Understanding residential waste sorting behaviour with situational factors: a data-driven approach

Abstract

Waste separation at source is perceived as an effective Municipal Waste Management strategy, and the success of such a strategy depends on understanding the drivers of proper waste sorting behaviour. The Theory of Planned Behaviour (TPB) has been extensively applied to determining the importance of different psychological constructs in waste sorting behaviour. Despite evidence of its validity in specific contexts, in urban contexts one requires understanding how the built environment affects waste sorting behaviour. Furthermore, the TPB is typically applied starting from pre-defined items assigned to its constructs. This study introduces the use of Exploratory Factor Analysis as a data driven approach to define various TPB constructs from a collection of items, including situational factors such as distance to waste bins or the condition of recycling facilities, and shows how this technique outperforms the top-down approach. This study surveyed residents of Gothenburg, Sweden, to capture empirical data on factors known to affect the planned behaviour of waste separation. Structural Equation Modelling (SEM) is used to develop the extended TPB model and extract the drivers of waste sorting behaviour. Results from the study can extend the application of TPB to inform decision-making processes in residential waste sorting.

Keywords

Waste Management; Theory Planned Behaviour; Case study; Built Environment; TPB

1. Introduction

Municipal waste management is an urban service that imposes high financial and environmental costs on local governments (Kaza et al., 2018). Providing efficient solutions to address waste management issues can contribute to accomplishing several SDG targets. One of the most effective strategies to improve the efficiency of the waste management system is waste sorting at source. This means that residents are responsible for sorting their waste before disposal. Still, it requires committed residents, proper infrastructure, and adequate advertising campaigns to keep residents informed (Barata, 2003).

Although Sweden is one of the frontrunners in waste management (Alonso-Betanzos et al., 2017), according to Swedish Waste Management, 60% of the contents of the residual waste bins are missorted (Swedish Waste Management 2021, 2021). Currently, waste recycling averages 65%, with glass being 86% and plastic being 19% of the total composition. Using estimates from a medium-sized Swedish city of 100 thousand residents, the economic costs of waste missorting can add up to 1.46 million EUR (Rousta & Ekström, 2013). At a national scale, Ibrahim (2020) developed a risk map of improper waste sorting that showed that despite the recycling centres' having information about what can be recycled, the long distance to recycling centres offsets the benefits of clear information. In this study, the authors use geographic information to identify specific sites that need to increase the amount of bins and extend the opening hours window. Although waste sorting is simple enough to be implemented globally, it relies on the behaviour of residents, and municipalities need help finding effective alternatives to improve waste sorting.

The theory of Planned Behaviour (TPB) has been used to assess a variety of behaviours, and it has been extensively used to assess waste sorting and recycling. TPB proposes that the behaviour (in this case of waste sorting) is determined by a combination of attitude, subjective norms, perceived behavioural control and intentions. A better understanding of these constructs and the factors behind each one can provide valuable insights for policy-making seeking to increase waste sorting rates.

This study aims to model the behaviour of waste sorting, establishing a direct link with the built environment by employing the Theory of Planned Behaviour on data from a survey carried out in the city of Gothenburg, Sweden. It contributes to extending the TPB of waste sorting by including new situational factors, and by taking a data-driven approach to modelling the constructs using Exploratory Factor Analysis (EFA) and Structural Equation Modelling (SEM). Ultimately, the knowledge derived from this study can inform the development of more effective and tailored policies to improve residential waste management practices. These policies, grounded in empirical evidence and a nuanced understanding of the factors influencing behaviour, are essential steps towards achieving the dual goals of environmental sustainability and financial well-being in urban centres facing similar waste management challenges.

The following Section introduces the theoretical background, and Section three presents the methodological steps followed to develop the study. Finally, results are presented and discussed.

2. Theoretical Background

TPB is a psychological theory extensively explored to explain waste sorting behaviour (Phulwani et al., 2020). According to Ajzen (1991), the behaviour of people is determined by four primary constructs: Intention (INT), Social Norm (SN), Attitude (ATT), and Perceived Behavioural Control (PBC). Since these constructs are unobserved variables, they are considered latent, and their estimation requires combining observable variables to determine these constructs. In the original conceptualisation proposed by Ajzen, the constructs are defined using observable variables and how these constructs determine behaviour. The TPB states that ATT, SN and PBC predict the INT to behave in a specific way. Then, INT and, to some extent, PBC are used to explain people's behaviour. In addition, the TPB allows the inclusion of other constructs (Armitage & Conner, 2010; Davies et al., 2002; Davis et al., 2006).

