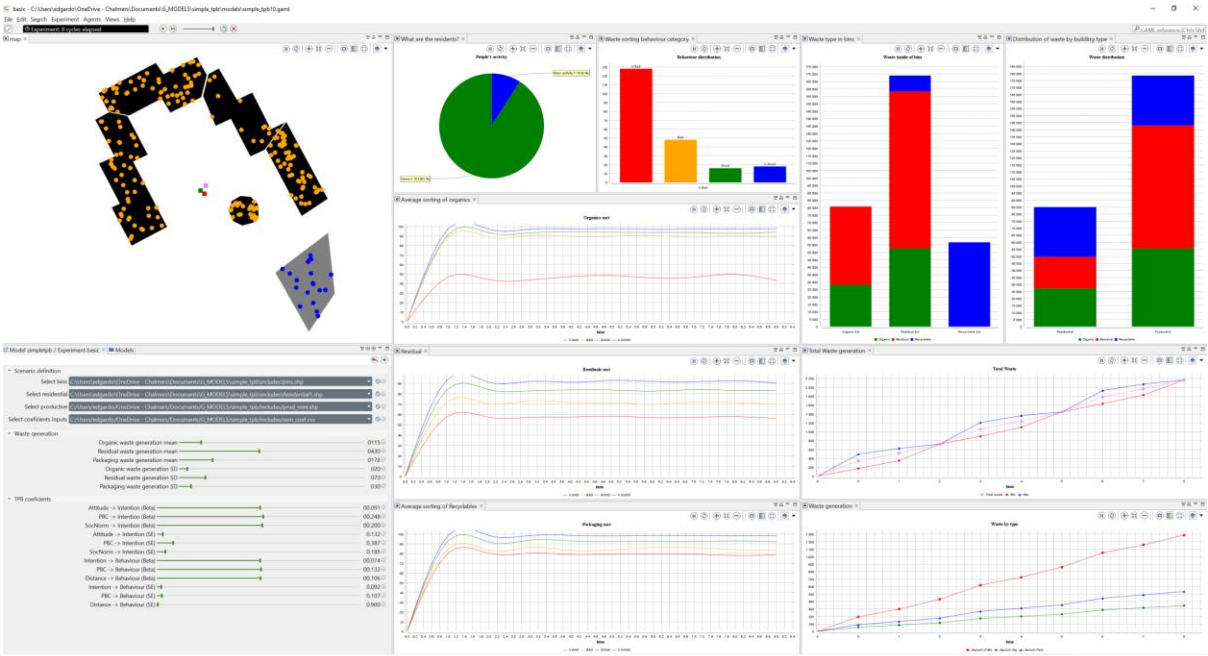
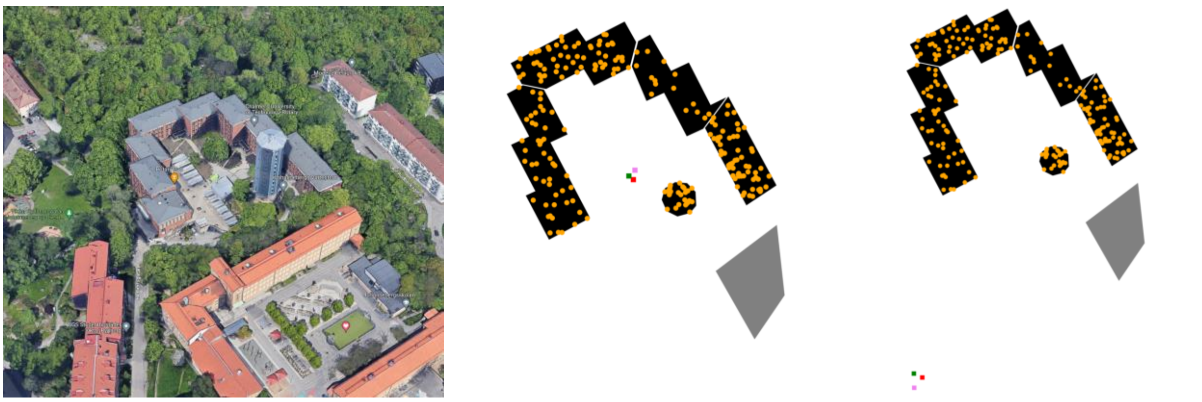


Figure 2. Simulation dashboard



Panel a: Urban situation Panel b: urban model Panel c: Far distance model

Figure 3. Simulation situation and scenarios