Previous research focused on waste sorting and recycling has shown evidence that awareness of consequences (M.-F. Chen & Tung, 2010; Issock Issock et al., 2020; Tonglet et al., 2004a), situational factors (Azlina et al., 2013; Govindan et al., 2022; Tonglet et al., 2004a; B. Zhang et al., 2019), self-identification (Issock Issock et al., 2020; Knussen et al., 2004) or past behaviour habits-(Knussen et al., 2004; Lakhan, 2018) are relevant constructs in specific contexts. Empirically, to test the validity of the pre-defined TPB model, researchers design a survey that captures distinct aspects of each construct.

Waste sorting behaviour using TPB has been extensively studied in different contexts, including Australia (Chan & Bishop, 2013), China (Ma et al., 2018; Shen et al., 2019; Wan et al., 2014; Y. Wang et al., 2021; Xu et al., 2017; D. Zhang et al., 2015), the UK (Tonglet et al., 2004b; Visschers et al., 2016), USA and Canada (Lakhan, 2018; Park & Ha, 2014), South Africa and Nigeria (Issock Issock et al., 2020; Khalil et al., n.d.; Strydom, 2018), Greece, Norway (Ofstad et al., 2017), India (Halder & Singh, 2018a) and Sweden (Stoeva & Alriksson, 2017). In these studies, a survey is conducted to capture empirical data for the TPB constructs. In most cases, because of the survey's extension with numerous questions, specific groups have been targeted, such as students or faculty members. Structural equation modelling (SEM) and confirmatory factor analysis (CFA) are prevalent statistical techniques to model the constructs from the survey results quantitatively.

Overall, there is evidence that together all TPB constructs, specifically for waste sorting, are valid at the same time (Chan & Bishop, 2013; Liu et al., 2022; Ofstad et al., 2017; Oztekin et al., 2017; Razali et al., 2020; Shi et al., 2021; Stoeva & Alriksson, 2017; Taylor & Todd, 1995; C. Wang et al., 2021; S. Wang et al., 2020). It is essential to notice differences across how these studies have measured these constructs and assessed waste sorting behaviour. Despite the evidence provided, there is no significant evidence of attitude affecting intentions (M.-F. Chen & Tung, 2010; Hu et al., 2021; Shen et al., 2019; Wan et al., 2014; Xu et al., 2017). The relevance of Social Norms has also been contested (Lakhan, 2018; Stoeva & Alriksson, 2017; Tonglet et al., 2004a; Y. Wang et al., 2021). There has been more statistical evidence of the importance of PBC towards Behaviour, but again, when seeking to determine intention, it falls short in several cases (M. F. Chen & Tung, 2010; Passafaro et al., 2019; Strydom, 2018; Visschers et al., 2016; Xu et al., 2017; Zaikova et al., 2022).

The study conducted by Stoeva & Alriksson (2017), is noteworthy for its comparative analysis of waste sorting behaviour among students in Bulgaria and Sweden. The study found significant differences in the waste sorting behaviour of the two populations, which highlights the importance of context-specific models like TPB. While the core TPB model was validated in the Swedish case, the subjective norm was not found to be significant in the Bulgarian case. Additionally, the study revealed that the model had a better fit in the Swedish case than in the Bulgarian case. Interestingly, the study extended the TPB model by including satisfaction with local facilities in the analysis. It was found that satisfaction with local facilities was not significant in Sweden, but it was significant in Bulgaria. These findings provide valuable insights into the factors that influence waste sorting behaviour and have implications for waste management policies in different contexts.

Two studies in the Swedish context provide evidence of the importance of three factors to improve waste sorting in cities: (i) better information, (ii) reduced distance to bins, and (iii) improved space and bins inside of homes. All these measures have proven to impact the Swedish context positively. In the first study, stickers were used to increase information, and the distance to bins was reduced from 2km to 50m, significantly affecting how people sorted different waste streams (Rousta et al., 2015). Moreover, better information is combined with improvements in the bins at home. Results (Bernstad, 2014) provided evidence that better information improved organic waste sorting by 10%, compared to 44%.

3. Methodology

The study presented here had two phases. The first phase encompassed all activities related to developing and deploying a TPB questionnaire among residents of Gothenburg city. The second phase included all activities associated with developing the Structural Equation Modelling (SEM) to evaluate the TPB and extract relevant information about how residents behave towards waste separation at source.

3.1. TPB Questionnaire

The literature of TPB specific to waste sorting or recycling was reviewed to extract a list of questions used in previous studies. Questions were preselected and adapted to the local context. Based on previous research, the questionnaire included questions to accommodate an extended version of the TPB with additional constructs. The survey was developed to capture situational factors (Issock Issock et al., 2020; Knussen et al., 2004), awareness of consequences (M.-F. Chen & Tung, 2010; Issock Issock et al., 2020; Tonglet et al., 2004a), self-identification (Issock Issock et al., 2020; Knussen et al., 2004) and past behaviour (Knussen et al., 2004; Lakhan, 2018). Since the survey was delivered to residents of Gothenburg, Sweden, the questionnaire was written in English and Swedish. As in previous studies that focused on a similar challenges, this work aimed to collect a minimum of 200 valid responses given the number of items in the TPB questionare (Chan & Bishop, 2013; Halder & Singh, 2018b; Passafaro et al., 2019; Stoeva & Alriksson, 2017; Tang et al., 2023; Tonglet et al., 2004b; D. Zhang et al., 2015).

A first draft of the questionnaire was translated into Swedish, and a pilot was done to evaluate how residents responded to the survey. Insights collected were used during the final stage of the survey development. The questions were modified, and different wording was used to reflect the response from the respondents. The survey was deployed online and distributed virtually via various social media platforms and physically through pamphlets that were placed in public spaces such as libraries, restaurants, schools, supermarkets, and cafes. The survey questions and results are available as Supplementary material.

3.2. Modelling TPB with Structural Equation Models

As discussed in the literature review section, the TPB investigates three primary constructs to explain an intention or behaviour. Since these constructs are not observed, variables are used to determine them. The survey was developed following a specific structure representing the three primary constructs plus four additional situational constructs. Two approaches were used and compared to create these constructs, and the TPB was validated using Structural Equation Modelling (SEM).

Typically, Confirmatory Factor Analysis (CFA) is used to measure unobservable (latent) variables such as SN or PBC. This approach can be used to validate a hypothesised measurement model or factor structure. It aims to assess the fit between observed data and a pre-specified theoretical model, which includes a priori assumptions about the relationships between observed variables and underlying latent factors. In our case, the main modules of our survey represent these factors and the first statistical model using CFA was developed. Using different goodness of fit indices, these constructs were evaluated to understand the degree of reliability (Kline, 2015).

On the other hand, Exploratory Factor Analysis (EFA) is a data-driven technique used to reduce the dimension of information. It aims to identify the underlying structure and patterns in the data by transforming the original variables into a smaller set of meaningful factors. EFA does not involve hypothesis testing; results are generated from pure mathematical operations. An EFA was implemented to investigate if an agnostic method could contribute to expanding the understanding of how the latent variables might be grouped. In this case, the researcher needs to specify the number of factors used to reduce the dimension of the information. A set of tests can be carried out to determine the optimal number of factors, but there is no unique answer or golden rule, and it is a research decision.

The results from EFA were compared against those from CFA and evaluated. The EFA model is preferred if it can reduce the data's dimension while passing the evaluation. The validity of the factors extracted and their robustness were evaluated using Cronbach's alpha, Composite Reliability (CR), Average Variance Extracted (AVE), Maximum Shared Variance (MSV) and by comparing Heterotrait-Monotrait Ratio of Correlations (HTMT) values against the correlation. When testing for discriminant validity, MSV and AVE must be analysed together. Here, the heuristics suggest that if the Maximum Shared Variance (MSV) is higher than AVE, it might imply discriminant validity problems. In this case, Attitude and Consequences can potentially have some issues. Cronbach's alpha to test internal consistency should be above 0.7.

After evaluating the different methods and combinations to create the constructs, one alternative was selected, and other SEMs were developed to assess the hypothesis raised in the TPB. Different combinations of constructs were tested to model behaviour, and multiple Goodness of Fit Indexes (GFIs) were used to determine the validity of the models (Kline, 2015). Finally, the best-fitting model was identified, and its results will be presented in the next section of the study.

Therefore, SEM or path analysis encompasses both measurement and structural models. The measurement model relates observed to latent variables, while the structural model tests all the hypothetical dependencies among latent variables based on path analysis.

The statistical analysis for this study was performed using R, mainly with a lavaan package to fit the SEMs and an effect size package to calculate the goodness of fit indices. The corresponding code and the reproduction of the results are provided as supplementary material.

4. Results

In this section, we first present descriptive statistics of the survey on waste sorting behaviour in the case of Gothenburg. Second, two methods to develop the TPB constructs are applied to the survey results, and the constructs are evaluated. Finally, the TPB for waste sorting behaviour is developed using SEMs.

4.1. Waste sorting behaviour

Between June 2022 and December 2022, the survey link was accessed by 460 residents of Gothenburg, and 63% of them completed it. After a process of data cleaning and deletion of missing values, a total of 275 valid responses were taken into consideration.

The survey showed that the respondents are relatively well-behaved. On average, they declared to sort their recyclable materials 88% of the time, sort their organic material 79% of the time and sufficiently sort their residual material 73% of the time. These three variables were combined to calculate an average waste sorting behaviour, which has a mean of 80% and a standard deviation of 16%. Regarding the intention of sorting waste, 95% of the residents responded positively, 4% declared neutral, and 1% responded negatively.

On average, 89% of the respondents use the deposit system (pant). Those who do not pant present an average waste sorting behaviour of 70%, and those who do pant have an average behaviour of 82%. Also, the survey revealed that residents who dispose of organic waste more than twice a week dispose of residual waste 1.7 times a week and 1.3 times per week for recyclable waste.

Figure 1 shows the responses to the 29 items from the survey that provided data to determine the latent variables or TPB constructs. The satisfaction levels with the waste management system reveal that 69% of the residents declared to be satisfied or very satisfied, 22% are indifferent, and 9% are not happy. When looking at different items within the general satisfaction, residents have shown dissatisfaction because they believe other residents need to sort their waste correctly (37%) and the containers need cleaning (37%). Although 66% feel that the waste containers are close to their homes, 21% feel dissatisfied with the distance. Among the items explored, residents seem to be most satisfied with the amount of information provided (77%).

It can be observed that the most disagreement in the responses was found in relation to Subjective Norms (SN). In this module, the level of disagreement among respondents varied between 36% and 44%.

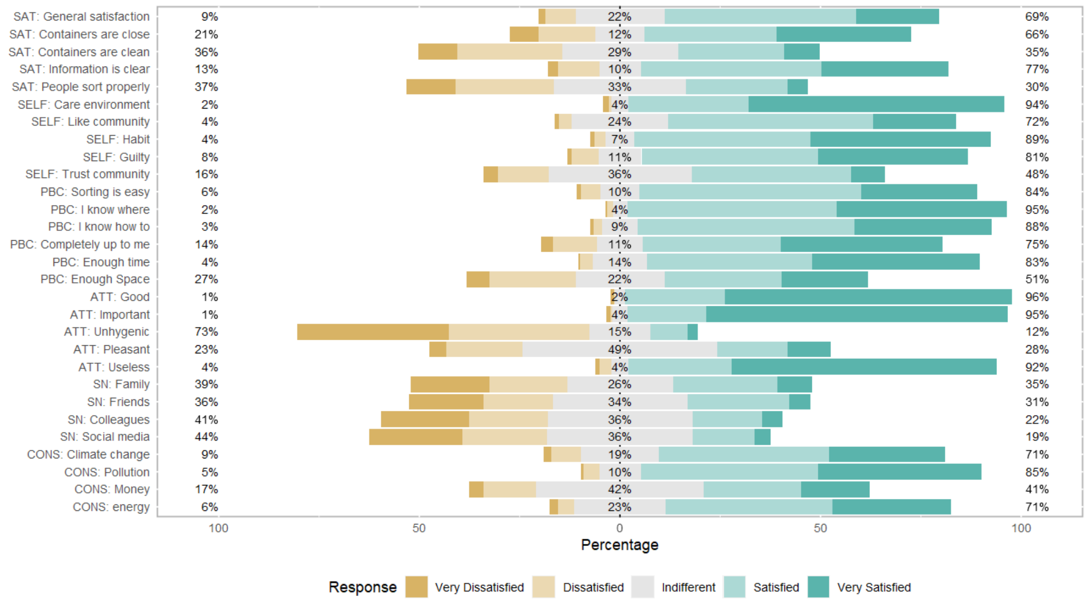


Figure 1 Survey Items used to determine TPB constructs

It is noteworthy that 25% of the participants in the survey provided their feedback through an open-ended text section. These comments offer insightful information on the challenges associated with waste sorting and disposal. A preliminary analysis of the responses revealed that the comments could be classified into four distinct categories, highlighting areas that require attention to improve the waste management system.

The first category refers to "Waste bins availability and usage", reflecting grievances about inadequate space for waste disposal during weekends, with overflowing waste bins, or while commuting to work or dropping off children at school. The second category relates to "Waste sorting challenges", highlighting the difficulties faced in sorting waste, and the lack of appropriate facilities for specific waste streams. The third category relates to "Hygiene and maintenance", expressing concerns about the lack of cleanliness, which in turn attracted insects and rodents. Finally, the fourth category relates to "Convenience and location", where participants suggested measures that could enhance the overall waste sorting experience. These included installing automatic doors, ensuring spacious containers, and making all the waste categories available at all recycling stations.

4.2. TPB Constructs

This section presents the results of the two approaches used to identify TPB constructs from the survey results. First, Confirmatory Factor Analysis (CFA) was used to determine the latent variables. The structure tested in this approach came from the literature review and the structure of the survey. The second approach was data-driven, and Exploratory Factor Analysis (EFA) was used to reduce the dimensionality of the data—resulting in 5 or 6 factors.

The goodness of fit for each case is presented in Table 1 and indicates that EFA models were performing slightly better than the Structure from the CFA. EFA with six factors presents the smaller Chi-square and Root Square Error of Approximation (RMSEA). Moreover, EFA 6 also has the highest Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI). Overall, EFA 6 performed better and was used in the study's next steps.

GFI	**Constructs**		
	CFA	**EFA 5**	**EFA 6**
chisq	787.8	623.6	554.9
df	362	314	284
rmsea	.065	.060	.059
cfi	.827	.868	.883
tli	.806	.852	.866
srmr	.080	.073	.072
aic	19715.7	17791.2	17085.5
bic	19979.7	18022.6	17327.8

Table 1 Evaluation of TPB constructs

After extracting the six factors, the data-driven approach produced a reasonable grouping of the items from the survey. The EFA method succeeded in grouping the items (variables) of the Consequences, Social Norms and Satisfaction constructs as they were included in the survey. The construct of Self-identification disappeared, and its items are distributed among the other constructs, mainly associated with Attitude and Satisfaction. A new factor grouping knowledge-related items was created. This factor includes several variables that initially belonged to PBC, but were capturing the residents' level of knowledge. The item satisfaction 3 in the survey corresponds to the level of satisfaction that the residents have over the available information level. Finally, the PBC construct only contains two items initially assigned to PBC, but includes two items of Attitude related to how hygienic the waste has been and how pleasant residents think sorting waste is.

The tests validating the resulting constructs are presented in Table 2. Most constructs present an acceptable level of Composite Reliability CR (> 0.7), indicating greater internal consistency and reliability of the measurement variables for each construct. PBC is the weaker construct and should be used with caution. The variance captured by these constructs (AVE) ranges from 0.31 to 0.55, providing evidence that the constructs contain a substantial amount of the variance. The Cronbach's alpha for PBC and Satisfaction are below the recommended threshold. Overall, the six constructs identified by EFA pass most of the tests or are within the limits of doing so.

In the calculation of the construct of Consequences, the most critical factor is understanding pollution (0.35), followed by an awareness of the consequences of climate change (0.23). For Social Norms, Friends are the most relevant item (0.45), followed by the perceived pressure by co-workers (0.22). The construct of knowledge was dominated by understanding how to separate waste (0.56), and similarly, in PBC, availability of time was the most influential factor (0.59). For the construct of satisfaction, the most significant coefficient was present in the overall level of satisfaction with the waste system. Finally, having a good attitude and feeling that sorting was necessary were the most influential items, with beta coefficients of 0.31 and 0.21, respectively.

	CR	AVE	MSV	Alpha C	Att	PBC	Soc	Know	Cons	Sat
Attitude	0.725	0.361	0.368	0.77		0.332	0.149	0.245	0.482	0.156
PBC	0.444	0.306	0.295	0,61	0.335		0.118	0.361	0.333	0.263
Soc norm	0.837	0.564	0.089	0.82	0.091	-0.003		0.04	0.308	0.081
Knowledge	0.761	0.443	0.295	0.75	0.248	0.543	-0.015		0.119	0.227
Consequences	0.799	0.510	0.368	0.81	0.606	0.272	0.298	0.139		0.105
Satisfaction	0.644	0.355	0.138	0.66	0.053	0.371	0.003	0.275	0.144	

Table 2 Fit assessment and validity test of the TPB constructs.

4.3. The behaviour of waste sorting

The TPB model of the behaviour of waste sorting was estimated using SEM. Although multiple specifications were tested and evaluated, only the three best-fitting models are presented (Figure 2), where the level of complexity was increased progressively. The first model in Panel a, represents the basic TPB formulation, and the subsequent models (Panel b and Panel c) represent extensions of the model. The three models were evaluated using different goodness of fit measurements following the literature recommendations.

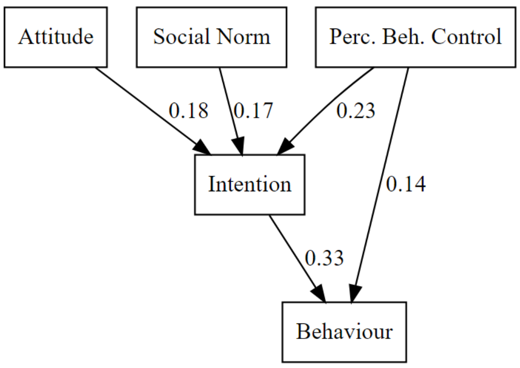
The first SEM (Model A) explores the formation of Behaviour with Intention and PBC and the formation of Intention with Attitude, Social Norms and PBC. Panel a) shows these constructs and the numbers in the arrows are the statistically significant standardised path coefficients with a confidence level of 5%. The model indicates that the path from Intention has more than two times the strength of the path from PBC to Behaviour. Moreover, PBC is the principal factor in explaining Intention. Attitude and Social Norms present similar importance, measured by the standardised path coefficients.

Model B (Panel b) extends the core model, including knowledge, satisfaction, and consequences. It is important to recall that knowledge contains variables of PBC. Still, the results from EFA gave evidence to isolate knowledge-related variables, such as satisfaction with information and knowing how to dispose of different waste materials. As a result, it should not be surprising that this construct provided results statistically significant in explaining both Intention and Behaviour. This model has shown that the consequences and satisfaction of local facilities are not statistically significant at 10%, thus being removed from further models. By including knowledge and extending the TPB, the strength of the intention to behaviour path has decreased, and part of its explanatory power is now explained by Knowledge.

Model C (Panel c) was the most complex and was built on the second SEM specification. This model includes the weighted distance to different bins and the dummy variable used to identify if the respondent engaged with the pant system. In this case, distance is the only construct that has a negative impact on behaviour, its path strength being as strong as PANT or PBC.

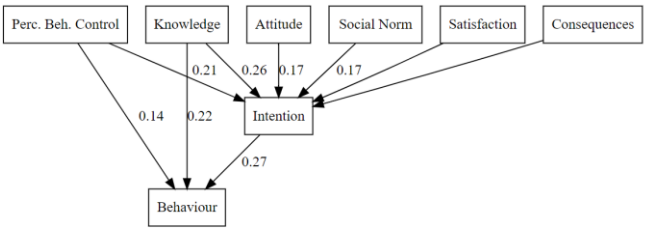
The three SEM specifications provide evidence to support the hypothesis behind the TPB. Model C performs better and contributes to increasing the statistical significance of some of the constructs, such as the coefficient of PBC, to determine behaviour. The p-value of this coefficient decreased from 0.023 to 0.015. In the three specifications, the hypothesis behind the TPB was validated.

The goodness of fit for the models are presented in the Appendix. It is worth noting that the main difference is found in the Relative Fit Index (RFI), which implies a good fit only for Model C. Regarding the Parsimony-Adjusted Measures Index (PANFI), no model gets a value higher than the considered cut-off of 0,5, suggesting that the optimal trade-off between model complexity and goodness of fit is not achieved. This is the only test that Model C fails. Therefore, it is considered a superior and preferable model to A and B. The results from then tests are included as an appendix in Table 3



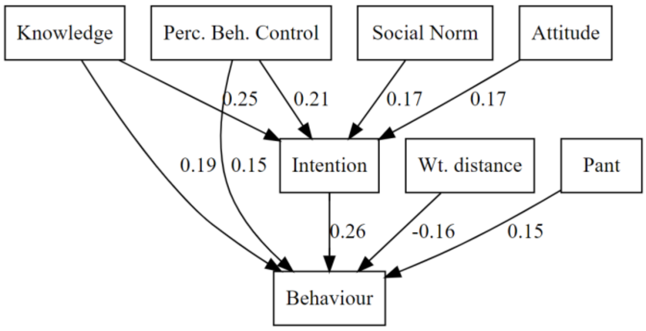
SEM	Path	Std.Err	P(>|z|)
Intention			
Attitude	0.176	0.089	0.009
PBC	0.234	0.044	0.000
Social norm	0.171	0.051	0.010
Behaviour			
Intention	0.334	0.095	0.001
PBC	0.144	0.053	0.027

Panel a. Path diagram of Model A and SEM results. Base TPB



SEM	Path	Std.Err	P(>|z|)
Intention			
Attitude	0.169	0.086	0.010
PBC	0.208	0.044	0.000
Social norm	0.168	0.051	0.012
Knowledge	0.256	0.058	0.000
Satisfaction	0.053	0.050	0.365
Consequence	0.055	0.073	0.441
Behaviour			
Intention	0.273	0.093	0.005
PBC	0.141	0.050	0.022
Knowledge	0.225	0.050	0.000

Panel b. Path diagram of Model B and SEM results. Base TPB extended with knowledge, satisfaction, and consequences



SEM	Path	Std.Err	P(>|z|)
Intention			
Attitude	0.172	0.083	0.006
PBC	0.214	0.044	0.000
Social norm	0.170	0.050	0.008
Knowledge	0.255	0.057	0.000
Behaviour			
Intention	0.255	0.084	0.004
PBC	0.147	0.048	0.013
Knowledge	0.194	0.047	0.000
Distance	-0.157	0.116	0.016
PANT	0.152	2.922	0.006

Panel c. Path diagram of Model C and SEM results. Base TPB extended with knowledge, distance, and RECYCLING

Figure 2 Path diagram of models A, B and C. Complemented with SEM results.

5. Discussion

This study provides three SEM that validate the TPB for residential waste sorting behaviour. In all cases, the primary TPB constructs contribute to determining the intention and behaviour of waste sorting. These results are also consistent with the fact that satisfaction with facilities does not play a role in the Swedish context but that statistical evidence supports the TPB's core hypothesis. Although the constructs' significance is essential, their weight differs from those presented before (Stoeva & Alriksson, 2017), where Attitude was the most critical factor, although this previous study focused on university students. The present study found evidence that PBC and knowledge are more significant factors than attitudes and social norms.

The first extended model (Model B) included Knowledge, and Model C added situational factors such as distance and whether the residents were engaged in the deposit system. Results from Model C are aligned with previous findings from Borås (Sweden) that show that reducing the distance to waste bins and increasing the awareness of residents improve the ratio of properly sorted waste (Rousta et al., 2015). This results are also consistent with previous studies that showed evidence that distance to bins decreases the behaviour to sort and participate in recycling programs (Ibrahim, 2020; Li et al., 2020)

In this study, we used Factor Analysis to test the presumption of how variables from the different survey items should be used to identify pre-defined TPB constructs. Results from this intermediate step showed that the presumed grouping of items via Confirmatory Factor Analysis (CFA) underperformed compared with the data-driven approach (EFA). Moreover, EFA explained better how the different items should be grouped. At this moment, we recommend future studies to include and evaluate the constructs using data-driven approaches. This study demonstrated that the variables require the creation of a construct labelled as knowledge. Moreover, the method suggested that these variables should be regarded as part of Attitudes instead of considering the construct of self-identification. PBC should also capture issues of hygiene and pleasantness since these factors can determine residents' self-efficacy.

In this study, researchers determined the behaviour of waste sorting by surveying how residents dispose of different types of waste. This helped to demonstrate that there is no single way of sorting waste and that different behaviours are associated with different types of waste.

5.1. Limitations

First, the number of valid responses used in the present study is at the lower end of what would be acceptable to generalise the results to the entire population of Gothenburg. Extending the survey to a larger population would guarantee that the results can be representative at the city level, and would increase their statistical power. Moreover, capturing responses from more residents would have enabled the use of the zip code to estimate absolute distances to waste bins instead of relying on self-reported distances. However, the number of surveys is consistent with previous studies, and future efforts should focus on expanding the sample (Chan & Bishop, 2013; Shi et al., 2021; Stoeva & Alriksson, 2017; Tonglet et al., 2004b)

Secondly, as in previous studies, the present study does not survey or monitor the residents' waste bins, and this information is crucial to establish the link between what people declare and what is quantified by waste management agencies. The gap between actual waste separation and how well we think we perform the task is known, and it is suggested that TPB studies should be paired up with actual measurements, in this case, of waste sorting (Ma et al., 2023; Perrin, D; Barton, 2000). Similarly, these models are based on self-declared information, and it would be essential to quantify the social norms better.

Finally, it is essential to improve access to the databases and scripts used in earlier studies that assess the TPB for waste sorting to understand better the context and how previous contributions evaluated it. Since measuring behaviour differently and extending TPB in various directions can lead to inconsistencies, making survey results and methods used openly accessible can enhance the comparability and reproducibility of the results. Furthermore, if TPB is to be relevant in policymaking, a direct link to quantifiable measurements of the built environment or waste amounts should be established.

6. Conclusion

Based on the Theory of Planned Behaviour (TPB), this study presented an extended model of waste sorting behaviour that incorporated knowledge and the distance to waste bins as part of Situational Factors. This model was developed and evaluated using data collected from a survey of residents of Gothenburg, Sweden. The results from the study show that the extended TPB model presents a better fit, but in all cases, the core TPB propositions are valid. Furthermore, a data-driven approach based on Exploratory Factor Analysis was used to determine the TPB constructs and their factors, which outperformed the conventional Confirmatory Factor Analysis approach that relies on pre-defined constructs.

Results from the extended model suggest that improvements in the perceived knowledge and convenience of residents can improve waste sorting. Since receiving a cash deposit when returning packages (Pant) was proven statistically significant in the models, specific attention should be given to the location where this exchange happens. This occurs in some supermarkets, therefore, extending this network and integrating other waste sorting facilities could result in better waste sorting. This study also shows that waste sorting behaviour is multidimensional and that different waste streams can present different behaviours. Usually, the behaviour of waste recycling is assessed, but these results show the importance of considering the behaviour towards other waste streams. Residents can be good-behaved towards packages, but organics are disposed of in residual bags. This suggests that the convenience of organic waste bins can affect the performance of waste management systems. The results from the analysis of the survey show that although, on average, residents from Gothenburg sort waste adequately and are relatively satisfied with the infrastructure, PBC and distance to bins influence the behaviour, meaning that in places where waste sorting is less established, this factor could be of greater importance.

More research on how these findings can be linked to actual waste separation is crucial for designing effective waste management systems. Therefore, it is recommended that psychological models are integrated with quantifiable measurements of the built environment, residents' social networks and actual waste surveys. Future studies could use geographic information on the locations of residents to estimate the distance to recycling facilities. Precise information on distances, time and efforts can help determine how much waste sorting and recycling activities are affected by convenience. Similarly, quantifying the space at home used for waste and recycling could provide insights into how homes could be improved to reduce the barriers towards waste sorting by improving the PBC of residents. Moreover, TPB models and other efforts to determine waste sorting behaviour should be accompanied by accurate measurements of waste. Finally, TPB can be integrated into other modelling techniques, such as systems dynamics or Agent-Based Models. These combined models could be used as Decision Support Systems to enable policymakers to study different what-if scenarios of urban waste management systems.

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8. Appendix

Goodness Fit	MODEL A		MODEL B		MODEL C		
	Value	**Test**	**Value**	**Test**	**Value**	**Test**	***Threshold***
P(Chi-sq)	0.248	Pass	0.239	Pass	0.447	Pass	*0.05*
GFI	1.000	Pass	0.999	Pass	1.000	Pass	*0.95*
AGFI	0.998	Pass	0.994	Pass	0.997	Pass	*0.90*
NFI	0.967	Pass	0.938	Pass	0.972	Pass	*0.90*
NNFI	0.964	Pass	0.891	No pass	1.006	Pass	*0.90*
CFI	0.990	Pass	0.967	Pass	1.000	Pass	*0.90*
RMSEA	0.038	Pass	0.059	No pass	0.000	Pass	*0.05*
SRMR	0.021	Pass	0.022	Pass	0.015	Pass	*0.08*
RFI	0.883	No pass	0.800	No pass	0.911	Pass	*0.90*
PNFI	0.276	No pass	0.289	No pass	0.299	No pass	*0.50*
IFI	0.990	Pass	0.969	Pass	1.002	Pass	*0.90*
N	*275*		*275*		*275*		
Df	*2*		*2*		*4*		
Chi	*2.785*		*2.863*		*7.705*		

Table 3. Conventional cut-off criteria of various goodness of fit.

*Notes: **Chisq** assesses the overall fit and the discrepancy between the sample and fitted covariance matrices. **GFI/AGFI**: (Adjusted) Goodness of Fit is the proportion of variance the estimated population covariance accounts for. Analogous to R2. **NFI/NNFI/TLI**: (Non) Normed Fit Index. **CFI**: Comparative Fit Index is a revised form of NFI. Compare the fit of a target model to the fit of an independent or null model. **RMSEA**: Root Mean Square Error of Approximation is a parsimony-adjusted index. **SRMR**: Standardized Root Mean Square Residual represents the square root of the difference between the residuals of the sample covariance matrix and the hypothesised model. **RFI**: Relative Fit Index, also known as RHO1. **IFI**: Incremental Fit Index adjusts the Normed Fit Index (NFI) for sample size and degrees of freedom. **PNFI**: the Parsimony-Adjusted Measures Index. Extracted from R package effect size. For more details about indexes and cut-offs, visit effectsize at CRAN.*